Aeromedical Evacuation
Aeromedical Evacuation
Management of Acute and Stabilized Patients

Foreword by Paul K. Carlton, Jr., MD
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With 122 Illustrations
As Surgeon General of the United States Air Force, it is a real pleasure to write this foreword for the first modern textbook describing the medical aspects of aeromedical evacuation (AE). This textbook would not only have proven invaluable to me and my colleagues as we served our nation in Europe and Southeast Asia during the 1980s and early 1990s, but today it will provide an absolutely invaluable resource for all medics in the Department of Defense. I would like to say a special thanks to Bill Hurd, whose idea it was to publish this textbook and whose persistence was crucial to making it a reality.

As described in chapter 2, AE has always been a vital link in the chain of medical care provided for all our soldiers, sailors, Marines, and airmen. Without AE, neither I nor any of my fellow Surgeons General could guarantee proper “full-spectrum” medical care to our military men and women around the globe. This is our collective responsibility, regardless of where in the world disease or injury occurs. Because of the huge distances involved in moving many of our patients, AE has always been a challenge, but never more so than today.

Beginning with Operation Just Cause in Panama (1989), it became apparent that our troops would, at times, suffer injury in a location where only minimal stabilizing medical care is available. In such situations, AE is absolutely critical to assure we can quickly move patients to state-of-the-art trauma centers, even though such centers are hundreds or thousands of miles away. During Operation Desert Shield/Desert Storm (1990 to 1991), the amount of sealift required to move “mobile hospitals,” together with the time required to set them up, mandated that the medical services of all military branches find a new way to deliver medical care to combat troops.

My predecessors and I, together with the Surgeons General of the Army and Navy, worked throughout the 1990s to streamline our medical forces. The end result is a truly light, lean, mobile, and capable array of medical forces that can arrive quickly on-scene for medical support of virtually any deployment anywhere in the world. However, such forces are equipped only for stabilization-type procedures and are far less capable than the old fixed facilities we had deployed in Europe during the Cold War. We simply must have the capability to
move our casualties out of the theater of operations as quickly as possible, and AE is the key to making that happen. In fact, today we can aeromedically evacuate patients who are stabilized but not stable—providing critical care in the air—greatly enhancing the speed and capability of our AE service.

Currently, the only people with more than a mere casual understanding of the issues involved in moving patients are those USAF Reserve and Air National Guard forces (mostly nurses and administrators) assigned to AE units, together with a handful of active-duty personnel who have served in one or two AE-related assignments during their careers. This textbook is rich with invaluable information that captures that experience and supplements Air Force guidelines and publications on AE.

This textbook will also prove a valuable resource to civilian physicians as they make decisions regarding the medical factors they must consider as they move their patients back to or around the United States. As the world’s economy has become more integrated, American companies are stationing ever more Americans in foreign countries where medical care is often far substandard to expectations. The result is an increasing number of civilian patients who also need AE back to the United States. Further, even within the United States, subspecialty centers such as pediatric cardiothoracic surgery and burn centers often require the movement of patients over thousands of miles.

I heartily congratulate the editors and chapter authors of Aeromedical Evacuation: Management of Acute and Stabilized Patients. I am confident it will become a much used resource by the thousands of physicians, nurses, and technicians charged with the responsibility of moving patients over long distances using aircraft. These individuals include members of all branches of the military and the many civilians involved in the commercial AE industry. For them, this book may be, quite literally, a “lifesaver.”

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Abbreviations

AFB: Air Force Base
Brig Gen: Brigadier General
BS: Bachelor of Science
BSN: Bachelor of Science in Nursing
CAPT: Captain (USN)
Capt: Captain (USAF)
CFN: Chief Flight Nurse
CFS: Chief Flight Surgeon
CNA: Certified, Nursing Administration
CNS: Clinical Nurse Specialist
COL: Colonel (USA)
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FS: Flight Surgeon
LTC: Lieutenant Colonel (USA)
LtCol: Lieutenant Colonel (USAF)
Lt Gen: Lieutenant General (USAF)
MAJ: Major (USA)
Maj: Major (USAF)
MBBS: Bachelor of Medicine, Bachelor of Surgery
MC: Medical Corps
MD: Doctor of Medicine
MPH: Master of Public Health
MS: Master of Science
MSN: Master of Science in Nursing
NASA: National Aeronautical and Space Administration
NC: Nursing Corps
PhD: Doctor of Philosophy
RAF: Royal Air Force
SFS: Senior Flight Surgeon
USA: United States Army
USAF: United States Air Force
USAFR: United States Air Force Reserve
USAR: United States Army Reserve
USNR: United States Naval Reserve
WHO: World Health Organization
Part 1
The Need
Aeromedical evacuation (AE) is the long-distance, usually greater than 300 miles, air transportation of patients after medical treatment that is adequate to assure a successful movement. It is most commonly performed using specially configured fixed-wing aircraft with highly trained aeromedical personnel in attendance. AE is inherently different than medical evacuation (MEDEVAC), which refers to the emergency transportation of patients to the nearest appropriately equipped medical facility prior to definitive treatment. When air transportation is required, MEDEVAC is performed almost exclusively using rotary-wing aircraft.

Under ordinary circumstances, the vast majority of AE is elective. For elective AE, air transportation is delayed sufficiently long after definitive therapy so that the rigors of air travel are unlikely to result in medical decompensation of the patient. The patients are stable and in the convalescent phase of their disease or injury course. Because even the most stable patient may experience difficulty during AE, specially trained flight nurses monitor the patients in-flight. However, most elective AE is accomplished on aircraft that have limited equipment for dealing with medical emergencies.

A more precarious category of AE is termed urgent. Urgent AE refers to the air transportation of a potentially unstable patient to save life or limb, primarily because the necessary medical facilities or personnel are not available locally. Urgent AE has many similarities to MEDEVAC. For both types of aeromedical transport, the patient cannot be definitively treated prior to flight and is often medically unstable. The goal of both is to get the patient to the closest medical facility that possesses the necessary assets to treat the patient’s condition.

For urgent AE, a physician with experience in handling the patient’s medical condition usually accompanies the patient and medical equipment specific to the patient’s condition is also made available if possible. Because the appropriate physicians and equipment are sometimes difficult to obtain when needed, the USAF has recently developed the Critical Care Air Transport (CCAT) Team concept for these patients.

A recent revolution in military medical affairs has resulted in the need for a third approach to AE that we have referred to in this text as contingency. Contingency AE refers to air transportation of stabilized (rather than stable) patients as soon as possible after treatment adequate to assure the movement to definitive care without adverse sequelae. At a minimum, a stabilized patient has an assured airway and stabilized fractures, all hemorrhage is controlled, and fluid resuscitation has begun.

The reason for development of the contingency AE concept is clear. In most potential theaters of war in the world, it is impossible to provide adequate fixed or mobile medical facilities to allow for full patient recovery and convalescence in the geographic area where their injury occurred. The previous doctrine of establishing enough portable hospitals to handle a large number of patients for an extended length of time is no longer practical for
a variety of reasons. Fortunately, technological advances have resulted in the development of an AE system that can transport patients out of theater for definitive surgery, recovery, and convalescence, thus negating the need for a large in-theater medical capability.

Although the concept of contingency AE has developed as a military model, it has clear civilian applications. Natural or manmade disasters may also result in more casualties than can be handled by local facilities. Likewise, an impending military conflict or natural disaster may require the movement of recently treated patients to a medical facility away from the danger area.

The difference between elective and contingency AE (ie, stable vs stabilized patients) has significant medical implications. Whereas a convalescing stable patient is unlikely to decompensate, a recently treated, stabilized patient may be much more likely to do so. This results both from the stress of AE and because decompensation is certainly more common earlier in the course of most disease or injury processes, especially in the immediate postoperative period. Further, the potential early problems that patients may experience are often unique to their specific medical condition.

In all cases, the potential stress of AE on patients must be carefully considered. Despite advances in technology, the AE environment is often harsh (Fig. 1.1). A limited number of air ambulances are available that minimize the noise and vibration, maximize lighting, and limit the hypobaric effects of altitude on the patient. However, even in peacetime, the majority of AE is performed using specially reconfigured aircraft that are otherwise used for transportation of personnel or equipment. Military transport aircraft reconfigured for AE are well known for the stresses they put on both
the patients and the aeromedical crew during prolonged flight.

Whether elective of contingency, safe and successful AE depends on appropriate patient selection and preparation. Knowledge of the best time to transport patients and the complications that may occur, as well as ways to prevent and treat these complications, is an imperative. While it may be true that “there is no absolute contraindication to AE,” it is also true that “there is nothing therapeutic about AE.” The injudicious use of AE can result in unnecessary complications for those patients who are transported prematurely or those transported without adequate resources to handle potentially foreseeable complications. Selection and medical preparation of the patient for AE should be tailored to each patient’s condition. A thorough understanding of both the problems that may occur in-flight and the limited medical treatment available during AE is always required.

This book is intended to be a comprehensive summary of the medical needs and considerations for patients undergoing long-distance AE. To this end, we have two specific goals. The first is to carefully examine the problems and limitations of medical care in-flight. This information should increase clinicians’ appreciation of the medical flight environment when considering AE for their patients.

The second goal is to analyze the unique AE problems and risks for patients with specific conditions. In light of the need to perform both elective and contingency AE when appropriate, the patients and their conditions are examined for specific considerations in each type of AE. For contingency AE, the patients must be evaluated at the earliest time that safe air transportation is possible. Special emphasis is placed on this preconvalescent period because the patient may be more sensitive to the stresses of flight and decompensation may be more likely. Criteria are given for patients with specific conditions that should be fulfilled prior to AE. The preparation and equipment required for safe transportation and the complications that can be expected are also examined.

For elective AE, the ideal time for air transportation during the routine course of illness, injury, or in the postoperative period is examined. Certain criteria should be met prior to AE when there are no limiting factors for convalescence prior to AE. The late complications unique to the condition that can occur when a patient is exposed to the stresses of AE and methods to prepare for these complications are delineated.

We hope that the information in this book will serve as a reference for both the military and civilian clinicians who need to prepare patients for AE. Only by thorough understanding of the stresses of flight and the risks specific to our patients’ conditions can we provide safe long-distance AE for both the stable and stabilized patient.
Aeromedical evacuation (AE) has a long and fascinating history of trial and error, success and failure, and ultimate achievement. The determined progress of AE, which parallels the advances in human flight, has been the result of man’s desire to avoid the “ultimate sacrifice” of death while bravely defending his country’s vital interests. Although early development of AE progressed slowly, its many champions steadfastly believed that air transport of the wounded could significantly decrease the morbidity and mortality of those injured in battle. The story of AE began in the early part of the 20th century as an important facet of military medicine. In the modern era, AE has risen to new heights with the implementation of technological advances in both flight and medicine.

Before World War I

The concept of moving the wounded by air began almost simultaneously with the concept of fixed-wing aircraft flight. Shortly after the Wright Brothers successfully flew their first airplane, two United States Pirmy (USA) medical officers, Captain George H. R. Gosman and Lieutenant A. L. Rhodes, designed an airplane built to transport patients. Using their own money, they built and flew the world’s first air ambulance at Fort Barrancas, Fla, in 1910. Unfortunately, on its first test flight it only flew 500 yd at an altitude of 100 ft before crashing. This flight, followed by Captain Gosman’s unsuccessful attempt to obtain official backing for the project, proved to be only the beginning of many challenges for this new concept.

World War I Era

World war I will not be remembered for the extent that AE was used, but as a time when air ambulance design made significant progress by trial and error. A French medical officer, Eugene Chassaing, first adapted French military planes for use as air ambulances. Two patients were inserted side-by-side into the fuselage behind the pilot’s cockpit. Modified Dorand II aircraft were used at Flanders in April 1918 in what was the first actual AE of the wounded in airplanes specifically equipped for patient movement.

The United States also used airplanes for evacuating the injured from the battlefield in World War I, but found it difficult to use planes not designed for patient airlift. Specifically, the fuselages were too small to accommodate stretchers and the open cockpit exposed patients to the elements. The USA Medical Corps used airplanes primarily to transport flight surgeons to the site of airplane accidents to assist in the ground transportation of casualties.

By the end of the War, the USA realized the need to transport the wounded by air. In 1918, Major Nelson E. Driver and Captain William C. Ocker converted a Curtiss JN-4 “Jenny” biplane into an airplane ambulance by modifying the rear cockpit to accommodate a standard Army stretcher (Fig. 2.1). This allowed
the USA to transport patients by airplane for the first time.

Between the World Wars

The success of the Curtis JN-4 Jenny Air Ambulances during World War I paved the way for the further development of AE. In 1920, the DeHavilland DH-4 aircraft was modified to carry a medical attendant in addition to two side-by-side patients in the fuselage. Shortly thereafter, the Cox-Klemin aircraft became the first aircraft built specifically as an air ambulance. This airplane carried two patients and a medical attendant enclosed within the plane. In 1921, the Curtis Eagle aircraft was built to transport four patients on litters and six ambulatory patients. Unfortunately, in its first year in service a Curtis Eagle crashed during an electrical storm, killing seven people.

Despite this apparent setback, aeromedical transportation continued to progress. In 1922, the USA converted the largest single-engine airplanes built at the time, the Fokker F-IV, into an air ambulance designated as the A-2. In the same year, a USA physician, Colonel Albert E. Truby, enumerated the potential uses of the airplane ambulances:

1. Transportation of medical officers to the site of crashes and bringing casualties from the crash back to hospitals.
2. Transportation of patients from isolated stations to larger hospitals where they could receive better treatment.
3. In time of war, transportation of seriously wounded from the front to hospitals in the rear.
4. Transportation of medical supplies in emergencies.

Transportation of patients by air began to take on operational importance as well. In 1922, in the Rifian War in Morocco the French Army transported more than 1200 patients by air with a fleet of six airplanes. In 1928, a Ford
Tri-Motor was converted to an air ambulance capable of carrying six litter patients, a crew of two pilots, a flight surgeon, and a medical technician.\(^1\) Also in 1928, the US Marines in Nicaragua developed what we now call “retrograde aeromedical transport.”\(^1\) Nonmedical aircraft that transported supplies into the jungle were used to evacuate sick and wounded patients to the rear on the return flight. This concept continues to be an essential part of modern AE doctrine.

In the 1930s a registered nurse and visionary, Lauretta M. Schimmoler, believed that one day there would be a need to evacuate the wounded by air and for 15 years was a proponent for establishing the Aerial Nurse Corps of America. However, not everyone supported this premise. Mary Beard, RN, the Director of the Red Cross Nursing Service in 1930, stated, “No one of our nursing organizations, no leading school of nursing, nor any other professional group, has taken up this subject seriously and definitely tried to promote the organization of a group of nurses who understand conditions surrounding patients when they are traveling by air.” In 1940, the Acting Superintendent of the Army Nurse Corps stated, “The present mobilization plan does not contemplate the extensive use of aeroplane ambulances. For this reason it is believed that a special corps of nurses with qualifications for such assignment will not be required.”\(^2\) The War soon demonstrated the necessity of AE.\(^2\) Large numbers of casualties needed to be transported back from distant theaters of war. Because designated AE aircraft did not exist, the Army Air Force made it their policy to use the transport planes for AE flights as their secondary mission. Regular transport aircraft were reconfigured for AE using removable litter supports. In this way, aircraft that had transported men and supplies to the theaters of operation could be utilized as AE aircraft for the return trip. By January 1942, Army Air Force C-47 aircraft had transported more than 10,000 casualties back from Burma, New Guinea, and Guadalcanal.

In light of this obvious need, the first Air Surgeon of the Army Air Force, Lieutenant Colonel David N. Grant, strongly supported AE.\(^2\) In 1941, Grant advocated AE as a way to “lighten and speed the task” of casualty transportation, and pointed out that AE would be available when other means of transportation were not. The first Medical Air Ambulance Squadron was established in 1942.

As AE evolved, it became clear that specially trained personnel were needed to optimize casualty care during air transport. Because there were not enough physicians to put on every AE flight, Grant proposed establishment of a flight nurse corps.\(^2\) Despite opposition from the Army Surgeon General, the designation of “Flight Nurse” was created for specially trained members of the Army Nurse Corps assigned to the Army Air Forces Evacuation Service. In February 1943, the first class of Flight Nurses graduated from Bowman Field, Ky, after a 4-week course that included aeromedical physiology, aircraft loading procedures, and survival skills.

World War II

At the beginning of World War II, it was commonly believed that air evacuation of the sick and wounded was dangerous, medically unsound, and militarily impossible.\(^2\) The Army Medical Department did not believe that the airplane was a substitute for field ambulances, even when it was necessary to evacuate casualties over long distances. The Surgeon for the Army Air Force Combat Command, Major I. B. March, was concerned that field ambulances would not be sufficient to cover the aerial paths of the Air Forces. In response, the Surgeon of the Third Air Force, Lieutenant Colonel Malcolm C. Grow, stated that the “chief stumbling block in the way of air ambulances has been the lack of interest on the part of the Army Surgeon General . . . . Until he accepts the airplane as a vehicle for casualty transportation, I doubt if very much can be done about it.”\(^2\) The War soon demonstrated the necessity of AE.\(^2\) Large numbers of casualties needed to be transported back from distant theaters of war. Because designated AE aircraft did not exist, the Army Air Force made it their policy to use the transport planes for AE flights as their secondary mission. Regular transport aircraft were reconfigured for AE using removable litter supports. In this way, aircraft that had transported men and supplies to the theaters of operation could be utilized as AE aircraft for the return trip. By January 1942, Army Air Force C-47 aircraft had transported more than 10,000 casualties back from Burma, New Guinea, and Guadalcanal.

In light of this obvious need, the first Air Surgeon of the Army Air Force, Lieutenant Colonel David N. Grant, strongly supported AE.\(^2\) In 1941, Grant advocated AE as a way to “lighten and speed the task” of casualty transportation, and pointed out that AE would be available when other means of transportation were not. The first Medical Air Ambulance Squadron was established in 1942.

As AE evolved, it became clear that specially trained personnel were needed to optimize casualty care during air transport. Because there were not enough physicians to put on every AE flight, Grant proposed establishment of a flight nurse corps.\(^2\) Despite opposition from the Army Surgeon General, the designation of “Flight Nurse” was created for specially trained members of the Army Nurse Corps assigned to the Army Air Forces Evacuation Service. In February 1943, the first class of Flight Nurses graduated from Bowman Field, Ky, after a 4-week course that included aeromedical physiology, aircraft loading procedures, and survival skills.
Soon regular AE routes were established and hospitals were built along airstrips to care for the wounded who needed to remain overnight along the route. In early 1943, AE aircraft began transatlantic flights from Prestwick, Scotland, to the United States. By the end of the same year, the transpacific AE flights transported patients back to the continental United States via Hawaii. In 1944, a southern Atlantic route to the United States was added, originating in North Africa with stopovers in the Azores and Bermuda (Fig. 2.2). Aircraft used for AE during the War included the C-54 Skymaster, C-46 Commando, C-47 Skytrain, C-64 Norseman, and C-87 Liberator Express. Bombers and tankers were sometimes used for tactical AE to move patients from forward battle zones.

The number of patients transported reflects the importance of AE during World War II. This number increased by 500% from 1943 to 1945. At its peak, the Army Air Force evacuated the sick and wounded at a rate of almost 100,000 per month. In 1945, a 1-day AE record was set at 4704 patients.

The risk of death during AE had dropped in 1943 to 6 of every 100,000 patients. By the end of the War, it was only 1.5 of every 100,000 patients. AE was listed along with antibiotics and blood products as among the most important medical advances in decreasing the mortality rate associated with warfare. In 1945, General Dwight D. Eisenhower stated, “We evacuated almost everyone from our forward hospitals by air, and it has unquestionably saved hundreds of lives—thousands of lives.”

The post-War drawdown changed the face of the US military AE system. By 1946, the system consisted of 12 aircraft at the School of Aviation Medicine and one C-47 at each of 12 regional US hospitals. In 1947, the U.S. Air Force (USAF) was established, and in 1949 was given the official role of providing AE for the entire US military.

The Korean War

The unexpected start of the Korean War in 1950 caught the AE system as unprepared as the rest of the US military. There was no AE system set up in Korea and there were few medical facilities located near airstrips anywhere in the Far East. Because of a lack of organizational
infrastructure and available AE aircraft, the Army was required to develop a system of tactical AE in the Korean theater. Due to a critical shortage of combat-ready troops, the wounded were kept as far forward as possible so that they could be returned to combat as soon as they were physically able. In the early months of the conflict, most patients were evacuated by ship from Korea to Japan, even though empty cargo planes were available.\textsuperscript{1}

With the establishment of the Far East Air Force, the logistics of establishing an operational AE system was made a top priority.\textsuperscript{1} Without adequate dedicated AE aircraft, the concept of retrograde aeromedical airlift presented the best solution. After offloading personnel and cargo near the forward battle area in central Korea, C-54, C-46, and C-47 aircraft were used to transport casualties further south in Korea or to Japan. In the first 6 months of the war, over 30,000 casualties were evacuated by air. As the fighting became more intense, over 10,450 combat casualties were airlifted between January 1 to 24, 1951.\textsuperscript{1}

By fall 1952, the C-124 Globemaster became the primary air cargo aircraft, almost completely replacing the C-54. When configured for AE, the massive C-124 accommodated 127 litters or 200 ambulatory patients. It also had the advantage of a shorter enplaning and deplaning time and required a smaller medical aircrew than the C-54. Unfortunately, because of its size, the C-124 could not land in Pusan to evacuate patients from this area. Instead, the smaller C-46 aircraft, which carried a maximum load of 26 patients was used for intra-theater AE in Korea and Japan.\textsuperscript{1}

By the conclusion of the Korean War in 1955, the USAF AE system was again capable of safely moving a large number of casualties within the theater and back to the United States. This system certainly contributed to the decreased death rate of the wounded during the Korean War, which was 50% less than that seen during World War II.\textsuperscript{1}

Pre-Vietnam War

In the years immediately after the Korean War, the peacetime AE system continued to serve the Department of Defense (DoD) by transporting military and civilian patients from the overseas theaters back to the United States, much like today.\textsuperscript{1} A new aircraft, the Convair C-131A Samaritan, became the first airplane designed specifically for AE. This first fully pressurized twin-engine transport was designed as a “flying hospital ward,” complete with air conditioning and oxygen for patients, and had the capability to carry bulky medical equipment, such as the iron lung and chest respirator. The Samaritan accommodated 40 ambulatory or 27 litter patients or a combination of both.

In 1968, the McDonnell Douglas C-9A Nightingale made its debut as the state-of-the-art medium-range, swept-wing twin-jet aircraft used almost exclusively for the AE mission.\textsuperscript{1} The Nightingale is a modified version of the McDonnell Douglas Aircraft Corp’s DC-9. It is the only aircraft in the present-day USAF inventory specifically designed for the movement of litter and ambulatory patients, and can carry 40 ambulatory patients, 40 litter patients, or a combination of both (Fig. 2.3).

Vietnam War

In 1964, the United States entered the Vietnam conflict. Again, the peacetime AE system had to be built up to meet the wartime needs of the US military. Initially, C-118 and C-130 cargo aircraft were used to evacuate patients within Vietnam and to offshore islands. When the C-141 Starlifter jet-powered cargo aircraft became available in 1965, it was given the AE mission in addition to its primary cargo mission. By 1967, the Pacific Air Forces Aeromedical Evacuation System had 17 operating locations throughout the Pacific. The C-118 became the workhorse for in-theater AE, allowing the C-130 to concentrate on its cargo mission.\textsuperscript{1}

The character of the combat in Vietnam made tactical AE especially important. Small transport aircraft, such as the C-123, would arrive at small airstrips carrying cargo. Within a matter of minutes, the aircraft would be unloaded and reconfigured to carry patients.

The number of patients transported by the USAF AE system during the Vietnam War was astounding. During the 1968 Tet Offensive, 688 patients were processed within the Pacific...
Aeromedical Evacuation System on a single day. In May 1968, 12,138 casualties were evacuated from Vietnam on 154 AE missions. By 1969, the Military Airlift Command AE system evacuated an average of 11,000 casualties per month. An all-time single-day high of 711 patients were moved out of Vietnam on March 7, 1969. In the closing months of 1969, patient movements began to decline to less than 7500 per month.\textsuperscript{1} During the Vietnam War, many advances were made in AE.\textsuperscript{1} An important finding was that wartime casualties did not do as well if prematurely placed on long flights. For this reason, patients were stabilized in combat hospitals and then transported to offshore islands for definitive treatment. Patients were allowed to convalesce and then either be returned to duty or transported back to the United States for prolonged treatment. The average stay in-theater prior to long-distance AE was more than 1 week.\textsuperscript{4} Although Saigon fell in 1975, the Pacific AE system stayed relatively unchanged for many years.

**Post-Vietnam War**

In 1975, responsibility for the DoD AE mission was shifted to the Military Airlift Command and remained there for the next 17 years. Four active-duty AE squadrons and 28 Reserve and Guard units maintained the peacetime AE system and remained on standby for any worldwide contingency. Anytime and anywhere there was a disaster, bombing, or contingency, the AE system was there. The three primary aircraft used for AE during this period were the C-9A Nightingale, C-141 Starlifter, and C-130 Hercules.

The USAF AE system participated in many noteworthy missions in the next two decades.\textsuperscript{3} In 1975, USAF AE participated in Operation Babylift out of Saigon. During this operation, a C-5A Galaxy crashed due to mechanical problems, resulting in the single greatest loss of life during an AE flight. In 1977, active and reserve AE units assisted in the transport of those injured in a B-747 collision in the Canary Islands. In 1983, more than 400 wounded were
evacuated from Grenada during Operation Urgent Fury. Several hundred wounded were evacuated from Panama in Operation Just Cause in 1989. In 1990, elements of the US Air National Guard and USAF Reserve formed a provisional Aeromedical Evacuation Squadron in Saudi Arabia as part of Operation Desert Shield. The USAF AE system played a vital role in Somalia in 1992 and 1993 during Operation Restore Hope. Routine AE missions continued to be flown in the Balkans to support the military operations there. From the post-Vietnam era until today, the AE system has remained relatively stable in its routes, airframes, and missions.

The Present

In the last half of the 1990s, AE underwent further evolution in response to changes in US military doctrine. Modern conflict has resulted in fewer casualties with little lead time. Critically ill patients have had to be evacuated long distances to the nearest comprehensive medical facility because there has often been inadequate time to set up a contingency hospital. This has required the movement by the US AE system of stabilized in contrast to stable convalescing patients. This, in turn, requires the ability to provide intensive care during AE. To this end, the USAF has developed Critical Care Air Transport Teams to augment regular AE crews.

The complexity of contingency AE has resulted in administrative changes in the AE system as well. The DoD has assigned the role of setting policy for the flow and care of military casualties worldwide to the US Transportation Command. Overall responsibility for AE training, patient care standards, and patient care equipment standardization has remained the responsibility of the Air Mobility Command.

In some cases, history almost appears to repeat itself. AE has gone full circle from the days of the Jenny and the Cox-Klemmin, air transporting only two patients in a small plane. Today, many urgent military AE missions utilize the C-21, which can hold a maximum of two litters and a limited medical crew. This is also the case for civilian air ambulances and helicopters. But, we have come a long way from the small airplane with an open cockpit to a jet aircraft with a medical platform that supplies oxygen and electrical capabilities and carries a crew trained in critical-care-in-the-air skills.

The history of AE continues to be written. With the rapid technological advances in both air travel and medicine, it is only natural that AE continues to be refined and reengineered on almost a daily basis.

References

Civilian aeromedical evacuation (AE) has evolved extensively over the past several years. Not long ago, patients were deemed too sick to be transferred or kept at a community hospital facility until they were considered “stable.” Today, critical patients (such as those on biventricular assist devices, intra-aortic balloon pumps, etc.) are transferred by aircraft to tertiary centers on a routine basis.

Civilian AE has come a long way from its humble beginnings as a derivative of military transport. This is primarily because there are considerable differences between military wartime transport and civilian peacetime transport. In times of war, the echelons of care are well defined, the mode of transport is usually known, and the receiving facility is certain. Peacetime air medical transport is a different story, primarily because of the multiple considerations involved in the transfer of the critically ill patient.

The political and logistic considerations involved in transport of a critically injured or ill patient in times of peace often exceed any conflicts encountered when moving patients in times of war. Politics are injected into even the simplest patient transfer by third-party insurance and other contractual agreements (eg, HMOs, PPOs, out of network, etc.). These agreements often dictate which AE service must be used and to which hospital the patient can be transferred. Other variables that must be considered for civilian AE include the crew configuration, the mode of transport (ie, ground vs air, rotary wing vs fixed wing), and which conditions preclude transportation. This last issue merges into the liability issues that are unique to civilian AE. This chapter will update the civilian and military physician on the different types of civilian air transport and the clinical considerations that must be considered in peacetime AE.

Ground Transport vs AE

There are two principal factors that should be taken into account when considering AE: time and treatment. For most patients, such as those with multiple trauma, the most important advantage that AE has over ground transportation is the decreased time required for transport to a trauma center. However, for other patients continuation of critical care is the most important aspect of the transportation. When a patient in cardiogenic shock is on an intra-aortic balloon pump or extracorporal membrane oxygenation (ECMO) device, the requirements for medical expertise and careful management are more important than speed. Survival of the patient is the obvious absolute priority. Sometimes it seems to take an inordinate amount of time to prepare the patient for safe transport. However, this preflight preparation may be lifesaving in complicated cardiac or neonatal cases.

In addition to time and treatment, a third factor to consider is the physical environment that separates the patient from the destination. In some cases, a 45-minute flight over a mountain range may replace a 3-hour ambulance ride over rough terrain. In other cases, the roads
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may be straight and flat but a 1-hour flight can replace a 4-hour ambulance ride in and out of city traffic. Because the length of time the stabilized patient spends between medical facilities increases the risk of medical decompensation, this is not a trivial issue. The physician must weigh all of these factors when making the decision to transport a patient by ground transportation or AE.

Types of Aircraft

The mission profile of an AE service is established by a combination of the type of aircraft used and the ability of its aeromedical crews. Aircraft used for AE differ dramatically in their safety profile, range, and payload capabilities. The medical experience and expertise of aeromedical crewmembers can also be widely variable. A firm knowledge of these factors will help the physician optimize the chances of safe transfer for the patient, even if the patient suddenly decompenses during flight.

Rotary-Wing Aircraft

Most community hospitals rely on the local rotary-wing aeromedical services for transporting a patient to a tertiary care center because they can land on or near both medical facilities and accident sites (Fig 3.1). In general, twin-engine helicopters are favored for their increased load capacity and added safety (Table 3.1). The larger the aircraft and engine, the more versatile payload capability and the greater the range, which can vary from 300 to over 500 statute miles. In places where weather can become a factor, an aircraft equipped to fly by instrument flight rules (IFR: “in the clouds”) is preferred over those that can only fly by visual flight rules (VFR: “visual reference with the ground”). The ability to determine the aircraft’s position by global positioning satellite (GPS) is also a desirable feature to help the aircraft get to the exact location of a distant medical facility or accident site, even in inclement weather. Another helpful feature, which is not standard in most rotary-wing aircraft, is a second pilot. A second set of hands and eyes, especially at an uncontrolled landing site or in changing weather conditions, can be an invaluable asset. Emergency Medical Service (EMS) crews often wait for the “thumbs-up” from the pilot to ensure safe approach to the running aircraft. In this respect, the second pilot adds another set of eyes for safety in and around the operating aircraft (Fig 3.2).

Figure 3.1. Civilian rotary-wing aircraft require a 100- × 100-ft loading area free of debris and obstruction (photo by Frank S. Sallie).
In our experience, the dual-pilot, IFR-rated Sikorsky S-76 has proven to be a versatile aircraft for transporting several trauma patients or for handling complex equipment needs such as dual isolettes, balloon pumps, and ECMO machines (Fig 3.3). Many hospital-based AE services utilize smaller rotary-wing aircraft such as the BK 117.

The type of aircraft utilized will depend on the mission profile of the aeromedical service. A single-pilot A-Star aircraft with VFR capability is probably appropriate for a service in a hot desert environment in Arizona, where sunshine predominates. Whereas areas such as Seattle, Cleveland, or Buffalo may benefit from a larger aircraft with IFR capability, or the addition of a second pilot, because snow and moist climates make for more difficult flying conditions. Budgetary restraints are also having an impact on which airframe is used. The cost of parts, fuel, and refurbishment continue to rise. This, in addition to shrinking reimbursements for critical care transports have caused many hospitals to change their airframes or

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**Table 3.1. Comparison of helicopters commonly used for civilian medical transport.**

<table>
<thead>
<tr>
<th></th>
<th>Bell 206</th>
<th>Bell 222</th>
<th>EuroCopter Dauphine</th>
<th>EuroCopter BO-105</th>
<th>EuroCopter BK-117</th>
<th>Sikorsky S-76B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine configuration</td>
<td>Single</td>
<td>Twin</td>
<td>Twin</td>
<td>Twin</td>
<td>Twin</td>
<td>Twin</td>
</tr>
<tr>
<td>Range (statute miles)</td>
<td>369</td>
<td>434</td>
<td>578</td>
<td>345</td>
<td>324</td>
<td>403</td>
</tr>
<tr>
<td>Maximum cruise speed</td>
<td>127</td>
<td>156</td>
<td>183</td>
<td>149</td>
<td>153</td>
<td>178</td>
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<tr>
<td>Maximum takeoff weight (lb)</td>
<td>4450</td>
<td>8250</td>
<td>9369</td>
<td>5511</td>
<td>7385</td>
<td>11,700</td>
</tr>
<tr>
<td>Useful load (lb)</td>
<td>2163</td>
<td>4874</td>
<td>4341</td>
<td>2643</td>
<td>3545</td>
<td>7623</td>
</tr>
<tr>
<td>Rotor diameter (ft)</td>
<td>37</td>
<td>42</td>
<td>39</td>
<td>32</td>
<td>43</td>
<td>44</td>
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<tr>
<td>Passenger compartment interior (ft)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>6.7</td>
<td>9.2</td>
<td>8.0</td>
<td>14.1</td>
<td>9.4</td>
<td>7.9</td>
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<tr>
<td>Width</td>
<td>3.9</td>
<td>4.2</td>
<td>6.3</td>
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<td>5.5</td>
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<tr>
<td>Height</td>
<td>3.8</td>
<td>4.8</td>
<td>4.5</td>
<td>4.1</td>
<td>4.2</td>
<td>4.5</td>
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**Figure 3.2.** A secondary pilot gives the “thumbs-up” signal, signifying that it is safe to approach the aircraft (photo by Frank S. Sallie).
to get out of the business of air transport altogether.

**Fixed-Wing Aircraft**

While some helicopters have a range of around 300 to 400 miles, the fixed-wing turbo prop or jet aircraft has a range varying from hundreds to thousands of miles. Fixed-wing aircraft also travel at much greater speeds. A rotary-wing aircraft must rely on its main rotor for both generating lift and creating forward thrust for flight, thus reaching a practical limit of around 200 knots. In contrast, modern AE Lear Jets routinely cruise at 400 knots, decreasing the time taken to travel long distances by more than half. Fixed-wing aircraft do, however, have several drawbacks compared to rotary-wing aircraft.

The greatest disadvantage of fixed-wing aircraft is that they require an airport. This means an additional ground ambulance trip to and from the airport on both the referring and receiving sides of the transport.

A second drawback is that loading and unloading of the patient is in general more difficult with a fixed-wing aircraft when compared to a rotary-wing aircraft. Many of the rotary-wing aircraft have been extensively modified with patient transport in mind. Because high-speed flight limits engineering options, most civilian fixed-wing aircraft modified for AE (eg, the Lear Jet) are still relatively difficult to load litters into. In some aircraft, the doors and cabin are so narrow that a litter must be rotated up to 30 degrees about its long axis to be loaded. Unfortunately, some patients or equipment may not be able to tolerate these movements. Fortunately, large military aircraft used for AE (eg, C-9A, C-130, C-141) do not share these problems (see chapter 8).

It should be noted that some companies use their fixed-wing aircraft only part time for AE. For economic reasons many jet AE operators use their aircraft to move business people when not moving patients. A certain amount of time may be needed to convert their aircraft to a medical configuration and acquire the appropriate medical crew. In these cases, the referring physician should assure that the AE service is in compliance with Federal Aviation Regulation Part 135 for air taxi operation and is accredited by the Commission on Accreditation of Medical Transport Systems. Most large tertiary-care hospitals have fixed-wing AE services they utilize on a frequent basis, and thus
will be able to recommend a particular service to the referring physician. Military AE during peacetime is arranged through Air Mobility Command via the Global Patient Movement Requirements Center (GPMRC). The GPMRC is a joint service agency under the US Transportation Command (USTRANSCOM) responsible for coordinating military AE between theaters (eg, from Europe to the United States) throughout the continental United States (CONUS), and from nearby offshore locations such as Puerto Rico. It is extremely important to give the TRANSCOM officer as much information about the patient and requirements as possible so that the appropriate decision can be made whether to utilize USAF or civilian AE aircraft. USTRANSCOM maintains a list of commercial providers that meet the appropriate professional standard, which includes the specific medical capabilities of each provider.

AE Crew Configuration

The composition of an aeromedical flight crew is designed to safely carry out transport of the patient or patients and manage any adverse sequela that may result from either the disease process or the act of transporting the patient. The type of mission being flown will determine the specific makeup of the crew. However, for both logistic and economic reasons, physicians are often not part of the crew of routine AE flights. In any case, the diversity of skills found in mixed crews (nurse–physician, nurse–paramedic, and nurse–respiratory therapist) may be more advantageous than crews of like training (nurse–nurse, paramedic–paramedic).

Physician–Nurse Crews

Several AE services that operate from a tertiary-care facility, including our service at Metro Life Flight, have a medical crew consisting of a physician and critical care nurse (Fig 3.4). This crew mix is necessary to care for the types of patients who are routinely transported to a level-one trauma and burn center and cardiac surgical referral centers. Advanced training and expertise is required to operate medical devices such as intra-aortic balloon pumps, ECMO devices, and biventricular assist devices and care for complex trauma casualties during flight. The on-board physician adds certain procedural expertise and a broad

**Figure 3.4.** A MetroHealth Life Flight medical crew consisting of a physician and critical-care nurse are assisted by an emergency medical service (EMS) at the roadside (photo by D.S. Resch).
knowledge base that can be particularly useful in the complicated patient. The presence of a physician also eliminates the need to contact base physicians for decision-making authority or permission to give certain drugs. If the transport service does not have an on-board physician, the referring physician will carry the bulk of responsibility and liability for that patient during transport until the patient is received by the accepting physician.

Nurse-Only Crews

Not all patients need a physician on-board. Many services use a crew consisting of two critical care flight nurses. This is particularly useful for the rotary-wing service, which provides mostly interhospital ICU to ICU transfers. Typically, AE flight nurses have at least 3 years of prior critical care or emergency medicine experience, and many are EMT or paramedic certified.

Nurse crews require medical control by a physician. This is ideally achieved using written protocols that allow the nurse to operate and perform medical duties under the license of the physician medical director. Another important aspect of medical control is the ability of the nurse to directly communicate with a physician when needed.

Nurse–Paramedic Crews

Many rotary-wing AE services use a relatively practical and cost-effective paramedic–nurse crew. The paramedic brings valuable and practical prehospital treatment experience to the team that often complements the critical care background of the flight nurse. This crew mix is advantageous when the majority of flights are accident scene evacuations but is less suited for the transport of critically ill patients, where additional physiology and medical knowledge is needed. An attempt to remedy this situation has been made by the development of the “critical care paramedic.” Unfortunately, a paramedic with this advanced training cannot be considered an equivalent replacement for a critical care nurse or a physician. However, paramedics do bring considerable expertise in regards to extrication and field care, training and expertise that is traditionally lacking in the nursing and physician education. Again, medical control is required as with any crew in which a physician is not present.

Military AE Crews

Even during peacetime, routine military AE aircraft are configured to transport 40 or more patients, both ambulatory and by litter. The standard AE medical flight crew consists of one flight nurse and three flight medical technicians for each 10 patients and thus is very flexible. For unstable patients, the crew is augmented with physicians with the special skills required. Because of the need to transport critically ill patients, the USAF has developed Critical Care Air Transport (CCAT) Teams. Each team is made up of a critical care physician, a critical care nurse, and a respiratory therapist trained in AE of critically ill patients.

When contracting with GPMRC/USTRANSCOM for fixed-wing AE services, it is important for the referring physician to give as much information to the transport coordinators as possible so that they can assist in tailoring a transport team that will meet the needs of the patient. If the referring physician believes his patient requires a physician–nurse team, then he must make this specific request known to the USTRANSCOM representative. The makeup of the provider team allocated to the flight may be expressed in terms of aeromedical crew member levels, which gives numerical designations to crew members based on level of training (Table 3.2).

Types of Patients Requiring Transport

The predominant diagnoses are remarkably similar in both the peacetime military and civilian communities, namely, childbirth, heart attacks, strokes, accidents, and infections. Likewise, many hospitals in both the military and civilian communities have specific limitations to their care based on their diagnostic and therapeutic capability and/or the experience level of their staff. For this reason, it is often necessary in both systems to transfer patients to a higher
level of care offered at a tertiary center (Table 3.3).³

When the capabilities of your medical facility have been exceeded, there are several steps necessary to effect a safe transfer. First, you must confirm that the gaining facility has the capability to meet all of the patient’s requirements. This is usually accomplished by direct communication with the receiving physician. Next, you must identify which AE service is the best qualified to carry out the transfer because their capabilities may be vastly different. The referring physician must be comfortable that the patient will fall well within the AE service’s mission profile, even in the “worst case” medical scenario. The crew should always have ample supply of the medications needed to support the patient in case of an unscheduled landing or diversion due to aircraft mechanical failure, weather, or other unforeseen circumstance. A general rule of thumb is to have three times the calculated amount on hand.

### Cardiac Patients

Cardiac patients are among the most common critically ill patients transported by civilian AE. The most common scenario is a patient with an acute myocardial infarction who has not responded adequately to thrombolytic therapy at a local medical facility. Because urgent

<table>
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<tr>
<th>Table 3.2. USAF aeromedical crew member levels.</th>
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<tbody>
<tr>
<td>Level</td>
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<tr>
<td>1</td>
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<thead>
<tr>
<th>Table 3.3. Patients requiring air medical transport.</th>
</tr>
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<tbody>
<tr>
<td>General considerations</td>
</tr>
<tr>
<td>Optimal scene time or time for interhospital transport dictated by patient’s illness or injury</td>
</tr>
<tr>
<td>Distances to be covered, local geography, and traffic conditions</td>
</tr>
<tr>
<td>Carrier and personnel availability</td>
</tr>
<tr>
<td>Weather conditions</td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td>Trauma/scene</td>
</tr>
<tr>
<td>Trauma center evaluation needed and with ground transport greater than 15 min</td>
</tr>
<tr>
<td>Mass casualty with local facilities exceeded</td>
</tr>
<tr>
<td>Mechanism of injury consistent with high-impact trauma</td>
</tr>
<tr>
<td>Rural location</td>
</tr>
<tr>
<td>Trauma/interhospital considerations</td>
</tr>
<tr>
<td>Head injury with Glasgow less than 13, lateralizing signs, or open injury with CSF leak</td>
</tr>
<tr>
<td>Spinal cord injury</td>
</tr>
<tr>
<td>Widened mediastinum, major chest wall injury, or blunt or penetrating cardiac injury</td>
</tr>
<tr>
<td>Patients requiring protracted ventilation</td>
</tr>
<tr>
<td>Pelvic ring disruption with shock and evidence of continuing hemorrhage; open pelvic injury</td>
</tr>
<tr>
<td>Severe facial injury with head injury</td>
</tr>
<tr>
<td>Concomitant head injury and other body system injury</td>
</tr>
<tr>
<td>Multiple fractures</td>
</tr>
<tr>
<td>Burns with associated injuries</td>
</tr>
<tr>
<td>Auto crash or pedestrian injury with velocity greater than 25 mph</td>
</tr>
<tr>
<td>Intrusion into vehicle by 20in or greater</td>
</tr>
<tr>
<td>Ejection of patient or rollover</td>
</tr>
<tr>
<td>Death of occupant in same crash</td>
</tr>
<tr>
<td>Penetrating injury to the abdomen, neck, head, or thorax</td>
</tr>
<tr>
<td>Fall greater than 15–20ft</td>
</tr>
<tr>
<td>Age greater than 55 or less than 5 with comorbid injuries</td>
</tr>
<tr>
<td>Known metabolic or cardiac disease with comorbid injuries</td>
</tr>
<tr>
<td>Burns requiring burn center evaluation and treatment</td>
</tr>
<tr>
<td>Late secondary criteria</td>
</tr>
<tr>
<td>Sepsis</td>
</tr>
<tr>
<td>Prolonged ventilation with pulmonary rehabilitation needed; ARDS aggressive tertiary care</td>
</tr>
<tr>
<td>Single- or multiple-system failure</td>
</tr>
<tr>
<td>Major tissue necrosis</td>
</tr>
<tr>
<td>Medical</td>
</tr>
<tr>
<td>Rescue angioplasty or CABG</td>
</tr>
<tr>
<td>Advanced tertiary care for multisystem failure</td>
</tr>
<tr>
<td>Sepsis</td>
</tr>
<tr>
<td>Acute abdomen in a facility with no surgical support</td>
</tr>
<tr>
<td>Need for tertiary care realized</td>
</tr>
</tbody>
</table>

Source: Adapted with permission from Blumen and Rodenberg.³
ventricular assist devices and some biventricular devices have mechanical mechanisms that can be used to maintain patient perfusion in the event of pump or power failure. Intra-aortic balloon pumps, however, will need manual inflation and deflation of the balloon to avoid thrombosis.

For patients with profound cardiogenic shock, positioning in fixed-wing aircraft is also an important consideration. When possible, the patient’s head should be oriented toward the rear of the aircraft so that the acceleration of the aircraft during take-off will force the blood toward the brain and heart instead of away from it. This essentially gives the patient a momentary boost in preload.

Dissecting Aortic Aneurysm
A symptomatic aortic aneurysm, usually related to atherosclerosis or hypertension, is another common indication for civilian AE. In-flight leaking or rupture manifests as increased pain and hypotension. The only effective method to sustain the patient long enough to get to the operating room is the liberal use of blood products and isotonic volume expanders. Although many referring physicians request a surgeon accompany their patients in case of rupture, there is no record of a successful thoracotomy in flight for this disease process, nor is it likely that one could be accomplished.

Recent Cardiac Arrest
It is sometimes necessary to transport by AE a patient who was recently resuscitated from cardiac arrest and who is still moderately hemodynamically unstable. The crew must have all necessary equipment to carry out further resuscitation (eg, defibrillators, airways, oxygen, suction, etc.) in the event the patient arrests in flight. In addition, several antiarrhythmic drugs of differing classes (eg, beta-blockers, calcium channel blockers, magnesium, amiodarone, lidocaine, procainamide, etc.) should be available. If there is any question regarding need for cardioversion, it should be done prior to flight. There is no benefit in adopting a “wait and see” attitude because of the difficulties attending to an in-flight cardiac arrest.
3. Emergent Evacuation of the Peacetime Casualty

Figure 3.5. A flight surgeon performs an in-flight echo with a sonoheart portable echocardiography machine (photo by Frank S. Sallie).

Figure 3.6. When specialty equipment is used in-flight (e.g., biventricular assist devices and intra-aortic balloon counterpulsation) the AE crew must have special training and expertise for safe transport (photo by Frank S. Sallie).
Intracranial Hemorrhage

Patients with intracranial hemorrhage may need to be transferred by AE so that they can receive either medical or surgical treatment. Patients with ischemic stroke may need to be transported to the tertiary facility within 3 hours from time of onset to receive appropriate thrombolytic therapy and possible angioplasty. The aeromedical crew should be prepared to provide an emergency airway should the patient’s condition deteriorate. Seizures should be anticipated and prepared for by having appropriate amounts of anticonvulsants available for use.

Patients with hemorrhagic stroke or intracranial hemorrhage secondary to trauma may be transferred so that they can receive emergency neurosurgical treatment. The aeromedical crew should ensure that the patient has a patent airway and an adequate gag reflex, and be prepared to provide emergent airway intervention if the patient deteriorates in-route. A worsening neurological exam during flight is important information to the surgeon because it may indicate the need for expedient surgical intervention. It is for this reason that routine chemical paralysis should be avoided unless warranted by the patient’s condition. This will help the aeromedical crew identify a worsening neurological exam in a more expeditious manner.

Patients who have already had neurosurgery for head trauma are at risk of increased cerebral edema secondary to changes in atmospheric pressure during AE using fixed-wing aircraft. Ventricular shunts and osmotic diuretics may decrease this risk. However, care must be taken to keep the cerebral perfusion pressure within a reasonable level by keeping the mean arterial pressure high enough to avoid compromise of the cerebral perfusion pressure. For this reason, it is sometimes necessary to add dopamine to the patients list of intravenous medications.

Pulmonary Patients

There are some important considerations in patients with pulmonary disease, regardless of whether it is of medical or traumatic origin. The change in atmospheric pressure, especially during fixed-wing AE, can be enough to cause significant changes in oxygenation or ventilation of a patient.

Medical Conditions

Patients with pulmonary disease can pose major challenges to the aeromedical transport team. The first concern of the crew should be maintenance of the patient’s airway. Patients with a decreased mental status, heavy secretions, or labored breathing should be intubated prior to transport because their condition will almost certainly worsen at altitude.

The most difficult pulmonary cases are those patients with severe adult respiratory distress syndrome (ARDS) who are not adequately oxygenated despite intubation and positive pressure ventilation. A patient whose oxygen saturation is only 90% despite being on a ventilator with an FiO₂ of 100% and 15 cm of positive end-expiratory pressure (PEEP) will probably not tolerate AE.

Pulmonary Trauma

The aeromedical crew should be vigilant in monitoring for changing dynamics that may occur in the traumatized patient with chest injuries and be prepared to provide the necessary treatments. Placement of a definitive airway may be needed in patients with concomitant pulmonary injuries. Complications that arise from positive pressure ventilation must also be watched for and treated, especially in the traumatized patient. Pneumothorax is an especially important issue for AE patients because even a simple 20% pneumothorax at sea level will expand at altitude and may lead to total collapse of the lung. A traumatic pneumothorax of any size requires the placement of a chest tube with a Heimlich valve prior to AE. Tension pneumothorax discovered in-flight should be treated and relieved by needle thoracostomy. A significant air leak or a hemopneumothorax that develops in-flight will require placement of a thoracostomy tube if a qualified AE crewmember is available.

Neonatal Transportation

Neonates absolutely require specialized teams and equipment for safe transport. The equipment and personnel necessary to accomplish
this mission account for a large part of any flight program’s budget, despite the fact that they may account for less than 25% of the volume of business. Dedicated AE crews trained solely for the transport and care of the neonate patient are ideal. Neonatal nurses and physicians usually replace the routine adult or pediatric team members for these specialized transports.

The heavy and cumbersome equipment needed for neonatal transport (eg, isolette, ventilator, and specialized supplies) adds significantly to the overall weight of the aircraft. Many small rotary-wing aircraft can carry only one incubator and thus require either multiple flights or multiple aircraft to transport twins or higher-order multiple births. Larger aircraft are capable of carrying twin isolettes and crews, but careful consideration of weight and balance on the part of the pilot(s) is needed. ECMO units or high-frequency jet ventilators require additional qualified personnel as well.

Rarely is a neonatal transport a “load and go” situation. Considerable time is expended at the referral facility to achieve adequate stabilization and preparation for safe transport of the neonate. Optimization of ventilation, oxygenation, and temperature control is critical to successful AE transport of the neonate. Environmental temperature, altitude, and travel distance are factors that are weighed in the clinical decision-making process by the neonatal flight crew and greatly impact the amount of time spent at the referral facility in preparation for transport.

Obstetric Patients

Obstetric transport requires considerable skill and confidence on the part of the aeromedical crew. It is required whenever the referral facility is unable to provide the needed level of service to either the mother or neonate. Indications for maternal transportation include preterm labor, premature rupture of membranes, eclampsia and preeclampsia, abruptio placenta, and placenta previa. AE crews who perform emergency obstetric transport must be ready to assist the mother and provide the initial neonatal resuscitation should a precipitous birth occur.

Certain careful considerations must be made before transporting the obstetric patient. First, the patient in active labor who is dilated beyond 6cm should not be placed on the aircraft because it is difficult to effectively assist the mother in the small environment of the aircraft. If the patient is in advanced labor, it is far safer to deliver the infant at the referral institution and then transport the mother and child postdelivery.

In all cases of emergency maternal AE, the patient should be transported on a litter and receive nasal oxygen at 4L/minute. If there is any sign of maternal or fetal compromise, the patient should be supine and in the left Trendelenburg position. A large-bore intravenous catheter should be in place to allow the administration of fluid or blood in the event the patient requires aggressive resuscitation. In-flight portable ultrasound has been used to make fetal heart rate determinations, as it offers the advantage of being able to visualize the heart rate. Doppler techniques used in the past are limited due to the noise-filled aeromedical environment. External electronic fetal monitoring can be used. However, the medical utility of this has not been demonstrated because there is little that can be done in-flight in the event of an ominous tracing.11

Pediatric Patients

Emergent transport of a child occurs for a number of reasons, but the majority of emergent evacuations in the pediatric population come about either due to traumatic injury, sepsis, or airway compromise.

Trauma

After the first year of life, trauma is the leading cause of death in the pediatric population. Burns, smoke inhalation, drowning, blunt traumatic injury, spinal cord injury, child abuse and neglect, falls, and suicide collectively add to the epidemic number of pediatric deaths and disabilities that occur each year. It is not uncommon for children to engage in dangerous adult behaviors that put them at significant risk for death and serious injury. Of particular concern is the rise in penetrating trauma in the pediatric population related to gun and knife wounds associated with gang activities and drug-related violence.
There are specific differences in pediatric trauma that are of interest to the aeromedical crew. First, pediatric trauma patients are much more likely to sustain head injury than their adult counterparts. This is related to the fact that, in children, the head accounts for a large body surface area and relative weight in comparison to the remainder of the body. Secondary brain injury occurs as a result of hypoxia, hypercapnea, hypovolemia, seizures, and cerebral edema, all of which can lead to an increase in intracranial pressure (ICP). During AE, cerebral perfusion can be optimized by intubation and mild to moderate hyperventilation.

The second important difference in children is that they do not show signs of hemodynamic decompensation until late in the course of the disease process. Hypotension is a late sign in the pediatric trauma patient, and thus tachycardia should be used in the child to gauge the need for fluid resuscitation. If needed, the aeromedical crew should begin fluid resuscitation with repeated boluses of isotonic solution (20 cc/kg). If multiple fluid boluses fail to stabilize the pediatric trauma patient, blood products may be required.

**Sepsis**

The toxic-appearing child can have a rapidly progressive downhill course and thus warrants special consideration on the part of the flight crew. Emergency in-flight treatment consists of bolus intravenous fluid therapy, vasopressors, and broad-spectrum intravenous antibiotics.

**Airway Compromise**

The pediatric airway is short and small in comparison to the adult airway and thus is particularly susceptible to obstructions from conditions such as asthma, croup, epiglottitis, and foreign body. One millimeter of tissue edema decreases the pediatric airway lumen by a factor of four. Unfortunately, the usual seatbelt harness by which we normally ensure safe transport in a seated position may prevent these patients from assuming a sniffing position when necessary. Lethargy and bradycardia are ominous signs in this population and are precursors to impending respiratory arrest. Should a child with an airway problem begin to deteriorate, the flight crew must be prepared to obtain an emergency airway.

The crew must be capable of obtaining an emergent airway in a matter of minutes, most commonly by endotracheal or nasotracheal intubation. Transtracheal jet insufflation may be lifesaving in these patients if endotracheal intubation is impossible or impractical. Because carbon dioxide begins to accumulate immediately, this is a temporary solution and retrograde intubation or completion of the surgical airway is necessary.

**Trauma Patients**

The evacuation of the trauma patient in peacetime usually falls into one of two categories: acute and convalescent. The acute phase usually refers to the aeromedical team responding to the scene of an accident or a smaller community hospital to provide emergent care and evacuation for the acutely injured patient. The care provided is consistent with the Advanced Trauma Life Support primary survey and treatment (see chapter 12). Scene stabilization is usually limited to airway interventions, containment of gross hemorrhage, and spinal immobilization. Chest tubes, intravenous lines, blood infusion, and other modalities are usually initiated and continued in-flight to prevent delay in transport of the patient to a trauma center. Our program also performs the focused abdominal sonography for trauma (FAST) ultrasound during flight to identify patients with hemoperitoneum to expedite triage at the trauma center. Thus, the aircraft and crew are an extension of the trauma team, bringing critical-care skills to the patient in the field. 

Airway management is perhaps the single most important aspect in the care of a trauma patient. AE crews must be able to establish and maintain an airway in the most difficult patients, even in the vibrating, noisy, poorly lit environment of an aircraft in flight. Medications for rapid-sequence intubation are used frequently by the crews. If an airway cannot be established by the oral–tracheal route, then the crew need to be prepared to rapidly establish
an airway surgically. Other resuscitation measures utilized by AE crews, such as chest tube placement, intravenous lines, thoracotomy equipment, ultrasound, and blood products, are all useless if the patient does not have a patent airway.

The second category of trauma patients requiring aeromedical evacuation is the convalescent category. These patients have already been stabilized and many times have already had surgery at the referring institution but require either specialized care or perhaps rehabilitation closer to home. Such patients rarely require acute interventions on the part of the flight crew but may need adjustments in their therapy or equipment to ensure safe travel and transport.

Conclusion

The sickest of patients can be transported by AE under the right circumstances with the right crew capabilities. The civilian aeromedical industry has a wide variety of aircraft, medical configurations, pilot configurations, and capabilities. It is important, both from a medico-legal and patient care standpoint, for any who wish to transport a patient by air to know what transport capabilities are available in the local area. It is also important to know the limitations and contractual agreements of both the sending and receiving medical facilities. Prior to transport, the physician must be aware of the preflight preparation based on the patient’s condition and disease process, especially in light of the potential impact that barometric pressure changes and exposure to the elements can have on the patient. Safe patient transportation by air depends on careful planning and a reasonable understanding of the process of AE.

References

Military aeromedical evacuation (AE) must necessarily focus on the combat casualty. To this end, it is useful to explore the history and recent experiences of war. In addition, the new millennium brings forth a whole new array of military contingencies including stability support operations, humanitarian missions, and reactions to terrorist actions. This chapter will provide a brief overview of these important historic elements and attempt to shed light on what the immediate future may hold for AE operations. In addition, a brief overview of the principles of modern combat casualty care will be presented to highlight the current state of the art in tactical care.

History of Combat Medicine

Armed Conflict of the Past

The history of combat medicine is as old as that of armed combat. The first reliable evidence of combat wounds comes from ancient Egypt around 2000 BC. A mass grave of some 60 soldiers shows evidence of wounds and arrows still in the body. Later, the Greeks developed a crude system of caring for casualties of battle, and arranged special barracks or ships (“klisiai”) for their care. During this era, surgical care was crude and consisted of removing arrowheads and barbed spears by either pushing them through or enlarging the hole with a knife. Treatment for pain relief and infection prophylaxis was limited to oral or topical plant extracts, and songs and charms were used to treat hemorrhage.

The Romans advanced combat casualty care by establishing a series of Valetudinarian, or casualty care centers, during the 1st and 2nd Centuries AD. The Romans also established a medical corps in the legions. Epitaphs record at least 85 Roman army physicians. Following the fall of the Roman Empire, there is little recorded evidence of other major advancements in combat casualty care until well over a millennium had passed.

In the late 16th Century during the French–Spanish civil and religious wars, the French physician Ambrose Paré pioneered the use of both ligature to achieve hemostasis (instead of cautery) and nutritional care to speed recovery. In the early 19th Century, another French physician, Dominique Larrey, pioneered the use of triage to care for wounded combatants. He also developed the concept of “far forward care” by putting hospitals and surgeons close to the battle lines.

In the late 19th Century, anesthesia was introduced and the era of modern care began. Unfortunately, death, disability, and disfigurement remained common. For example, during the Crimean War (1853 to 1856) the mortality rate from penetrating abdominal wounds was 93% for English and 92% for French soldiers. During the American Civil War, the Union Army experienced a similarly high mortality rate of 87% from penetrating abdominal wounds.

Other contributions made during the 19th Century included the introduction of wound
antisepsis by Lister and nursing care by Florence Nightingale. Despite these advances, mortality ranged from 14% to 31% for extremity gunshot wounds and 26% for amputations.\(^7\)

By the end of World War (WW) I, the mortality rate from abdominal wounds had declined from 85% to 56%, an improvement attributed to early surgery.\(^8\) Blood transfusion therapy also began in WW I. Further refinements were brought to combat casualty care during WW II, including better evacuation, anesthesia, and surgical technique (Fig 4.1). Antibiotic therapy, in particular penicillin, dramatically changed the outcomes of many cases and brought the first effective treatments to sepsis and gangrene. Anti-infective agents (eg, penicillin, sulfa drug, and quinine) also began to impact disease, long the biggest killer on the battlefield.

The combination of disease and nonbattle injuries (DNBI) represents a tremendous threat to both the collective mission and the individual combatant. Historically, DNBI has accounted for more combatant deaths than all other causes combined. During armed conflicts, US forces have historically sustained only 20% of casualties from battle, with the balance being DNBI.\(^9\) In 1942, 55% to 65% of the US Forces planning to attack Guadalcanal contracted filariasis, an invasion of the lymph system by a parasitic roundworm that can cause inflammation, abscesses, and elephantiasis. Also during WW II the famous unit, Merrill’s Marauders, suffered nearly 100% attack rates of diarrhea while in Burma. The disease was so uncomfortable that it is said an entire platoon cut the seats off their pants because the severe diarrhea had to be relieved during gun battles.\(^9\)

Figure 4.1. Casualties aboard a lighter on the island of New Georgia, SW Pacific, 1943 (USA Signal Corps photo by Wendlinger, courtesy of USA Center of Military History).
Environmental factors, too, have plagued warriors throughout the ages. The brutal Russian winter halted the overwhelming advances of both Napoleon’s army in the 19th century and Hitler’s forces a century later. In contrast, excellent logistics and good preventive medicine reduced US heat casualties in the Saudi desert during Operation Desert Storm. In future conflicts, DNBI will most likely continue to compromise the largest fraction of casualties. The AE system must be capable and prepared to handle these problems.

Combat stress or psychiatric disease has also plagued modern forces and was widely recognized by WW I. Data from Vietnam and the 1982 Lebanon War shows that some conflicts may generate an exceptional number of combat stress casualties. By the close of the Vietnam War, a combat stress casualty rate of 2.5% was reported, equivalent to just under half the wounded-in-action rate.\(^\text{10}\) Up to one fourth of all hospitalized casualties were neuropsychiatric in nature. During Operation Desert Storm (1991), in contrast, few serious combat stress cases resulted despite a long and often tedious buildup phase. This improvement has been attributed, at least in part, to the avoidance of sleep deprivation and dehydration and the regular use of critical incident stress debriefings.\(^\text{10}\)

During both the Korean and Vietnam Wars, mortality from combat wounds continued to decrease (Table 4.1). This change for the better is believed to reflect the combined improvements in evacuation, resuscitation, and surgical and postoperative care.\(^\text{2}\) During the Vietnam War, helicopter transport from the point of injury to hospital was common, as was the administration of intravenous fluids by trained enlisted medics (Fig 4.2).

**Table 4.1.** US combatants dying of combat wounds during selected wars.

<table>
<thead>
<tr>
<th>War</th>
<th>Period</th>
<th>% Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mexican</td>
<td>1846–1848</td>
<td>15</td>
</tr>
<tr>
<td>American Civil</td>
<td>1861–1865</td>
<td>14</td>
</tr>
<tr>
<td>Spanish–American</td>
<td>1898</td>
<td>7</td>
</tr>
<tr>
<td>WW I</td>
<td>1918</td>
<td>8</td>
</tr>
<tr>
<td>WW II</td>
<td>1942–1945</td>
<td>4.5</td>
</tr>
<tr>
<td>Korean</td>
<td>1950–1953</td>
<td>2.5</td>
</tr>
<tr>
<td>Vietnam</td>
<td>1965–1972</td>
<td>3.6</td>
</tr>
</tbody>
</table>

*Source: Adapted from USA data.*\(^\text{2}\)

![Figure 4.2. During the Vietnam War, the UH-1 “Huey” helicopter was extensively used to quickly evacuate casualties (USA photo taken 20 miles southwest of Dak To, 1967, courtesy of USA Center of Military History).](image)
Modern Military Operations

The post-Vietnam War era is marked by brief conflicts, often of high intensity but relatively light in casualty production. It is instructive to examine these conflicts, as they are likely to be more similar to future actions than the large-scale continental wars of the past. Other likely threats that will face the United States and allied forces in the foreseeable future include operations other than war, often referred to as “OOTW.” Most often, these will be in the form of stability support operations, such as humanitarian assistance and peacekeeping operations. The disease and injury patterns will most likely be different than those experiences during armed conflicts of the past (Fig 4.3).

The British experience in the Falkland Islands War of 1982 is typical of the modern, brief conflict. Over 500 casualties were evacuated out of the theater, including 233 postoperative patients who had received only resuscitative surgery. During the 1983 invasion of Grenada by US forces (Operation Urgent Fury), 18 US soldiers were killed, 116 were wounded, and 28 received nonbattle injuries. The US attack in Panama in 1989 (Operation Just Cause) resulted in 25 killed and 323 wounded in action in the 6-day operation.

These recent conflicts underscore important trends in medical support for regional conflicts. The first trend is the need for capable medical assets to accompany the assault force. There may be little or no time to establish traditional field hospitals in these brief conflicts. The shooting may be over before such a large hospital could be deployed and operating. The second trend is the requirement for rapid evacuation off the battlefield, often directly out-of-theater, which can require the AE system to handle casualties who may not have the benefit of complete stabilization. This was illustrated in Operation Just Cause, where the majority of the 275 serious casualties were evacuated directly from Howard AFB, Panama, to San Antonio, Tex. Some casualties arrived in San Antonio within 12 hours of their injuries. A third trend is the need for the medical assets accompanying the force to be fully capable of managing the types of patients anticipated. In Operation Just Cause, resuscitation and even some surgery was performed well forward of the traditional zones of care.

During Operation Desert Storm in 1991, the US military forces sustained only 331 US mortalities and 353 wounded in action. Ironically, most of the deaths resulted from noncombatant injuries and 107 were the result of allied fire (fratricide). Because of the large buildups of US forces in the region prior to the allied invasion, there was a large medical infrastructure available to handle many more casualties. It is uncertain, however, if the medical assets would have been effective in the face of the large casualty figures initially anticipated (as high as 40,000). It is even more uncertain if the future conflicts will allow the luxury of a 5-month buildup of combat and medical forces before the outbreak of ground hostilities.

The value of far-forward care and rapid evacuation is evidenced in the Soviet–Afghanistan War in the 1980s. Afghanistan guerrillas had no access to organized battlefield care and instead were forced to seek treatment 4 days’ travel time away in Pakistan. The hospital in Pakistan that treated many of these casualties reported few wounds of the head, neck, thorax, or abdomen, traditionally some of the most common types of combat injuries. Presumably, casualties with these types of injuries perished because of delays in care.

More recently, the shift in US operations has been toward stability support operations such as peacekeeping and humanitarian missions. These types of operations tend to be prolonged, involve only sporadic conflicts, and generate few combat casualties. Consequently, the need for a large surgical presence is diminished. Disease, nonbattle injuries, and preventable health risks (eg, sanitation and vector control) assume a greater importance, and the military medical system must be prepared for these types of needs.

Humanitarian missions, in particular, can present a real challenge for a military medical system designed for combat trauma. The Cuban
and Haitian refugee crises in the mid-1990s generated thousands of patients, many of whom were elderly or children. The lack of military resources in geriatrics, pediatrics, infectious disease, gynecology, and primary care proved a handicap in this environment. Although casualties were few in number, the September 11, 2001 terrorist attacks in New York City and Washington, DC underscores the absolute need for broad medical capability in military medicine. The military did respond to these sites and was fully expected to care for civilian casualties.

Essentially no combat wounds and remarkably few disease and nonbattle injuries characterize the Balkan peacekeeping mission, which is still ongoing at the time of this writing. This type of low-casualty operation has also spawned another phenomenon in the contemporary military: increased expectations on the part of both the troops and the public for a higher standard of care. Previous conflicts have always been marked by a degree of austerity, remoteness, and hostility that tempered expectations regarding the quantity and quality of care delivered during the operation. Pressure is mounting for the US military to achieve medical care standards resembling those available in the continental United States. Whether realistic or not, these expectations will likely challenge the military health system as it continues to provide support for a wide array of missions. These expectations have been reinforced by the rapid treatment and evacuation of special forces and other troops wounded deep within Afganistan during the so-called war on terrorism against the Taliban.

**Traditional Combat Casualties**

**Bullet and Shrapnel Wounds**

Gunshot (ballistic-type) injuries and shrapnel (fragment) injuries remain the largest threat on the traditional battlefield. Data from the Vietnam War shows that 51% of combat deaths were due to ballistic-type injuries and 47% from shrapnel. Ballistic-type injuries accounted for 77% of British casualties during the Falkland Islands War and 52% of US casualties in Operation Desert Storm. Anatomically, the
extremities are most vulnerable, with the lower extremity being twice as likely to be wounded as the upper extremity (Table 4.2). Although data are incomplete at this writing, anecdotal reports from the ground war in Afghanistan against the Taliban reinforce this trend. This is probably due in part to the larger body mass of the lower extremities resulting in greater exposure and the proximity of the legs to landmines, a common cause of shrapnel injuries in modern conflicts. Fortunately, extremity wounds are survivable, in particular if good hemorrhage control is achieved immediately after the injury.

Improvements in both medical care and evacuation have the potential to decrease the number of combatants who survived the initial injury but died subsequently in the medical system. During the Vietnam War, the percentage of casualties dying after entering the medical system varied greatly depending in the location of injury (Table 4.3). Over one third of head and thoracic wound deaths occur in the medical system. Increased attention to treatable problems, such as airway obstruction, tension pneumothorax, and shock, may improve this rate. Although abdominal wounds show a relatively low lethality, early surgery and prevention of late deaths from sepsis may further improve outcome. The best outcome was seen in extremity wounds, although room for improvement still exists. It is likely that in future conflicts extremity wounds will represent the same or greater preponderance because of improvements in body armor.

While the treatment of combat trauma shares many similarities with civilian trauma care, important differences exist (Table 4.4). The main differences between military- and civilian-style care reflect differences of environment, equipment, and on occasion clinical priorities. However, it cannot be overemphasized that the principles of good patient care do not change, and any differences in combat casualty care are overshadowed by the similarities with standard trauma care.

### Blast and Burn Injuries

Thermal injury is a significant cause of morbidity in war. Isolated burn injury is uncommon and is usually associated with incendiary devices. However, thermal injury frequently accompanies blast and fragment injuries from bombs, mortars, shells, and mines. In Operation Desert Storm, 26% of wounded Americans had significant thermal injuries. Initial management of burns is similar to civilian burn care. Because airway assurance is

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**Table 4.2. Location of combat wounds (%) among several wars and conflicts.**

<table>
<thead>
<tr>
<th>War</th>
<th>Head and neck</th>
<th>Thorax</th>
<th>Abdomen</th>
<th>Extremities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vietnam</td>
<td>14</td>
<td>4</td>
<td>4</td>
<td>76</td>
</tr>
<tr>
<td>Falklands</td>
<td>14</td>
<td>7</td>
<td>11</td>
<td>68</td>
</tr>
<tr>
<td>Panama</td>
<td>6</td>
<td>11*</td>
<td>11*</td>
<td>80</td>
</tr>
<tr>
<td>Desert Storm</td>
<td>17</td>
<td>4</td>
<td>6</td>
<td>71</td>
</tr>
</tbody>
</table>

* Thoracic and abdominal wounds combined.

*Source:* Adapted from USA data.²²

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**Table 4.3. Lethality of combat wounds (%) by location in Vietnam.**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Head</th>
<th>Neck</th>
<th>Thorax</th>
<th>Abdomen</th>
<th>Extremity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Killed immediately</td>
<td>34</td>
<td>8</td>
<td>41</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Died of wounds</td>
<td>46</td>
<td>8</td>
<td>34</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Survived</td>
<td>17</td>
<td>17</td>
<td>9</td>
<td>6</td>
<td>69</td>
</tr>
</tbody>
</table>

Figures add up to >100% because of overlapping injuries.

*Source:* Adapted from USA data.²²
crucial, intubation is a consideration in any burn patient at serious risk for airway compromise. Any standard intravenous fluid-dosing scheme (such as the Brooke or Parkland formula) is effective at replacing the massive fluid losses associated with burns. Electrocardiogram monitoring is an important consideration in any severely burned patient owing to significant electrolyte and fluid imbalances. Escharotomy can be lifesaving in selected cases and should be performed when necessary, in particular when the patient is embarking on a long AE journey. Because minimal anesthesia is needed for this procedure, it should be considered a far-forward procedure.

Blast injuries, like burns, are common accompaniments of shrapnel wounds from explosive devices. It is unusual to encounter an isolated blast injury, unless the victim was protected from shrapnel and thermal burns by mechanical means. Ironically, protective body armor may actually potentiate the effects of blast while providing life-saving protection from fragments. So-called “blast-effect” munitions may also cause isolated blast injury because these devices cause enormous blast waves but have no casing or shrapnel fragments to expel.

Air-filled organs suffer the greatest damage from blast. The three primary organs affected are the lungs, the hollow gastrointestinal viscera, and the middle ear. Lung damage is primarily disruption of the alveoli with resultant pulmonary edema and respiratory distress. Arterial gas (air) emboli are a distinct possibility, especially with mechanical ventilation. Pneumothorax is possible but uncommon.

Severe hollow viscous damage usually manifests by rupture. Tympanic membrane rupture is not life threatening but has considerable battlefield implications because hearing loss makes it difficult for troops to both hear commands and protect themselves adequately.

Battlefield management of blast injuries is initially focused on maintenance of ventilation and oxygenation. High-flow oxygen can reduce the effects of any possible gas emboli that occur. If a large embolus is suspected, placing the patient in the left lateral decubitus position may help prevent the emboli from reaching the brain or other vital organs. Initial management of hollow viscera rupture includes fluid resuscitation and antibiotic coverage. Definitive care will require laparotomy. Tympanic membrane injury usually requires no specific therapy because most cases will heal spontaneously.

### Field Treatment

Far-forward battlefield care can be divided into three stages of care: (1) care under fire, (2) tactical care, and (3) evacuation care.\(^1\) Care under fire is that care rendered when the patient and medic are under imminent threat of enemy fire. By necessity, such care is abbreviated, rapid, and austere. The first priority is protection and this is accomplished through return fire, cover, and concealment. The second priority is extraction of the casualty into a safer zone. The preferred method of extraction is self-extraction, where the casualty runs or crawls to safety under his or her own power. However, if the casualty is seriously wounded assisted extraction by drags or carries probably will be required. Medical care while under fire is limited to the control of any significant bleeding by tourniquet to prevent exsanguination. All other procedures cannot be justified because they either take too long or expose the provider to excessive risk.

Once the casualty is brought under cover or concealment, or the enemy has fled or been suppressed, the next stage of care begins. Tactical care is the emergency field care traditionally performed by far-forward medical personnel.

Airway management, controlling hemorrhage, and treating shock are the primary goals

---

4. Combat and Operational Casualties

<table>
<thead>
<tr>
<th>Factor</th>
<th>Military</th>
<th>Civilian</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bullet velocity</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Frequency of shrapnel injury</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Anatomic location</td>
<td>Extremities</td>
<td>Torso</td>
</tr>
<tr>
<td>Comorbid disease</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Contamination of wounds</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Evacuation time</td>
<td>Long (&gt;2h)</td>
<td>Short (&lt;30min)</td>
</tr>
</tbody>
</table>
in tactical care. Manual airway maneuvers and proper positioning, eg, recovery or lateral recumbent position, will assure an airway in most cases. Intubation can be lifesaving in casualties exhibiting airway obstruction or respiratory failure. In up to 0.4% to 0.6% of all conventional battle casualties, a surgical airway may be required.19–20

Direct pressure or a tourniquet will control most external bleeding, but intrathoracic or intra-abdominal bleeding is much more problematic. Overzealous fluid resuscitation may actually worsen outcome in these cases. Instead, maintaining relatively modest hypotension (eg, systolic blood pressure 80 to 90 mm Hg) may reduce blood loss and promote clot development. A rational approach to the use of fluids has been proposed and includes minimal use of fluids in cases of uncontrolled internal hemorrhage and modest fluid boluses, eg, 1000 mL initially, for cases of hemorrhagic shock after bleeding has been controlled.18

When it comes to the choice of fluid for intravenous resuscitation, there is no definitive data that supports the use of colloid over crystalloid. Normal saline and Ringers lactate are the recommended fluids, based on availability, low cost, compatibility, and familiarity. Colloids and blood products may have roles in particular cases. Although synthetic blood products and other oxygen-carrying alternatives may one day redefine the role of fluid resuscitation, they are not yet available for routine clinical use. Recent reports suggest hypertonic saline may be preferable to ordinary crystalloid. An added benefit is reduced weight of the product.

Supplemental oxygen is an important adjunct in treating shock. However, for combat casualty care it has been traditionally de-emphasized because of weight, bulk, and resupply constraints. The gradually increasing availability of oxygen concentrators and generators in forward units is likely to change this. If available, high-flow oxygen should be administered to all casualties in shock, with respiratory distress, or otherwise seriously compromised.

The final stage of care is evacuation care, which begins once the casualty enters the formal evacuation chain. This chain begins with a wheeled or helicopter ambulance at the unit level and lasts until the casualty reaches either definitive care in a combat support hospital or an aeromedical staging facility in preparation for evacuation from the theater of military operations.

Evacuation care is similar to tactical care except the patients and attendants are on the move. Because of the cramped quarters and constant jostling, evacuation care is necessarily limited to the essentials. Automatic ventilators, intravenous infusion pumps, and automated sphygmomanometers are all in use in civilian ambulances and have been proposed for evacuation care. However, until they are available in the field tactical medics will continue to manually perform ventilation, IV fluid titration, and blood pressure measurements. Because of these requirements, a single attendant has a limited ability to provide complicated lifesaving procedures while en route. All members of the medical evacuation team must take these limitations into consideration when preparing or receiving casualties.

Disease and Nonbattle Injuries

Disease and nonbattle injuries (ie, DNBI) encompass all diseases and injuries sustained during an armed conflict that are not a direct result of enemy action. Included in this category are infectious diseases, environmental exposure, and injuries such as from falls. Historically, disease and nonbattle injuries represent the greatest threat on the battlefield, dwarfing the effects of combat wounds in terms of both morbidity and mortality. The greatest causes of disease and nonbattle injuries that must concern commanders and medical planners alike are the extremes of heat and cold and both vector-borne and diarrheal illness.

Perhaps the best example of the enormous impact of disease and nonbattle injuries on combat effectiveness and strategic success is Napoleon’s invasion of Russia. Of the 600,000 soldiers who started the operation in June 1812, only 100,000 remained by December. While 100,000 died in battle, over 200,000 died of starvation, cold, and disease.21 The balance of
Napoleon’s troops were captured, deserted, or were hospitalized.

In WW II, Field Marshal Rommel's renowned “Afrika Corps” suffered severe losses from disease and nonbattle injuries. For every one of his troops killed in combat, three were lost to disease. Despite his prowess on the battlefield, it could be argued that Rommel, like Napoleon, ultimately failed because of his ignorance of the impact of disease and nonbattle injuries.22

More recent conflicts have avoided the huge effects of disease and nonbattle injuries in terms of human lives. However, DNBI still represents a significant operational challenge. In US conflicts this century, disease and nonbattle injuries consistently accounted for 5% of combat mortalities and considerably greater morbidity.23 A review of more recent conflicts suggests that between 26% and 36% of combat troops presenting for care have been unable to return to duty because of disease and nonbattle injuries.23 During the Gulf War, disease and nonbattle injuries far outnumbered direct combat injuries. Two US Navy hospitals experienced a combined disease and nonbattle injury load of 1820 casualties during a 6-month period.24 Burkle et al reported a 6% nontraumatic casualty rate for allied forces and an 11% rate for enemy forces treated by allied facilities.25 The majority of the disease and nonbattle injury cases were diarrheal and respiratory illnesses, and to a lesser degree orthopedic injuries and dermatologic and psychiatric problems.26,27

Psychiatric disease has been recognized as an important cause of nonbattle casualties since the turn of the century. Both the WW I term “shell shock” and the WW II term “battle fatigue” refer to the psychological effects of combat. Today, the term “combat stress” is used to refer to the spectrum of psychological problems resulting from acute and chronic exposure to combat.

Data from the Vietnam War illustrate the potential impact of combat stress on unit effectiveness.28 As the War was just getting underway in 1965 to 1966, the casualty rate from combat stress was approximately 12 per 1000 troops. By 1970, the rate had more than doubled. This large fraction of troops hospitalized for combat stress significantly decreased unit combat effectiveness throughout the War.

### Contemporary Military Casualties

Following the collapse of the Soviet Union in the 1980s, it has become increasingly apparent that future battles and military operations will be less likely to resemble wars of the past. Future engagements are more likely to be regional conflicts than large-scale wars. Operations other than war, including humanitarian assistance and peacekeeping operations, are growing in frequency. Nontraditional “asymmetrical” threats loom ever larger, and include limited nuclear war and chemical and biologic attacks (Table 4.5). Lastly, there is a subtle but important shift occurring in the nature and frequency of combat wounds. Each of these factors separately will require a significant adjustment of the military medical posture. Together, these factors compel a complete medical refocusing for operational care. This section will explore the contemporary military medical mission and introduce the types of casualties that can be expected in the new millennium.

<table>
<thead>
<tr>
<th>Weapon</th>
<th>Likelihood of risk</th>
<th>Casualty potential</th>
<th>Targetability</th>
<th>Portability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Biologic</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Nuclear</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

### Table 4.5. Characteristics of nuclear, biologic, and chemical threats.
Weapons of Mass Destruction: Nuclear, Biologic, and Chemical Threats

Few catastrophes are as fearsome as the explosion of a nuclear weapon or the release of chemical or biologic agents. In the Cold War era, such warfare was contemplated only in the context of massive, strategic battles. The possibility of meaningful medical response with a virtually unlimited number of casualties was, at best, severely limited. Consequently, military medicine developed a “common-task” approach to nuclear, biologic, or chemical (ie, NBC) attacks, where all soldiers, medical or nonmedical, were expected to provide only the most basic care to these casualties.

In the post-Cold War era, nuclear, biologic, or chemical weapons have proliferated. As the risk of a global nuclear war has decreased, the risk of limited, tactical use of nuclear, biologic, or chemical weapons has risen dramatically (Table 4.6). This increased risk, coupled with the potentially finite number of casualties that is often the result of limited nuclear, biologic, or chemical attacks, has allowed the military to draw up plans for meaningful medical response.

The first step in this development is leaving behind the simplistic, common-task approach. Military medical providers must achieve a greater degree of sophistication in terms of the level of care offered. It is no longer enough for the military medical system to focus totally on acute surgical trauma, but now must be equally prepared to treat nuclear, biologic, and chemical casualties. The second step is to prepare to deal with new or unusual toxins and pathogens because of the rapid evolution of chemical and biologic weapons. The post-September 11, 2001 global threat of terrorism only serves to highlight the potentially disastrous effects of weapons of mass destruction.

The contemporary approach to treating chemical and biologic agents relies heavily on early detection and identification of the offending agent. In the absence of a clear etiology, treatment will have to be directed at symptoms. Many chemical and biologic agents cause death through respiratory failure and shock, so airway management, mechanical ventilation, and intravenous fluid therapy remain the cornerstones of empirical therapy.

Nerve agents perhaps represent the greatest chemical threat. Successful treatment requires early and aggressive treatment with the injectable antidotes, atropine and pralidoxime. Timing is crucial because only early antidotal therapy will likely improve outcome. For this reason, soldiers are trained to recognize the symptoms of nerve gas exposure and use autoinjection devices for both self-care and buddy care in the field. Once in the medical system, diazepam or other anticonvulsants are important adjuncts in the prevention and treatment of nerve-agent-induced seizures.

Other chemical agents posing significant risk include cyanides, pulmonary agents, and vesicants. The former two classes are less suitable for battlefield employment because of their dispersal and persistence characteristics. Their ease of manufacture, however, makes them ideal for terrorist or insurgent use. Vesicants, because of their high degree of persistence, can be an effective area denial tool for a tactical operation.

<table>
<thead>
<tr>
<th>Nation</th>
<th>Nuclear</th>
<th>Biologic</th>
<th>Chemical</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Russia</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Ukraine</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Byelorus</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>France</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Iraq</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>North Korea</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pakistan</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iran</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Libya</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algeria</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Syria</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taiwan</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burma</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ethiopia</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Adapted from USA data.
Treatment approaches for each of these chemical agent classes is complex and only occasionally adaptable for use by unsupervised nonmedical personnel. Traditional cyanide treatment necessitates a somewhat risky combination of nitrites and thiosulfates. Recently, experts have argued against such treatments in cases of inhaled cyanide toxicity, noting the therapy may exacerbate the patient’s condition. The experimental drug hydroxycobalamin offers a future hope for an effective antidote without the untoward side effects of current therapy. There is no specific antidote for pulmonary agents or vesicants, so the mainstays of therapy are oxygen, bronchodilators, and rest. The key to minimizing vesicant injury is early (within minutes) decontamination in the field to reduce exposure. The characteristics of selected chemical agents been well described (Table 4.7).32

Biologic weapons are the least understood of the nuclear, biologic, and chemical threats, but because of the incredible potency and transmissibility of some of these agents they are potentially devastating.33,34 To complicate matters, the broad array of potential biologic agents makes the development of effective countermeasures difficult (Table 4.8).35 Biologic toxins

**Table 4.7. Characteristics of selected chemical agents.**

<table>
<thead>
<tr>
<th>Agent</th>
<th>Effect Onset</th>
<th>Primary site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nerve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tabun (GA)</td>
<td>Lethal</td>
<td>Rapid</td>
</tr>
<tr>
<td>Sarin (GB)</td>
<td>anticholinesterase</td>
<td></td>
</tr>
<tr>
<td>Soman (GD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VX (cyanides)</td>
<td>Lethal</td>
<td>Very rapid</td>
</tr>
<tr>
<td>Cyanide (AC)</td>
<td>cytochrome a3 inhibitor</td>
<td>Lungs</td>
</tr>
<tr>
<td>Cyanogen (CK)</td>
<td>Pulmonary</td>
<td>Immediate</td>
</tr>
<tr>
<td>Pulmonary</td>
<td>irritant</td>
<td></td>
</tr>
<tr>
<td>Phosgene</td>
<td>Contact</td>
<td>Delayed</td>
</tr>
<tr>
<td>Vesicant</td>
<td>irritant</td>
<td>Rapid</td>
</tr>
<tr>
<td>Mustard (HD, HN)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosgene oxime (CX)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lewisite (L, HL)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: Adapted from USA data.*32

**Table 4.8. Characteristics of selected biologic agents.**

<table>
<thead>
<tr>
<th>Agent</th>
<th>Stability</th>
<th>Incubation</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anthrax</td>
<td>High</td>
<td>1–6 d</td>
<td>Shock, death</td>
</tr>
<tr>
<td>Botulinum paralysis</td>
<td>High</td>
<td>24–36 h</td>
<td>Respiratory failure</td>
</tr>
<tr>
<td>Brucellosis</td>
<td>Moderate</td>
<td>1–4 wk</td>
<td>Pneumonia, shock</td>
</tr>
<tr>
<td>Cholera</td>
<td>Moderate</td>
<td>1/2 h–5 d</td>
<td>Severe diarrhea</td>
</tr>
<tr>
<td>Pneumonia plague</td>
<td>Low</td>
<td>2–3 wk</td>
<td>Pneumonia, shock</td>
</tr>
<tr>
<td>Ricin</td>
<td>High</td>
<td>&lt;36 h</td>
<td>Shock and death</td>
</tr>
<tr>
<td>Staphylococcal enterotoxin B</td>
<td>High</td>
<td>1–6 h</td>
<td>Nausea, vomiting, diarrhea, shock in high doses</td>
</tr>
<tr>
<td>Trichothecene mycotoxin</td>
<td>High</td>
<td>Minutes to hours</td>
<td>Vescant like</td>
</tr>
<tr>
<td>Tularemia</td>
<td>Low</td>
<td>2–10 d</td>
<td>Shock, death</td>
</tr>
</tbody>
</table>

*Source: Adapted with permission from Christopher et al.*34
are naturally occurring chemical weapons that have their effect by exposure rather than infection, and include botulinum, ricin, T2 mycotoxin, and staphylococcal enterotoxin B. Infectious agents include anthrax, plague, brucellosis, smallpox, and cholera. The anthrax-related terrorism in the US postal system underscores this threat.

To be effective, the medical evacuation system must be capable of treating victims of biologic agents. Expertise in resuscitation, airway and ventilatory management, and fluid maintenance will be required. Antibiotic and antitoxin selection and use is important, so physicians, nurses, and ancillary providers must be familiar in prescribing and administering these drugs. The AE system must be capable of maintaining isolation of infectious biologic casualties who pose a communicable threat. For long-distance AE requiring out of the country stopovers, contingency plans must be developed in the event that landing permission is refused for aircraft carrying such patients.

Nuclear weapons are the most devastating weapons known to man. Even a small bomb can yield utter destruction to the area at ground zero and cause considerable damage many thousands of meters away (Table 4.9). As a frame of reference, the nuclear weapons exploded at Hiroshima and Nagasaki would be considered small by modern standards. The proliferation of nuclear weapons (Table 4.6) in the world demonstrates the potential threat and the need for medical preparedness for nuclear casualties.

Nuclear bombs deliver energy and cause damage through three primary mechanisms:

**Figure 4.4. Distribution of energy released from a typical nuclear bomb (USA photo).**

<table>
<thead>
<tr>
<th>Size</th>
<th>Nuclear radiation*</th>
<th>Thermal energy†</th>
<th>Blast‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kT</td>
<td>0.71</td>
<td>0.77</td>
<td>0.28</td>
</tr>
<tr>
<td>20 kT</td>
<td>1.3</td>
<td>1.8</td>
<td>1.0</td>
</tr>
<tr>
<td>100 kT</td>
<td>1.6</td>
<td>3.2</td>
<td>1.4</td>
</tr>
<tr>
<td>1 MT</td>
<td>2.3</td>
<td>4.8</td>
<td>3.8</td>
</tr>
<tr>
<td>10 MT</td>
<td>3.7</td>
<td>14.5</td>
<td>11.7</td>
</tr>
</tbody>
</table>

* 1000 CGY.
† 50% incidence of 2nd-degree burns.
‡ 50% incidence of serious injury.
nation. The entire medical and evacuation system must be fully prepared for this possibility. The AE system will need to be prepared to use detection equipment for biologic and chemical agents and take additional decontamination steps prior to allowing patients to board aircraft.

Operations Other Than War

The increased military involvement in operations other than war, in particular humanitarian missions, has great potential to alter the casualty load and patient profile. Despite the recent increase in frequency and duration of these types of deployments, the concept of military assistance in disasters is not new. As early as 1792, Congress sanctioned Army involvement in humanitarian relief efforts. In 1902, over 10% of the active Army strength participated in the relief of the San Francisco earthquake. In the aftermath of Hurricane Andrew, 23,000 US troops were deployed for disaster relief.

Peacemaking, peacekeeping, and similar missions generate casualty profiles somewhere between traditional battles and humanitarian missions. Depending on such factors as conflict intensity, peace enforcement, and infrastructure of the area, the military medical and evacuation system will face variable conditions. A certain degree of traditional combat injuries can be anticipated, together with injuries to non-combatants from snipers, mines, and shelling. If the existing national medical infrastructure is damaged, inoperative, or inadequate, large numbers of the civilian population may present to military medical facilities for treatment of significant disease and nonbattle injuries. Military medical planners must anticipate this demand and establish clear guidelines on the role of the military medical forces in treating both the civilian population and wounded combatants from warring factions.

Peacekeeping and peacemaking operations can be expected to generate large numbers of general medical, obstetric–gynecological, pediatric, and geriatric-type patients. Relatively few penetrating injuries will be seen. The following examples may give some perspective to the potential problems that can present. During the Somalia military relief effort, of those patients treated by the military medical system 52% were female and 49% were less than 13 years old. During the 1995 siege of Sarajevo Bosnia-Herzegovina, nearly 15,000 wounded children were treated. The age range of war injury casualties in one state hospital in Sarajevo was from 3 to 88 years. In Operation Provide Comfort in northern Iraq, while providing relief to as many as 760,000 Kurdish refugees, US and Allied Force medical personnel treated 2971 patients under 12 years old.

Other Challenges of the 21st Century

Lasers, masers, particle beam weapons, and other so-called directed energy devices are not yet tactically deployed but represent potential future threats. The little data available on the injury patterns caused by these weapons suggest that focused thermal burns, in particular to the eyes, will be the primary threat. Particle beam weapons are largely experimental, but have the interesting characteristic of not only transmitting thermal radiation but also kinetic energy (as from a bullet or missile).

A changing battlefield injury profile may also result from changes in tactics and defensive equipment in this millennium. Body armor, in particular, has the potential to convert many lethal missile wounds of the trunk and head into nonlethal blunt trauma. This potential shift of injuries among combat casualties will challenge a military medical system largely accustomed to dealing with penetrating trauma. The extent of this shift is unknown, but the US military alone is pouring millions of dollars into developing effective protective armor systems for ground troops. In addition, protective body armor may actually potentiate the effects of primary blast while simultaneously decreasing mortality from shrapnel. This may result in an increase in the number of casualties with isolated blast injury, which historically have been relatively uncommon.

Conclusion

The types and numbers of casualties expected from a given military operation can be as broad and varied as the types of missions themselves.
Traditional combat wounds from missiles, blasts, and burns will continue to figure prominently in many conflicts. However, injuries from nuclear, biologic, and chemical weapons, as well as disease and nonbattle injuries, are likely to increase in relative importance in future battles. In operations other than war, such as humanitarian missions, the military medical system can expect the whole range of human diseases and conditions. Providing adequate care in the context of a military organization can be a challenge. However, careful attention to history and lessons learned can improve planning and ease the burden of meeting the mission.

References
4. Combat and Operational Casualties


Part 2
The Means
Battlefield and tactical medical evacuation (MEDEVAC) encompasses all the movement of casualties within the theater of operations. This includes both movement of patients from the point of injury or illness to the nearest medical facility (Fig 5.1) and movement of patients between medical facilities until the patient is ready for aeromedical evacuation (AE) back to the United States. In most theaters, final in-theater destination will be the aeromedical staging facility.

Over the years some ambiguity has developed for the meaning of the term MEDEVAC. Originally, it was employed to describe any patient movement on the battlefield. With the advent of patient transportation by rotary- and fixed-wing aircraft, many people have used the term to refer to several different types of patient movement, including long-distance transportation of patients by air. In response, some authors have used alternative terms to refer to battlefield patient movement, including casualty evacuation and tactical evacuation. Throughout this chapter and textbook we will use the traditional US Army definition of MEDEVAC as the ground or air movement of casualties from the battlefield to a medical facility and between medical facilities. A related term, casualty evacuation (CASEVAC), has also been used to describe the initial movement of patients in the tactical environment and avoid confusion with the nontactical (strategic) air transport of patients between medical facilities. However, different sources define this term in slightly different fashions, which can be a source of confusion.

Throughout this book, the term AE will be used to refer to the long-distance air transportation of patients, usually for distances greater than 300 miles. This chapter will focus on the most far-forward elements of MEDEVAC and examine the movement and en route care of patients from the point of injury or illness to the first- or second-level medical facility.

History

MEDEVAC owes its inception to Napoleon’s surgeon-in-chief, Dominique Larrey. He introduced the “Flying Ambulances,” horse-drawn carriages that entered the battlefields to retrieve and care for the wounded soldiers. Battlefield evacuation continued to evolve during the American Civil War, when the first dedicated horse-drawn carts were used to clear casualties off the battlefield. Later, when motorized transport became available, trucks were used to haul the wounded. World War II saw the first widespread use of dedicated motorized field ambulances to transport casualties from the battlefield to medical facilities and between medical facilities. Helicopters were introduced for tactical evacuation during the Korean War and perfected during the Vietnam War. The modern inventory now includes a large number of specialized ground and air ambulances.

Throughout the history of MEDEVAC, important advances have continued to be made in both the speed and versatility of the vehicles used. This has resulted in dramatic decreases in
the time it takes wounded soldiers to receive treatment, a fact often credited with the improved casualty survival rates. Unfortunately, equivalent advances in transport have not been realized at the front lines of the battlefield. Wounded soldiers must still be transported, usually by manual or litter carries, to a vehicle or helicopter waiting a safe distance from the conflict. Carrying an 80-kg soldier with another 20 kg of critical gear over rough terrain remains an exhausting task with few technological advances.

Likewise, en route care has not improved as rapidly as evacuation vehicles such as helicopters. Limited medic training, austere, harsh conditions, and sparse equipment continue to make it difficult to provide high-quality medical care in the back of a field ambulance. However, there is a growing realization among military medical leaders that the goal of military medicine should not be merely to provide austere medical care but rather to provide the highest-quality medical care possible in an austere environment. Important advances in techniques for using oxygen and intravenous fluid therapy, splinting, and bleeding control have provided incremental improvements in the care rendered in the tactical environment. However, major advances in medical care during MEDEVAC will only be possible with the increased presence of skilled medical providers and high technology in the forward environment.

MEDEVAC Principles

MEDEVAC is much more than the simple movement of casualties from the battlefield. For this reason, six basic principles of battlefield and tactical MEDEVAC have been identified (Table 5.1). The key principle is that MEDEVAC itself is a medical “intervention” or procedure subject to physician judgement. When and where a patient is evacuated, and by what means, should always be determined by a physician, either directly or through delegation by protocols and standing operating procedures. In contrast to civilian patient evacuation, military mission requirements and command approval are critical steps in the MEDEVAC decision-making process. Ultimately, of course,
patient evacuation is a warfighter’s command decision, but it should be made largely on medical recommendation.¹

“Speed and effectiveness” of transport is another important principle of MEDEVAC because it reflects the ultimate goal: the rapid transportation of casualties to a medical facility. The supporting principle of “proximity of resources” is a major challenge because the tactical environment is harsh and chaotic and limits the reach of evacuation assets. In most circumstances, the evacuation platform (eg, vehicle or helicopter) will need to be relatively close to the anticipated concentration of casualties to ensure a rapid response.

The principle of “medical care” refers to the en route patient care provided. This medical care is what separates merely moving casualties from genuine MEDEVAC. The principle of “appropriateness” refers both to utilizing the best mode of evacuation (eg, ground or air) and bringing the casualties to the most appropriate medical facility, which is usually (but not always) the closest facility.² The principle of “precedence” refers to the categorization of patients by need for evacuation. Together, appropriateness and precedence support the triage concept, whereby casualties are sorted and resources conserved to maximize benefit. During a mass-casualty situation, medical providers frequently encounter a mismatch of patient needs and evacuation resources and therefore must make difficult triage decisions to assure the limited resources are utilized most effectively. Applying the principles of appropriateness and precedence will help deal with this mismatch.

### Echelons of Care

A basic understanding of the military echelons of care system is needed to fully comprehend the concept of battlefield and tactical MEDEVAC. This system describes a hierarchy of medical care and facilities designed to support the war fighting elements (Table 5.2).³ Although these designations are current at the time of this writing, both military medical doctrine and nomenclature are changing at a rapid rate.

Echelon I is located closest to the fighting (forward edge of battle area). Because of the proximity to the battle, echelon I care is austere and its elements are light and mobile. It

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Table 5.1. Basic principles of battlefield and tactical MEDEVAC.

<table>
<thead>
<tr>
<th>Medical intervention</th>
<th>Speed and effectiveness</th>
<th>Proximity of resources</th>
<th>Medical care</th>
<th>Appropriateness</th>
<th>Precedence</th>
</tr>
</thead>
</table>

Table 5.2. Echelons of military medical care.

<table>
<thead>
<tr>
<th>Echelon</th>
<th>Military hierarchy</th>
<th>Personnel/facility</th>
<th>Type of care</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Unit</td>
<td>Self/buddy aid</td>
<td>First aid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combat lifesaver</td>
<td>First aid, beginning</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>emergency treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combat medic</td>
<td>Emergency medical treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Battalion aid station</td>
<td>Advanced trauma and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>medical management</td>
</tr>
<tr>
<td>II</td>
<td>Division</td>
<td>Medical company (clearing</td>
<td>Initial resuscitation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>station)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>Corps</td>
<td>Combat support hospital</td>
<td>Resuscitative surgery and</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>medical care</td>
</tr>
<tr>
<td>IV</td>
<td>Echelons above</td>
<td>Combat support hospital</td>
<td>Definitive care</td>
</tr>
<tr>
<td></td>
<td>Corps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Out-of-theater</td>
<td>Fixed medical facilities</td>
<td>Restorative and</td>
</tr>
<tr>
<td></td>
<td>continental US</td>
<td></td>
<td>rehabilitative care</td>
</tr>
</tbody>
</table>
includes four levels of care that become progressively more sophisticated. Self-aid and buddy-aid is first aid applied by nonmedical fighting troops. Combat lifesaver care is more advanced medical aid provided by fighting troops with limited medical training. An Army medic, a Navy or Marine Corps corpsman, or an Air Force medical technician provides “combat medic care.” These are the first medically trained providers encountered in the field and provide emergency medical treatment at the basic life support level, in some cases with intravenous fluid therapy.

For the US Army and Marines, the battalion aid station is the first medical facility available to casualties and is staffed by both a physician and physician assistant. It is rather austere and highly mobile, with advanced trauma life support capabilities, including endotracheal intubation, tube thoracostomy, intravenous medication, and other physician-directed medical care.

Echelon II is a divisional-level “clearing station” that is staffed by a medical company of physicians, nurses, and medics. Casualties are examined to determine treatment needs and evacuation precedence. Emergency medical treatment, including initial comprehensive resuscitation, is provided and supported by limited radiographic, dental, and laboratory services with whole blood capacity. It provides patient-holding capability for soldiers expected to return to duty within 3 days, roughly at the general ward level under the supervision of a licensed practical nurse.

Echelon III is the first medical facility a casualty will encounter on the battlefield. At present, this will be a combat support hospital in the US Army system. Echelon III hospitals provide comprehensive resuscitative surgery and medical care. Medical providers include general surgeons and both surgical and medical subspecialists with comprehensive anesthesia and nursing support. Patients who are unlikely to return to duty are evacuated as soon as possible after stabilization.

Echelon IV was by tradition represented by comprehensive theater hospitals designated as general, field, or station hospitals. These large and poorly mobile facilities provided definitive medical and surgical care and were equipped with a broad array of support services. Because today’s operational requirements call for a more flexible and mobile medical facility, it unlikely that a true echelon IV hospital capability will exist in future warfighting theaters of operation. Instead, an enhanced combat support hospital in the theater, plus direct evacuation of “stabilized” patients to the United States, will meet this echelon IV requirement.

Echelon V represents the fixed hospitals located overseas outside the theater of operations and in the continental United States. These are primarily military medical facilities, augmented within the United States by the Veterans Administration, and civilian hospitals as part of the National Defense Medical System. Definitive and rehabilitative care of all types may be found in echelon V facilities.

The numeric sequence of these echelons may appear to imply a rigid stepwise movement of patients from echelon I to echelon II and so on. This may have been true in its earliest conception but is too inflexible for the modern and dynamic operational environment of modern warfare. A strict hierarchy of units and echelons is unlikely to exist on the modern battlefield, where speed, envelopment, penetration, and deep attacks blur any sense of a “front line.” The “rear area,” where echelon III and IV hospitals were by tradition set up, is no longer static or safe. The impact these changes have had on the echelon system is apparent in the virtual elimination of echelon IV facilities. Certainly, this substantial decrease in theater hospital resources increases the charge given to the strategic AE system, as patients previously hospitalized in the theater will now have to be transported back to the nearest echelon V facility.

Another major change in military medical doctrine is the increased forward availability of medical expertise and technology. “Forward surgical teams,” whose expertise was previously available only at echelon III facilities, are now located in traditional echelon II units. The modern addition of surgical capability to echelon II units further blurs the distinction between echelons. Obviously, the AE system must evolve in concert with the rapidly changing capabilities of forward medical facilities to ensure that the principle of appropriateness
continues to be met when matching patient needs to medical capabilities.

### Precedence

A key concept in the care provided to the casualty during evacuation is the MEDEVAC principle of precedence. Correctly choosing which casualty goes first and to which medical facility is central to providing good MEDEVAC. Individual precedence decisions made will impact the overall effectiveness of the evacuation effort. For this reason, medical commanders must ensure that precedence decisions are made by the most qualified medical provider, and in many cases this may not be the most senior or highest-ranking medical officer.

The US Army system uses four standard categories to determine MEDEVAC precedence, to which a fifth surgical category has been recently added (Table 5.3). “Urgent” patients need immediate evacuation and cannot tolerate a delay of more than 2 hours without significantly risking death or disability. The “urgent surgical” subcategory was created to emphasize the patient’s need for acute surgical intervention, thus alerting the evacuation team to transport the patient to a surgery-capable facility. “Priority” patients are less likely to deteriorate and can tolerate an evacuation delay of 4 hours. “Routine” patients are unlikely to deteriorate and can tolerate an evacuation delay of 24 hours. “Convenience” patients are being evacuated for reasons other than medical necessity, as the name implies. These MEDEVAC precedence categories should not be confused with the standard NATO triage designations (ie, immediate, delayed, minimal, and expectant), which identify treatment priorities rather than evacuation precedence.

<table>
<thead>
<tr>
<th>Priority level</th>
<th>Designation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Urgent</td>
<td>Evacuated as soon as possible and within 2 h to save life, limb, or eyesight or prevent complications of serious illness or permanent disability</td>
</tr>
<tr>
<td>IA</td>
<td>Urgent—surgery</td>
<td>Must receive far-forward surgical intervention to save life and stabilize for further evacuation</td>
</tr>
<tr>
<td>II</td>
<td>Priority</td>
<td>Requiring evacuation within 4 h or his medical condition could deteriorate to such a degree that he will become an urgent precedence or will suffer unnecessary pain or disability</td>
</tr>
<tr>
<td>III</td>
<td>Routine</td>
<td>Requiring evacuation within 24 h, but whose condition is not expected to deteriorate significantly</td>
</tr>
<tr>
<td>IV</td>
<td>Convenience</td>
<td>Evacuation is a matter of medical convenience rather than necessity</td>
</tr>
</tbody>
</table>

Source: Adapted from USA data.

### Assessment and Care

Assessment and care during tactical evacuation is a compromise between the provision of optimal care and the realities of a harsh, austere, often hostile battlefield environment. Assessment is limited by noise, movement, and light restrictions. Ongoing medical care is also
hindered by equipment shortages, multiple casualties, and limited provider skills. Despite these limiting factors, effective assessment and care is possible in this environment.

The approach to ongoing care during MEDEVAC evacuation is based on the principles of good prehospital care (Table 5.5). The focus is on the airway, breathing, and circulatory status of the casualty. If available, electronic physiological monitors (eg, sphygmomanometer, pulse oximeter, and capnometer) should be employed. Because this type of equipment is frequently unavailable in the chaos of battle, the provider accompanying the casualty will need to rely on traditional inspection, palpation, and auscultation for assessment.

The adequacy of both the airway and breathing can be roughly estimated by observing or palpating chest excursion. The traditional technique of breath sound auscultation is often impossible in the noisy tactical environment. Electronic monitoring is extremely useful in this environment, and pulse oximetry showing peripheral oxygen saturation >95% indicates satisfactory central oxygenation. In patients receiving supplemental oxygen, pulse oximetry allows accurate titration of flow rates to keep the saturation >95%, thus conserving scarce oxygen supplies. In an intubated patient, electronic capnometry is another method to assure airway patency. Alternative manual methods include direct visualization of tube placement by laryngoscopy, an esophageal detector device, and observation of respirophasic condensation on the tube.

Pulse and blood pressure are the primary indicators of circulatory status. Electronic physiological monitors can reliably measure these parameters, even in the presence of significant noise and motion. Manually obtained pulse and blood pressure are more difficult to accurately obtain in the tactical environment. Capillary refill, indicative of peripheral vasoconstriction, is a reasonable alternative indicator of circulatory status that can be used in this environment. Refill time in excess of 3 seconds suggests circulatory compromise, and is best observed at a central location such as the forehead, neck, chest, or abdomen. Cold exposure can also prolong capillary refill, especially in the extremities.

Bleeding must always be controlled by whatever means necessary. Direct pressure almost always controls external hemorrhage and is the technique of choice. If direct pressure can be applied and maintained, a tourniquet is almost never needed. A tourniquet may be required if direct pressure cannot be maintained because of high casualty-to-provider ratio, if there is a need to move quickly, or under other tactical considerations. Once a tourniquet is applied, it should not be loosened until bleeding can be controlled.

### Table 5.5. Approach to evacuation (ongoing) care.

<table>
<thead>
<tr>
<th>Airway</th>
<th>Ensure patency and adequacy of airway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breathing</td>
<td>Ensure adequacy of ventilation and oxygenation</td>
</tr>
<tr>
<td>Circulation</td>
<td>Ensure all bleeding is controlled</td>
</tr>
<tr>
<td>Disability and drugs</td>
<td>Provide appropriate fluid support</td>
</tr>
<tr>
<td>Extras</td>
<td>Monitor mental status and neurological response</td>
</tr>
<tr>
<td></td>
<td>Recheck splints and dressings</td>
</tr>
<tr>
<td></td>
<td>Administer appropriate medications</td>
</tr>
<tr>
<td></td>
<td>Keep casualty comfortable and warm</td>
</tr>
<tr>
<td></td>
<td>Provide reassurance and support</td>
</tr>
<tr>
<td></td>
<td>Ensure casualty is properly restrained against falls and crashes</td>
</tr>
</tbody>
</table>

*Source: Adapted with permission from Butler et al and De Lorenzo and Porter.*
controlled through other means. In general, a tourniquet should not be removed until the casualty has reached a medical facility capable of initiating and maintaining an adequate resuscitation, even if this means leaving it on for hours.

The approach for administration of intravenous fluids to casualties in the field has recently undergone significant changes. For years, the standard approach for patients suspected of having hemorrhagic shock was to administer massive amounts of crystalloid and colloid fluids in an effort to maintain a normal blood pressure. Recent trends in the care of penetrating injuries in the field are moving toward administration of just enough crystalloid fluid to maintain modest hypotension (eg, systolic blood pressure of 80 to 90 torr). In contrast, current guidelines for isolated serious head injury suggest an avoidance of significant hypotension. For both conditions, it is now recommended that fluid administration be judicious in the initial management of combat-related trauma (Table 5.6). Administration of additional fluid may be medically appropriate in some circumstances, especially when there is a delay of >2 to 4 hours between the time of injury and definitive medical care.

Drugs are playing an increasingly important role in combat care. Morphine for pain control is one of the few drugs traditionally used on the battlefield. Sufficient morphine or other potent analgesics should be administered, preferably by the intravenous route, to all casualties who are in pain. The appropriate clinical end point is relief of suffering rather than complete relief of pain. This ensures an adequate therapeutic effect while minimizing the risk of undesirable side effects such as apnea and hypotension. It is inhumane and poor medical practice to undertreat pain on the battlefield based on an excessive fear of inducing respiratory depression or altering the neurological or abdominal examination. Such patients need appropriate analgesia.

Antibiotic administration on the battlefield is now recommended for infection prophylaxis for casualties with penetrating injuries from bullets and fragments. Early administration may be most effective, and a typical regimen is a single intramuscular or intravenous dose of a broad-spectrum cephalosporin (eg, cefazolin or mezofixin, 1 to 2 g). Tetanus prophylaxis with tetanus–diphtheria toxoid is also indicated for inadequately immunized casualties, most commonly civilians and foreign troops.

Chemical or biologic attacks bring a new dimension to the use of lifesaving medications on the battlefield. Many chemical agents have antidotes or treatments that are effective if used promptly. Tactical medical providers must be familiar with atropine, pralidoxime, and diazepam for nerve agents, nitrites and thiosulfate for cyanide, and inhaled bronchodilators for pulmonary agents, at an absolute minimum. Repeated dosing of these medications may be required throughout the evacuation chain. Biologic agents are another potential threat and the evacuation chain must be ready to begin drug treatment at the earliest possible time.

Table 5.6. Rational approach to administering intravenous fluid in the tactical setting.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Fluid amount (Isotonic Crystalloid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No shock</td>
<td>Saline lock</td>
</tr>
<tr>
<td>Compensated shock, hemorrhage controlled</td>
<td>1000mL bolus</td>
</tr>
<tr>
<td>Compensated or uncompensated shock with suspected intrathoracic or intraabdominal hemorrhage</td>
<td>1000mL bolus, may repeat up to 3000mL</td>
</tr>
<tr>
<td>Uncompensated shock, hemorrhage controlled</td>
<td>1000mL bolus, may repeat up to 60mL/kg</td>
</tr>
<tr>
<td>Isolated head injury, no shock</td>
<td>Saline lock</td>
</tr>
<tr>
<td>Isolated head injury with shock</td>
<td>1000mL bolus</td>
</tr>
</tbody>
</table>

Source: Adapted with permission from Butler et al. and De Lorenzo and Porter.
The last major element in evacuation care is to ensure the patient is warm, comfortable, and safe. Hypothermia is an often-overlooked complication of injury and is exacerbated by the environmental exposure, fluid resuscitation, and prolonged transport times, all common in tactical MEDEVAC. Verbal and tactile gestures of reassurance are also an important aspect of care and should be provided.

Transfer of Care

Eventually, the tactical MEDEVAC system interfaces with the medical facility or the theater AE system. The effective transfer of care requires good communication between all elements, both verbal and written. Neither needs to be lengthy, but should highlight key aspects of the casualty’s condition and treatment.

The standard instrument for written documentation of medical care before and during MEDEVAC is the Field Medical Card (FMC) (Fig 5.2). This abbreviated document includes basic demographic data, key physical findings, and treatment rendered. Ideally, the FMC should only take a minute or two to complete. Carbonless copies allow the initiator to keep a record for future accountability. The card itself is then attached to the casualty in a convenient fashion.

Another aspect of the transfer of care is medical regulating. This process for the regulation of patient movement is crucial to manage patient flow. The objectives of medical regulating are to (1) ensure an even distribution of patient load, (2) provide adequate beds and treatment capabilities for current and anticipated needs, and (3) ensure that patients requiring specialized care get to the appropriate facility. Historically, medical regulating was only concerned with theater-level AE. However, as automated systems become more effective, regulating will begin at the level of tactical MEDEVAC and might one day begin at the point of injury.

Two systems are in current use in the tactical environment for medical regulating: the Defense Medical Regulating Information System (DMRIS) and the Automated Patient Evacuation System (APES). DMRIS is an online, computerized system designed to permit the interfacility transfer of patients. It currently operates at the fixed medical facility level but will be extended forward to theater and tactical levels through modernization. APES supports the USAF AE mission out of the theater. APES can exchange information with DMRIS with the ultimate goal of both being improved effectiveness and efficiency throughout evacuation.

Transportation

The overall goal of MEDEVAC is the safe and effective movement of the casualties. Transportation modes might include manual carries, ground vehicles, aircraft, watercraft, or a combination of these depending on the circumstances. All members of the military medical team should have a general familiarity with the common transportation modes used for MEDEVAC.

Manual Carries

In combat and many military operations other than war, the manual carry is the primary means of moving casualties from the point of injury or illness to a point of safety where the medical evacuation can begin. Despite tremendous advances in many other areas of evacuation, manual carries remain almost unchanged over the centuries. While agility and finesse are essential to executing all manual carries, there remains no substitute for physical strength and endurance. Manual carries can be exhausting work and necessarily have a range limited to a few hundred or thousand meters.

Manual carries and drags may aggravate fractures and wounds because they offer little stable support for the casualty’s body. Moving the casualty along the long axis of the body will minimize further injury to the casualty. Ongoing care is impossible during a manual carry. If possible, life-threatening bleeding should be controlled with a tourniquet prior to movement. Airway management, ventilation, and patient monitoring must be delayed until the casualty reaches a point of safety.
Figure 5.2. Field Medical Card. Both the front (A) and back (B) of the card are utilized for both MEDEVAC and AE.
<table>
<thead>
<tr>
<th>Date/Time</th>
<th>12. REASSESSMENT / RÉASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time / Heure</td>
<td></td>
</tr>
<tr>
<td>BP / PS</td>
<td></td>
</tr>
<tr>
<td>Pulse / Poul</td>
<td></td>
</tr>
<tr>
<td>Resp / Resp</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date / Time</th>
<th>13. CLINICAL COMMENTS / DIAGNOSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date / Heure</td>
<td>INFORMATION MÉDICALE / DIAGNOSTIQUES</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date / Time</th>
<th>14. ORDERS / ANTIBIOTICS (SPECIFIED) / TETANUS / IV FLUIDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date / Heure</td>
<td>DIRECTIVES MÉDICALES / ANTIBIOTIQUES (Spécifié) / TETANUS / IV FLUIDE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date / Time</th>
<th>15. PROVIDER / OFFICIER MÉDICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date / Heure</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disposition</th>
<th>16. DISPOSITION / DISPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Returned to Duty / Retour à l'Unité</td>
<td>Time / Heure</td>
</tr>
<tr>
<td>Evacuated / Evacué</td>
<td></td>
</tr>
<tr>
<td>Deceased / Décédé</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Religious Services / Services Religieux</th>
<th>17. RELIGIOUS SERVICES / SERVICES RELIGIEUX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baptism / Baptême</td>
<td>Prayer / Prière</td>
</tr>
<tr>
<td>Anointing / Onction</td>
<td>Communion / Communion</td>
</tr>
<tr>
<td>Confession / Confession</td>
<td>Other / Autre</td>
</tr>
</tbody>
</table>

B DD Form 1386, DEC 91 (Back)

**Figure 5.2. Continued**
Military Casualty Evacuation: MEDEVAC

Litter Carries

Litter transportation offers modest improvements over manual carries. Some support and comfort is afforded the patient, and spinal immobilization, fracture splinting, oxygen therapy, and other static treatments can often be maintained during movement. Airway management, ventilation, and other dynamic care remains difficult to perform, however.

Litter carries have the additional advantage that the work of transporting a patient can be shared by two to four persons, markedly increasing the potential range of transport. The obvious drawback, however, is that up to four persons are committed to moving one patient.

Litters are lightweight, portable, durable, and readily available on the battlefield. They are also widely used to move patients in and around medical facilities and on and off evacuation vehicles. Therefore, all military medical providers should be familiar with their use.

Ground Vehicles

Ground vehicles are the most common platform used to move casualties over relatively long distances on the battlefield. Current US military doctrine places dedicated ambulances in the war-fighting maneuver units such as an arm or infantry battalion. In most scenarios, battlefield casualties will be carried or dragged several hundred meters to a point of relative safety (e.g., the casualty collection point) where a ground ambulance can pick them up. As a result, ground ambulances can be expected to get fairly close to the point of injury in many cases.

There are several ground ambulances in use today (Table 5.7). The M996/M997 “Humvee” ambulance is built on the highly successful high-mobility multipurpose wheeled vehicle (HMMWV) chassis (Fig 5.3). The HMMWV is organic to medical platoons of light-infantry battalions and most medical companies and can accommodate up to four litter patients.

The M113 armored ambulance is little more than an ordinary armored personnel carrier outfitted to accommodate up to four litters (Fig 5.4). It is a pre-Vietnam era design and suffers from thin armor, slow speed, and a jarring ride. It is organic primarily to the medical platoon in armor and mechanized infantry battalions.

The US Army is hoping to replace the aging M113 with the armored medical evacuation vehicle (AMEV), which is built on the M2/M3 Bradley fighting vehicle chassis. The AMEV offers greater armor, speed, range, comfort, and room than the M113 and has provisions for onboard oxygen. In addition, it offers protection against chemical and biologic agents. The high price tag, however, will likely delay its deployment for years. The Stryker, a new wheeled armored vehicle for the Army’s medium weight brigade is based on the LAV III already in use by the US Marine Corps. This new vehicle comes in a variety of configurations including an ambulance, and offers a combination of protection, moderate weight, maneuverability and speed that enhances versatility.

Helicopters

Helicopter ambulances have been a high-visibility element of the MEDEVAC system since their introduction for this role during the Korean conflict. By the end of the Vietnam War, MEDEVAC helicopters offered speed and versatility unmatched by ground platforms. They are largely unaffected by terrain and can reach remote areas inaccessible to
Figure 5.3. M997 wheeled ambulance (photo by Robert A. De Lorenzo).

Figure 5.4. M113 armored ambulance (photo by Robert A. De Lorenzo).
Military Casualty Evacuation: MEDEVAC

Disadvantages include the cost and their vulnerability to small-arms fire. This latter factor accounts for the doctrine of keeping helicopter pick-up points a safe distance from direct hostile fire. For this reason, most casualties will still need to be carried to a point of safety by a combination of manual or litter carry and ground vehicle transportation prior to “dustoff.”

The UH-1 Iroquois (“Huey”) is a Vietnam-era airframe that remains on active service some 30 years after its introduction (Fig 5.5). It is a single-turbine, twin-blade rotor aircraft with a capacity of six litter patients.11

The UH-60 Blackhawk is the current replacement for the UH-1 (Fig 5.6). It is a twin-engine, quad-rotor blade airframe with improved range and speed over its predecessor. Like the UH-1, the UH-60 has a capacity of six litter patients. An improved version of the Blackhawk, the UH-60Q, has been proposed as a primary air ambulance. The Q model has improved engine power and performance plus built-in oxygen, suction, lighting, and monitoring capability.12 Unfortunately, the high cost of each aircraft has slowed widespread deployment.

Limitations of MEDEVAC

MEDEVAC, using either helicopter ambulances or their ground counterparts, shares two significant limitations: availability and limited patient care en route. Battlefields and disasters are fluid and dynamic situations, making it impossible to preposition ambulances where they will most be needed, even in the unlikely event that large numbers were available. Field medical providers must be capable of improvising transportation when ambulances are not available. Using nonmedical vehicles and personnel for casualty evacuation, including trucks, buses, and nonmedical helicopters, is a well-recognized part of US Army contingency planning.1

The second greatest limitation of tactical MEDEVAC is the difficulty involved in providing en route or ongoing care. Both ground and air platforms currently in use are cramped, noisy, poorly illuminated, and prone to vibration, jarring, and sway. Patient access, assessment, monitoring, and intervention are difficult, at best. Only in the most modern platforms are there provisions for on-board oxygen and suction. Airway, breathing, and monitoring
equipment are not built-in and thus must be brought on-board separately.

Despite these equipment limitations, perhaps the greatest is the limitations of care providers in terms of both numbers and training. Most ground and air ambulances have one or two attendants assigned for up to six critical patients. Obviously, if more than one patient requires intensive bedside care (e.g., active bag-valve-mask ventilation) the single attendant’s capacity to provide care is exceeded. Ironically, it is a common personnel practice to assign a junior or inexperienced medical technician to the job of ambulance attendant.

The rigors of MEDEVAC create two challenges for military medical providers. First, patients being prepared for tactical evacuation must be adequately stabilized for the journey. Extra effort should be made to anticipate problems en route. For example, providing critically injured patients with two intravenous lines (in case one fails) before embarking may prevent the need for restarting a line. The second challenge occurs at the receiving medical facility. Casualties being off-loaded from ambulances need a thorough reassessment and, if needed, intervention to correct urgent problems.

Conclusion

MEDEVAC encompasses all movement of the movement of patients: from the point of injury to the nearest medical facility, between medical facilities at different echelon levels, and finally to the site of embarkation out of the theater. A key component of MEDEVAC is the provision of ongoing casualty care. To assure the success of what is one of the most important missions of military medicine, all military medical providers need to be familiar with the basic concepts and components of tactical MEDEVAC.

References


Triage is a French word meaning to pick out or sort. It was first introduced into the English language during World War I as a military process of classifying casualties. The modern definition, according to Gunn, is “the selection and categorization of the casualties of a disaster with the view to appropriate treatment according to the degree of severity of illness or injury and the availability of medical and transport facilities.” Numerous studies and writings exist that address the methodology of triage. However, there is little attention provided to triage prior to transport, especially in regard to aeromedical evacuation (AE). This chapter addresses mass-casualty events (civilian or military) where triage is performed under circumstances in which the number of patients exceeds the normal capabilities and resources for a prolonged period of time. Triage becomes a critical aspect of AE in mass-casualty events requiring special skills and considerations.

Mass-Casualty Triage

Mass-casualty care has three principle elements: triage, basic field stabilization, and evacuation. The objective of mass-casualty triage is to accomplish the greatest good for the greatest number in the shortest time, and it is this type of triage we will discuss in this chapter. Civilian mass-casualty triage contrasts with that of military triage, where the stark realities of combat require that the first objective is to determine who can be quickly treated and returned to combat immediately following treatment. In such military triage, treatment and evacuation of the more seriously injured is an important, but secondary, objective.

Sophisticated mass-casualty triage principles were applied in the Korean War and improved upon in both the Vietnam and Persian Gulf Wars. Mortality rates were reduced from 4.7% in World War I to 1% in the Vietnam War. Rapid triage and stabilization treatment, together with immediate helicopter evacuation and well-equipped and staffed echelon-level hospitals, were major factors that contributed to the low mortality rate in Vietnam. In a medical echelon system, such as the military’s, retriage is required at every level in the chain of evacuation, and thus triage must be a dynamic process (Fig 6.1).

Triage Situations

A “triage situation” is any situation where the total patient requirement exceeds available resources, thus requiring temporary prioritization of critical care. An example of this most often occurs in rural hospital emergency departments when a limited number of providers are faced with two or more critically injured patients. A triage situation will exist until on-call assistance arrives or casualties are evacuated to an advanced-care facility. The few studies that address AE triage deal primarily with these casualty-limited events in remote or inaccessible areas. However, these studies still have some applicability to mass-casualty AE, especially as they relate to recognition of the appropriateness of aeromedical procedures.
the impact of physiological and environmental factors, and skills required of aircraft and crew, as discussed later in this chapter.

Triage Criteria

Just as there are differences in the types of triage, ie, mass casualty and military, there are different criteria used to determine which patients are moved first. The two most common criteria are inclusion and exclusion.

Inclusion Criteria

The most common criteria used in the vast majority of civilian mass-casualty events are inclusion criteria. Civilian triage does not utilize the military echelons of care but does utilize the same decision-making factors, such as likelihood of medical success and conservation of scarce resources. In the United States, both military and civilian triage incorporate Advanced Trauma Life Support (ATLS), Advanced Cardiac Life Support (ACLS), and Advanced Pediatric Life Support (APLS) standards of care. These have also become the inclusion criteria expected for triage management in most developed countries where adequate resources and personnel exist. When there are an abundance of resources, inclusion criteria prescribe that all necessary resources be utilized first on the “sickest” patient. This approach to triage methodology and the decision-making process has been refined for the different locations at which it may be employed, including the scene of the disaster, the civilian or military hospital emergency department entrance, and x-ray and surgical suites. Unfortunately, the requirements for or influence of AE triage in this process have rarely been addressed.

Exclusion Criteria

Recent experiences during complex humanitarian emergencies (eg, Somalia, Rwanda, and the former Yugoslavia) have been remarkable both for the massive numbers of casualties (primarily civilian) and the extremely limited resources available. In these situations, definitive care is unavailable for most casualties. The result is that triage occurs at only one level, ie, the besieged hospital, where further evacuation (ground and air) is often impossible (Fig 6.2). Mass-casualty events during complex emergencies often require triage officers to make exclu-
sion criteria decisions that reflect the relative scarcity of multiple basic medical provisions, including resuscitation equipment, surgical expertise, blood supplies, electricity, clean water, and security for both patients and medical personnel, as required by international humanitarian law and the Geneva Conventions.\textsuperscript{9,11} When a medical system is overwhelmed, this is the only possible way to keep scarce resources available for patients with a reasonable chance for survival.

Guidelines for applying exclusion criteria must be determined as early as possible when triage is required for this type of complex mass-casualty event. As soon as the relative scarcity of medical provisions has been determined, triage personnel must agree on which casualties have little hope for survival without using a large amount of resources (eg, patients requiring cardiac resuscitation, immediate surgery, or substantial blood transfusion). These patients will be treated only with comfort measures. This use of seemingly harsh exclusion criteria for aggressive treatment were required in Kigali, Rwanda, where over 20,000 trauma casualties were triaged by underresourced relief organizations. It was also used in Rwandan refugee camps, such as Goma, where the intravenous (IV) fluids available for rehydration during cholera epidemics were extremely limited.\textsuperscript{12} Decisions using exclusion criteria become even more critical if evacuation options are unavailable, limited, or threatened. The potential remains high for triage officers to deploy to locations where they may face these difficult decisions during a mass-casualty event or armed conflict.

Triage Considerations in Large-Scale Weapons of Mass Destruction (WMD) Events

WMD may occur as a result of a terrorist induced biological, chemical, nuclear, or mixed event. Also, an explosive device may be purposefully contaminated with a bioagent or chemical resulting in a confusing, early or delayed, clinical presentation of an otherwise physically traumatized victim. In a large-scale WMD event (PICE stages I–III), triage will be practiced in a resource-constrained environment. Exclusion criteria will be utilized, and
as such, AE capability and capacity may be severely compromised. In Table 6.1, column A describes the potential for additional casualties. Column B describes whether resources are overwhelmed and, if so, whether they must be augmented (disruptive) or first need to be reconstituted (paralytic). Column C describes the extent of geographic involvement. The PICE stage refers to the likelihood that outside medical assistance will be needed.

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**Biological Terrorism**

A primary objective of current education and training of healthcare providers in the clinical recognition and management of biological agents, and in the use of detection technologies, is to determine, as early as possible, whether the bioagent is contagious. In a non-contagious bioagent environment (eg, anthrax), standard patient precautions will be followed. There will be few contraindications to AE. With a contagious bioagent (eg, smallpox) triage must consider the vulnerability of AE personnel, their equipment and aircraft. In general, contagious victims will not receive AE unless containment equipment and personnel protections (ie, portable isolation units, protective gear, vaccination coverage, etc.) are guaranteed.

**Chemical Terrorism**

AE triage criteria will vary depending on the chemical used and whether the victims have been appropriately decontaminated before flight. As was the case in preparations for the Persian Gulf War, decontamination equipment must be available for AE aircraft and equipment. If not, AE becomes exclusionary in the triage and management process.

**Nuclear Bioterrorism**

The contraindications of triaged victims are less critical to individual victims unless the AE is entering a contaminated area. As with any large-scale WMD event, the decision-makers must, early in the triage process, determine how AE assets will, if ever, be used and under what circumstances and operational protocols.

**Mixed Agent Terrorism**

All triage personnel must consider the possibility that victims in a terrorist event, especially those experiencing an explosive device, have suffered additional exposure to a biological (eg, botulism toxin) or chemical agent (eg, nerve gas). Nerve gas may cause spasms in exposed voluntary muscles observed during the triage process, requiring immediate decontamination before AE and surgery.

**Aeromedical Triage**

Aeromedical triage is extremely complex and requires knowledge of multiple factors. It can be defined as the triage support that prioritizes and prepares patients for AE, including appropriate specialized care during transport. Aeromedical triage requires attention to unique physiological and air transport environmental factors that may directly affect: (1) the decision to transport, (2) pre-existing triage and evacuation priorities (3) treatment and resource allocation, and (4) risk analysis decisions.

In both battlefield and true mass-casualty events, there is often no reasonable alternative to AE. Therefore, aeromedical triage must ensure that appropriate triage methods are utilized to prevent the misuse of limited aircraft and still move patients efficiently. Lack of proper triage has been shown to limit patient transfer and the efficiency of long-distance AE. Triage officers, both military and civilian, responsible for mass-casualty care are required to incorporate and communicate critical aeromedical factors into the management process.

The triage officer requires a myriad of critical information to make AE triage decisions.
Triage teams must maintain an umbrella view of the larger triage and evacuation system with its capabilities, responsibilities, and limitations, as well as exercising the flexibility needed to work within this complex system. With numerous advances in AE being made daily (eg, telecommunications, training of personnel, capability of aircraft), triage officers must stay current so that they may incorporate their knowledge of aeromedical factors into their triage decisions.

Patient triage is one of the basic requirements that all AE systems must meet in addition to medical crew training, in-flight patient monitoring and treatment, and access to appropriate target medical facilities. In turn, each aeromedical triage system should meet certain minimal requirements. If triage is done properly by the triage officer, the patients will receive care in a continuum throughout evacuation, not just a simple flight in an aircraft.

AE Triage Minimal Requirements

1. The triage officer and escorting providers should be aware of the differences between working in the airborne environment and working in the static ground-based facility of the field environment.

2. All patients must receive a primary survey designed to identify indicators of impending or existing respiratory failure or shock. This survey should include an assessment of how aeromedical physiological and environmental factors might contribute to respiratory failure or shock. At a minimum, this should include a systematic evaluation of the airway, breathing, circulation, and immobilization.

3. Triage officers should conduct frequent repeat triage using clear guidelines to ensure optimal and rapid modification of medical care during transport.

4. Triage officers should use clinical protocols for specific injuries and illnesses, based on mechanism of injury, physiological status of the patient, and predicted transport times, to improve outcomes and significantly reduce the interval between injury and patient arrival at an appropriate medical facility.

5. Medical care must be of high enough quality that the condition of mass casualties will not deteriorate more during AE than would have occurred on the ground.

6. Triage officers must have advanced medical knowledge of triage and evacuation priorities, modes of transportation, transport management, and hospital destination to minimize triage-related errors, eliminate medical bottlenecks, and afford early and appropriate definitive care to those most in need.

7. Guidelines must be in place to minimize unnecessary casualty transfers resulting from either undertriage or overtriage as described below.

8. The triage officers must be mindful that crisis intervention begins at the scene, both during and after evacuation, for casualties, relatives, rescuers, and health workers.

Factors Influencing Triage Decisions

In any mass-casualty situation, the possibility of either overtriage or undertriage always exists, and it is the purpose of aeromedical triage support to minimize this waste. In overtriage, relatively minor injuries are either sent to trauma centers with far more capability than required or are transported more quickly than their condition requires. In undertriage, patients with life-threatening injuries are either transported too slowly or to facilities incapable of treating them. In day-to-day civilian practice, an acceptable overtriage rate is 50%, primarily because capability far exceeds requirement. However, in a mass-casualty situation a waste of either transportation or treatment assets is unacceptable. There are a number of key factors that can be used to influence the best possible triage decisions described below (Table 6.2).

Triage and Evacuation Priorities

Mass-casualty field triage refers to the sorting and classification of patients, assessing patients to determine the most appropriate receiving facility, and specifically deciding whether to bypass the closest hospital in favor of another. The goal is to ensure that all seriously injured
patients are brought to a trauma or specialty referral center while maximally utilizing scarce resources. Flight crew expertise and ability to monitor, resuscitate, and provide critical procedures during air transport are critical to the overall triage process.

**Triage Categories**

Both qualitative and quantitative methods of triage are used to classify patients into triage categories. Qualitative methods classify patients subjectively into a group of categories, usually two to five in number. Quantitative methods use various types of numeric scales to place an “exact” value on the patient’s need to move. In mass-casualty events, triage categories must be kept simple and functional and complement the unique requirements of the aeromedical environment. For this reason, the authors have developed a modified four-tiered qualitative sorting system that communicates aeromedical factors critical to transport and treatment:

**Priority 1: Immediate.** Seriously injured with reasonable chance of survival if transported by air to a proper facility. Expectations are that advanced care will continue or be enhanced during transport.

**Priority 2: Delayed.** Casualties can wait for care or air/ground transport. Basic first aid, retriage, and monitoring are provided. Triage officer determines both priority and sequence of air transport, accelerating the transport if condition deteriorates, a transport opportunity hastens care and recovery, or space allows.

**Priority 3: Minimal.** No impairment of function, can either treat self or be treated by a non-professional. Appropriate for ground transportation. Should not reenter air transport triage process.

**Priority 4: Expectant.** Extremely critical or moribund casualties with little hope of survival under the best of circumstances of medical care. Will not benefit from air evacuation.

**Quantitative Scoring Methods**

Although experienced triage officers rely on their best clinical judgement, no triage guidelines perfectly predict which patients are truly emergencies. Quantitative methods that assign an objective score to a casualty’s clinical status can assist assessment and triage, especially in identifying those casualties most suitable for evacuation to trauma facilities. A study has shown that the instinctive or “gut feeling” was unreliable alone, but when used in conjunction with a mechanism of injury scoring system it enhanced the identification of major trauma casualties. Complicated scoring systems or time-consuming evaluations are to be avoided due to risk of delay in transport, but such quantitative systems do have value.

Multiple quantitative scoring systems have been developed to predict survival outcomes. These systems are based on a number of different criteria including anatomy, injury severity, physiological measurements, and mechanism of injury. An example of the effectiveness of one such system is a trend toward increased survival observed among patients transported by helicopter with higher injury severity scores. In general, anatomic and physiological criteria as measured by the Trauma Score provide the triage officer a means to predict survival outcomes and audit the system more accurately with information about the
severity of a patient’s injuries or condition than criteria based on mechanism of injury alone.\textsuperscript{16} To be useful, the anatomic and physiological criteria must be clear, concise, and readily determined by field personnel. Incident criteria such as the anatomic factor and mechanisms of injury scoring tend to result in excessive over-triage but are valuable in raising suspicion of serious injury.\textsuperscript{3} The Revised Trauma Score for Field Triage is a quantitative system that has been used to predict survival outcomes and therefore, indirectly, the feasibility of air transport and aircraft suitability.\textsuperscript{19}

Number of Casualties

By definition, mass-casualty situations involve the movement of large numbers of casualties. Effective measures must be utilized to accurately assess the effectiveness of each mass-casualty triage effort.\textsuperscript{20} One measure of effectiveness for triage is associated with how well patients were transported to the medical facility that could meet their need on the first transport. This measure is the ratio between interhospital transfer due to triage errors and the total casualty population who needed transfer.\textsuperscript{21}

Types of Casualties

Virtually all mass-casualty events will generate a significant number of trauma casualties who will present with a wide variety of injury patterns. When considering the most common types of injuries, two important factors should always be kept in mind. First, the chief causes of death are hemorrhage, sepsis, and respiratory failure (e.g., adult respiratory distress syndrome [ARDS]).\textsuperscript{3} Second, hypovolemic shock will be overlooked by trained medical personnel in many casualties.\textsuperscript{1}

Blunt/Crush Injury

To make appropriate triage decisions for casualties with blunt or crush injuries, a number of important factors must be considered. AE can reduce predicted mortality for casualties with blunt injuries by more than 50%.\textsuperscript{22} However, these types of injuries are missed more often than penetrating injuries. Appropriate triage of these patients to trauma centers for definitive care may be more critical than the timing of the transfer.\textsuperscript{14} A deadly combination is blunt injury followed by cardiac arrest, and physician intervention at the scene is not likely to improve mortality in these cases.\textsuperscript{23} Thus, it is appropriate to triage casualties who have both blunt injury and cardiac arrest into the “expectant” category.

Head Injury

Appropriate AE triage of closed-head injury patients is crucial and requires considerable judgement and expertise. In one study, a 9% reduction in head injury-related mortality has been attributed to AE.\textsuperscript{24} These casualties can be divided into groups based on their risk of significant head injury. The high-risk groups appropriate for immediate AE are those casualties who have one or more of the following:

1. Depressed levels of consciousness indicated by a Glasgow Coma Scale (GCS) of 13 or less, focal neurological signs.
2. Decreasing levels of consciousness.
3. Penetrating skull injuries.
4. Those with evidence of a depressed or basilar skull fracture.

The moderate-risk group of casualties are those who had a brief history of loss of consciousness, change in consciousness, progressive headache, vomiting, or posttraumatic amnesia.\textsuperscript{25} These casualties create the most difficult triage decisions. In the primary survey, the triage officer must evaluate and monitor the level of consciousness (LOC) by the awake, verbal, pain, and unresponsive (AVPU) scale, and re-evaluate this every 15 minutes.\textsuperscript{24,25} Any casualty experiencing variations in LOC is reassigned to the high-risk group and requires immediate evacuation.

The lowest-risk group is made up of casualties who have remained alert and have a normal neurological examination. Their AE can be delayed because they have less than 1 in 1000 chance of having a significant head injury.\textsuperscript{24,25}

Burn Injuries

Appropriate triage of burn and inhalation injuries is crucial because this category
predominates in many mass-casualty events, such as hotel fires and airshow accidents.\textsuperscript{26} Immediate evacuation is indicated for casualties with second-degree burns involving 10\% or more of body surface area (BSA), third-degree burns of 5\% BSA, burns involving face, eyes, ears, hands, feet, or perineum, or any burn associated with a fracture. Immediate evacuation is also indicated for casualties with circumferential burns of extremities or digits because they may require an escarotomy.\textsuperscript{26}

Burn patients are among the most difficult to move, and excellent triage decisions are crucial to successfully move them. Because of airway burns and inhalation injury, some patients may be too unstable for flight without preflight treatment. Common procedures that may be required to make a patient stable enough for evacuation include insertion of catheters, immediate pulmonary care, escharotomy, and adjustments of IV fluids.\textsuperscript{27} Triage officers should remind the aeromedical crew of the risk for unsuspected pneumothoraces\textsuperscript{28} during flight and specifically request the in-flight availability of pulse oximeters, needle aspiration equipment, and supplemental oxygen for these patients.

**ARDS/Chest Trauma**

Immediate evacuation to appropriate ICU facilities is indicated for any casualty with ARDS. This potentially life-threatening complication can develop in any seriously injured trauma casualty, especially one who has had blunt or blast injuries. The triage officer must take into account the risk of altitude-related hypoxemia, which can be partially compensated for by breathing supplementary oxygen, as long as cardiac output and hematocrit are adequate.\textsuperscript{29} Casualties with severe ARDS should be transported in helicopters flying at low altitudes or pressurized fixed-wing aircraft with supplementary oxygen and pulse oximetry.

**Orthopedic Injuries**

Orthopedic injuries are common and frequently missed injuries associated with mass-casualty events such as earthquakes and building collapse.\textsuperscript{1} If orthopedic injuries are associated with prolonged extrication, the casualties are also at risk for compartment syndrome and acute renal failure (see Blunt/Crush Injury). Stable orthopedic patients triaged as “delayed” should be immobilized while awaiting transport. The triage officer must assure that weights are removed from any traction devices prior to flight and ensure that patients with air splints are properly managed during flight.\textsuperscript{30}

**Chemical Contaminated/Mixed Contaminated–Surgical Trauma Casualty**

These casualties should be suspected whenever large numbers of casualties occur and chemical contamination from an industrial accident or terrorism cannot be ruled out. Fasciculation of muscle groups and in muscles of an exposed wound or traumatic amputation should alert the triage team to possible nerve gas exposure.\textsuperscript{31} Even in the presence of contamination, triage decisions must still be based on the patients’ total medical condition, including ambulatory status, respiratory status, and additional injuries.

Decontamination before transfer is critical, because contaminated patients may get worse in the closed environment of an ambulance or aircraft and further place aircraft crew at risk. Iran–Iraq War nerve gas casualties, thought to be decontaminated days before, were sent without any precautions to France on a commercial flight for specialized treatment, only to contaminate unsuspecting flight attendants and crew.\textsuperscript{32} In the Tokyo sarin attack, casualties triaged as minimal were not decontaminated at the scene, worsened during evacuation, and contaminated both transport and hospital-based health providers. Before the Persian Gulf War, plans were developed to use helicopters in the decontamination process, but this required extensive aircraft washing facilities unlikely to be available during peacetime.\textsuperscript{3} The triage officer should make certain that the proposed destination medical facility has the capacity to offer further decontamination antidotes, and ventilation support.

**Pediatric**

Critically injured or ill pediatric patients are extremely vulnerable during AE. One of the
most common reasons for AE of pediatric patients in a mass-casualty situation is head injury due to the relatively large size of the head in relationship to the rest of the body. Brain complications can be compounded by AE because altitude-related hypoxia is the most common complication of pediatric air transport. It is the triage officer’s responsibility to make sure that the medical aircrew is prepared to take steps to minimize this risk.

**Combative/Violent Patient**

In the overall evacuation process, from patient identification to successful outcome at destination, many overlapping agencies and organizations are involved in the triage process. The potential for confusion and miscommunication are probably the greatest for combative or violent patients. The responsibility of the triage officer when confronted with neuropsychiatric patients is often incompletely understood. For mass-casualty triage purposes, bizarre behavior should be assumed to be the result of head injury, hypoxia, or toxin exposure until proven otherwise. Unless the patient is known to have a preexisting neuropsychiatric condition, it is critical to search for such acute causes and begin appropriate treatment. The triage officer should advise the AE crew if there is a need for attendants, sedation, or restraints.

**Transportation Management**

Once the decision is made to move a patient through the AE system, a number of factors must be considered to properly manage the transportation. Among these factors are the procedures that AE crews can reasonably perform in the air, the equipment available, the skills of the crew, and the physiological effects of flight.

**Procedures Performed by Flight Crews**

The AE crew can be expected to accomplish a limited number of medical procedures for a variety of reasons, including noise, poor lighting, constant vibration with intermittent severe turbulence, and limited space. Procedures commonly performed by aeromedical crews include:

- nasogastric tube insertion
- endotracheal intubation
- cardiopulmonary resuscitation
- IV lines
- central venous access
- extrication and splinting
- bladder catheterization
- venous cutdown
- tube thoracostomy
- cricothyrotomy
- pericardiocentesis
- MAST garment application

These procedures are best performed prior to flight. The triage officer must first consider the pertinent physiological and aeromedical constraints that may affect the procedure. He must also assure that limited supplies and equipment are not used on expectant patients.

A common consideration is the timing of endotracheal intubation. If performing this procedure on the ground will delay evacuation, experienced aeromedical crew members can intubate both adults and children in-flight, even if neuromuscular blockade paralysis is required for intubation.

A casualty with multiple trauma will often require placement of a chest tube or needle aspiration. Patients who undergo emergent tube thoracostomy in the field are at increased risk for complications, in particular from a malfunctioning or malpositioned chest tube that may require repositioning in-flight. Alternatively, needle catheter aspiration is a rapid intervention for the treatment of suspected tension pneumothorax, which has been shown to be relatively safe and effective and have low morbidity.

The triage officer should make special arrangements for cardiac patients with temporary pacemakers and automatic defibrillators. These devices must be set to a mode where the vibrations of flight will not trigger any inappropriate firings. If the preflight setting and equipment allows, permanent pacemakers should be programmed to nonatrial sensitivity or asynchronous mode before the patient is on-board the aircraft. The triage officer should ensure that this type of cardiac-related electrical
equipment is compatible with the aviation environment, both in fixed-wing and rotary-wing aircraft.38

Physiological Factors

A number of physiological factors must be considered in the decision to send patients in the AE system, but none are more important than respiratory factors. Adequate patient ventilation is the cornerstone of safe, successful AE. Common effects of AE that may hamper patient ventilation include altitude-related hypoxia, gas expansion, and even acceleration forces.28,39–41 Triage officers must have a solid grasp of the inherent limits of the aeromedical environment and a well-developed understanding of altitude-related pressure effects on pulmonary physiology, procedures, and medical devices used during flight.39,41

Altitude Hypoxia

In a mass-casualty event, oxygen therapy during flight may not always be available. If patients at risk for hypoxia are being transported without supplemental oxygen, both the aircrew and aeromedical crew should be advised that altitude restrictions may be required. It must be remembered that pressurized cabins provide only partial atmospheric pressure, with minimum pressures usually equivalent to an altitude of 8000 ft.28 Pulse oximetry is a useful way to determine which patients are desaturating in-flight. Unfortunately, if oxygen is in short supply these devices will almost certainly be as well.

Accelerative Forces

Gravitational forces are important factors in the AE environment, but should rarely affect triage decisions. However, triage officers should be aware that certain patients, eg, head trauma, should have their litter positioned so their heads are toward the rear of the aircraft to maintain their cerebral circulation.

Gas Expansion

Changes in altitude associated with AE can have serious effects for patients with untreated pneumothorax, gas gangrene, or air trapped in the cranium or abdomen.42 Diminished ambient air pressure causes gases in closed spaces and tissues to expand rapidly. Fortunately, gas expansion will in general not be a problem when flying below 5000 ft (1500 m).42 Penetrating eye injuries may also worsen with altitude. The triage officer should alert the AE crew if there are any patients who may be at risk for gas expansion, and a decision must be made whether or not to establish an altitude restriction.

Mode of Transportation

There is risk in mass-casualty events that AE will be used inappropriately. In one wartime study, only 22% of patients were found to have benefited from AE as compared to calculated road ambulance evacuation. This resulted despite a high percentage of trauma patients, rural setting, and poor road conditions and emphasizes the need to devise a system that can screen out unnecessary flights.43 Crew safety and the high costs of flying are two important considerations in the triage process.42 Casualty-limited events, such as a two-casualties automobile accident, are especially prone to the overuse of helicopter evacuation for casualties with low severity scores, which has been reported to be as high as 85% of flights in some studies.44 Decisions to use helicopters for trauma patients are more often based on physician attitudes about air transport than triage guidelines,44 making a trained triage officer role invaluable in these situations.

The decision to use aircraft should not be made lightly even in mass-casualty events. One of the major responsibilities of the triage officer is to assist in the determination of the need to use aircraft, what type of aircraft to use, and for what purpose is an aircraft required. Indications for AE include the need to circumvent geographic impediments, cover large distances in a short time, access isolated areas, and, most critically, get the casualties quickly to specialized medical care. In a mass-casualty situation, the triage officer may not have any control over the type of aircraft that arrives, but once aircraft are available they should be used to benefit the most patients possible.
Use of aircraft in urban mass-casualty events is rarely indicated. However, aircraft may be required to transport patients from local medical facilities to Level I trauma centers or specialized care facilities (e.g., burn centers). These moves should occur after initial stabilization at the local hospital. In addition, the use of aircraft to rapidly transport qualified personnel to the scene or to a nearby treatment facility may be an expedient triage decision.

Rotary-Wing vs Fixed-Wing Aircraft

In the civilian AE setting, helicopter missions outnumber fixed-wing missions in a ratio of 7:1.46 In mass-casualty events in field conditions, immediate air evacuations are almost exclusively by helicopter because of their unique capabilities. Helicopters deploy rapidly, require shorter preflight planning, do not require an airfield for landing, and provide more rapid turnaround times critical for mass-casualty evacuations.46 Vertical take-off avoids complications caused by horizontal accelerative/decelerative forces. A helicopter's normal flying altitude is less than 2000 ft (600 m) above ground level, so hypoxia is rarely a problem.47 These advantages of helicopters may be offset in some circumstances by their disadvantages compared to fixed-wing aircraft. These disadvantages include short range, small passenger/patient load, vibration, noise, no pressurization, weather limitation, and increased risk of motion sickness.47

Studies suggest that improved clinical outcomes are associated with helicopters that are faster and provide more cabin space. Most cabins provide for one belted crew member at the patient's head and one on the side to monitor vital signs and perform necessary non-airway–related procedures. Helicopters with a two-patient capacity greatly increase demands on the flight crew and diminish access and care to both patients.20 Triage officers must communicate with the aircrew to ensure an appropriate provider-to-patient ratio, as well as compliance with maximum take-off weights. This final point is crucial because take-off weights can easily be exceeded due to the weight of certain medical equipment.48

Fixed-wing aircraft have the disadvantage of requiring an airfield and needing more pre-flight planning time, but are less hampered by weather. With proper triage and in-flight medical care, casualties can be transported 800 miles or more without increasing transport-related mortality. These long-range movements are almost always accomplished to provide access to a major trauma center or burn center. Compared to a helicopter, cabin spaces are much larger and usually pressurized. Because of the decreased cabin pressure at usual cruise altitude, oxygen supplementation is routine for all at-risk patients at altitude. Triage officers must assure that aircraft have enough oxygen to meet all patient needs before the aircraft departs.

Crew Safety, Skills, and Composition

Optimal aeromedical triage is dependent on the medical input and guidance by trained and experienced triage officers. Their roles include protocol development, training, and continuing education in mass-casualty care as well as coordination of lessons learned in aeromedical triage and evacuation. The most important qualifications for a mass-casualty triage officer include good judgement, broad-based knowledge of aeromedical factors, and solid leadership and management skills. It is crucial that the on-site individual with the greatest skills serve as triage officer regardless of professional training (i.e., doctor, nurse, paramedic).

It is critical for on-scene triage officers to know the composition and skills of available AE crews and match casualties with both aircraft and crews. This is often made difficult by the unpredictable mix of airframes, crew composition, and skills that are available during a mass-casualty event. An abiding principle is that no mission should be flown if it cannot be accomplished safely.

The types of aircraft and crews available will differ greatly depending on whether they are civilian or military. Civilian programs utilize small to midsized aircraft (most commonly helicopters), often with a single pilot (see chapter 3). The AE crew usually consists of two highly trained medical crew members, usually a combination of technicians, paramedics, nurses, or physicians. They are in general always equipped with state-of-the-art medical equipment.42 The USAF uses a variety of transport
aircraft in the AE role (see chapter 8), all of
which have at least two pilots and an aeromedical
crew structured to meet the needs of the patient load. By tradition, military programs
operate larger aircraft and utilize two pilots per
aircraft. Safety is a high priority, with emphasis
on crashworthiness and protective gear. And,
finally, because the historical mission is one of evacuation of multiple stable casualties in
wartime, military aircraft by tradition utilize
aeromedical crewmembers with limited train-
ing in critical care and limited equipment. The
current development of the Critical Care Air
Transport (CCAT) Team concept will change
this crew factor.

To comply with legal and operational
requirements, it is important that the skill
level of the AE crew be of the highest quality
possible, even during mass-casualty events. Because the skills of AE crews can vary greatly,
the triage officer may have to arrange for aug-
mentation of the crews with trained medical
providers. Studies on how varying compositions of
AE crews effects patient outcomes have been
mixed. No objective differences in outcome
of severity-paired patients were found between paramedic–nurse and nurse–nurse teams. Use
of paralytic drugs by paramedics is becoming
standard care in many out-of-hospital systems, and nurses providing ATLS during
flight perform equally when compared with
physicians. However, a 35% improvement in
outcome for blunt trauma patients was
associated with using flight nurse–flight phy-
sician teams over nurse–paramedic-staffed
helicopters.

The addition of a flight surgeon to AE crews
during military actions has been shown to
provide the flexibility to transport and resusci-
tate critically ill patients during flight. Dedicated MEDEVAC flight surgeons fill a unique
and valuable role in some circumstances. Nor-
wegian experience has shown benefit in having
a designated physician specially trained in aero-
space medicine and acute medicine/surgery as
a permanent crewmember.

Crew composition is not usually a peacetime
triage factor, but could easily become a part of
the triage decision in wartime. The limited
supply of intensive-care physicians and nurses
could easily force a decision regarding whether
to send these doctors and nurses with a flight or
keep them at the staging facility.

Weather and Environmental
Conditions
Triage officers must have a working knowledge
of the effects rain, fog, haze, clouds, airframe
icing, turbulence, and wind shear have on the
decision to fly. Conventional disaster managers
do not necessarily understand the nuances of
visual meteorological conditions (VMCs) and
instrument flight rules (IFRs). So, the triage
officer is responsible for interpreting these find-
ings to site managers whenever conditions
might prohibit or alter triage and evacuation
options.

Evacuation Destination
Prior to AE, the triage officer must consider
both the specialization and intensity of care and
services available at the destination site. The
availability of operating rooms and qualifica-
tions of medical personnel (not merely avail-
able hospital beds) are determining factors for
triage-to-destination decisions. In short, if the
casualties require a full trauma center then the
transportation plan must assure that they arrive
at such a center.

Telemedicine as an Aeromedical
Triage Tool
Advances in telemedicine and telecommunications, as a resource tool, have the potential to
positively influence triage decisions in the field
and then remotely care for the victim in-flight.
For more than a decade, commercial airlines
have been utilizing telemedicine services to
assist in-flight passenger medical emergencies. Specifically, telemedicine has been used for special-
ity consultation, access to medical information,
and biomedical monitoring/forwarding of patient parameters via special flight-worthy
monitoring systems and equipment. A survey
carried out by the FAA reported that flight
crews complied with medical advice in 97% of
cases, and diversions of aircraft resulted in
hospital admissions 86% of the time. Tele-
medicine services provide a 24-hour medical
emergency hotline (via radio, telephone, and
satellite) for direct and immediate consultation with board-certified emergency physicians qualified in remote diagnosis and trained to deal with illness and injury at altitude, and provides physicians immediate access to specialists in more than 45 fields of medicine.\textsuperscript{55}

In addition, special equipment has been adapted for in-flight utility. Tests have shown that useful vital sign information (ECG, blood pressure, transcutaneous pulse oximetry, and respiratory parameters) can be transmitted from an isolated location to a distant triage officer even at communications speeds as low as 2400 baud.\textsuperscript{56} These devices can be operated under remote guidance and utilize a portable lightweight computer unit connected directly with any available communications, including cellular phones. Units are adapted to Inmarsat (utilizing two Inmarsat mini-M terminals, one for voice and one for data) so that data can be transmitted over large bodies of water, allowing triage support from anywhere in the world.\textsuperscript{56}

The Telemedicine Instrument Pack (TIP) was successfully tested onboard a US Space Shuttle flight (STS-89) in 1998 and has proved to be equally operational on air ambulances.\textsuperscript{57} The DoD has developed a Life Support for Trauma and Transport (LSTAT) or “Smart Stretcher” that functions as an entire ICU utilizing embedded microminiaturized devices to monitor vital signs and the regulation of various fluid and medication administration by remote physicians.\textsuperscript{58,59} The civilian counterpart Mobile Intensive Care Rescue Facility (MIRF) allows for stand-alone intensive-care management (multifunction monitor, ventilator, infusion pump, syringe pump, and defibrillator) and fits into a large range of aircraft for transport of the critically triaged.\textsuperscript{60}

Conclusion

Triage officers have an opportunity to contribute greatly to the effective management of mass-casualty events, transforming the casualties to patients as they move from the disaster to a hospital bed. The factors unique to aeromedical triage support are critical to overall mass-casualty triage, evacuation, and management. Advanced technologies such as telemedicine/telecommunications have the potential of augmenting aeromedical triage decision making from great distances.

References

15. Anantharaman V. Burns mass-casualty disasters: Aetiology, predisposing situations and initial
45. Magnus AK, Kristiansen IS, Thoner J. Emergency helicopters health services in the grey
49. Thomas F, Clemmer TP, Orme JF. A survey of advanced trauma life support procedures being performed by physicians and nurses used on hospital aeromedical evacuation services. Aviat Space Environ Med 1985;56:1213–1215.
Patient Staging for Aeromedical Evacuation

William W. Hurd, Anthony M. Rizzo, Eunice K. Taylor, and John M. McNamara

Staging is a general military term that refers to the careful preparation and organization of personnel and equipment prior to deployment. For aeromedical evacuation (AE), patient staging includes the preparation of the patient, personnel, and equipment prior to the AE flight. Although the term is infrequently used in the civilian world, every patient must be effectively staged prior to any AE flight regardless of the venue.

From a medical perspective, patient staging is of the utmost importance. Once in the air, the medical care available to the patient is entirely dependent on the thoroughness with which pre-flight preparations have been made. Complications or emergencies can be effectively treated only if the appropriate equipment, medical supplies, and trained medical personnel are available. Unanticipated in-flight emergencies may receive only the most rudimentary emergency care because the medical supplies, medications, and medical expertise available during a routine AE flight are relatively limited. Subsequent care for unexpected complications is usually delayed until emergency diversion to a medical treatment facility is accomplished. Any lack of planning not only increases discomfort for the patient but also may adversely affect the patient’s health.

In light of the inherent limitations of AE, patient staging has three main medical purposes: first, to appropriately select patients for AE; second, to arrange for the appropriate in-flight equipment and personnel; third, to prepare the patient both medically and psychologically for flight.

Medical Clearance for AE

In all cases, the patient must be determined to be healthy enough to withstand the rigors of AE. At the same time, any special patient needs must be identified. In the military AE system, specific peacetime protocols have been developed for preflight medical clearance. In a contingency situation, the greatly increased number of patients who must be moved quickly may complicate medical clearance. Although the specific personnel involved may be different for civilian AE, the medical considerations remain the same.

The importance of preflight screening for AE is related to the difficulty in both detecting and treating patient decompensation during flight. Detecting in-flight medical decompensation is made difficult by two factors common during military AE. First, the noisy and dark environment of many of the airframes used for AE hinders the ability to detect small changes in the patients’ conditions. Although the interior of the C-9 Nightingale (the aircraft most commonly used for AE during peacetime) is well lit, it has approximately the same ambient noise level of a commercial aircraft. During a contingency operation, only a minority of military patients will be transported on these aircraft. The aircraft commonly used for tactical and strategic AE (eg, C-141, C-130) are noisy and dark, with significant amounts of vibration and potentially extreme swings in temperature from hot to cold. All of these factors hinder the ability to detect changes in the patients’ conditions.
Another factor that makes detecting changes in the patients’ conditions difficult is the high patient-to-provider ratio that occurs in mass-casualty situations. A military AE medical flight crew consists of 1 flight nurse and 3 flight medical technicians for each 10 patients. Because a fully loaded C-141 can carry over 100 litter patients, the number of patients per provider may be higher in a contingency situation. The decompensation of a single patient further draws attention away from the other patients. As a result, many changes in condition that would be noticed in a quiet, brightly lit hospital environment might go unnoticed for hours during a difficult AE flight.

The treatment of patients who become unstable during flight is likewise more difficult during AE because of several factors. The first is the noisy and dark environment as discussed above. Lack of space is a second critical factor. When a C-141 is used to transport multiple litter patients, as many as 100 litters are “stacked” in tiers of 4 patients, with only 21 in of clearance between litters (Fig 7.1). This configuration results in the top stretcher being located more than 5 ft above the deck. Little meaningful patient care can be done at this level without removing the litter from its tier and placing it on the cabin floor.

A final factor that makes treatment more difficult is a lack of specialized equipment and training. While all flight nurses, technicians, and physicians are trained in basic emergency treatment, routine AE flights are equipped only with standard emergency equipment and drugs. If the risk of patient decompensation is significant, special arrangements must be made for extra personnel and equipment to assure that

![Figure 7.1. A flight nurse checks on patients in a USAF C-141 Starlifter configured to hold litter patients during an AE exercise (USAF photo by Airman 1st Class Angela Furry).](image-url)
the patient receives optimal care during AE. This is a key function of staging because failure to make appropriate special arrangements prior to AE may make it difficult or impossible to effectively treat unexpected changes in patient condition during flight.

**Peacetime vs Contingency AE**

There are considerable differences between peacetime and contingency AE during armed conflict or a natural disaster. During peacetime, the vast majority of military AE is elective and, in most cases, the timing of such AE is based on medical considerations. This is in contrast to AE during a contingency, where patients may need to be moved at the first available opportunity for logistic considerations, the most important of which is the lack of comprehensive medical care locally. For the purposes of this textbook, contingency AE is defined as AE of casualties as soon as possible after stabilizing treatment, for logistic reasons.

**Peacetime AE**

For AE during peacetime, the referring physician performs medical screening and primary preparation (Fig 7.2A). This is done in conjunction with a flight surgeon familiar with AE to make sure that altitude, personnel, and equipment-related limitations are considered. Prior to AE, the transfer must be coordinated with an accepting physician at the receiving medical treatment facility. In the military system, final AE clearance is given after review of each patient’s diagnosis, condition, and

![Figure 7.2](image)

**Figure 7.2.** Graphic representation of the differences between peacetime and contingency AE as performed by the USAF AE system. During peacetime (A), the transfer is primarily between USAF medical treatment facilities, with ASF personnel playing a relatively minor role in their medical care. During contingency AE (B), ASF personnel will play a much greater role in the medical care of stabilized patients en route. Note that neither physician-to-physician coordination nor individual medical clearance for AE may be possible during contingency AE, making the role of the ASF critical for successful AE.
special needs by an experienced flight nurse (patient movement clinical coordinator) at the Global Patient Movement Requirements Center (GPMRC). As the patient passes through the aeromedical staging facility (ASF), medical personnel verify that the patient is stable and has the necessary supplies and medications for the flight (see later in this chapter).

Contingency AE

A sudden increase in the number and severity of patients requiring military AE will necessarily alter the way patients are medically cleared. During contingencies, such as armed conflict or natural disaster, a much smaller percentage of the treating physicians will have the background or time to clear the patients for AE. In addition, flight surgeons are unlikely to be readily available in a non-USAF medical facility. During an armed conflict, the majority of patients will originate in Army medical facilities, where physicians expert in the treatment of battlefield trauma are less likely to have the expertise to clear patients for AE. Further, mass casualties may overwhelm the GPMRC system and will almost certainly make it impossible to individually coordinate patients with the referral physicians at the accepting medical facility.

For these reasons, the responsibility for medically clearing and preparing patients for military AE will often shift to ASF medical personnel during a contingency operation (Fig 7.2B). The ASF will serve as the point of medical clearance for most patients requiring AE and may be the point of origin for some patients. Undoubtedly, there will be less time and personnel to manage a greater number of patients.

At the same time, the types of patients transported by contingency AE make appropriate medical clearance even more critical. During a contingency operation, most patients will not be in the stable convalescence phase of their recovery. Patients who have only recently been treated and stabilized in a medical facility will be at increased risk of medical decompensation before or during the AE flight. Experience teaches that transportation of patients before they are reasonably stabilized can have tragic results.²

AE Movement Precedence

Movement precedence categories have been developed to assist the GPMRC during peacetime in assuring that patients are moved in an appropriately timely fashion with the appropriate personnel and equipment. They can also be applied to casualties during contingency AE if the number of casualties exceeds the AE capability. These categories reflect the patients’ conditions but not necessarily their medical stability (Table 7.1).³

Routine AE

Stable patients who need little medical monitoring or care in-flight are classified as routine. These patients may be in the convalescent phase of their illness or injury or may have a stable condition that makes them unlikely to experience medical decompensation. They are most often ambulatory, although some may require transportation by litter because of their conditions.

Urgent AE

In peacetime, a certain percentage of patients will require quicker transportation than can be afforded by routine AE. The most drastic of these are patients designated for urgent AE. This is defined as patients who require emergency AE to save life, limb, or eyesight or prevent serious complications of injury or existing medical conditions. In almost all cases of urgent AE, the driving factor is that the medical expertise or equipment is not available to treat the patient in a local medical facility. Because these patients are often unstable, they may also require special expertise or equipment and thus may also be classified as special AE (see later in this chapter).

Priority AE

These are patients who must be transported by AE within 24 hours, usually because appropriate care is not available locally. In some cases, the patient may be medically stable and require minimal in-flight monitoring or care. More
commonly, the patient may be relatively unstable and require the special expertise or equipment of special AE.

Special AE

This refers to any patient who requires special expertise, equipment, or in-flight care not normally offered by the AE system. Many patients classified as urgent or priority AE will be relatively unstable and require special care during AE. These patients must be accompanied by physicians, nurses, and/or other providers who are expert in the management of their critical problems. In the military system, these augmenting personnel usually originate from the referring medical facility. However, with the development of the Critical Care Air Transport (CCAT) Teams program, a team of specially trained medical personnel may be brought from a different medical facility specifically for this transportation.

Aeromedical Staging Facility

For military AE, the ASF serves as an entryway to the AE system. During peacetime, the ASF accomplishes this through many important functions, including patient preparation, final medical clearance, and transportation to and from the flight line. ASF personnel confirm that the appropriate supplies and medications are sent with the patient. They also serve as a double check for medical clearance for AE by verifying that patients are in the same condition as when they left the medical facility.

The role of the ASF dramatically expands during a contingency or mass-casualty operation. The ASF medical personnel may be the first caregivers experienced in AE medicine to evaluate the patient and thus may be responsible for medical clearance of AE. In addition, the rapidly increased demands placed on the medical system during these types of operations may require the ASF to provide a wide variety of care, including medical–surgical ward care, intensive care, and emergency care.

Peacetime Roles of the ASF

During peacetime, the majority of AE patients will be categorized as routine and the majority of these will be ambulatory. The primary ASF role is to coordinate the safe transition of these patients from the medical facility to the AE system. This mission can be categorized into several specific tasks.

Medical Care and Preparation for AE

Medical preparation is critical to the safety of patients during AE and is probably the most specialized role of the ASF. To this end, the patients’ medical stability for AE must first
be confirmed. For inpatients, vital signs must be monitored during the several hours they are in the ASF. These patients must receive appropriate fluids and medications, as ordered by the referring physician. Sudden changes in these patients’ conditions are uncommon because these are usually stable convalescing patients. However, ASF medical personnel must have the knowledge and equipment to perform emergency resuscitation because sudden decompensation remains a risk for all patients.

Verification that the patient has an appropriate supply of medications and other patient needs is another important aspect of preparation for AE. This is critical, especially when a large number of patients are being transported, because a limited amount of extra supplies are available on the aircraft. Unexpected delays en route may occur due to changes in the medical condition of other patients on the flight or changes in itinerary, weather conditions, or operational limitations of the aircraft or flight crew. This may result in the need for a much greater amount of supplies or medications than was originally planned. Further, specialized medications are in particular difficult to obtain in smaller or foreign medical facilities located near sites where an AE flight is likely to be delayed. Because of this, the ASF attempts to provide the patient with several days’ supply of all required medications, even if the planned AE flight is only a matter of hours. For military AE, the standard is 3 days’ supply for intratheater AE and 5 days’ supply for intertheater AE.4

During peacetime, special AE patients often do not spend time in the ASF because of the acuity of their medical condition. Rather, they are transported directly from the referring medical facility to the flight line, and at the conclusions of their flight they are transported directly to the accepting medical facility. The medical care of these patients is primarily under the control of the augmenting medical personnel. However, the coordination and transportation for AE remains the responsibility of the ASF personnel.

Security

The ultimate safety of an AE flight depends on careful preflight screening of the passengers and their personal assets for dangerous items. Antihijacking precautions, in the form of metal detection devices, x-ray machines, and other strategies, are imperative for both civilian and military AE operations.

Patient Transportation

A relatively unique role of the ASF is to provide safe transportation for patients under challenging conditions (Fig 7.3). This involves transporting ambulatory and litter patients from the ASF to the aircraft via ground transportation (van, ambulance bus, or ambulance). Although the primary goal is to avoid patient injury, avoiding aircraft damage is also extremely important. The manner in which they are transported will be determined by a flight surgeon prior to transportation (Table 7.2).5

Litter patients must be carefully moved from the ASF onto the bus or ambulance and then onto the AE aircraft (Fig 7.4). The demands of this role make it potentially one of the most dangerous duties carried out by ASF personnel during peacetime. The patients are at risk of injury during transportation, as is obvious to anyone who has ever carried a litter. The ASF personnel are at risk of musculoskeletal injury when moving heavy patients to the awkward places found in both ground vehicles and aircraft. The task is complicated by the variation in AE aircraft configuration, as shown in chapter 8. In addition, the hardware necessary to secure patient litters may cause injury to the litter carrier’s fingers and hands. To minimize these risks, ASF personnel must be extensively trained in patient movement techniques so that they are familiar with challenges posed by the configuration of the various ground vehicles and aircraft.

Patient Sustenance and Comfort

Another extremely important role of the ASF is the sustenance and comfort of patients awaiting AE because it is not uncommon for patients to remain in the ASF for several days. ASF personnel must assure comfortable lodging for both ambulatory and litter patients and their nonmedical attendants. The patient arrangements must take into consideration the types
7. Patient Staging for Aeromedical Evacuation

and severities of their illnesses. ASF staffing provisions must accommodate all types and severities of illness and injury 24 hours per day, 7 days per week.

Another important mission of the ASF is to make sure that patients receive appropriate meals on the ground and in the air. Each ASF has nutrition technicians on-staff to make sure that regular and special dietary needs of patients are met, as determined by referring physicians.

Psychological support of patients is essential to AE. Many patients are experiencing serious injuries or illnesses for the first time in their lives, and most are about to undertake their first AE flight. If unprepared, the stress and isolation of the AE environment may further increase their apprehension and delay their healing and recovery. For this reason, a non-medical attendant (usually a family member) should be allowed to accompany the patient whenever possible during peacetime. In the military system, the referring physician determines the need for a nonmedical attendant.

Roles of the ASF for Contingency AE

Implications of Stable Rather Than Stabilized Patients

When a large number of patients must be transported out of theater during an armed conflict or a mass-casualty operation, the role of the ASF dramatically increases in scope. During contingency AE, patients are moved as soon as possible after initial stabilization. From a medical perspective, these “stabilized” patients are markedly different from the “stable” convalescing patients transported by AE during peacetime. In the past, patients were allowed to convalesce prior to AE, as shown in the Vietnam War, where the average length of

**Figure 7.3.** C-17 Globemaster configured to transport 36 littered patients and 48 ambulatory patients using a three-tier litter system. Lifting heavy patients to shoulder level requires both strength and skill to avoid injury to the patient or litter bearers or damage to the aircraft (USAF photo).
his or her diagnosis and present condition. This is one of the critical issues that will be covered in the clinical chapters in this book. Premature AE may result in potentially avoidable medical complications, morbidity, and, in the worst case, mortality. Depending on the availability of specially trained transport teams and equipment, there are certainly absolute contraindications to AE.2

### Table 7.2. AE categories used by the US Military.

<table>
<thead>
<tr>
<th>Inpatient Category 1: Psychiatric</th>
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<tbody>
<tr>
<td>Litter</td>
</tr>
<tr>
<td>1A Severe: Requiring restraints, sedation, and close observation</td>
</tr>
<tr>
<td>1B Intermediate severity: Potentially dangerous, but not presently disturbed, who require sedation; restraints should be available</td>
</tr>
<tr>
<td>Ambulatory</td>
</tr>
<tr>
<td>1C Moderately severe: Cooperative and reliable under observation</td>
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<tr>
<th>Categories 2 and 3: Medical/surgical</th>
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<tbody>
<tr>
<td>Litter</td>
</tr>
<tr>
<td>2A Immobile litter patient: Unable to move unassisted</td>
</tr>
<tr>
<td>2B Mobile litter patient: Able to move unassisted under emergency circumstances</td>
</tr>
<tr>
<td>Ambulatory</td>
</tr>
<tr>
<td>3A Patients going for treatment or evaluation: All medical and surgical conditions excluding drug or alcohol abuse</td>
</tr>
<tr>
<td>3B Recovered patients returning to station</td>
</tr>
<tr>
<td>3C Patients with drug or alcohol abuse going for treatment</td>
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<tr>
<th>Category 4: Infants and children &lt;3 y old</th>
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<tbody>
<tr>
<td>Ambulatory</td>
</tr>
<tr>
<td>4A Infant or child going for treatment traveling in an aircraft seat</td>
</tr>
<tr>
<td>4B Infant or child returning from treatment traveling in an aircraft seat</td>
</tr>
<tr>
<td>Litter</td>
</tr>
<tr>
<td>4C Infant requiring an incubator</td>
</tr>
<tr>
<td>4D Infant or child going for treatment traveling by litter</td>
</tr>
<tr>
<td>Ambulatory outpatients</td>
</tr>
<tr>
<td>4E Infant or child, ambulatory outpatient</td>
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<tr>
<th>Category 5: Outpatient adults and children &gt;3 y old</th>
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<tbody>
<tr>
<td>Ambulatory</td>
</tr>
<tr>
<td>5A Patient going for treatment or evaluation: All medical and surgical conditions excluding drug or alcohol abuse</td>
</tr>
<tr>
<td>5B Patient with drug or alcohol abuse going for treatment</td>
</tr>
<tr>
<td>5C Psychiatric patient going for treatment</td>
</tr>
<tr>
<td>Litter</td>
</tr>
<tr>
<td>5D Patient going on litter for comfort for treatment or evaluation: All medical and surgical conditions excluding drug or alcohol abuse</td>
</tr>
<tr>
<td>5E Patient returning from treatment going on litter for comfort</td>
</tr>
<tr>
<td>Ambulatory</td>
</tr>
<tr>
<td>5C Patient returning from treatment</td>
</tr>
</tbody>
</table>

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<tr>
<th>Nonpatient Category 6: Attendant</th>
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<tbody>
<tr>
<td>6A Medical attendant</td>
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<tr>
<td>6B Nonmedical attendant</td>
</tr>
</tbody>
</table>

Source: Adapted from Department of the Air Force.8

The medical implications of contingency AE are two-fold. First, the earliest time for safe AE must be determined for each patient based on convalescence prior to AE from the theater was 7 days from the time of injury. However, in a contemporary contingency operation it may not be possible to keep patients in-theater for even a matter of days after definitive medical treatment.
The second medical implication of contingency AE is that patients will be at increased risk for early complications and medical decompensation because they are relatively early in the course of their diseases or injuries. These possibilities must be anticipated because lack of preparedness will make it impossible to effectively treat them in flight.

**Medical Care and Preparation for AE**

During a contingency, patients early in the recovery phase of their injuries or illnesses are certainly more likely to have acute changes in their medical conditions, potentially requiring emergency resuscitation while they are in the ASF awaiting AE. Therefore, early recognition and prompt treatment will require a highly skilled and trained medical and nursing staff. All of the peacetime medical roles of the ASF discussed above are even more important.

**Medical Clearance for AE**

A relatively unique role of the ASF during a contingency operation will be medical screening of stabilized patients for contingency AE. Ideally, all patients who reach the ASF will have already been cleared for AE. In reality, this may not always be the case in a contingency situation, as noted by J.M. McNamara (written communication, October 1993). Many medical personnel treating patients outside of the ASF may have little AE experience and thus will be unable to adequately evaluate the patients’ ability to undergo AE. During military operations, approximately 98% of the casualties are Army and Marine personnel, and medical personnel organic to the respective service branch (with limited AE experience) will treat the majority. Experience from recent contingency operations indicates that medical clearance for AE will be the responsibility of the flight surgeons assigned to the ASF, as noted by J.M. McNamara (written communication, October 1993).

Another different aspect of AE during a contingency operation with a large number of casualties is the lack of direct communication between the referring and receiving physicians that occurs during peacetime. Communication
between the theater and receiving medical facilities may be limited to the number, diagnoses, and severity of the patients. In most cases, the ASF will act as the interface between the sending and receiving medical facility. Prior to AE, updated patient information will be forwarded to the GPMRC for worldwide patient tracking by a new automated system known as the TRANSCOM Regulating and Command & Control Evacuation System (TRAC2ES).

**Patient Transportation**

Patient transportation is also dramatically different in a contingency situation because both the number of patients and the number of personnel required to move them will markedly increase. The transportation teams will be under significant stress related to transporting a large number of patients with traumatic injury, as well as the long hours that may be required. Other factors that may affect transportation are challenging weather and road conditions, plus an overtaxed flight line. Further, in a wartime scenario patient transportation may have to be carried out in chemical ground ensemble. Despite the absence of these factors in routine operations, the focus of peacetime training must be to prepare for and minimize these effects.

**Patient Subsistence and Comfort**

Patient subsistence and comfort remains a high priority during a contingency operation. It is especially important to appreciate the psychological stress associated with unexpected injuries resulting from combat or natural disaster. Nursing and medical staff will need to ensure that the psychological and emotional status of all patients is assessed as part of the preflight screening. All ASFs have a psychological care team on-staff specifically for this purpose.

**Prioritization of Patients for AE**

Prioritizing patients for AE is a standard part of patient staging. During peacetime, this is done at the GPMRC level because the patient capacity of AE is much greater than the patient load. In a contingency operation, the number of casualties may be significantly greater than the AE capacity. As a result, prioritization of patients for transportation at the ASF level may become a major issue. The following considerations must be taken into account for this purpose.

**Availability of Transportation**

The most obvious potential limitation will be the availability of ground and air transportation. Each AE flight will be configured for a certain number of ambulatory and litter patients. This configuration can be varied depending on the number and types of casualties, equipment, and supplies required and the number of medical personnel available. In the military setting, close coordination between the ASF, the Theater Patient Movement Requirements Center (TPMRC), and the GPMRC will be mandatory to optimize AE efficiency. If the number of patients for each category exceeds the AE capacity, other prioritization criteria will be required.

**Intensive-Care Support**

In a large contingency operation, another limiting factor will be the amount of intensive-care support available, both in the ASF and in-flight. With the advent of CCAT teams, trained intensive-care personnel and specialized equipment for AE will be more readily available. However, the number of critical patients may be greater than the number of CCAT teams. Every AE flight must be staffed with appropriate medical personnel, equipment, and supplies to care for both the critically ill and less acutely ill patients aboard.

**Medical Urgency of Continued Care**

The final consideration in a contingency situation is the medical urgency of continued care. Although contingency AE will result in the movement of all patients as quickly as possible, those patients who are urgent or priority must be recognized and moved at the earliest time that appropriate personnel and equipment are available.
Hospital Ward Care

During a large contingency operation, the ASF role in hospital ward care may be unexpectedly expanded. Hospital ward care is only a minor part of the peacetime ASF role because most of the patients are ambulatory and the litter patients are usually in the convalescent, outpatient phase of their illnesses. Most seriously ill special AE patients are transported directly from the medical facility to the flight line. During a contingency, military plans direct that patient time in the ASF will be limited, as there will be limited medical support and supplies. However, with a large number of casualties both the theater medical system and the AE system may both be overloaded. There may be rearward pressure in theater medical facilities to transfer patients to ASFs to make room for incoming casualties. AE delays related to lack of aircraft, weather, or crew limitations may result in patients remaining in the ASF longer than planned. Finally, overtaxed ground transportation may make it difficult to send ASF patients back to the medical facility in the event of AE delays. As a result of the inevitable “fog of war” associated with contingency operations, the ASF should be prepared to provide some degree of medical and surgical ward care.

Patient Organization in a Contingency ASF

Multiple problems are inherent in taking care of a large number of patients in a contingency ASF. Military planners have envisioned the need for ASFs large enough to care for up to 250 casualties. This large group of patients with variable medical problems must be carefully organized both to optimize medical care with limited personnel and allow appropriate prioritization for AE.

Organization by Diagnosis

Diagnosis is the most obvious basis for organizing patients. Patients with severe injuries or illnesses should be grouped together to optimize nursing and medical care. The best example is severely burned patients, who should be grouped because they will require specialized and intensive nursing care in terms of fluid replacement and pain relief. Postoperative and posttraumatic patients can also be grouped because they need both pain relief and careful observation for signs of hemodynamic instability or other complications.

Infectious Disease Considerations

During the planning stage, a contingency ASF should design an infectious disease isolation area because with large numbers of patients the infectious disease considerations are important. In a wartime scenario, more than one half of the casualties will result from disease, and many of these patients may be infectious. A more recent threat is biologic weapons. Both residual contamination and communicable disease may present risks to both medical personnel and other casualties.

Psychiatric Patients

Another group of patients requiring special consideration is those with psychiatric diagnoses. These are patients who might exhibit disruptive behaviors, including combativeness or disorderliness. The sight of severely injured patients may agitate them as well. At the same
time, some of these patients may need close observation. For these reasons, an isolated observation area should be set up for psychiatric patients.

Medical Stability

For purposes of ASF organization, patient can be roughly divided into three levels of stability: stable, stabilized, and unstable. Stable patients are those unlikely to medically decompensate and require minimal medical care and monitoring. These patients would be outpatients under normal circumstances. Many of these patients will be ambulatory, and those with less serious injuries can be kept separate from the more seriously ill patients.

Stabilized patients are those who have been treated but, because they are relatively early in the convalescent phase of their illness, are at higher risk for medical decompensation. These patients will need a higher level of medical monitoring similar to inpatient medical facility care.

Unstable patients are those who have decompensated, either en route or since arriving at the ASF. When patients are transported early in the course of their recovery, “resuscitation is a frequent requirement.” For this reason, a special acute care area should be set up for resuscitation and equipped with a full array of resuscitation equipment. Once resuscitated, these patients will require the equivalent of intensive care until they can be returned to the medical facility or are stable enough for AE.

Importance of AE Staging: A Case Report

One of the authors (A.M.R.) and his wife were victims of a terrorist attack while stationed in an African country. The author sustained a flail chest and lacerations but was ambulatory, whereas his wife was injured critically. Her injuries included blunt head trauma associated with concussion, severe injury of the right arm with soft-tissue avulsion and multiple fractures, and fractures of the right leg and pelvis. The author received first aid from a US Marine while he stabilized his wife at the US Embassy. Military AE was not available because the United States had no landing rights in this country. For this reason, arrangements were made to transport both patients on a civilian airliner to a Middle Eastern country. The wife was transported by stretcher in a semiconscious state without medical support and the author accompanied her as an ambulatory patient. The only medical personnel and supplies available during the flight was the author and the limited supplies he could carry (eg, bandages, intravenous fluids).

Upon arrival in the Middle Eastern country, the author’s wife was taken to a foreign military hospital, where local physicians did not expect her to live and thus offered only palliative care. Two American expatriot nurses were allowed to care for her throughout the night and treat her with intravenous fluids, antibiotics, and blood transfusions. The following day, the critically ill patient and her less seriously injured husband were transported by US military AE aboard a C-9 Nightingale. After a change of aircraft in Athens, they landed in Frankfurt and arrived at Wiesbaden USAF Medical Center approximately 48 hours after the initial injury.

At the Medical Center, she received three surgical procedures over a 3-day period and was placed in a body cast. On the fourth day (approximately 6 days after the injury), she was determined to be stable enough for elective AE and placed on a fully loaded C-141 bound for the Continental United States, with her injured husband as her nonmedical attendant. Because the body cast did not fit between the tiered stretchers in a supine position, she was wedged between the first- and second-tier litter positions at a 45-degree angle.

The flight was originally scheduled to last 7 hours. However, a pregnant patient with a diagnosis of premature labor delivered unexpectedly in-flight, and the flight was thus diverted to England. The plane was delayed on the ground for several hours for an equipment malfunction. Once airborne, the remainder of the flight was uneventful. However, the noise, cold, vibrations, and inability to change positions, combined with the isolation and fear, were almost intolerable for the wife.
During the flight, she required hand-feeding, intravenous fluids, Foley catheter care, and medications. Because of demands on the nurses by other patients, these tasks were performed principally by her injured husband. The ability of a nonmedical attendant with medical training to carry out the required care during flight was crucial to successfully completing this mission.

Approximately 12 hours after leaving Germany, the AE flight arrived in the United States. However, she did not reach a medical facility for an additional 2 hours because of difficulties in unloading the C-141. Her first examination revealed a decubitus ulcer due to the long period of absolute immobility during flight, which subsequently required skin grafting.

After a 31-day hospitalization and two additional surgical procedures, she subsequently made a full recovery. However, the memory of this AE flight from Germany to the United States will always remain with this patient as a frightening memory of the most difficult aspect of her medical care. This case is a graphic example of the stresses associated with AE and the critical role of adequate preflight preparation and in-flight care.

Conclusion

In peacetime, the ASF serves as a hybrid between a hospital ward and an air terminal. When a patient suddenly decompensates, the ability of medical personnel to effectively respond can be lifesaving. In a contingency situation, the ASF plays an expanded and more critical role in the AE system. Our ability to effectively plan for a contingency will ultimately determine our ability to “bring them home safely.”

References

Any aircraft that can carry passengers can conceivably be used for aeromedical evacuation (AE), depending on the situation. In response to the special needs of AE, multiple aircraft have been specifically designed for AE. Unfortunately, it is impossible to discuss every aircraft used for AE throughout the world. Instead, this chapter will deal with the most important factors that must be considered in choosing the correct aircraft for the patient or patients’ needs, including alternative methods of moving patients. To illustrate these important factors, this chapter includes a detailed discussion of the aircraft presently used by the USAF for AE, together with a civilian jet representative of the many aircraft used by the commercial air ambulance industry.

It is obvious why military medical personnel should be familiar with USAF aircraft used for AE. However, it is important for civilian medical personnel to be aware of USAF aircraft as well because in a disaster situation AE assistance can be requested through the DoD. As the events of September 11, 2001, clearly showed, a requirement to move large numbers of casualties may arise suddenly, and the USAF AE system could prove crucial to meeting the patients’ needs. The USAF AE system is a national treasure that has been called upon for over 50 years to move casualties resulting from military operations (both armed conflicts and operations other than war) and civilian disasters beyond the local capability to respond. Although the DoD does not exist to compete with civilian air evacuation companies, the USAF AE system has moved more patients around the world than any other organization, including large numbers of civilians. In addition to aircraft specifics, this chapter will describe the capability of the USAF AE system.

Aircraft Selection for AE

To select the best possible aircraft for any AE mission, both logistic and patient-related factors must be considered. Although patient-related factors are paramount, logistic factors may often determine the type of aircraft needed. These logistic factors include the number of patients, the distance required for the particular AE mission, and the runway length at the AE sites of origin and destination. Patient-related factors include the need for pressurization, the amount and type of special AE equipment needed, and the aspects of aircraft configuration that affect patient care. Depending on the situation, each of these factors can be critically important in making the ultimate decision on which airframe or combination of airframes best meets the particular requirements. The following is a detailed discussion of each factor.

Logistic Considerations

Number of Patients

The total number and complexity of patients is often the determining factor regarding which aircraft is used. If only one or two patients need movement, then virtually any aircraft is capable...
of meeting this need. When large numbers of patients need to be moved from the same place, the solution becomes more complex. Adding to the complexity of large patient movements is the fact that tragedy is frequently associated, eg, the Oklahoma City bombing. In such instances, the airfield serving one’s patients will also be involved with a dramatic increase in air traffic, which will limit the departure or arrival “slots” for AE missions. As a result, using multiple aircraft may not be a viable option and a large aircraft, eg, the C-141, may become the only solution to move large numbers of seriously wounded patients.

Distance

The distance required to move the patient from origin to destination will determine whether AE is the appropriate means and will also limit the choices of aircraft once that decision is made. In general, AE should not be considered unless the distance is too great to be accomplished by more readily available means of transport, eg, ground ambulance or medical helicopter. Rarely is there a reason to consider AE for distances shorter than 300 miles.

Once the decision is made that AE is required, the type of aircraft capable of meeting the requirement becomes more limited (Table 8.1). This is especially true for the USAF, which is often asked to accomplish missions that seem impossible at first glance. An example is the movement of critical burn patients thousands of miles without stops, eg, from Japan to San Antonio. On the other hand, if the distance were short enough, eg, less than 1000 miles, then virtually any of the aircraft used for AE, including all those discussed in this chapter, would suffice.

Aircraft Range

Range is another crucial determinate because all aircraft have a finite distance they can fly with a full load and still arrive safely at the destination. The range for all USAF AE aircraft is measured in thousands of miles, but may be shorter for some civilian aircraft. In-flight aerial refueling can extend the range of certain USAF aircraft (eg, the C-141) if the needs of the patients are critical. This is most frequently accomplished when moving severely injured patients from Japan or Korea to the United States. However, because of the difficulty, expense, and potential danger, in-flight refueling is rarely used for routine AE. Related to range is the cruise speed of the aircraft. Although the C-130 has a long range, its cruise speed is slow enough that the flight time differential between the C-130 and a jet aircraft over long distances makes the choice of a jet much more likely.

En Route Stops

The effective range for aircraft commonly used for AE varies from 1250 to over 5000 miles (Table 8.1), but this range can be extended almost indefinitely by the judicious use of en route stops. Assuming each leg is within their range, en route stops allow any aircraft to move patients over long distances. This method has been extremely important for the USAF in moving patients from the Western Pacific region to medical facilities in Hawaii during the 1990s. The use of en route stops may become even more important for military AE in the future as the premier long-distance transport, the C-141, becomes less available.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>C-9A</th>
<th>C-141</th>
<th>C-130</th>
<th>C-21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (nautical mi)</td>
<td>2500</td>
<td>5000</td>
<td>3000</td>
<td>1250</td>
</tr>
<tr>
<td>In-flight refueling capability</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Maximum patients (total)</td>
<td>40</td>
<td>128</td>
<td>80</td>
<td>6</td>
</tr>
<tr>
<td>Ambulatory</td>
<td>40</td>
<td>90</td>
<td>46</td>
<td>6</td>
</tr>
<tr>
<td>Litter</td>
<td>40</td>
<td>103</td>
<td>74</td>
<td>2</td>
</tr>
</tbody>
</table>
Available Medical Care at the En Route Stop

The availability of medical care at the en route stop becomes extremely important for long-distance AE. This consideration is crucial because aircraft frequently experience mechanical problems or weather constraints that prevent take-off from the en route location. Therefore, a planned delay of 2 hours for refueling can easily turn into a delay of several days, so a plan for providing care to one’s patients becomes critical.

Landing Limitations

Another potentially life-threatening danger to the flight and medical crew exists when problems arise at an en route stop and alternate airfields are unavailable. This factor alone would have forced the USAF to drop consideration of using en route stops to move patients out of the Western Pacific, i.e., the risk of running out of gas trying to find the small islands used as en route stops would have been too great a risk to plan such a mission. Fortunately, recent improvements in navigation using global positioning satellites (GPSs) have minimized this danger.

Lavatory and Feeding Station

The ability to feed patients and provide them with adequate lavatory facilities must be considered for all missions. This is not an absolute requirement for all patient moves, but is crucial for long nonstop missions. The C-9A was designed with basically the same capability as the airline DC-9s, so it can be considered the top of the line. Many civilian aircraft used by AE companies have comparable capability, although few are as robust as the C-9A. The C-141 relies on a large removable module called the “comfort pallet” to meet this requirement. The C-130 has minimal capability but its usual short-duration missions do not in general require it.

Runway Length for Landing/Take-off

Medical planners do not routinely consider runways and runway environments in their analyses, but runways can easily become the limiting factor in completing a mission. Runway environment is frequently a problem for the USAF as it meets the needs of the DoD around the world, and often is the constraining factor that mandates the use of a specific aircraft, e.g., the C-130, when another aircraft would have been preferred. This factor is rarely a problem for civilian moves from one large metropolitan area to another because the runways at the airports serving such cities are almost always long enough to meet the requirements of any of the aircraft described in this chapter.

Patient-Related

Pressurization

One of the unique aspects of AE, when compared to ground and sea casualty transportation, is the issue of cabin pressure. Although most medical conditions are unaffected by decreased pressure, there are several medical conditions (e.g., decompression sickness) that are adversely affected by cabin pressures lower than those found at sea level. It is extremely important that the flight crew, i.e., pilots, be made aware of any altitude restrictions that are required for medical indications during AE.

All modern aircraft used for AE are pressurized such that the cabin pressure never drops below a pressure equivalent altitude of 9700 feet (unless an unplanned decompression occurs). If patients require altitude restrictions on this basis, an aircraft that is more efficiently pressurized (such as the C-9A) should be used whenever possible.

Within the limitations of the patients’ medical condition, it is important to keep cabin altitude restrictions to a minimum (i.e., allow a cruising altitude as high as possible). The reason for this is that the aircraft pays a huge price in terms of both speed and fuel to accomplish an altitude restriction. For example, the C-9A aircraft has a range of 2500 miles at a cruising altitude of 35,000 ft but only a range of 2000 miles at 18,000 ft, the altitude required to maintain cabin altitudes near sea level. Further, ground speed is in general less at the lower altitude. The net result is that the mission takes longer and may require more en route stops, both of which can adversely affect the patients.
**Special AE Equipment**

The range of capability provided by special equipment used to move patients has dramatically increased over the past several years. Types of equipment include electrical equipment, oxygen and ventilatory equipment, suction devices, and multiple other types of special equipment. These pieces of equipment are challenging to use in the AE environment for several reasons.

**Electrical Requirements**

Use of electrical equipment is taken for granted on hospital wards but cannot be assumed on any AE mission, even those using well-designed AE aircraft. Although most equipment used in patient transport today is battery capable, the length of many AE missions exceeds even the longest battery capability. Most civilian aircraft used for AE, and the USAF’s C-9A, have existing electrical plug-in capability with the correct voltage/frequency used by medical equipment. However, even in these aircraft the total patient need may exceed capability.

USAF transport aircraft that can be modified for AE (eg, C-141, C-130) are not set up to use modern AE medical equipment on-board. The current solution is a bulky transformer that converts the aircraft-generated electricity to a usable voltage and frequency. It is known affectionately as “Big Bertha” because it weighs approximately 130 pounds, with a size of $11 \times 14 \times 36$ in. The size and weight of this transformer becomes a constraint in itself because it cannot be carried as a routine piece of equipment in all C-141s.

**Medical Oxygen**

Because the effective cabin altitude of most aircraft used for AE is between 6000 to 8000 ft, consideration of medical oxygen should occur for all but the most stable patients. The C-9A serves as the model, with humidified oxygen available at all litter stations. Again, USAF transport aircraft modified for AE (eg, C-141, C-130) are not set up to administer medical oxygen to a large number of patients. Individual patients can be given supplemental oxygen from either a portable oxygen canister or connectors to existing aircraft oxygen sources.

**Suction**

Suction is also an integral element of medical care for the seriously injured patient. The C-9A and most commercial AE aircraft have suction available at all litter stations. On military transport aircraft, such as the C-141, movable suction devices are placed near those patients requiring it, and the capability of such suction devices is “low-tech” at best.

**Aircraft Characteristics**

**Aircraft Entry Doors**

A crucial limiting factor in transporting litter patients by AE is the difficulty involved in loading litters into the aircraft. Civilian and military aircraft specifically designed for AE do not present a problem in this regard. The C-9A was designed with a retractable ramp that allows crew members to easily meet this requirement. The size of the rear entry of the C-141 and C-130 are also more than adequate. Unfortunately, the C-21 form of the Lear Jet was not designed to carry litters, and placing them on-board is relatively difficult.

**Cabin Space**

The cabin area must have adequate room for the medical crew to meet the needs of all patients. In general, this is not a problem with either the civilian or military aircraft used routinely for AE. However, the routine litter spacing for most military AE configurations is 21 in, so meaningful procedures often require removing patients from their litter tiers. Also, small jets like the Lear Jet provide little crew space.

**Climate Control**

Maintaining a comfortable temperature is important when transporting patients for long distances, as sick and injured patients may have difficulty regulating their core temperatures. Although commercial airliners sometimes have a difficult time trying to maintain the “ideal” temperature in all parts of the aircraft cabin, differences in various parts of these aircraft are negligible. Both the C-9A and commercial AE aircraft accomplish uniform comfort reason-
ably well, but having a large supply of blankets is still crucial for all missions.

However, the problem of temperature control is highly significant in the huge cabins of military transport aircraft. It is not unusual during AE in these aircraft for some patients to require several blankets while others are shedding clothes to remain cool! Sensitivity of the medical flight crew to this problem can be vitally important.

Cabin Noise Levels

The noise level during flight varies significantly for different aircraft. For the C-130 and C-141, the noise level is approximately 95 to 100 dB during flight and thus ear plugs are required for all passengers and crew. For the C-9A and commercial AE aircraft, noise is considerably less (approximately 70 to 80 dB), but it is still a factor that needs consideration. Auscultation is almost impossible during AE, even with stethoscopes specifically developed for this purpose. For this reason, alternative means of monitoring the patient have been developed, such as digital readout of blood pressure cuffs and pulse oximeters.

Cabin Lighting

Lighting levels in aircraft cabins vary dramatically. The C-9A represents the benchmark for lighting, while the C-130 is poorly lit. AE crews must be aware of the lighting levels of the aircraft in which they will be flying so they can bring supplemental lighting on-board for those aircraft that require it.

Specific Aircraft

This section will describe the general characteristics, strengths, and weaknesses of the USAF aircraft and a representative civilian aircraft most commonly used for AE. In addition, ways to use other aircraft for AE in emergency situations are described.

C-130 Hercules

The C-130 has a truly unique role in the world of AE. Its versatility in take-off and landing, together with its large capacity, make it ideal for moving large numbers of patients from remote locations. Although there are some limitations that will be discussed in this section, it is safe to state that the USAF could not execute its worldwide mission without the C-130.

Since its introduction to the USAF inventory in the 1950s, the C-130 has arguably become the most versatile aircraft ever developed (Fig 8.1). Its roles are extremely diverse, extending far beyond the primary role of airlifting small loads of supplies and equipment to remote locations, a role it has executed in countless conflicts and civilian emergencies. It also flies into hurricanes to track motion and access strength. It serves as a flying gunship, a role vital to Operation Just Cause in Panama and the recent war in Afghanistan. Finally, it has a role germane to this text, i.e., serving as the primary AE platform to reach patients in remote locations. The capability to land on virtually any cleared, semi-improved surface has made the C-130 a vital part of the USAF's ability to move any patient from any place at any time. An example of this was shown during the Gulf War when the C-130 flew missions (fortunately few) into southern Iraq to move patients from the Army units attacking the enemy in that part of the desert. These missions required landing on a crude road, and could not be accomplished with any other aircraft.

General Characteristics

The C-130 is a four-engine turboprop aircraft with a cruise speed of approximately 380 mph. It has a fuel capacity that allows it to cruise for approximately 10 hours, giving it a range potential of approximately 3500 miles. However, for the reasons described under weaknesses, the C-130 would only be used as a last resort to move patients over such a long distance. Its high wing configuration prevents debris from ruining the engines while operating in poorly improved airstrips. It has a short take-off (4700 ft) and landing (2900 ft) capability unmatched by any other large aircraft. Its maximum litter capacity is 74, and the litter stanchions (the supports into which the litters are placed) used in this role are kept on-board at all times. This factor adds incredible flexibility to the fleet of C-130s
as they operate in a variety of missions around the world. Using web seats along the sides of the cabin, a maximum of 92 ambulatory patients could be moved. However, the discomfort and potential damage to patients would make such a configuration reasonable only for a short mission when no other alternative was available. In military situations such as an airfield under fire, the C-130 can also be floor-loaded safely with 15 litter and approximately 30 ambulatory patients. The usual configurations for moving combinations of litter and ambulatory patients will be described at the end of this section.

**Strengths**

By far the greatest strength of the C-130 is its ability to land on short, minimally improved surfaces. Obviously, helicopters can also be used to pick up patients in similar situations, even with the total absence of any airstrip. However, the limitation of helicopters is the small number of patients that can be moved by each aircraft. So it is this one crucial strength that will keep the C-130 a vital member of the AE team for years to come. Medical planners simply would not have been able to develop a viable plan to move the projected casualties during the Gulf War without this capability. This same capability makes virtually any en route stop a viable option, so medical planners can use the C-130 for missions of extremely long distances. However, the weaknesses described later make such planning a last resort.

The patient movement capacity, i.e., potential for 74 litter or 92 ambulatory, makes the C-130 an ideal aircraft for medical planners as they attempt to minimize the number of far-forward AE missions required to support front-line troops in wartime. Although potential range (approximately 3500 miles) is a strength, the lack of comfort for the patient would make such a mission unlikely. The final strength of this aircraft is the ease of loading through the rear “clamshell” door. This wide open space allows crews to load large numbers of patients in approximately 20 minutes, including engine-running onloads (EROs). Such EROs would only be accomplished at airfields under fire from the enemy or when ground time had to be minimized for another compelling reason.
Weaknesses

Noise is a major problem in the C-130 cabin, often making it necessary to shout within 18 in of the “listener” to be heard. As a result, verbal communication between crew members is difficult and communication between medical crew and their patients is often impossible. Obviously, procedures requiring auscultation are impossible. Lighting is also extremely poor throughout the cabin, so medical crews must have a plan for providing lighting adequate enough for patient evaluation. Electrical connections are available for attaching transformers, e.g., the Big Bertha described earlier, but even with the transformer electrical equipment support is extremely limited. The combination of limited space between litter stanchions and the effect of moderate turbulence, present on virtually every mission, makes care for patients extremely difficult. Simple care such as feeding and taking vital signs are easy, but more complex procedures are difficult. The only laboratory facilities available are a funnel that leads to the exterior of the aircraft, with a curtain for privacy, and a small chemical seat with a privacy curtain. There is no food service available, so boxed lunches are the only means of feeding patients. Climate control is poor, with cabin temperature rarely in the comfortable range. Neither patient oxygen nor suction is available, so both of these must be brought onto the aircraft for all missions requiring them. Finally, the C-130 cannot pressurize to sea level.

Configurations

The USAF uses four different configurations for the C-130 in its AE role.1 The first provides 30 litter spaces with 46 web seats for ambulatory patients and AE crew (Fig 8.2). This configuration provides the most space for the ambulatory patients, so it would be used when “stretching room” for ambulatory patients was important. The second configuration provides 70, 73, or 74 litter spaces with 6 seats for AE crews (Fig 8.3A). This configuration would only be used when a specific large load of litter patients was required. A third configuration provides 20 litter spaces with 44 sidewall seats, and this configuration would be used when space for medical equipment or cargo in the

Figure 8.2. Interior of C-130 Hercules configured for tactical AE.
forward central portion of the cabin floor was required. The final configuration provides 50 litter spaces and 30 sidewall seats (Fig 8.3B). This configuration is the one most commonly used in contingency or wartime operations because virtually any patient loads at the locations supported by the C-130 would include a combination of litter and ambulatory, with the majority being litter.

A unique feature of the C-130 is that all litter stanchion equipment needed to configure for AE is carried with each of the many (several hundred) C-130s deployed worldwide at any time. The total number of litter patients described in the configurations above depends on stacking 5 patients in each litter tier with approximately 21 in of spacing between patients. Although the USAF practices this method of loading, the highest of the five patients is both difficult to load and virtually completely inaccessible for crew members to treat. Therefore, depending on circumstances, the medical crew director might well decide to load only four patients per upright station, thus giving more comfort to the litter patients and making nursing care more practical. Such a decision would only be made if all patients could be moved.

Summary

From the strengths and weaknesses it is obvious that the niche for the C-130 is moving patients out of “harm’s way” from far-forward positions. Every effort will be made to minimize the length of these missions so the patients can be delivered to greater medical capability as soon as possible. Later transfer to another aircraft will be done if further movement is required. This aircraft will remain a vital part of the USAF inventory as long as this requirement exists and other aircraft cannot meet the need.

C-9A Nightingale

The C-9A is truly the “Cadillac” of the AE fleet (Fig 8.4). The patient care amenities that are
built into the cabin area, together with the capabilities of the aircraft itself, make it ideal for a number of roles. It is used primarily for midrange missions into improved runways, but can also be used in a strategic, ie, long-distance, role if there are adequate en route stops.

By the mid-1960s it had become apparent to the entire military establishment, including then US President Lyndon B. Johnson, that the fleet of aircraft being used for AE in the Vietnam War were entirely inadequate. To address this problem, a team of flight surgeons, flight nurses, and enlisted AE technicians was formed to work with McDonnell Douglas Corp on a modification to the DC-9 for the sole purpose of performing AE missions. The result is the C-9A that has served the DoD as its only dedicated AE asset for over 30 years. Given the relatively low number of average flying hours per aircraft, it should be capable of continuing in that role for many more years. There are a total of 19 C-9As deployed around the world. Usually, 10 aircraft are located at Scott AFB in Illinois, 5 are in Europe, and 4 are in Japan, but the airframes are moved to whichever theater has the greatest need.

Although the majority of C-9 missions over the past 30 years have been flown in the continental United States, it has proven its flexibility by serving as an urgent AE asset for multiple patients in the Western Pacific and Europe. This role was necessitated by the frequent lack of availability of the C-141, the premier long-range AE asset. The C-141 fleet is rapidly drawing down (it has decreased by about 50% from 1995 to 2000), and it is committed to more worldwide airlift missions than ever before. Therefore, this “bridging role” for the C-9A is likely to continue and may even increase. It is fortunate that navigational aides have improved enough that the C-9A can reliably locate the small islands in the Pacific needed for en route stops. Without this reliability the C-9A could not possibly take over this mission, even for a short time.

Although the C-9A has rarely been used for actual wartime missions, the concept of using it for that role was proven in a military exercise called Reforger during the late 1980s. Depending on the timing of actual casualties, the C-9A could easily become the only available asset to move patients in the early days of a conflict. The other airframes, ie, the C-141, C-130, and C-17, would likely be totally committed to the role of getting “shooters” and their materiel into the war zone. Further, the historical doctrine of reconfiguring (ie, changing from transport to AE) these aircraft for a return AE mission might not be followed in future conflicts. This change in doctrine is due to the fact that recon-
figuration takes too long to be practical in a constrained lift environment. The advantage of the C-9A is that it could land already configured for the exact patient requirement, load quickly, and then leave without clogging the airfield.

General Characteristics

The C-9A is a modified version of the McDonnell Douglas DC-9 commercial airliner. Multiple interior modifications for the AE role will be described in the section on strengths. The most dramatic exterior modification is the large rectangular hole cut into the left side of the fuselage with a retractable ramp fitting into that hole. This modification gives the aircraft the capability to immediately begin loading litter patients wherever it lands. The C-9A is a twin-engine jet (engines mounted on the tail section) with a cruise speed of approximately 500 mph. Its fuel capacity gives it a range of about 2400 miles, thus making it an intermediates-range AE aircraft. As described earlier, this range, coupled with appropriate intermediate stops, makes it an acceptable long-range aircraft if needed in that role. The length of runway required for landing (2700 ft) and take-off (5000 ft) limits the number of airfields the C-9A can utilize, but this is not in general a “showstopper” in accomplishing a mission. During the Gulf War, the USAF decided to severely limit the planned use of the C-9A in the Southwest Asia theater. This decision was primarily based on concern over the poor quality of the runway environment in that theater, which could have easily destroyed an engine, resulting in a “broken” aircraft and clogged airfield. In summary, the use of the C-9A is flexible but not unlimited.

Strengths

Because the C-9A was designed specifically for the AE role, its strengths far outnumber its weaknesses, its first strength is flexibility to accomplish long-distance (strategic) as well as intermediate-length missions. While en route stops are a potential constraint, appropriate stops can almost always be found to stretch the C-9A from an intermediate AE aircraft into a long-range aircraft. While the C-9A is not considered a quiet aircraft, it is quiet on a relative scale when compared with other USAF aircraft used in the AE role. Communication between crew members is not difficult, nor is it difficult to communicate with patients who can talk above a whisper. However, use of a stethoscope is limited to a special type that was developed specifically for use on this aircraft. Lighting is excellent in virtually all parts of the cabin so assessment of patients is as close to optimum as possible in the AE environment. Appropriate electrical outlets are available at every patient position so supporting equipment is possible for all patients without carrying transformers.

The retractable ramp makes loading of litter patients easy at every stop. This ramp is covered with a nonslip surface that has proven reliable moving patients in every possible weather condition. Ambulatory patients can be loaded through stairs at the front and rear of the aircraft, just as they are with the commercial models of this aircraft. The cabin space is excellent for providing access to each patient under virtually all conditions. In the 40-litter configuration, the ability to care for the patients located on the top litter position would be limited, but there is still adequate room to easily move such patients to the cabin floor while delivering intensive care. Lavatory and food services are excellent because they are essentially unchanged from those found in the commercial version of this aircraft. As a result, feeding and providing “creature comforts” to patients is better in the C-9A than in any other AE aircraft.

Medical oxygen and suction are available at 11 positions in the cabin, 3 in the forward special care area, and 8 in the remainder of the cabin. They are located so that each potential litter tier will have access to both. Climate control is excellent when compared to other AE aircraft but is still not perfect, and will likely become worse as the aircraft ages. This is easily overcome by providing blankets to those who need them. The C-9A is capable of pressurizing to sea-level atmospheric pressure so it can move all patients, including those with decompression sickness. However, the cruise altitude required to pressurize is so low (usually around 18,000 ft) that the range
of an altitude-restricted mission becomes a real challenge.

Weaknesses

Because the C-9A was designed specifically for the AE role, its weaknesses are limited. While its landing and take-off length is excellent for most uses in the continental United States, its ability to meet the DoD requirements around the world is limited. Despite this relative weakness, the C-9A remains the one asset within the USAF that cannot be diverted to other missions.

Although limited cabin noise is a relative strength, budgetary constraints in the late 1990s required the USAF to cancel plans to place new engines on the C-9A fleet. These engines are required to meet current civilian airport external noise restrictions. Although this could theoretically become a problem in wartime, it is hard to imagine that the FAA would deny landing rights to the C-9A if no other means were available for moving casualties. In peacetime, there are multiple ways to move patients who require access to noise-restricted airfields. The patient capacity of 40 is a relative weakness vis-à-vis the C-130 and C-141, but as a result the comfort of patients and accessibility by the medical crew is maximized.

Configurations

The USAF utilizes 13 different configurations that are combinations of litter and ambulatory seats, ranging from 1 tier of litters in the special care area and 40 seats to 10 tiers of litters and no seats. The patient seats are rear-facing, airline first-class sized, with two seats on each side of a center aisle. In all configurations there are seats built in for the medical crew, with a nurse’s station just aft of the special care unit on the right side of the cabin. A large storage area for special equipment, blankets, and patient-specific items is located opposite the nurses’ station. There is also a sink and refrigerator opposite the special care area. All of these features remain regardless of the exact combination of litters and seats.

The C-9A has a large storage area in the belly of the aircraft below the cabin. This storage area contains the equipment necessary to change the mix of seats and litters, a capability that proves crucial when the requirement changes at one of the mission’s en route stops. During peacetime, the C-9 most frequently flies with a configuration using 3 litter tiers and 30 or 34 seats (Fig 8.5A). In general, four seats are given up for each litter tier, but as these two configurations show, the exact locations of the tiers can change this ratio. The most litters possible is 40, and such a configuration would only be used in wartime (Fig 8.5B). Even then, it is difficult to envision the exact patient requirement that would make the C-9A the most efficient means of meeting that requirement (Fig 8.6).

Summary

The C-9A is a wonderful asset for the entire country and it stands ready for a wide variety of disasters, whether military or civilian. As mentioned previously, the AE system could be made available in disaster through the joint military command called US Transportation Command. Even though the C-9A has been used to move peacetime DoD patients around the United States during most of its life, it is a proven asset that provides flexibility for medical planners in a wide variety of missions.

C-141 Starlifter

The C-141 has been the premier strategic (long-range) AE airframe for the USAF from the time it first became operational. It has great strengths, eg, virtually unlimited range with aerial refueling, but also has weaknesses, such as limited numbers of airfields from which it can operate. It has accomplished this strategic mission so well that the USAF faces a great challenge in replacing this capability with another aircraft.

The C-141’s primary role for the military is long-range airlift of cargo, passengers (although this role is mostly accomplished with contracts today), and patients. The C-141 has been the workhorse of the DoD for moving large numbers of patients over long distances for almost four decades (Fig 8.7). It has been an
Figure 8.5. C-9A Nightingale configured for (A) peacetime AE and (B) maximum litter patients.

Figure 8.6. Interior of a C-9A Nightingale configured for maximum litter patients.
absolutely vital link for the thousands of active-duty members and their families deployed around the world. However, it is currently reaching the end of its useful life, and each month more C-141s are taken out of the actively flying inventory and retired to the aircraft “bone yard” in Arizona. Because the requirement to move cargo in support of multiple contingencies has increased markedly in the 1990s, the availability of this aircraft for the AE role has diminished, in particular in the Western Pacific.

**General Characteristics**

The C-141 is a multiple-purpose aircraft designed to transport passengers, cargo, and patients. Its cruise speed is 550mph with a maximum range (unrefueled) of over 5000 miles, making it a high-speed, high-altitude, long-range airlifter. Its take-off and landing distances are dependent on exact weight, but in all cases are long (over 6000ft). All planned AE missions are equipped with a comfort pallet that provides cooking capability and lavatory facilities.

**Strengths**

One of the greatest strengths of the C-141 is its ability to accomplish air-to-air refueling from USAF tankers. This eliminates the need for any consideration of en route stops, regardless of mission length, and therefore negates the problems caused by these stops. Because there is a slight risk to the patients and medical crew from increased turbulence during contact with the tanker aircraft, missions are not routinely planned using this procedure. An example of how this capability has proven tremendously beneficial is moving severely burned patients from Korea to San Antonio, where the Brooke Army Burn Center is located. Appropriate timing of each burn move and minimizing the total length of time required for transfer between hospitals is directly correlated to better outcomes, so this capability is vital for military operations. It is by far the largest-capacity AE aircraft, having the capability to move a combination of 128 litter and ambulatory patients in one configuration and 103 litter-only patients in another. As described earlier, its range is a tremendous asset, limited only by the crew rest requirements for the pilots. The
rear clamshell doors, which provide a gently sloping ramp to the flight line, make loading of patients extremely easy. Cabin space is large and, with the exception of those litter patients positioned at the top of each tier of litters, patient accessibility is good. With the comfort pallet in place, feeding and lavatory facilities are certainly adequate. The C-141 does have the capability to pressurize to sea level, but doing so negates many of the previously mentioned strengths.

**Weaknesses**

When the C-141 is fully loaded with patients and the fuel required for its maximum range, runway length for take-off becomes long. As a result, planning to use this aircraft in both peacetime and war is limited to a few “strategic” airfields in all theaters. Noise is a real problem in the cabin, ranking somewhere between the C-130 and the C-9A. As a result, communication is extremely difficult. Light is extremely poor throughout the cabin and the medical crew must have a plan for providing adequate light to assess their patients. Electrical support is severely limited. There is only one outlet in each latrine that can supply 115-V/60-cycle AC, but these outlets are used solely for electric shavers. There are several electrical outlets in the cabin, but the previously described transformers must be used to supply appropriate electricity to medical equipment. Obviously, this requirement complicates AE planning because there are a limited number of transformers in the USAF inventory. Assuring that the transformers are in the right place at the right time can become a major problem. Although therapeutic oxygen is available in the cabin, it is supplied at high pressure (300 psi) through seven outlets located on two separate panels. These outlets must be attached to devices called therapeutic oxygen manifold systems (TOMS), each of which can supply three litter patients. Climate control is poor at best. It is not uncommon for litter patients located on the top tier position to complain of excessive heat while ambulatory patients near the sides of the cabin are complaining about “freezing” feet! Again, blankets and imagination are the only way to overcome this problem.

**Configurations**

The USAF uses five different configurations for AE missions. In four of these configurations, a comfort pallet is located at the front of the cabin. The maximum litter configuration, 103 litter capacity (Fig 8.8A), uses only portable lavatories and urinals and is therefore limited to a maximum of 12 hours’ duration for each mission. The most commonly used configuration utilizes rear-facing airline-type seats with 42-in spacing, which achieves a total load of 23 to 46 litter and 60 to 90 ambulatory patients (Fig 8.8B). Another configuration that uses web troop seats on the side of the cabin for the ambulatory patients maximizes total patients (48 litter and 80 ambulatory) (Fig. 8.9). However, because the role of the C-141 is long-distance and long-duration missions, this configuration is rarely used because of discomfort for ambulatory patients.

**Summary**

The C-141 brings a unique long-range, high-volume capability to the world of AE, a capability unmatched by any other aircraft, military or civilian. As the total number of C-141s remaining in the active USAF inventory decreases, the difficulty in filling the void it leaves becomes more apparent each passing month.

**C-17 Globemaster**

The C-17 is the newest transport jet in the USAF inventory and, among its other missions, it has the capability to perform the AE role. It has multiple strengths that would make it ideal for this role. However, the total number of aircraft currently planned for purchase is so small (80) that its availability for AE is questionable. Because the C-17 is so new to the USAF fleet, it does not have a track record as an AE aircraft.

**General Characteristics**

The C-17’s incredible capabilities were first demonstrated during the initial deployment of
Figure 8.8. C-141 Starlifter configured for (A) maximum litter patients and (B) a combination of litter and ambulatory patients.

Figure 8.9. Interior of C-141 Starlifter configured for a combination of litter and ambulatory patients.
troops to Bosnia in late 1995 (Fig 8.10). Its primary mission is flying large loads, especially oversized loads, directly to minimally improved short runways. It is also designed to accomplish other missions, including AE and support of Army airborne units. However, the total number of aircraft currently planned for purchase, ie, only 80, will probably limit the number of times this aircraft is used in AE. Nevertheless, kits have been designed and manufactured that will allow the C-17 to accomplish the AE mission. As with any new system, multiple problems were discovered in the initial tests of the AE configuration, but none of the required "fixes" for these problems were complicated and the solutions are occurring at the time of this writing.

**Strengths**

Virtually every previously described characteristic of an AE aircraft is a strength for the C-17. Perhaps its greatest strength is its unlimited range with aerial refueling. A close second is the ability to land on almost any semi-improved airfield. This combination makes it ideal for moving patients from almost any location directly back to the United States without en route stops. Its litter stanchions will accommodate 36 litter patients and a variable number of ambulatory patients depending upon the types of seats used (Fig 8.11). Noise and lighting are almost as good as the C-9A and are certainly better than the C-130 or C-141. The large clamshell doors make loading extremely easy. Cabin space is huge and the litter support structure gives excellent access to each patient. Comfort pallets are used to provide feeding and lavatory facilities, as with the C-141. Climate control is better than either the C-130 or C-141 but not as good as smaller cabins (eg, the C-21). Pressurizing to sea level is possible with the usual mission constraints.
Weaknesses
Because the C-17 was not built primarily for AE, there is neither built-in oxygen nor suction. Like other large aircraft, climate control requires plenty of blankets to make sure all patients are warm enough. Undoubtedly the greatest weakness of the C-17 is the fact that few airframes are likely to be made available for the AE role.

Configurations
Recently, two configurations of the C-17 have been approved for AE. In one, there are only 3 litter tiers utilized, giving the capability to move 9 litter patients and 54 ambulatory seats on the periphery of the cabin. In the second configuration, there are 12 litter tiers, giving a total capacity of 36 litter and 54 ambulatory patients. In both configurations, up to 48 centerline seats can be added, but doing so makes the peripheral seats outboard of the litter stanchions unavailable. As the C-17 is used in the AE role, experience will show which of these configurations works best. One obvious advantage of using the existing peripheral seats is that all C-17s can be configured this way without having seats available.

Summary
In summary, the C-17 is a superlative aircraft for accomplishing the AE mission for all the reasons listed under strengths, especially its speed, range, and short landing capabilities. At this time the small number of aircraft planned for the USAF force will almost certainly be fully employed in other missions, so it remains to be seen how much AE this aircraft will see.

C-21 Lear Jet
While the C-21 was not originally acquired for the AE role, it has proven itself highly effective in moving the right type of patient. Moving neonates to the limited number of DoD
neonatal units has become the AE mission for which it is best known.

**General Characteristics**

The C-21 is a small twin-engine jet with a cabin large enough for six people or one litter plus two attendants (Fig 8.12). The USAF procured it in the early 1980s with a primary role of moving high-ranking DoD personnel in peacetime and moving critical parts and people in war. In the late 1980s, AE was added to its missions. Several civilian air ambulance services use versions of the same Lear Jet, but all of these have been specifically designed for the AE role.

**Strengths**

The C-21 requires little runway for take-off or landing and can therefore move patients into or out of most locations. The range is about 2000 miles at a cruise speed of about 500 mph. This combination provides a capability to move patients throughout the United States. Noise is minimal and lighting is excellent. Because of the small size, climate control in the cabin is also excellent. A final strength is the ability to pressurize to sea level.

**Weaknesses**

Patient capacity is the greatest weakness, but that is in general not a problem because its mission is almost always picking up only one patient. It does not have equipment support, but batteries are adequate for its mission because flight times rarely exceed battery capability. Entry is a problem for adult litter patients because of a built-in closet near the door. Cabin space is extremely limited, and unlike all other USAF AE aircraft the crew cannot stand up in the cabin. The only lavatory is a chemical seat not readily available, and there are no feeding facilities. Finally, there is no oxygen or suction capability.

**Configuration**

If only ambulatory patients are being moved, the C-21 does not require any modification. It simply uses its existing four individual seats and two-person bench-type seat to move the patients and crew. If a litter or neonatal isolette

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*Figure 8.12. C-21 Lear Jet (photo by Lieutenant Colonel John M. McNamara).*
is used, two seats on the same side are removed and the litter or isolette is installed.

**Summary**

The C-21 is an excellent AE aircraft for specific patients. Its niche is newborns and ambulatory patients for whom quick transportation is most important, eg certain organ recipients. Its small entryway, relatively short range, and lack of room to fully utilize equipment for some patients will always limit its use.

**Boeing 767**

A brief description of the Civil Reserve Air Fleet (CRAF) is necessary to understand why the Boeing 767 is part of an AE textbook. Under the CRAF program, all US airlines are given the opportunity to sign contracts in which they agree to release specific numbers of aircraft for use by the USAF in crisis situations. The benefit of the CRAF program for the USAF is that airframes are leased for a specific price only when absolutely needed in a contingency. This program saves the USAF millions of dollars by preventing the purchase and operation and maintenance costs of owning the aircraft. Analysis by medical planners in the early 1980s indicated a need to use the CRAF to meet the AE requirement, and the Boeing 767 was selected for this role.

**General Characteristics**

The Boeing 767 is a twin-engine jet used by the airlines for transcontinental or transoceanic routes, thus making it ideal for strategic AE (Fig 8.13). To make the 767 AE capable, the USAF purchased a number of conversion kits that are used to transform the interior of the 767 into a premier AE aircraft much like the C-9A. The kits used for this conversion are comprised of a number of different parts. First, litter support structures were developed to connect with the fittings that remain on the cabin floor after the commercial passenger seats have been removed. The second component is an oxygen delivery system that utilizes oxygen storage containers in the cargo belly of the aircraft, together with tubing to bring the oxygen to each litter station.

Electrical fittings were added to assure an electrical system that will deliver 110-V, 60-cycle electrical current to each litter station. Finally, nursing workstations were developed that attach into remaining floor fittings.

**Figure 8.13. Boeing 767.**
**Strengths**

The long range of the 767 makes it ideal for the strategic AE mission, allowing it to accomplish all missions except those requiring aerial refueling. It has tremendous capacity to move patients. The exact number of patients moved will depend on the mix and severity of patients’ injuries, but will be around 100 in any possible configuration. Noise is not a problem because the cabin is quieter than even the C-9A. Lighting is excellent throughout the cabin. Oxygen and electrical equipment are both supportable by the conversion kit. Cabin space is excellent, providing excellent access to every patient (Fig 8.14). The lavatory and feeding capability is unmatched because this is an airliner. Climate control is first class, again because this is an airliner.

**Weaknesses**

The greatest weakness is the difficulty in loading patients onto the 767. Although a new ramp with the same pitch as the C-9A ramp has made loading easier, it still takes up to 2 hours to load. There is no suction capability built into the conversion kit. It cannot pressurize to sea level and so cannot move decompression sickness patients. Finally, like the C-141, there are a limited number of airfields that meet its landing or take-off requirements. This should not be a constraint because of the locations at which it is planned to serve.

**Configurations**

As described above, there are multiple possible configurations using the conversion kits. At the time of this writing, the responsible organization, Air Mobility Command, has not published a configuration so none is shown here. Basically, all configurations will allow approximately 100 patients to be moved.

**Summary**

The Boeing 767 has proved itself in tests with mock patients, but thankfully it has never been required in a full contingency role moving “real” casualties. Since it is such a ubiquitous commercial aircraft there should always be adequate numbers available if they are ever
required for fitting with the existing patient conversion kits.

Civilian Airframes

Challenger 601-3R

This aircraft is reflective of the wide variety of aircraft used to move patients in the civilian air ambulance industry (Fig 8.15). It is highly capable as shown in the following discussion.

General Characteristics

This twin-engine jet is among the most capable jets serving the civilian AE mission, and is the only true wide-body aircraft used in the general aviation AE role today. With a cabin width of 8 ft, 2 in, it is capable of seating ambulatory patients three or four abreast (Fig 8.16). The cabin height of 6 ft, 1 in, allows for comfortable movement of patients and medical crew but is significantly shorter than any of the USAF aircraft previously described except the C-21. It has a cruise speed exceeding 500 mph and a range of 3400 nautical miles.

Strengths

The greatest strength of this airframe, as well as others used by the civilian air ambulance industry, is the robust list of equipment available for each mission and the outstanding crew-to-patient ratio. This ratio is possible because of the limited number of patients carried in most
missions. All reputable civilian air ambulance systems have access to exactly the mix of doctors, nurses, and technicians needed to meet any patient’s needs. A list of typical equipment immediately available in the stretcher/ICU position includes the items shown in Table 8.2.

Noise within the cabin is less than the C-9 and lighting is excellent. The cabin environment is easily temperature controlled, primarily due to its relative small size.

**Weaknesses**

Although the Challenger 601 has a longer range than the C-9A, it is still not long enough for transoceanic missions without en route stops. Therefore, the same considerations described in using the C-9A for a transoceanic role apply to this aircraft. This airframe can move relatively few patients. The maximum capacity is two litters and up to nine ambulatory patients, as long as none require extensive nursing care. Cabin space is adequate for crew movement but less than any of the USAF airframes described previously. Loading of litter patients is possible without undue tilting of the litter but is still more difficult than loading any of USAF aircraft.

**Configuration**

The configuration remains as shown in Figure 8.14 for virtually all missions, although both litter positions in the intensive-care part of the cabin are not used in all missions. The seats shown in the diagram can be used for either ambulatory patients or medical crew members depending on the requirements of the patients.

**Summary**

The Challenger 601 is a highly capable AE airframe and is representative of the highest level of AE capability available in the general aviation environment. There are multiple other jet aircraft used in the commercial AE mission, including the Lockheed 731, the Hawker 3A, and the Falcon 50, all of which have essentially the same strengths and weaknesses described above.

**Alternative AE Capabilities**

Even with the best possible planning, occasions will arise when none of the previously described airframes are available. To address such situations, other alternatives should be considered including the following.

**Palletized Patients**

An exciting concept developed at Charleston AFB is the concept of preloading patients onto standard USAF pallets. These pallets are square wooden structures that are used to move military supplies and equipment around the world. Their advantage is that they can be immediately loaded onto USAF aircraft, much like the containers used in worldwide airlift. Patients are loaded onto these pallets prior to the aircraft arrival, and this cuts load time to an absolute minimum. In this concept, patients are secured to standard pallets using field-style mobile litters tied down with standard straps. All supporting equipment is also secured using standard USAF straps. As a result, small numbers of litter patients can be completely ready for loading at those far-forward airfields where turnaround time for transport is critical. Using this technique, patients can be loaded onto transports in less than 5 minutes immediately after they have unloaded their inbound cargo. These patients are completely ready for the mission, including all required support equipment. Reconfiguring the same aircraft for an outbound AE mission would take at least 30 minutes and potentially as much as 2 hours. This difference might be vital in convincing the

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**Table 8.2. Equipment commonly used by commercial AE companies.**

<table>
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<tr>
<th>Equipment</th>
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<tbody>
<tr>
<td>Defibrillator with pacing capability</td>
</tr>
<tr>
<td>One ventilator</td>
</tr>
<tr>
<td>End-tidal carbon dioxide monitor</td>
</tr>
<tr>
<td>Oxygen monitor</td>
</tr>
<tr>
<td>Two IV pumps capable of supporting three lines per pump</td>
</tr>
<tr>
<td>Two oxygen outlets</td>
</tr>
<tr>
<td>Two suction canisters</td>
</tr>
<tr>
<td>Six electrical outlets with 115-V/60-cycle current</td>
</tr>
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appropriate command authority to release an aircraft for an AE role. The feasibility of this concept has been proven using mock patients in the C-17 at Charleston, but has not progressed to a fully implemented plan at this time.

Commercial Airline Seats

For certain patients, the urgency to move may preclude waiting for a properly equipped and staffed AE airframe. In most cases commercial airline service is available to meet such patient’s needs, with the obvious exception being those requiring a flying intensive-care unit. Usually, such moves should be accomplished by purchasing two side-by-side first-class seats. This allows the patient to rest appropriately on long flights and provides the medical attendant immediate access to the patient. This method is often used by commercial AE companies in the Western Pacific region, where multinational companies have small numbers of US citizens working in many nations separated by thousands of miles of ocean. Most of these countries lack western-quality medical service but have airline service, thus making such moves practical with little delay. Using this technique, one can safely move a patient for $2000 to 3000 when commercial AE service might cost as much as $50,000.

Conclusions

In summary, the USAF possesses a wide variety of aircraft with a proven capability of moving large numbers of patients. Each aircraft used in the AE role has specific strengths and weaknesses as described. While the civil air ambulance industry is highly capable of moving small numbers of patients, their experience with large numbers is limited. Therefore, in the event of a sudden disaster requiring AE of large numbers of patients, the expertise and capability of the USAF (through US Transportation Command) will be required.

Reference

The air transport of patients encompasses a range of missions from long-distance, fixed-wing aeromedical evacuation (AE) movements to short-distance, rotary-wing “scene” pickups. While certain aspects of the transport receive different emphasis dependent on distance, mode of transport, and patient condition, the overall goals remain the same (Table 9.1). In attempting to meet these goals, a number of questions will arise regarding the approach. Are there any special considerations for the movement of critically ill or injured patients by air transport? Who is best qualified to provide en route care? What types of equipment are safe for use in the flying environment? What is the best means of monitoring the patient in-flight? What are the basic skill levels required to be a part of the team?

While the specifics of care provided on the ground and in the air should not change significantly, there are a number of considerations and limitations that the transport team must be aware of when moving the critically ill patient. Some of these areas are covered in other chapters discussing preflight triage, aeromedical staging, airframe capabilities, and in-flight treatment options. Additional chapters detailing specific conditions, such as trauma, burn, and psychiatric injuries, highlight relevant considerations for those diagnoses. In this chapter, the first section examines the general impact of the classic flight stressors on patient physiology and care delivery. The role that decreased barometric pressure, temperature, noise, vibration, decreased humidity, acceleration, and fatigue play in patient movements by air is not trivial.

The second section covers organizational issues, such as manpower, equipment, and training considerations, in the establishment and maintenance of a critical-care air transport service for AE. Integration of these areas with a solid clinical background will allow most providers to accommodate to the flying environment where they can deliver “critical care in the air.”

Patient Flight Physiology

Aviation medicine has long been concerned with the effects of altitude and flight stresses on the performance of the aircrew. Less is known about the influence these factors have on the care and outcome of critically ill patients moved within an AE system, in particular during long flights. It is not difficult to anticipate that the environmental stresses associated with flight have the potential to disrupt the delivery of care provided to the patient during transport. These stresses impact not only the patient but those managing care as well.

Beyond a straight assessment of the environmental factors, the platform being used to transport the patient may ameliorate or magnify the potential problems. As discussed in chapter 8, most fixed-wing military aircraft used for AE do not protect medical personnel or patients from the stresses of flight to the same degree that commercial airliners protect their passengers. Patients moved on rotary-wing transports experience more vibration and noise than those on fixed-wing missions. Duration of
exposure to these stressors will also play a role in their impact on the patient. The response to a short scene mission in a helicopter will most likely be different than that seen with a 12-hour transatlantic flight.

In this chapter, we will review the general impact of the classic flight stressors on patient physiology and care delivery. In subsequent chapters, the role, decreased barometric pressure, temperature, noise, vibration, decreased humidity, acceleration, and fatigue have on patient care will be related to specific disease or injury conditions. An understanding of altitude physiology combined with disease- or injury-specific considerations will better prepare you to not only ready the patient for aeromedical transport but also allow you to anticipate and respond to potential problems.

Stresses of Flight

Barometric Pressure Changes

The most prominent environmental consideration in AE operations is the impact of changes in barometric pressure on oxygen delivery and gas expansion. The acceptable altitude range in which physiological functions are minimally impaired is limited to a fraction of the Earth’s atmosphere. From sea level to 12,000 ft, most normal individuals can move with no or minimal impairment.1 Above this level, normal function is progressively impaired unless appropriate environmental interventions are made. Movement of patients through this environment requires an understanding of the classic gas laws and an application of their principles as they apply to normal and abnormal physiology.

### Gas Laws

Most of the physiological results of ascent and descent within the Earth’s atmosphere can be explained by several elementary principles of gas behavior.

**Boyle’s Law.** When the temperature remains constant, as in the human body, a volume of gas is inversely proportional to the pressure surrounding it. This principle explains why a balloon expands as it ascends and also why a volume of trapped air expands in a body cavity when the pressure around it is reduced. A given volume can expect to be doubled at 18,000 ft (5500 m). The formula for Boyle’s Law is

$$\frac{P_1}{P_2} = \frac{V_2}{V_1},$$

where temperature is constant and $P_1$ = initial pressure, $V_1$ = initial volume, $P_2$ = final pressure, and $V_2$ = final volume.

**Henry’s Law.** The amount of gas in a solution varies directly with the partial pressure of that gas over the solution. Therefore, if pressure is reduced above the solution some gas will come out of solution. This principle explains why carbon dioxide bubbles are released when a carbonated beverage container is opened and why nitrogen bubbles may come out of solution in body tissues during ascent. The nitrogen bubbles can lead to altitude-induced decompression sickness. The formula for Henry’s Law is

$$\frac{P_1}{P_2} = \frac{A_1}{A_2},$$

where $P_1$ = initial partial pressure of a given gas, $P_2$ = final partial pressure of a given gas, $A_1$ = initial amount of gas dissolved in a given solution, and $A_2$ = final amount of gas dissolved in the same solution.

**Dalton’s Law.** The total pressure of a mixture of gases is equal to the sum of the partial pressures of each gas in the mixture. The pressure exerted by each gas in a mixture is independent of other gases in the mixture. Remember, the atmospheric pressure at sea level is 760 mm Hg. This total pressure equals the partial pressures of nitrogen (78%), oxygen (21%), and trace gases (1%) making up the atmosphere.
The formula for Dalton’s Law is

\[ P_t = P_1 + P_2 + P_3 + \ldots + P_n, \]

where \( P_t \) = total pressure of the mixture, \( P_1, P_2, P_3, \ldots \) = partial pressures of the individual gases, and \( n \) = total number of gases present.

Dalton’s Law explains how exposure to a high ambient altitude reduces the available oxygen. As ambient altitude increases, the partial pressure of oxygen decreases even though the percentage of oxygen remains the same. For example, at sea level the partial pressure of oxygen (PO2) is 21% of 760 mm Hg or 160 mm Hg. Correspondingly, with a reduction of total pressure the partial pressure of each gas will decrease proportionately. At 18,000 ft (5500 m), PO2 is 21% of 380 mm Hg or 80 mm Hg.

Charles’ Law. When volume is constant, the pressure of a gas increases or decreases proportionally to an increase or decrease in its temperature. Evidence of this law can be seen in the small decrease in pressure recorded from an oxygen cylinder taken from ground level on a hot day to an unpressurized aircraft altitude of 10,000 ft (3056 m). Consequently, the cooler temperature at this altitude leads to a decrease in the pressure within the oxygen cylinder. The formula for Charles’ Law is

\[ \frac{P_1}{P_2} = \frac{T_1}{T_2}, \]

where volume is constant and \( P_1 = \) initial pressure, \( T_1 = \) initial temperature, \( P_2 = \) final pressure, and \( T_2 = \) final temperature.

Hypoxia

One of the principle areas of interest to individuals involved in AE is hypoxia, its effects on patients and medical personnel, and the equipment used to prevent it. Patients requiring AE frequently have a number of factors that already predispose them to developing hypoxia, defined as oxygen “deficiency” sufficient to cause impairment of function. A decrease in barometric pressure with a reduction in the inspired partial pressure of oxygen may be enough to push the “stabilized” patient over the edge. In a classic 1969 study looking at casualties being transferred from Vietnam to other locations, 95 of 201 postoperative surgical patients developed a PaO2 of less than 60 mm Hg when flying at cabin altitudes between 3000 to 7500 ft.

Four Classic Physiological Categories of Hypoxia. Hypoxic hypoxia occurs as a result of a decrease in the partial pressure of oxygen in the lungs or of other conditions that reduce the diffusion of oxygen across the alveolar–pulmonary capillary membrane. This is the most common type reported in flying personnel exposed to a lowered partial pressure of oxygen at high altitude. Additional causes include ventilation perfusion defects, airway obstruction, and apnea. Partial compensation through an increase in tidal volume and respiratory rate can be seen starting at 5000 ft (1500 m) with a resulting drop in PaCO2 (Fig 9.1). Additional compensation occurs through increases in heart rate and cardiac output resulting in a decrease in the arteriovenous oxygen difference with an elevation in mean capillary oxygen tension.

Pressurized aircraft, including commercial airliners, rarely exceed a cabin pressure altitude of 10,000 ft (3000 m). Because PaO2 at that altitude is approximately 60 mm Hg (O2 saturation 90%), the majority of patients and normal passengers would be minimally affected at that cabin pressure. In a small study looking at 29 patients with known or suspected ischemic heart disease requiring AE, Bendrick et al demonstrated that 5 (17%) of these patients dropped their oxygen saturation to less than 90%. The average cabin altitude during the flights was 6900 ft (2108 m) in a C-9A aircraft, representing the usual flight profile for this type of AE mission. In all cases, the addition of 4 L/min of oxygen corrected the level of desaturation.

Hypemic hypoxia occurs when there is a reduction in the capacity of blood to carry a sufficient amount of oxygen. This includes blood loss (anemic hypoxia), dyshemoglobinemias, excessive smoking, and carbon monoxide poisoning. For medical personnel and patients who smoke tobacco products, the formation of carboxyhemoglobin through the inhalation of carbon monoxide will make the individual more susceptible to this type of hypoxia. Typically, military aircrew members who donate blood are grounded for 72 hours following
blood donation due to the reduced hemoglobin level.

To illustrate the contribution of anemia to the development of hypoxia at reduced barometric pressure, it is necessary to examine the impact of the reduced partial pressure of oxygen on the oxygen-carrying capacity of blood. Oxygen-carrying capacity is defined as

\[ \text{CaO}_2 = (1.34 \times \text{Hb} \times \text{SaO}_2) + (\text{PaO}_2 \times 0.0031), \]

where \( \text{CaO}_2 \) = oxygen content of arterial blood, \( \text{Hb} \) = hemoglobin, \( \text{SaO}_2 \) = % arterial oxygen–hemoglobin saturation, and \( \text{PaO}_2 \) = partial pressure of arterial oxygen.

At a sea level equivalent of 760mmHg, with a \( \text{PaO}_2 \) of 102mmHg, \( \text{Hb} \) of 15g/dL, and \( \text{SaO}_2 \) of 98%, each 100mL of blood could carry approximately 20mL of oxygen. This is reduced to 19mL per 100mL of blood due to venous admixture with unsaturated blood. The content drops by one half when the hemoglobin drops from 15 to 7g/dL; however, the extraction remains constant at 5 to 6mL of oxygen per 100mL of blood. Thus, the venous saturation drops from 75% to less than 50%, leaving no reserve for additional oxygen demands when there is an associated drop in inspired oxygen.

Stagnant hypoxia occurs when there is a reduction in total cardiac output, pooling of the blood, or restriction of blood flow reducing oxygen delivery. This includes problems commonly found in critically ill or injured patients such as congestive heart failure, shock, and positive pressure ventilation. This concept can be extended to specific organ systems such as the development of cerebral vasoconstriction and reduced blood flow that occurs with hyperventilation. The use of supplemental oxygen will often be necessary in patients with stagnant hypoxia, in particular when any of the other contributing factors such as altitude (hypoxic) or reduced carrying capacity (hypemic) is present.

Histotoxic hypoxia occurs when the utilization of oxygen by the body tissues is hindered. This includes carbon monoxide poisoning, cyanide poisoning, and alcohol ingestion. For the AE patient, this is not in general a contributing factor except in specific cases of known exposure, such as burn victims (carbon monoxide) and cyanide (sodium nitroprusside) toxicity.

Gas Expansion
Changes in barometric pressure produce effects beyond hypoxia. According to Boyle’s Law presented above, a volume of gas is inversely proportional to the pressure surrounding it (Fig 9.2). This resulting gas expansion can adversely affect not only the medical crew but patients and equipment as well. The end product of gas expansion in patients and crew can be actual tissue damage or pain that will affect mission performance.
The terms used to describe the effects of barometric pressure changes include dysbarism, barotrauma, and decompression sickness. Dysbarism represents the general topic of pressure-related injuries. Barotrauma refers to the direct injuries that are a result of the mechanical effects from an applied pressure differential. Finally, decompression sickness relates to the complications associated with the evolution of gas from tissues and fluids of the body.

The most common sites of trapped gas disorders in the typical patient or medical crew member involve the ears, sinuses, gastrointestinal tract, and, rarely, teeth. When considering the potential for problems with the air transport of patients, you may need to consider other areas, including medical equipment and air introduced into other anatomic sites as a result of injury or operation.

Barotitis media or “ear block” is an acute or chronic trauma of the middle ear caused by the difference of pressure between the air in the tympanic cavity and mastoid air cells and that of the surrounding atmosphere. During ascent, expanding gas within the tympanic cavity is vented. The Eustachian tube usually functions as a one-way valve to allow this gas to escape from the middle ear. On descent, however, the volume within the middle ear contracts, causing the tympanic membrane to retract. Active opening of the Eustachian tube using positive pressure from the nasopharynx or by using the jaw muscles usually suffices to equalize the pressure differential: yawning, swallowing, or the Valsalva maneuver.

This process of expansion and contraction can cause significant complications if the normal corrective procedures are ineffective or impaired. Severe pain, nausea, vertigo, tinnitus, perforation of the eardrum, and bleeding can occur with an associated temporary impairment of hearing. Medical crew members should be aware of the early symptoms of barotitis media. In patients or crew with congestive symptoms, topical vasoconstrictors such as 0.25% phenylephrine spray may be beneficial when used 15 minutes before descent or take-off. Severe symptoms should be reported to the director of the aeromedical crew because the aircraft may have to increase altitude again to allow equalization of pressure in the middle ear before reattempting descent. Finally, politerization may be required to equalize pressures. This involves the delivery of pressurized air using a handheld compression device (Politzer bag) or compressed air through the nose to open the Eustachian tube.

The implications of gas expansion and barotitis media are less clear for the comatose, psychotic, or disoriented patient. Do not forget to evaluate those patients who have been

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**Figure 9.2.** Impact of altitude on gas expansion. At the highest cabin altitude expected during flight in a pressurized aircraft (10,000 ft), gas expands to 1.5 times the original volume.
nasotracheally intubated or who have nasogastric tubes in place because they are prone to develop edema and Eustachian tube dysfunction. You should observe patients for evidence of increased irritability or agitation during descent, which may accompany the discomfort associated with increased middle-ear pressures. Direct examination of the tympanic membrane for significant retractions may rule out this problem.

**Barosinusitis** occurs when there is obstruction of airflow that normally passes in and out of the sinus cavities without difficulty. The presence of an upper-respiratory infection may produce swelling of sinus mucosal membranes that will obstruct normal venting. On ascent, this will produce pain or pressure below (maxillary), above (frontal), or behind the eyes. More commonly, problems occur during descent. The use of the Valsalva maneuver will frequently provide at least temporary relief. Vasoconstrictors and return to a higher altitude may also be necessary. When considering the AE patient, barosinusitis may occur in patients with abnormal nasal pathology or inflammation such as facial trauma or nasal instrumentation (intubation, nasogastric tubes).

**Barodontalgia** occurs when trapped air in abscesses, dental fillings, or caries expands, resulting in severe pain during ascent. This is an uncommon problem and can be confused with barosinusitis involving the maxillary sinuses. In the case of barodontalgia, only one tooth is usually involved whereas several of the upper teeth on the affected side are symptomatic with maxillary barosinusitis. Therapy is limited to descent and pain control with appropriate follow-up.

**Barogastralgia** or gas expansion in the gastrointestinal tract is rarely serious with cabin altitudes less than 10,000 ft (3045 m) where gas expansion is typically 1.5 times the volume at sea level (Fig 9.2). Patients or crew who eat hasty, large meals with foods and carbonated beverages known to produce gas may on occasion experience problems related to gas expansion. In patients with gastrointestinal problems such as bowel obstructions, ileus, or motility problems, the amount of expansion may be excessive and produce symptoms of discomfort, abdominal pain, belching, flatulence, nausea, vomiting, shortness of breath, and, in extreme cases, vagal symptoms. Preflight placement of a nasogastric tube, if not already done, should be accomplished in these patients and be left unclamped during flight. Some recommendations suggest avoiding high-altitude exposure in postabdominal surgery patients for 24 to 72 hours following surgery due to the potential for associated intrabdominal air trapping. The pregnant patient, in particular in the third trimester, may also be at higher risk of having discomfort related to gastrointestinal gas expansion.

**Intrathoracic** air presents a special consideration because it is contained within a fixed space. The management of the patient with a pneumothorax requires the medical crew to consider several issues. Even patients with an asymptomatic pneumothorax can develop significant decompensation with gas expansion inside the thorax. An untreated pneumothorax is considered an absolute contraindication to movement by aircraft except in the absence of respiratory compromise and ability to maintain cabin altitude equal to that at the point of origin. Even under these circumstances, the medical team should have the capability to provide definitive treatment should the patient’s condition change. The safest approach is to electively place a chest tube before flight with an appropriate collection system.

In a patient requiring air transport, if already present, the chest tube should be left in place before flight even if it could otherwise be removed. If recently removed, at least 24 hours should elapse before transport and an expiratory chest radiograph showing no reaccumulation of the pneumothorax is obtained before flight. In addition, an occlusive dressing should be applied to the chest tube site. For all patients with chest tubes, they should be connected to a rigid, non-glass collection system with a Heimlich or other one-way valve. Water levels should not be changed during ascent or descent although the suction level, if used, should be checked frequently.

**Intracranial** air is one of the rare areas of gas expansion that can be potentially devastating. Whether it is from a penetrating injury, surgery, or diagnostic study, the presence of intracranial air requires close monitoring of the air
transport patient. If the patient needs to be moved, you should consider maintaining cabin pressure equivalent to the point of origin. In addition, the presence of a cerebrospinal fluid leak from the ears or nose raises theoretical concern for drawing in air or bacteria during ascent/descent.

*Medical equipment* that contains air can also be adversely affected by gas expansion. Items such as MAST garments and pneumatic splints may become excessively distended on ascent or may not function as intended with volume loss during descent. Endotracheal tube cuff management presents a particular problem. Cuff expansion at decreased barometric pressures can result in excessive pressure on the tracheal mucosa and rapid decompression could theoretically lead to tracheal injury or rupture. Stoner and Cooke demonstrated this in 1974 using an animal model and suggested that endotracheal tubes with pressure-regulating valves on the pilot balloon or foam cuffs be used to avoid the problems related with cuff expansion (Fig 9.3).7 Another recommendation is that saline be used to expand the cuff during aeromedical evacuation because expansion would be minimal. Figure 9.4 shows the cuff pressure response from 0- to 15,000-ft altitude with air, saline/air, and saline. Care must be taken when using saline expansion because there is a variable and steep volume–pressure response curve in commonly used endotracheal tubes (Fig 9.5). We currently recommend that the endotracheal tube or tracheostomy tube cuff be inflated with sterile saline using the “minimal leak technique” to avoid tissue damage or air leak due to gas expansion and compression during all phases of flight. If air is used, the cuff pressure should be checked and adjusted with changes in cabin altitude.

Other equipment considerations include distention of balloon bladder catheters, intravenous (IV) solution bags, and aortic balloon pump function. Finally, some research has been conducted on the performance of mechanical ventilators at altitude. Special attention should be paid to the delivered tidal volume of transport ventilators used during AE when the cabin pressure is decreased. While some ventilators have automatic compensation, others do not and the delivered tidal volume and/or rate may change with alterations in cabin altitude (Fig 9.6).8–10

### Cabin Altitude/Pressurization

To reduce the problems associated with hypoxia and gas expansion, most aircraft have a system to produce cabin pressurization using engine bleed air. The pilot can sometimes regulate the cabin pressure and ventilation by varying the amount of air forced into the cabin and adjusting the overflow while correcting for the known leak rate. Malfunction of this system...
Figure 9.4 Changes in mean cuff pressure associated with changes in altitude for a standard 8.0-mm ID endotracheal tube (Portex) with air (solid circles), saline plus 2 cc air (open circles), and saline (solid squares) filled cuff using a laryngeal model.

Figure 9.5. Pressure responses for saline-inflated endotracheal tube cuffs in a laryngeal model (unpublished data courtesy of the author).
or aircraft structural damage may result in a loss of cabin pressure or decompression. The cabin volume, size of the defect, altitude, and pressure differential will then impact problems related to the decompression.

Aircraft such as the USAF C-9A maintain a constant cabin pressure (isobaric system) as aircraft altitude increases. With this type of system, the pressure differential between cabin pressure and ambient pressure increases with altitude. The C-9A maintains a pressure schedule slightly greater than ambient to 8000 ft and then maintains 8000 ft through its certified ceiling. The C-141, on the other hand, uses an 8.6-psi isobaric-differential pressurization system. The cabin altitude will remain at sea-level or ground-level pressure until the aircraft reaches 21,000 ft. Above this level, the system maintains a pressure differential of 8.6 psi to the service ceiling of the aircraft. For example, at 40,000 ft the ambient pressure is 2.72 psi with a cabin pressure of 11.3 (8.6 + 2.72) psi. This corresponds to an altitude of 8000 ft. Figure 9.7 graphically demonstrates these two pressurization schemes.

Altitude Restrictions

The decision for an altitude restriction or the need to provide supplemental oxygen administered at altitude should be based on several considerations. Most fixed-wing aircraft normally used for AE must fly at altitudes much lower than their normal cruise to maintain sea-level pressurization in the cabin. Flying at lower altitudes increases their fuel consumption, decreases their range, and increases the probability of turbulence. Inappropriate cabin altitude restrictions can result in the use of alternate routes that lengthen air miles flown and increase time and cost of flight. Individuals with a PaO2 at or below 60 mmHg (90% saturation) at sea level will probably demonstrate hypoxia at or above 2000 to 4000 ft. The treatment for problems of oxygenation is not an altitude restriction but the appropriate management of inspired oxygen via an approved delivery system.

During aeromedical flights, patients with decreased pulmonary perfusion and those with cardiac conditions should be closely observed.
Patients having a pulmonary disease with an undetected coronary artery disease may be affected significantly by hypoxic hypoxia. In addition, patients with chronic obstructive pulmonary disease (COPD) should be administered low-flow oxygen therapy (1 to 2 L/min) via nasal cannula or 24% to 31% Venturi mask to regulate the delivered oxygen concentration.\(^\text{11}\)

**Temperature**

Ambient temperature decreases with increasing altitude at a rate of 2°C per 1000 ft up to 35,000 ft (about 1°C per 100 m).\(^\text{12}\) As a consequence, aircraft cabin temperature fluctuates considerably depending on the temperature outside the aircraft. This is caused by the inability of aircraft temperature controls to respond rapidly and the necessity to open aircraft doors at en route stops. Inside aircraft temperature variations from 15°C or lower to 25°C should be expected in winter flying, and in summer 20°C to greater than 35°C is not uncommon. These wide variations require the medical crews to be aware of cabin temperature changes in relation to performance and patient care/comfort. In addition, there can be degradation of equipment performance at the extremes of temperature.

The effects of thermal exposure can be magnified by other stresses, including vibration, dehydration, and alcohol/drug intoxication. In addition, climatic temperature variations may create air turbulence that can impact negatively on the aircraft, crew, or patient.

**Noise**

Noise represents one of the more troublesome stresses encountered during AE operations. It is can be defined as any sound that is unpleas-
ant, distracting, or in some other way undesirable. unprotected exposure to noise can produce one or more of the following undesirable effects: (1) degraded communications and patient evaluation, (2) temporary auditory threshold shifts (auditory fatigue), (3) permanent threshold shifts (sensorineural hearing loss), or (4) fatigue.

Interference with effective communications between providers and between the medical crew and the awake patient can disrupt the detection of changes in symptoms or conditions. As a result, the crew must frequently rely on other means to monitor and assess the patient’s condition. With high levels of noise such as that present on rotary-wing and military aircraft, close observation of the patient and visual alarms will supplement the usual forms of patient interaction and assessment. The ability to auscultate for breath sounds is almost impossible under most circumstances in flight.

Auditory fatigue induced by noise is frequently accompanied by a feeling of fullness, high-pitched ringing, buzzing, or a roaring sound (tinnitus) in the ears. These symptoms usually resolve within a few minutes of noise cessation but may take hours in some circumstances. Most of the significant symptoms of noise exposure, such as nausea, disorientation, and fatigue, in general occur with exposure to noise levels in excess of those seen during AE missions. Nonetheless, it is recommended that all personnel wear hearing protection during patient transport operations.

Vibration

Vibration, like noise, is inherent in all transport vehicles and may interfere with patient assessment and some routine physiological functions. The most common sources of vibration during air transport are the engines/rotors and air turbulence. When in direct contact with a source of vibration, mechanical energy is transferred, some of which is degraded into heat within those tissues that have dampening properties. The whole body response to sustained vibration is a slight increase in metabolic rate that is similar to mild exercise. Low-frequency vibration may also promote the onset of fatigue, irritability, and motion sickness. In conjunction with the other stresses of flight, the overall effect is magnified.

Because there is little that the pilot or crew can do to eliminate or decrease the amount of vibration, care should be taken in minimizing its effects. Patients should be properly secured, encouraged and assisted with position changes, and provided with adequate padding and skin care. Special care should be taken in the movement of neonates because they may be more susceptible to direct injury from both noise and vibration. In addition, vibration may cause dysfunction of activity-sensing pacemakers although other types of pacemakers should not be affected.

The potential deleterious effects of vibration extend to the equipment used during transport. Although evaluation of several pulse oximetry units demonstrated their capability to function in the flight environment, they are sensitive to motion and may display artifactual readings on occasion. Similarly, noninvasive blood pressure (BP) monitors will work well under most in-flight circumstances; however, they are still subject to the same accuracy limitations seen in the hospital.

Decreased Humidity

One of the more subtle stresses of flight is a decrease in cabin humidity. As altitude increases and air cools, moisture in the air decreases significantly. Thus, the fresh air supply drawn into the aircraft cabin comes from a very dry atmosphere. This dry air also replaces the moisture-laden cabin air such that the relative humidity is less than 10% to 20% on most commercial flights. Medical crew will develop chapped lips, scratchy or slightly sore throat, hoarseness, and general moisture loss. The patient with respiratory complaints or who is already dehydrated may have more significant problems. Patients requiring oxygen should receive humidified gas, and fluid intake of both the crew and patients should be monitored to minimize problems with dehydration.

Acceleration

Gravitational force, or acceleration, is negligible under most circumstances when discussing the
Fatigue

The end product of all the physiological and psychological stresses of flight associated with exposure to altitude is fatigue. Performance degradation with loss of attention and decrease in reaction time can be a significant contributor to a decrease in operational capability. This problem is often made worse by self-imposed stress such as the use of drugs, (including over-the-counter drugs, prescription medications, and stimulants such as caffeine), exhaustion, alcohol, tobacco, and poor dietary habits.

Organizational Issues

Team Composition

The “ideal” air medical crew composition has been a topic of discussion for a number of years without resolution.22–27 The mission requirements, scope of medical responsibilities, and personnel availability all contribute to the composition of the flight crew. A recent survey of civilian hospital-based flight programs in the United States shows that a nurse–paramedic composition is the most common combination although physicians, respiratory therapists, and emergency medical technicians are occasional team members.28

Currently, there are no national standards for the qualifications of medical personnel actively participating in the air transport of critically ill or injured patients.29 Recommended training for these aeromedical crewmembers include education and experience in altitude physiology, management of patients in the prehospital setting, and flight communications and safety. In addition, for nonphysician personnel, “they should have the ability and training to function autonomously in a variety of settings with treatment protocols if immediate communications with a physician is not possible or if immediate life saving actions are required.”30

Nurses

By far, the majority of flight teams include a registered nurse (RN) as the team leader. In the evolution of air medical services, the majority of air transports in the United States have been interhospital transports where patients are moved from the source hospital to one capable of providing a higher level of necessary care. As such, patients should anticipate receiving a level of care comparable to that
of the sending facility. The inclusion of RNs with specialized skills meets this need in most instances. According to the American Society of Hospital Based Emergency Air Medical Services’ (ASHBEAMS) recommended standards, “staffing the aircraft shall be commensurate with the advanced life support environment afforded by the airborne emergency care facility.”31 This staffing should include, at a minimum, “at least one specially trained registered nurse.”

Now, the “specially trained registered nurse” is most commonly a flight nurse. The National Flight Nurses Association has established practice standards for flight nurses and provided numerous position statements regarding the role of flight nurses in the delivery of care during air transport.30,32,33 The USAF has a six-week training program to provide registered nurses with the additional skills and experience to become military flight nurses. By covering the additional training and education described above, these individuals are better prepared to transport the critically ill and injured patients needing a higher level of care than that provided by basic transport services.

**Paramedics/Other Technicians**

The most common air medical crew configuration for use in the United States includes one RN and one paramedic.28 During the mid-1980s many flight programs turned from predominantly RN crews to ones that incorporated the prehospital skills of the paramedic. The National Flight Paramedics Association (NFPA)34 has stated that minimal training standards and qualifications for paramedics in this field should include:

1. Successful completion of an approved emergency medical technician (EMT)-paramedic course that utilizes Department of Transportation EMT-paramedic course guideline.
2. Biennial successful completion of an American Heart Association advanced cardiac life support provider course.
3. Successful completion of either a basic trauma life support course or prehospital trauma life support course with respective refresher courses as required.
4. Successful completion of an additional course of instruction (when available) designed for flight personnel and including specific air medical modalities and issues.
5. Three years’ experience in the field as an EMT working as an advanced life support provider.

Another development that will contribute to the increased use of paramedics in transport is the development of Critical Care Paramedic (CCEMT-P) training programs. A recent study examined the impact of a paramedic-staffed mobile intensive-care unit performing interfacility transports.35 The authors concluded that specially trained paramedics “can monitor and treat patients appropriately during interfacility transfers that traditionally would have required supplementation with additional hospital staff.” While this was a small study, the potential to use less costly personnel may cause some transport services to re-examine their current staffing mix.

**Physicians**

Few transport teams include routine, direct physician support on the aeromedical crew. In an attempt to determine whether the presence of physicians improves patient outcome, a number of studies have examined various programs with differing results. For example, Wright et al failed to demonstrate a change in mortality with physician involvement during the aeromedical transport of patients with traumatic cardiac arrest.36 In contrast, Baxt and Moody reported a decrease in mortality for blunt trauma patients without traumatic arrest when a physician was part of the transport team.22 The majority of studies of this type deal with prehospital management and scene responses where stabilization prior to transfer is the key issue. In a review of aeromedical transportation, Moylan observed that available data “demonstrate clearly that the interval between the accident and arrival of the helicopter medical personnel at the scene of the accident or outlying hospital—not the speed with which the patient is delivered to the tertiary care facility—is the key factor in improving survival.”37 If physician involvement has an impact on patient outcomes in most scenarios, it lies in the preflight stabilization of the critically ill or injured patient. This is not a trivial consideration because 24% to 70% of
transferred patients may be inadequately stabilized prior to transport.\textsuperscript{38}

For longer, fixed-wing transport, the same controversy exists. The USAF has employed a mix of flight nurses and AE technicians since the 1960s for the movement of patients by air. With recent changes in missions and logistic support, there has been increasing emphasis on physician involvement. During Operation Just Cause, when US Forces went into Panama, the AE system designed to move stable patients found itself with a requirement to transport fresh casualties.\textsuperscript{39} The inclusion of physicians on these flights and those generated during the Gulf War\textsuperscript{40} has led to the creation of the Critical Care Air Transport (CCAT) Teams. CCAT Teams are composed of an “intensivist” physician, critical-care nurse, and cardiopulmonary/respiratory therapy technician (Fig 9.8).\textsuperscript{41,42} The definition of an intensivist includes anesthesiologists, emergency medicine physicians, and pulmonary/critical-care medicine specialists. These are the physicians whom are more likely to be dealing with critical patients on a daily basis and be able to provide the degree of support necessary to establish stabilization prior to transport or while en route.

Beyond direct contributions to the transport team, physicians also provide support as air or transport service medical directors with established programs. A well-prepared medical director contributes greatly to the development of treatment protocols, quality processes, crew training, and administration. The degree of involvement, however, varies widely.\textsuperscript{43} Currently, most physician directors lack experience in air medical practice, in particular in the areas of medical training, practical experience, and longevity in their current position. Many of these positions are unpaid and performed on a part-time basis with responsibility for a wide range of skills not typically acquired during medical training. These deficits are similar to those associated with the aircrew members, where there is a lack of standardization in training, education, experience, and function. Organizations such as the Association of Air Medical Services (AAMS) and the Commission on Accreditation of Medical Transport Systems (CAMTS) have published standards that should improve this process.

\begin{figure}[h]
  \centering
  \includegraphics[width=\textwidth]{image.png}
  \caption{An emergency room nurse and a trauma surgeon monitor the temperature of a trauma casualty aboard a C-141 (USAF photo by Dewey Mitchell).}
\end{figure}
Equipment

The care and monitoring of patients in the aeromedical environment commonly requires the use of modern biomedical equipment. Devices that work perfectly fine in the intensive-care unit on the ground may not function as expected when taken to even moderate altitudes or may experience total dysfunction following loss of cabin integrity and rapid decompression. Beyond being able to tolerate the direct effects of altitude and other stresses of flight, aeromedical equipment must also be able to function safely in conjunction with the radiofrequency (RF) transmitting equipment found on the airframe. Not only must the medical devices not interfere with the communication and navigation systems found on the aircraft, those same systems should not produce electromagnetic interference (EMI) with the monitoring equipment. In 1989, 70% of neonatal transport equipment failed military-specific testing for potentially excessive EMI.

As discussed earlier in this chapter, the physiological stresses of flight can have a significant impact on a patient’s condition and the care he receives during transport. Beyond the effects of altitude on equipment outlined in the previous section, each of the stressors has the potential to alter the functionality of aeromedical equipment. At Brooks AFB in Texas, the USAF has the Aeromedical Research Group, which is devoted to evaluating and certifying biomedical equipment for use in military air transports. The testing procedures evaluate the impact of vibrations, acceleration/deceleration, rapid barometric pressure changes, and wide temperature shifts on a variety of medical devices (Table 9.2). Testing requirements are less stringent in the civilian community although recommendations exist for equipment used in air ambulances.

One of the more unique considerations in the flight environment is the power requirement for biomedical equipment. Unlike commercial power, which provides 110 VAC at 60 Hz, most fixed-wing aircraft operate on 110 VAC at 400 Hz or 12-V DC while rotary-blade aircraft in general operate on 28-V DC systems. With average rotary-wing missions in the United States taking a little less than 2 hours and fixed-wing transports lasting over 4.5 hours, transport equipment must have long-lasting battery support or be able to convert aircraft power to conventional 110 VAC at 60 Hz. This can be accomplished through frequency inverters or direct DC-to-DC conversion adapted to equipment battery packs.

Although frequency inverters are large and heavy, fixed-wing flights may necessitate their use due to the length of the mission. If lead-acid batteries are used, they must be sealed and protected to ensure case integrity. When estimating transport time in relation to battery life, do not forget ground transportation time as this will most likely be accomplished on batteries and can take a significant period of time.

Monitors

In 1993, the American College of Critical Care Medicine and other groups published guidelines for the transfer of critically ill patients. While these guidelines were targeted to generic intra- and interhospital transports, many of the recommendations are directly applicable to the movement of patients by air. In their approach to monitoring, the basic tenet was to provide the same physiological monitoring during transport as received in the intensive-care unit.

<table>
<thead>
<tr>
<th>Table 9.2. Environmental tests for aeromedical equipment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude testing</td>
</tr>
<tr>
<td>Rapid decompressions</td>
</tr>
<tr>
<td>High-temperature operation</td>
</tr>
<tr>
<td>Low-temperature operation</td>
</tr>
<tr>
<td>High-temperature storage</td>
</tr>
<tr>
<td>Low-temperature storage</td>
</tr>
<tr>
<td>Humidity</td>
</tr>
<tr>
<td>Vibration</td>
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<td></td>
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</tbody>
</table>
prior to transfer, if technologically feasible. They further established a minimal level of monitoring to include continuous monitoring with periodic documentation of electrocardiogram (ECG) and pulse oximetry and intermittent measurement and documentation of BP, pulse rate, and respiratory rate. In addition, certain patients based on their clinical status might benefit from monitoring by: capnography; continuous measurement of blood, pulmonary arterial, or intracranial pressures; and intermittent measurements of central venous and pulmonary arterial occlusion pressures or cardiac output.

The most basic of monitoring skills require no mechanical devices beyond a stethoscope and sphygmomanometer. In the flight environment, however, noise significantly limits the ability of the provider to use these simple tools for assessing BP and heart/breath sounds. The noise level typically seen in medical helicopters is 95 to 100 dB and is approximately 2000 times louder than heart tones and breath sounds. Even transport by fixed-wing aircraft does not guarantee an environment that will be adequate for auscultation. Military aircraft such as the C-130 Hercules and C-141 Stratolifter have noise exposures approaching those seen in rotary-wing aircraft. Assessment during transport by quieter commercial aircraft is not immune from interference either. The use of amplified stethoscopes and monitoring devices has not solved this problem although the advent of new techniques, such as esophageal stethoscopy, may resolve some of these limitations.

To compensate for the noise factor, other monitoring techniques must be used. Use of palpated systolic BPs taken at the radial or brachial site can be readily accomplished although they are notably inaccurate in the critically ill even when they can be obtained. Automated BP monitors, either as stand-alone devices or as components of an integrated monitoring package, using oscillometric or other methods of noninvasive measurements, are commonly used in this environment. Reported problems with the use of this technology in the transport environment include unreliability due to vibration or movement, difficulty visualizing screens due to positioning and ambient light, unsuitability for hypotensive patients, high power requirement, and lack of compatibility with disposable cuffs. They are, however, more accurate than those obtained by palpation.

Alternative methods for the noninvasive assessment of BP include the use of Doppler and pulse oximetry occlusion techniques where systolic BP determination following BP cuff release is detected by the return of blood flow or oximetry waveform, respectively. Alternatively, invasive BP measurements may be desirable, in particular in those patients at risk for significant hyper- or hypotension during transport. Current transport monitors such as the ProPaq Encore (Protocol Systems, Inc, Beaverton, Ore) include two channels of invasive pressure monitoring in addition to noninvasive measurement using oscillometric techniques (Fig 9.9).

ECG monitoring, a fundamental requirement in most transport situations involving the critically ill and injured, is prone to mechanical and electrical interference. While the ECG is useful in the diagnosis of pulseless electrical activity and arrhythmias, during long-term transports the ability to monitor for myocardial injury and ischemia is also highly desirable. Unfortunately, many transport monitors lack the resolution required to detect subtle changes. Some units, such as the ProPaq Encore, provide an extended bandwidth where ST segments may be accurately displayed and printed. The lack of automated ST segment monitoring, however, means that the transport team is directly responsible for detecting and analyzing any changes in this parameter. Care should be exercised in this regard because erroneous determinations can be made in patients based on ST segment monitoring using transport equipment.

The measurement of oxygen saturation and end-tidal CO₂ (EtCO₂) do not replace the need to assess the quality and distribution of breath sounds although these values can be useful in managing the critically ill patient. Pulse oximetry has been used in the aeromedical evacuation environment for a number of years with great success although not all models are suited for use in transport. With one model, as much as 25% of the measurement time was subject to interference during helicopter trans-
The ProPaq Encore and some other models incorporate electrocardiograph synchronization that significantly reduces motion artifacts in pulse oximetry measurements during rotary-wing patient transport. Similarly, EtCO₂ monitoring provides information on the adequacy of minute ventilation and the position of the endotracheal tube. While breath-to-breath values may be misleading, tending the EtCO₂ provides a better estimate of CO₂ exchange and minute ventilation requirements. The presence of sustained EtCO₂ following intubation provides evidence of correct positioning when other methods such as auscultation are not available in the flight environment. In addition, the presence of EtCO₂ may help with assessment of cardiopulmonary resuscitation because poor cardiac output is associated with a marked decrease in EtCO₂. Evaluations of several different models show that they will have a role in the air transport of intubated patients in particular when combined with an integrated monitoring package. An alternative EtCO₂ detection device is the disposable colorimetric CO₂ detector, such as the Easy Cap (Nellcor Inc, Hayward, Calif) (Fig 9.10). This simple device incorporates metocresol purple into a detection chamber where the presence of CO₂ changes the color of the detection paper from purple to yellow with some quantitative capability based on the degree of change. A significant limitation in the traumatized patient with significant airway secretions or the intubated patient receiving humidified gas is inactivation of the indicator strip if it becomes moist. The principle use of this device is the confirmation of tracheal placement of the tube following intubation.

Other monitoring modalities such as cardiac output, temperature, and neuromuscular function, commonly used in the ICU, may still be useful in the transport environment. Currently, there are no portable monitoring systems with integrated cardiac output measurement capability. The use of a portable blood gas analyzer to assess arterial and mixed venous oxygenation in combination with oxygen consumption calculations based on the Fick equation is possible during longer, fixed-wing transports provided a pulmonary arterial catheter is in place to obtain samples. Temperature monitoring is
possible through a number of approaches including liquid crystalline probes, thermistors, and infrared thermometers. Potential monitoring sites include aural, oral, nasopharyngeal, rectal, bladder, skin, and esophageal locations. The exact location chosen will depend on the equipment available, patient tolerance, and the degree of core temperature accuracy required for patient management. Beyond patient comfort, effective temperature management plays a role in the patient’s outcome, in particular in the trauma setting. In addition to the reliability and utility of different monitoring modalities in the flying environment, other factors of equipment design may limit the ability of specific monitors to function outside of their normal area of use. As previously noted, noise may significantly impair the ability to assess the patient directly. The ambient noise in the aircraft cabin will also limit the ability of caregivers to detect auditory alarms seen on most medical systems. This puts increased emphasis on the visual alarms and data presented by on-board medical systems such as ventilators, monitors, and other pieces of equipment. The adequacy of visual scanning may be hampered with the absence of auditory signals because this requires direct attention as opposed to noting auditory clues without having to divert from other tasks. Fromm et al noted the potential for significant delay in observation of visual alarms in the flying environment with the loss of auditory signals. In addition, many of the information displays used in transport-capable equipment were not designed for use in direct sunlight. Many of these screens can be visualized at limited angles, if at all, when used in an outdoor environment under direct sunlight conditions.

**Ventilators**

The need to develop special transport ventilators for the movement of military casualties was recognized during the United States’ involvement in Vietnam. Branson and McGough outline the definitions, characteristics, classifications, and necessary criteria for an ideal system in a 1990 review of transport ventilators (Table 9.3). When addressing the special requirements for transport by air, the ideal ventilator should also deliver a continuous mechanical ventilation (MV), without alteration in tidal volume (TV) or rate, across a wide range of barometric pressures. The newer transport ventilators in use and under development incorporate all of these features and more. Desirable additions such as built-in air compressors or other mechanisms to allow for the delivery of a variable $F_{\text{O}_2}$ are also available on many of the current models without the need to carry a separate air compressor.

When mechanical ventilatory support is required, how will altitude and the other flight
stressors impact ventilator performance? The potential for a decreased (or increased) barometric pressure to affect transport ventilator function has long been recognized. In 1969, Kirby et al reported on the function of the Bird Mark VIII Respirator at altitudes up to 34,000 ft equivalent (barometric pressure of 188 mm Hg) in dogs. They noted a decrease in ventilator rate and an increase in TV. The drop in the ventilator rate was attributed to alterations in the performance of the expiratory timer cartridge, which became overpressurized with the decrease in barometric pressure. The increase in tidal volume was only moderate and the overall MV was relatively unchanged.

More recently, Thomas and Brimacombe evaluated a modern transport ventilator, the Dräger Oxylog, under hypobaric conditions. This ventilator is a time-cycled, volume-constant ventilator with pneumatic logic controls. Like the Bird Mark VIII Respirator, the Dräger Oxylog showed a moderate increase in TV from 700 to 1442 mL at 30,000 ft with a decrease in ventilator rate from 12 to a little over 8 breaths/minute. The overall effect was an increase in MV of 13% and 45% at 6676 and 30,000 ft, respectively. Neither of these ventilators is microprocessor controlled, and the interplay of pneumatic controls limits the impact of altitude on the delivered TV.

The Univent Model 750 and Univent Eagle Model 754 (Impact Instrumentation, Inc, West Caldwell, NJ) are electronically controlled, time-cycled, pressure-limited transport ventilators. The observed increase in tidal volume of the Univent Model 750 comes close to that predicted by the application of Boyle’s Law (Fig 9.6). Because the delivered TV comes from a pressurized gas source at 45 to 55 psi, a certain “mass” of gas is delivered in the microprocessor-controlled time interval that expands by a factor of two at an altitude equivalent of 18,000 ft. This problem, however, is readily avoided in the field by disconnecting the patient from the ventilator and performing a recalibration of the ventilator after significant changes in cabin altitude. Because the calibration process takes almost 60 seconds to perform, certain patients may require manual ventilation during this procedure.

The Univent Eagle avoids this potential problem by the inclusion of an internal barometer. Changes in barometric pressure are continuously fed to the on-board microprocessor. In the microprocessor, the current pressure is compared to those located in a lookup table. At 5000-ft intervals, the microprocessor automatically adjusts the flow rate to compensate for the change in barometric pressure based on the correction factors in the lookup table (Les Sherman, personal communication, Impact Instrumentation, Inc, August 1997). These calibration factors are set at 5000-ft intervals up to 25,000 ft. Beyond the preset range, the ventilator can be expected to show an increase in tidal volume similar to that seen in the Univent Model 750. In the event of decompression at a high altitude, the increase in peak airway pressures should be blunted by the preset peak pressure limits. When these limits are exceeded, the ventilator stops the delivery of gas to decrease the risk of barotrauma. Both ventilators have this pressure-limiting feature.

In addition to the automatic compensation for changes in barometric pressure, the Univent Eagle incorporates a built-in air compressor to allow for an FIO2 of 0.21 to 1.0. The air compressor output is minimally affected up to 15,000 ft and should perform well in the AE role. The Aeromedical Research Group has accomplished additional testing of these and other ventilators at Armstrong Laboratories (Brooks AFB, Tex).

### Infusion Devices

Infusion pumps are the most common piece of equipment available in today’s air medical
There are a large number of portable infusion devices available for use during patient transport. While patients can receive IV fluids through a passive, flow-controlled system, any change in pressure in the IV fluid bag as a result of gas expansion can affect the delivery rate. Although this should not be a significant problem at usual cabin altitudes, cabin decompression can significantly alter the flow rate. In addition, rapid decompression can lead to rupture of pressurized bags used to drive higher flow rates when infusion pumps are not available. Thus, infusion devices are the preferred method of delivering both maintenance fluids and emergency medications.

Key considerations for selection of a transport infusion device include robustness, operation in multiple orientations, adequate anchorage, extended battery life, pressure-activated occlusion alarms, and a lightweight, compact size. Devices such as the IVAC MedSystem III (IVAC Medical Systems, San Diego) are well suited for this environment with the capacity for three independent delivery channels and 6-hour runtime using all channels at a rate of 125 mL/hour (Fig 9.11). Armstrong Laboratories have approved this system for use in military AE missions.

**Point-of-Care Testing Devices**

More recent additions to the equipment available for in-flight use are the point-of-care testing (POCT) systems. POCT allows medical providers to assess a wide range of clinical conditions in a rapid fashion at the site of patient interaction. While POCT has begun to impact on the delivery of care in the hospital setting, its potential for use in remote, field environments or during AE is just being realized. There are, however, challenges to providing this capability in the field. The environmental considerations are among the greatest threats for the use of POCT in remote or hostile environments. Not far behind is the issue of ensuring the repeated accuracy of the equipment.

Both the IRMA (Diametrics Medical, Inc., St. Paul, MN) and i-STAT (i-STAT Corp., Princeton, NJ) systems have operating temperature ranges that can easily be exceeded in field and flying conditions. The IRMA will operate from 15 to 30°C while the i-STAT has recently
been upgraded to 16 to 30°C. In our experience, this is one of the more common operating errors encountered when using the IRMA or i-STAT outside of the hospital setting. Both devices are capable of working in a low-humidity environment down to 0%; however, their upper limit is around 65% according to the manufacturer’s recommendations. Barometric pressure should not be a problem under most operating conditions. The IRMA is reported to function from 350 to 900 mm Hg (59 to 86 kP). An on-board barometer calibrates the system for the current barometric pressure prior to each use. The i-STAT (Fig 9.12) has recently completed testing at the Armstrong Laboratories, where there were no reported problems when using both electronic and liquid controls in a hypobaric environment. This testing resulted in an “approved” rating for its use aboard selected USAF aircraft used for AE.

In two studies that have taken this type of analytic capability out of the hospital and into the field setting, environmental temperature was a consistent problem. Both studies examined the utility of the i-STAT in this role, one in an ambulance service and the other in a helicopter rescue unit. The i-STAT performed well, with excellent consistency between samples obtained “on the move” and those run in the emergency department. However, both studies reported problems when the ambient temperature was cold and had to design special, insulated bags to protect the analyzers.

Drugs

The same space limitations that dictate the need for compact, efficient hardware also limit the amount of medications available during a transport mission. Thus, it is important to carry a range of medications that provide adequate coverage for emergent efforts to stabilize circulation, improve respiratory function, abolish seizures, reduce pain or stress, and treat toxicities. In a survey of 230 German physicians involved in emergency medical services, 10 essential emergency drugs and 13 important drugs (according to >70% of respondents) were identified for inclusion in a transport kit (Table 9.4). For longer flights that include a larger
number and variety of patients, the USAF also has a recommended list of medications for in-flight use (Table 9.5).

Note that neither list provides for the routine availability of neuromuscular blocking (NMB) agents despite the fact that they are the most commonly administered medication during preparation for interhospital transfer. Because they induce apnea, these agents present risks for serious complications and their use by inadequately trained personnel can be disastrous. The use of NMB agents during patient transport will typically be driven by one of two considerations. First, they are often used to facilitate airway management and endotracheal intubation. In the out-of-hospital setting, their use is controversial although a number of studies have documented protocols that are effective when combined with adequate training, even by nonphysician air medical personnel. Alternatively, a patient with a secured airway may require muscle relaxation as part of their in-flight management plan or continuation of preflight treatment. This includes the use of NMB agents as “chemical restraints” when a combative patient poses a threat to the crew. While the use of NMB agents in combination with a sedative/aminestic agent can produce the desired control, this does not obviate the need to evaluate for other, reversible causes of agitation such as hypoxia, hypoperfusion, and central nervous system derangements.

When transporting patients on extended flights, do not forget the need to plan for unexpected occurrences. An adequate amount of required medications, a two-day supply for in-country moves and five-day supply for international moves, should be available in the event of diversion to an unanticipated location due to aircraft malfunction or hostile weather conditions.

### Personal Equipment

Beyond those items necessary to provide direct patient care, air medical crews have a requirement to maintain personal protective gear for use in the flying environment. Depending on the mode of transport, fixed- vs. rotary-wing, these items can include helmets with face visors, long-sleeved Nomex uniforms, flame-retardant gloves, natural leather high-top boots,

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**Table 9.4.** Emergency drugs recommended by survey.

<table>
<thead>
<tr>
<th>Essential</th>
<th>Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>Nifedipine</td>
</tr>
<tr>
<td>Crystalloid infusion</td>
<td>Atropine</td>
</tr>
<tr>
<td>Epinephrine</td>
<td>Dexamethasone</td>
</tr>
<tr>
<td>Nitroglycerin</td>
<td>Diazepam (rectal)</td>
</tr>
<tr>
<td>Morphine</td>
<td>Dobutamine</td>
</tr>
<tr>
<td>Ketamine</td>
<td>Dopamine</td>
</tr>
<tr>
<td>Midazolam</td>
<td>Theophylline</td>
</tr>
<tr>
<td>Lidocaine</td>
<td>Dextrose 40%</td>
</tr>
<tr>
<td>Furosemide</td>
<td>Verapamil</td>
</tr>
<tr>
<td>Dextrose</td>
<td>Sodium bicarbonate</td>
</tr>
<tr>
<td>Atropine</td>
<td>Naloxone</td>
</tr>
</tbody>
</table>

**Table 9.5.** Routine medications available on USAF AE flights.

<table>
<thead>
<tr>
<th>Controlled drugs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demerol inj tubex 50 mg, 100 mg</td>
</tr>
<tr>
<td>Morphine sulphate inj tubex 10 mg</td>
</tr>
<tr>
<td>Percocet tabs 5 mg</td>
</tr>
<tr>
<td>Tylenol #3 tabs</td>
</tr>
<tr>
<td>Valium inj 10 mg</td>
</tr>
<tr>
<td>Valium tabs 5 mg</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Routine drugs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudoephedrine nasal spray</td>
</tr>
<tr>
<td>Atropine 0.1 mg/cc</td>
</tr>
<tr>
<td>Diphenhydramine caps 25 mg</td>
</tr>
<tr>
<td>Diphenhydramine inj 50 mg/cc</td>
</tr>
<tr>
<td>Chlorpromazine inj 25 mg/cc</td>
</tr>
<tr>
<td>Dextrose 50% inj</td>
</tr>
<tr>
<td>Digoxin 0.25 mg/cc</td>
</tr>
<tr>
<td>Digoxin tabs 0.25 mg</td>
</tr>
<tr>
<td>Phenytoin caps 100 mg</td>
</tr>
<tr>
<td>Phenytoin inj 50 mg/cc</td>
</tr>
<tr>
<td>Dopamine 40 mg/cc</td>
</tr>
<tr>
<td>Dramamine tabs 50 mg</td>
</tr>
<tr>
<td>Epinephrine inj 1:1000 &amp; 1:10,000</td>
</tr>
<tr>
<td>Haldol inj 5 mg/cc</td>
</tr>
<tr>
<td>Heparin lock flush 100 U/cc</td>
</tr>
<tr>
<td>Inderal inj 1 mg/cc</td>
</tr>
<tr>
<td>Isuprel 0.2 mg/cc</td>
</tr>
<tr>
<td>Furosemide 10 mg/cc</td>
</tr>
<tr>
<td>Liquid tears</td>
</tr>
<tr>
<td>Antacid</td>
</tr>
<tr>
<td>Naloxone (adult) 0.4 mg/cc</td>
</tr>
<tr>
<td>Nitroglycerin 2% paste</td>
</tr>
<tr>
<td>nitroglycerin IV 50 mg/vial</td>
</tr>
<tr>
<td>Potassium chloride (kcl) 2 meq/cc</td>
</tr>
</tbody>
</table>
and some form of hearing protection. Helmets may “reduce the risk of a fatal head injury eight fold” and, clearly, are indicated in personnel involved in rotary-wing transports. Nomex is designed to withstand high temperatures for a brief period, allowing crew members a chance to evacuate the aircraft in the event of fire. The use of flame-retardant gloves will provide similar protection.

**Conclusions**

The stresses of flight create new and unique considerations for the inexperienced medical provider during their initial involvement in the air transport of sick and injured patients. Not only must constant attention be paid to the impact of these stresses on a patient’s condition but on proper equipment performance and the ability of the caregivers to deliver the best medical support possible. Anticipation and prevention of potentially serious complications by vigilant patient monitoring and initiation of therapy is the responsibility of the entire medical crew during air transport. Appropriate ground training and familiarization with approved equipment will provide the crew members with the best opportunities for success.

**References**

51. Patel SB, Callahan TF, Callahan MG, Jones JT, Graber GP, Foster KS, et al. An adaptive noise reduction stethoscope for auscultation in...
In-flight nursing care during long-distance aeromedical evacuation (AE) requires clinical expertise, personal fitness, knowledge of airframe capabilities, an understanding of the physiological effects of flight, quick critical thinking skills, and a “large roll of duct tape.” In–3 The movement of a patient by air should not be considered a mere event but rather the continuation of the care plan and process that began with the initial patient contact. The collaborative abilities and efforts of the ground-based medical teams, aeromedical crew, and flight crew determines the successful movement of a patient by air.

Preflight Preparation

When the plan of care requires airlift, careful preparation must occur to minimize the effects on the human body of the harsh, relatively isolated, and hypobaric environment common during AE. Meeting in-flight care goals requires synergy between the on-the-ground medical team, flight crew, and aeromedical crew. In-flight care is very reliant on an accurate patient history, a primary physical assessment, and continued reassessment throughout the flight.

Patient History

A good patient history is vital and, in some cases, may provide more information about the patient’s present condition than does the primary physical assessment. It is critical to have an accurate primary diagnosis, know both the medications that the patient is allergic to and is currently taking, and be aware of significant past medical history that may complicate the patient’s current condition or transport. The use of the mnemonic “AMPLE” is a helpful way to make sure a complete general history is collected (Table 10.1). This information is useful in alerting the aeromedical crew to potential problems that may develop during transport.

Physical Assessment

After the history is obtained, a primary physical assessment of the patient helps confirm the patient’s condition, alerts the aeromedical crew to potential problems that might present during flight, and directs clinical interventions. A thorough secondary survey will provide more clinical information but may not always be possible prior to flight and is difficult during flight due to the noise and cramped environment.

After the initial treatment plan is established, the aeromedical and flight crew must then make plans to minimize the effects of flight that could be antagonistic to the traditional ground-based care plan. Patient preparation includes not only continuation of all medical treatment but also anticipation of what may occur based on the patient’s history, physical assessment, and the initial interventions performed. In some cases, the pretransport assessment and care may have to be accomplished in an austere environment with limited available resources, such as a mobile aeromedical staging facility (see chapter 7). With diagnostic and medical
capabilities limited both there and during flight, anticipatory planning is vital for the safe transport of patients. Patient responses to treatment and the stresses of flight can be difficult to predict, and thus all preflight planning should incorporate strategies to minimize and counter the affects of the airborne environment.

A useful management tool for this purpose is the “HERO” pneumonic (Table 10.2),² which is based on the concept that the combination of the patient’s disease or injury and the flight environment can stress and fatigue the patient’s systems just as much as a workout at the gym. An effective plan to hydrate the patient is crucial because of the extremely low cabin humidity and the duration of many missions.

### Countering the Stresses of Flight

The common stresses associated with flight may be especially deleterious due to certain conditions (Table 10.3).⁵,⁶ Although all have well-recognized countermeasures, these often have significant bearing on the overall airlift.

The stresses of flight can increase the risk of both hypoxia and hypercapnea, which frequently complicate in-flight management of a patient who was only marginally stable on the ground. A mild reduction in oxygen saturation, which can occur during airlift in any pressurized aircraft, may prove unexpectedly damaging to a marginal patient’s fragile condition. The risk for hypercapnea and hypoxia may be increased in any patient who has a decreased ability to transport vital nutrients, increased cardiorespiratory workload, or decreased level of consciousness. The airborne environment can pose a significant threat to these patients, even if they are asymptomatic at ground level.

Supplemental oxygen, or in extreme conditions a restricted cabin altitude during flight, may be required for patients who are at high risk of decompensating as a result of altitude-induced hypoxia. Because both hyperventilation and hypoxia present with similar signs and symptoms, anxious patients treated with oxygen may have to be coached to slow their rate of breathing.¹,⁷ An especially dangerous condition during flight is severe chronic pulmonary disease, where mild hypoxemia may be the primary central drive for respiration.⁸ In these cases, the crew must carefully adjust supplemental oxygen as the cabin altitude changes to avoid oxygen-induced apnea.

### Table 10.1. The mnemonic “AMPLE” is helpful when collecting essential patient history information before coordinating a patient care plan.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Allergies: What medications is the patient allergic to?</td>
</tr>
<tr>
<td>M</td>
<td>Medications: What medications is the patient currently taking?</td>
</tr>
<tr>
<td>P</td>
<td>Past history: Are there previous medical conditions that will compound this event or transport?</td>
</tr>
<tr>
<td>L</td>
<td>Last meal</td>
</tr>
<tr>
<td>E</td>
<td>Events/Environment related to injury</td>
</tr>
</tbody>
</table>

### Table 10.2. Preflight planning incorporates strategies that minimize affects of the airborne environment using the “HERO” pneumonic.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Hydration is critical; intravenous therapy should be considered for patients who will not or cannot take additional fluids by mouth</td>
</tr>
<tr>
<td>E</td>
<td>Exercise conservation; a patient may respond to flight as they would a stress test; limit stressful treatments when possible</td>
</tr>
<tr>
<td>R</td>
<td>Rest; if possible, medicate prior to flight and adjust dosages to counter the continuous vibration and poor circulation some patients experience during flight</td>
</tr>
<tr>
<td>O</td>
<td>Oxygen; additional oxygen may need to be provided during flight to maintain desired saturation levels; oxygen should be humidified.</td>
</tr>
<tr>
<td>O</td>
<td>Oral intake; diet plans should steer clear of caffeinated drinks and gas-forming foods; small frequent meals should be planned for patients prior to flight.</td>
</tr>
</tbody>
</table>
Altitude restrictions should be considered for patients with conditions where expanding air in a closed space can significantly limit perfusion or increase pressure. Penetrating head, face, chest, or ocular injuries with gas trapped in a closed rigid space will require an altitude restriction due to the risk of expansion and resulting pressure on surrounding vessels and tissues. Patients suffering from decompression sickness (eg, the bends) will also require an altitude restriction with supplemental pressurized oxygenation during flight to avoid expansion of trapped nitrogen bubbles in the joints and other areas of the body.

During ascent and descent, some patients may have problems equalizing as the cabin pressure changes. The potential risk for barotitis media (eg, ear block) may be determined by having patients attempt to clear their ears prior to flight. This may be difficult for patients with upper-respiratory infections or whose jaws are wired shut. In addition, the Valsalva maneuver should be avoided in patients with ocular injuries or aneurysms because it can cause momentary increases in cranial, ocular or intrathoracic pressure. Finally, it should be remembered that agitation during descent might be a symptom of ear block in patients.
who are noncommunicative because of age or altered mental status. When transporting patients known to have significant problems with ear block, a slower than normal descent or, in extreme cases, altitude restriction may be required.

Medication dosages, routes, times, and diet supplements may need to be altered to help counter the effects of the airborne environment. The dry environment during flight can result in thickened secretions and can cause ocular injury when the patient is unable to tear. All patients should receive additional oral hydration and, when required, humidified oxygen. Patients should be kept comfortably warm because a cool environment can slow vascular perfusion and alter medication absorption. The combination of these and other stresses of flight can increase the risk of motion sickness, especially during a turbulent flight.

The psychological response of patients to flight is often more difficult to predict than their physical responses. For patients known to be at risk for psychological problems, placement on the aircraft should take into account cabin lighting, sounds, security, and capability (see chapter 8). Various types of auditory and visual stimulations may trigger seizures or hallucinations, especially on propeller aircraft. Patients who become easily confused, such as elderly patients with “sundowner syndrome” or dementia, and patients recovering from drug-related hallucinations may manifest symptoms during flight regardless of the time of day. These patients may benefit from techniques that keep them appropriately oriented to time and space.

Careful preflight screening will identify patients who are dangerous to themselves or others and thus require constant observation during flight. If one-on-one observation is required for safety, the referring facility will need to provide an attendant. The patient’s plan of care, including the use of seclusion, sedation, and restraints, should be continued throughout the flight until the final destination is reached. The efficacy of patient restraint remains controversial, and thus the decision to restrain a patient in-flight must carefully weigh physical, psychological, ethical, and safety issues. When used, restraints must be continually re-evaluated to ensure they are accomplishing the desired affect on behavior while avoiding physical injury.

Pregnant patients offer unique challenges during airlift, as discussed in chapter 22. The mother is prone to hypoxia and dehydration during flight due to her increased cardiac workload, diaphragmatic impingement, possible occlusion of the ascending vena cava by the fetus, and increased nutritional and fluid needs. Allowing the mother to sit or lie tilted to the left will help decrease the effect of the fetus on the vena cava. Supplemental oxygen may also be added to ensure adequate perfusion. Small snacks with drinks need to be offered at least every 2 hours of flight. Mothers may be reassured that it is normal for the fetus’ activity level to change during flight in response to a change in environment.

Flight Preparation

In addition to medical considerations, several other factors need to be added to the care planning equation as outlined in Figure 10.1. The flight crew and aeromedical crew must have a common understanding of required altitude restrictions, flight route, alternate landing site capabilities, en route weather forecast, expected delays, weight, and balance considerations, and the estimated flight time. By combining conservative ground-based treatments with treatments aimed at minimizing the effects of a dry, dimly lit, vibrating, noisy, hypobaric environment, the patients should arrive at their definitive care location ready to move forward in their medical care and treatments.

Meticulous planning is critical for patient safety and it begins with the initial transport request. Once all the teams have established the patients’ expanded care plan for the flight, the airlift crew will need to assemble an airlift package that is easy to transport, allows for continued patient assessment over a variety of parameters, and will remain secured during all phases of flight. The proper monitoring and life-support equipment, including oxygen, must be obtained. The on-board electrical power must be compatible with the required equipment in terms of voltage, phase, and amperage. Appropriate types and amounts of medical supplies
and medications must be obtained and stored and include those needed for anticipated emergencies. Infection control and dietary needs must also be taken into account during the planning process. In addition to the basic patient needs, all food, supplies, and medications must be adequate to last for several days because delays or diversions due to mechanical or weather problems are common.

The flight environment is associated with many unique hazards that are not encountered in ground facilities. Equipment used at ground facilities may not be suited or could even be dangerous when used at altitude. For this reason, medical equipment must meet rigorous standards and testing to verify that it will continue to operate at altitude and during and following rapid decompression and tolerate

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**Figure 10.1. Basic planning tree for flight preparation.**
constant vibration. It also cannot emit electromagnetic pulses that can interfere with other aircraft systems.\textsuperscript{5,12} Equipment should operate at any angle and be easily decontaminated between patients.

When flying over water, patients and crew need to ensure adequate numbers and types of flotation rescue devices are available, especially those tailored for immobile patients. Medical supplies that are filled with air or that use air-filled balloons (such as cuffed endotracheal tubes or Foley catheters and MAST trousers) must be monitored during flight because of gas expansion at altitude. Balloon devices can be used after the air has been replaced with normal saline. Chest tubes must have either a one-way valve or an equivalent device in place for flight to prevent reflux of air or fluid back into the pleural cavity.\textsuperscript{12} Water-sealed chamber levels will vary during flight due to pressure changes and will require close observation. Intravenous solutions should be contained in plastic containers with nonvented drip sets. Plastic containers are preferred for flight because they are easy to handle, secure, do not break, and can expand or contract with barometric changes.

In-Flight Infection Control Considerations

The diversity of airframes and the nature of infectious disease challenge the airlift team and their infection control procedures. Knowledge of epidemiology, airflow, and equipment is important when trying to decrease the chance of exposure (see chapter 11). Given the nature of patient care, prudent infection control and use of personal protective apparel is a must. Standard precautions are well defined and should be universally applied. Strict reverse or protective isolation cannot be provided during routine AE flights. For this reason, patients with compromised immune status may need to be positioned in specific areas on the aircraft where airflow minimizes risk (Fig 10.2).

\textbf{Figure 10.2.} Examples of equipment use and security. A litter is placed over a burn patient to deflect direct airflow, provide a shield, and permit patient observation and in-flight treatment (USAF photo by Dewey A. Mitchell).
Individualized patient instruction on in-flight hygiene and personal item disposal is especially important for patients known to have infectious secretions. Although hand-washing remains the cornerstone of infection control, running water is not available on many AE aircraft. In these cases, antimicrobial hand wipes should be used. All contaminated linen and supplies need to be disposed safely, and this may require preflight coordination to ensure contaminated items are transferred and disposed of appropriately. An effective approach is to off-load all contaminated items along with the patient at their destination facility. The AE transport of patients with infectious airborne diseases, such as active pulmonary tuberculosis, can be hazardous. Special arrangements must be arranged prior to the flight to protect both the crews and other passengers.

Chemical and Biologic Contamination

Emergencies involving hazardous materials occur frequently worldwide and the threats of biologic contamination, warfare, and terrorism are growing daily. Despite these known risks, the lack of adequate decontamination facilities and protocols increases the risk that contaminated patients may arrive at the flight line for AE. Failure to adequately prepare for this situation can result in toxic exposure of both the ancillary health-care providers and the flight crew, not to mention potential contamination of the flight line and the aircraft.

Providing care to patients contaminated with a hazardous material requires advanced planning and specialized training and equipment. Prior to accepting a contaminated patient, the flight crew must verify that the patient, linen, clothing, and equipment have been decontaminated. A transport vehicle should never bring a patient directly from the “hot” zone to the flight line.

Even after decontamination, patients exposed to hazardous material with a high vapor pressure may continue to release toxic substances during transport. Decontaminated patients should be placed in the aircraft such that airflow patterns offer the most protection to others aboard the flight. Aeromedical crew members who have direct contact with the patient should wear protective apparel and handle all potentially contaminated articles appropriately.

Medicolegal Considerations

Despite the unique setting of AE, in-flight medical care is governed by the same legal regulations that govern medical care on the ground. Care and practice decisions during AE are governed by several standards, including (1) patient rights and responsibilities as outlined by the Joint Commission for the Accreditation of Healthcare Organization, (2) scope of practice laid out by medical and nursing practice acts, (3) care guidelines established by the Federal Aviation Administration and Federal Communications Commission, and (4) the Consolidated Omnibus Reconciliation Act. In addition, Flight Nurse Performance Standards have been published by the National Flight Nurses Association (Table 10.4). The United States Department of Transportation (USDOT) in conjunction with the National Highway Traffic Safety Administration (NHTSA) are publishing education guidelines, and the Commission of the Accreditation of Medical Transport Systems recently published new standards.

Legal jurisdiction is complicated when aircraft cross state and international boundaries. When the AE flight involves planned or unplanned landings in foreign countries, the medical teams and aircrew must be familiar with immigration, customs, and agricultural regulations and guidelines. AE systems that routinely make international flights must establish consistent policies and practices for such common nursing care practices as managing controlled drugs. Failure of the medical and flight crews to understand and follow the rules can result in AE delays and cause undue hardship for the patients and their families.

AE crews will have to consult with their legal liaison when specific patient transit issues or dilemmas arise. Common issues include obtaining permission for the nonemergency transport of unaccompanied minors or incompetent patients or informing a patient that, due to his or her body size or medical condition, the crew cannot assure safe egress during an aircraft
emergency. Both the attending physician and legal liaison should be notified when a patient requests release from the airlift before completing the transfer.

A “do not resuscitate” (DNR) directive for a patient with a terminal condition represents an important circumstance. When the attending physician writes a DNR order, the aircrew will provide all other general care as indicated. However, the family or patient may revoke the DNR order at any time during the flight.

Another important consideration is prisoner patients. When the patient being transported requires a guard, the referring agency is responsible for providing the guard. If the guard is armed, the aircraft commander must be informed so the guard’s weapons and ammunition can be under his or her control and stored during flight. At no time should any patient be physically attached to any part of the aircraft by handcuffs or restraint.

Two other special problems are in-flight births and deaths. Most commonly, the flight will need to make an emergency landing so that the situation can be medically and legally managed. If childbirth occurs in flight, the geographic location of the aircraft in latitude and longitude at the time of birth should be recorded to determine the appropriate registration and citizenship requirement. After completing the mother’s and infant’s care, the newborn will need to be added to the passenger list on the manifest. If an apparent death occurs in-flight, the patient should not be officially pronounced dead until the aircraft has landed because an accurate patient assessment is difficult during flight and the crew will need to ensure legal considerations are completed at the location where death is pronounced. If a birth or death occurs over a foreign country, it is important to know the policies of the country before landing to avoid flight delays or other problems.

Laboratory Considerations

At times, laboratory specimens, pharmaceuticals, limbs, or organs for transplant may need to be added to the airlift equation. Appropriate care of the specimens and documentation often requires considerable preflight coordination. The referring agency must arrange for any special equipment needed, such as refrigeration units, oxygen systems, or storage solutions, because these are not routinely available. If transportation will be labor-intensive, the crew should be augmented with additional trained personnel. All limbs and organs should be listed on the manifest prior to flight. The appearance and condition of forensic evidence should be documented prior to exposure to the airborne environment. To help maintain chain of custody, a trusted agent of the investigating organization should carry legal evidence in most cases. If organs for transplantation are being transported internationally, thorough preplanning is required to prevent administrative delays that could result in the organ being held by local authorities until viability is lost.

Safety and Security

Aircraft safety and security is a shared responsibility of the ground-based medical teams, aeromedical crew, and flight crew. All members’ actions affect not only their own safety but also the safety of the patients, other team members, and the entire aircraft. A lapse in safety can significantly undermine the ability of the crew to perform the diverse responsibilities required for patient care.

Patients need to be adequately prepared for flight. Standard antihijacking procedures should be used to verify that weapons are not carried onto the aircraft. All personal items and any medical supplies the passengers bring onto the aircraft need to be inspected and secured to prevent tampering or theft. Hearing protection needs to be provided to all patients prior to arriving at the aircraft.

Patient boarding for AE takes special preparation. Prior to boarding, all crew members need to review the plans for patient enplaning, positioning, deplaning, and emergency egress. Staging personnel familiar with flight line policies and safety considerations must be available to ensure safe patient enplaning and deplaning. Litter patients need special preparation for enplaning by the creation of an “airlift package” designed for patient observation, safety, and environmental stress protection (Fig 10.3). Special precautions should be taken with
excessive equipment and patient weight or when on- or off-loading is performed with the engine running or during inclement weather.

During taxi, take-offs, and landings, patients and crew need to be seated or supine with safety restraints in place and all equipment needs to be secured. If an aeromedical crew member needs to remain standing to provide medical care during these critical phases of flight, such as approach to landing, the aircraft commander needs to be informed.

Refueling is considered a hazardous time for military aircraft because of the remote, but real, risk of fire. Almost always, refueling will occur prior to patient boarding. If patients must remain on-board during refueling, all nonessential electrical equipment must be turned off. The fire protection personnel will need to know how many people are on-board, and a fire truck should be positioned in full view of the aircraft.

In-flight refueling, required for time-critical long-distance transport, is hazardous both because of the turbulence routinely encountered and the risk of midair collision. Prior to in-flight refueling, patient care activities must be completed, all nonessential equipment turned off, and patients, crew, and supplies secured. Nonessential communications between the medical crew and pilot during the critical phases of flight are prohibited, and only essential personnel are allowed on the flight deck.24 Throughout the flight, the aircraft commander and AE crew director should coordinate on all patient or medical team visits to the flight deck.

Patient Care During and Following In-Flight Emergencies

In addition to medical emergencies, the aeromedical crew must be prepared for aircraft-related emergencies as well. Immediate actions will be required to stabilize and possibly evacuate patients in the event of an aircraft fire crash landing, or ditching.25,26 Evacuation plans for each of these situations are a routine part

Figure 10.3. Meticulous care, planning, and accomplishment of safe patient on- and off-loading is crucial to the success of the airlift. During high-visibility missions, aircraft safety and patient privacy require crew attention to detail (USAF photo by Dewey A. Mitchell).
of every preflight crew briefing. During any in-flight emergency, the aircraft may experience extreme changes in attitude (ie, pitch, roll, or yaw). The first priority is to ensure cabin security regardless of the phase of flight. Once the aircraft commander decides it is safe to move around the cabin, each patient should receive a primary assessment, followed by a quick equipment check. If smoke is present in the cabin, the patients should be moved to the lowest possible position and their faces covered with moistened towels because medical oxygen masks do not protect from smoke. In the event of a sudden decompression, intravascular lines should be temporarily closed to prevent a fluid bolus and devices such as chest tubes or oral gastric tubes should be checked as soon as possible. If patients need to be evacuated, the crew should first direct ambulatory patients out of the aircraft to a safe area and then assist litter patients.

Another unique aircraft hazard is hijacking. If the plane is still on the ground when a hijacking attempt occurs, every attempt should be made to delay the movement of the aircraft. This will allow time for all appropriate agencies to coordinate a plan to prevent the hijacking and minimize danger to all on-board. Deadly force should be used to prevent or end a hijacking only as a last resort.26

Postflight Considerations

The movement of a patient by AE is not an isolated event but part of a continuum that begins when the decision for air transportation is made and ends when the patient reaches the accepting medical facility. Both patient planning and communication are crucial throughout this process, with goals of optimizing patient care, ensuring privacy, and promoting safety. Patient care planning must focus on meeting the physiological needs of the patient. However, it should also take into consideration the need of the patient’s family and the legal issues related to patient movement.

Coordination between the aeromedical crew and ground medical team begins during the initial phases of planning and is reiterated by radio within the last 2 hours before landing. The ground medical crew need to known the exact landing times and required ground-based transport needs. The flight line personnel will need final instructions prior to landing regarding patient deplaning plans, fleet services, and any decontamination cleaning needs.

Once on the ground, the first priority in a foreign country is to meet all agricultural, customs, and immigration requirements as quickly as possible. Staging personnel then off-load patients, along with their records, supplies, and life support equipment, and the aeromedical crew gives a patient report to the accepting medical authority. Aircraft discrepancies are reported directly to the flight crew and any mission discrepancies documented and reported as required.27 The aircraft, equipment, and supplies are then cleaned and restocked for the next mission.

Conclusion

There are few absolute contraindications to AE if both the patient and flight environment are appropriately prepared. The flight nurse’s special skills and knowledge are crucial for the safe, expeditious transport in a relatively isolated, hostile environment. Through cooperative planning and communication, ground-based medical teams and AE crews can ensure a seamless continuation of the patient care plan that meets established standards.

References


The operational decision to evacuate patients with communicable diseases or those who are biologic warfare casualties is complicated by many factors, including the etiologic agent involved. Unlike nuclear or chemical casualties, patients with contagious infections may transmit disease after external decontamination. Further, theater medical facilities might be overwhelmed by a mass-casualty disaster after an epidemic or biologic warfare attack, necessitating rapid evacuation (Fig 11.1).

Little has been published regarding the aeromedical evacuation (AE) of patients with communicable diseases or biologic warfare casualties. A recent search of the MEDLINE electronic database (1966 through January 2000) that queried the intersection of keywords “biological warfare” and “aeromedical evacuation” or “transportation of patients” yielded but a single citation.1

A comprehensive review of the AE of such patients would have to contain elements from several diverse disciplines. These would include disaster medicine, air transport medicine, critical-care medicine, the ergonomics and aerobiology of aircraft interiors, infection control, international aviation law and diplomacy, and the operational requirements and constraints of the USAF and other military and civil services. We have limited the discussion in this chapter to the ecology of aircraft interiors, disease transmission on-board aircraft, and highlights of the elements of military AE plans and capabilities and the emerging US military doctrine as they apply to the feasibility of the AE of patients with contagious infections and biologic warfare casualties. Unresolved issues will be identified with the goal of stimulating discussion and future research.

### Airframe as Microbial Environment

The engineering parameters of aircraft ventilation and pressurization are well known and tested extensively by aircraft manufacturers. While most studies of aircraft cabin air quality have focused on tobacco by-products and other chemical contaminants, few have addressed the ecology of airborne microbes. The few available studies of the aerobiology of aircraft interiors suggest that the modern aircraft interior is a less likely venue for disease transmission than most public places.1

### Ecology of Aircraft Cabin Air

Air vented into most aircraft cabins is sterilized during pressurization. To maintain an internal cabin atmosphere equivalent to about 8000 ft above mean sea level while at altitude, pressurized air is extracted from the main jet engine compressor, where it has been subjected to both high temperature (more than 250°C) and pressure (450 psi). The air is then cooled by a series of heat exchangers and vented into the cabin.2

Microbial survival times are also altered by variations in relative humidity.3 Because air at altitude has low relative humidity (10% to 15%), the resultant compressed cabin air does
also. Low humidity inhibits bacterial growth and stability but increases the survival and infectivity of certain airborne viruses. The influenza virus was found to survive longer in dry air (relative humidity <50%), while poliovirus survived longer in humid air (relative humidity >50%).

Ventilation: Air Distribution Systems and Airflow

The three most important factors that determine the incidence of infections spread by airborne particles in an enclosed space are the susceptibility of those exposed, the duration of exposure, and the concentration of infectious droplets or droplet nuclei. The concentrations of droplets and droplet nuclei increase when the generation rate is high, when the static volume of enclosed air is small, and when fresh air ventilation is low. Ventilation of any enclosed space decreases the concentration of airborne organisms logarithmically, removing approximately two thirds of the airborne droplets per air exchange.

The mechanism by which air is circulated though most large aircraft cabins depends on several factors. When on the ground, fans recirculate cooled or conditioned air throughout the cabin. When the engines are off, ventilation is provided in one of two ways: Either an auxiliary power unit runs the cabin ventilation system or preconditioned air is supplied by connecting a ground air-conditioning unit to an air manifold. In some aircraft, no fresh air is taken in until pressurization is begun at altitude. However, older military transport aircraft (such as the C-130 Hercules) use pressurized air from the engines for ventilation whether on the ground or aloft. At altitude, compressed air enters continually while air is vented overboard via an outflow valve. First-generation jet airliners (eg, Boeing 707s, Boeing 727s, DC-9s) and most military transports use 100% ambient (fresh) air for cabin supply.

The airflow design for most large aircraft is either circumperipheral or longitudinal. For both designs, conditioned air typically enters the cabin at standing head level. With the circumperipheral design, air circulates from
aircraft skin to midcabin, then down and back to the vents near the skin at floor level on the same side. With the longitudinal design, air circulates from the aircraft skin in the midsection to outflow valves either fore or aft. The outflow valves are sometimes along the hull (two on the Boeing 707: one at the forward edge of the wings and the other near the tail) or elsewhere along the fuselage (below the right cockpit floor in the C-130).

The type and direction of airflow during an AE flight has important implications for airborne spread of infection. In general, the circumperipheral mode is preferable to the longitudinal because it minimizes aircrew exposure to contaminated air. With the longitudinal design, the direction of airflow should be adjusted so that it is aftward by closing the forward outflow valves. In the C-9A Nightingale, cabin airflow is “top to bottom, front to back” and therefore contagious patients are placed as far aft and as low as possible.

The airflow for the C-141 takes on special importance because it is the main strategic AE airframe for the US military. This aircraft also has a longitudinal airflow design, where the air enters both on the flight deck and the aft cargo compartment. Air then flows toward two outflow valves located above the aft pressure bulkhead. Therefore, potentially infectious patients should be placed as far aft and as high as possible. The ventilation patterns of the C-17 transport, which may assume some of the strategic AE missions in the future, remain to be characterized.

The risk of airborne infection to the flight crew is related to the flight deck airflow design. In many commercial airliners, such as the B-707, the flight crew is somewhat protected by the independent flight deck ventilation system. As noted above, the C-141 flight crew is protected by the longitudinal system, where the air enters on the flight deck and flows aftward through the cabin. This is in contrast to the C-130, where the flight deck personnel may be at increased risk because all cabin air is drawn to the cockpit, where it is vented out.

Commercial airline cabin airflow has two important design features that may reduce respiratory droplet or airborne transmission. First, most cabins feature a flow design that is both circumperipheral and laminar, with air entering overhead, flowing down the sides, and exiting through vents above the floor. Second, they have relatively high air exchange rates, typically ranging from 15 to 20 exchanges per hour. This exceeds both the 12 air exchanges per hour that maintain air quality in modern office buildings and the 6 exchanges per hour recommended by the Centers for Disease Control and Prevention (CDC) for the hospital isolation rooms of patients with active tuberculosis. Unfortunately, the purging of air within the cabin may not always be uniform because of the laminar flow design. There may be decreased air circulation in fore and aft areas, resulting in stagnant zones while animal studies demonstrate that increased ventilation decreases airborne transmission in confined spaces. It is important to remember that ventilation alone is not sufficient to prevent all transmission of airborne pathogens.

High-Efficiency Particulate Air Filtration

Jet engine efficiency is decreased by the extraction of compressor air for delivery to the cabin because this air is not available for additional thrust. To economize, commercial airliners use systems that partially recycle cabin air, rather than continuing to supply 100% fresh air from the engines. The fraction of recirculated air ranges from 24% to 66%. The use of recirculated air may reduce air quality due to the recirculation of aerosolized contaminants. To counter this, most airlines have installed high-efficiency particulate air (HEPA) filters in their recirculation systems. These are 99.7% effective for removing particles of 0.3 μm diameter or larger.

Although HEPA filters were originally installed for passenger comfort (eg, for removing tobacco smoke), they also appear to reduce the risk of transmission of airborne pathogens. The droplet nuclei carrying measles, varicella, and tuberculosis are typically 5 μm or less in diameter. A study commissioned by the US Department of Transportation to evaluate the levels of bacteria, fungi, carbon dioxide, ozone, and tobacco products in recirculated airliner cabin air found that of microorganism
concentrations did not reach levels considered hazardous to health.\textsuperscript{18}

**Microbial Aerosols in Aircraft**

Because of concerns generated by lethal and untreatable viral hemorrhagic fevers, and a possible need to transport victims of these diseases by air, the ventilation and air-conditioning systems on pressurized, long-range transport aircraft were studied to evaluate the aerodynamics of aerosolized microorganisms.\textsuperscript{19} The two aircraft evaluated were the Lockheed Martin C-130E Hercules (the aircraft used for most tactical AE) and the Boeing 707-347C. At the time, the aviation engineering knowledge of ventilation and air pressure changes on these aircraft was extensive. The movement of smoke particles was observed and the dispersion of aerosolized spores of a nonpathogenic organism (\textit{Bacillus subtilis} var. globigii) was assayed at multiple cabin sites under various pressure and ventilation conditions. Results of both smoke and spore studies suggested that the optimal location for placing a highly infectious patient in the 707 would be the left rear of the cabin. When the aircraft was pressurized and the forward outflow valve was closed, contamination was largely restricted to the rear area, placing the flight crew at minimal risk if they stayed forward.

In view of its airflow design, it was no surprise that there was substantial drift of smoke from the cargo hold of the C-130 into the flight deck.\textsuperscript{19} Approximately 3\% of the spores released in the aft cabin reached the flight deck, probably enough to transmit infection over a prolonged flight if the organism had been infectious. The relative locations of the bleed valves and outflow valve would make plastic diaphragms impractical. One conclusion of the study was that high-containment isolators would be required to evacuate patients with potentially lethal contagious diseases in a C-130. These isolators would protect the flight crew and medical workers and allow refueling stops without alarming foreign governments, which might otherwise refuse international landing clearances (Fig 11.2).

\textbf{Figure 11.2.} Vickers aircraft transport isolator, designed for prolonged patient transportation and in-flight care (from Christopher and Eitzen\textsuperscript{51}).
A second conclusion of the study was that such patients should only be transported in long-range jet aircraft with the air distribution characteristics similar to those of a Boeing 707. However, significant air contamination occurs within the cabin while these aircraft taxi for take-off with the recirculation fans functioning. To avoid this, the starboard engines should be operated with the forward outflow valve closed, thus ensuring rapid air exchanges within the cabin. Potentially infectious patients should be boarded through the rear passenger hatch and then placed in the left rear of the cabin facing aft. To protect the flight crew, patients and medical workers should venture no further forward than midcabin and flight crew no further aft than that same point.

These concepts were applied, without empirical validation, in 1974, when the aft area in a 707 was used to transport a patient with Lassa fever. A 707 was selected because it was capable of a nonstop flight to Germany, obviating potential difficulties obtaining permission to refuel in a third country. This dedicated AE utilized extensive and unprecedented precautions to transport the patient (a German physician) from Lagos, Nigeria, to Hamburg. The patient was isolated in the rear of the cabin and a “neutral zone” was created using two polyvinyl chloride partitions. The outflow valves were configured to create a longitudinal pressure gradient in the cabin so that airflow was from the forward to the aft section. Finally, to avoid microbial dissemination via recirculated air the starboard engines were started to allow pressurization prior to boarding the patient through the aft door. After, the aircraft interior was fumigated with vaporized formalin for 6 hours, and there were no secondary cases.

The air was sampled for microorganisms on 36 domestic and international flights, including small and large jet airliners and turboprop commuter aircraft, between 1987 and 1994. It was assumed that all microbial contamination originated from passengers and crew because the air taken in from the engines was presumably sterile. It was also assumed that lower levels of microbial air contamination would correlate with a lower risk of disease transmission, although this has not been validated clinically. Control samples were taken at urban locations such as buses, malls, streets, and airports. Microorganisms were quantified by counting colony-forming units (CFUs) after 72 hours incubation, but no attempt was made to identify the organisms.

This study found no significant differences between air at seat level and higher sites, nor between coach, business, first-class, or galley sections. The highest counts came from samples taken near outflow vents, about 1 ft above floor level. Interestingly, the microbial air contamination found during flight was significantly lower than that found in cities, buses, and public buildings. Decreased passenger movement (ie, during sleep) correlated with lower numbers of CFU. The authors concluded that “the small number of microorganisms found in US airliner cabin environments does not contribute to the risk of disease transmission among passengers.”

Survey of Infectious Disease Transmission in Aircraft

The risk of transmitting infections in aircraft has probably been exaggerated. Most reports of disease transmission on-board aircraft describe foodborne outbreaks on commercial airliners, a discrete area of relevance to AE. The following is a brief summary of the transmission of several common pathogens.

Tuberculosis

Tuberculosis is an obvious concern aboard AE aircraft because it is a common and serious disease usually spread via airborne transmission, especially in confined spaces. Three conclusions about the risk of tuberculosis spread can be drawn from the limited number of published retrospective cohort studies of tuberculosis exposures aboard aircraft. First, the risk of tuberculosis transmission aboard an aircraft is apparently no greater than in other confined spaces, with reported conversion rates of 2% to 4%. Second, the duration of exposure appears to be important, with several studies reporting no tuberculosis transmission after exposure to an infectious patient after flights...
less than 9 hours in duration.\textsuperscript{27,28} Finally, the risk of conversion appears much greater for those seated within two rows of an infectious passenger on airlines with a laminar air flow system.\textsuperscript{29} Based on this information, the CDC recommended that “those known to be infectious travel by private transportation rather than by commercial aircraft.”\textsuperscript{25}

The CDC has also suggested three criteria to determine which passengers and flight crew members should be notified of the possibility of tuberculosis exposure.\textsuperscript{25} First, the person with tuberculosis was infectious at the time of the flight. Infectiousness can be assumed if the person was symptomatic with AFB smear-positive, cavitary pulmonary, or laryngeal tuberculosis or has transmitted the disease to household or other close contacts. Second, the exposure was prolonged (ie, duration of flight exceeded 8 hours). Finally, passengers and flight crew who were at greatest risk for exposure based on proximity to the infectious passenger should be given priority for notification. Routine tuberculosis screening for airline crew members has not been recommended as an occupational health measure.

**Influenza**

Air travel has significantly altered the epidemiology of influenza. Since the 1950s, it has become clear that influenza pandemics have followed major air transportation routes. Influenza has also been transmitted during flight. Because of confinement in a closed space associated with flight, these cases most likely constitute common-source, single-exposure outbreaks rather than the usual linear “person-to-person-to-person” epidemics.

Based on published reports, several conclusions can be drawn. First, prolonged ground delays may increase the risk, especially if the air ventilation system is not functioning. In one such report, 72\% of the passengers became ill and there was a strong association of the rate of illness with the duration of exposure to the ill passenger.\textsuperscript{30} Thus, a second conclusion is that the length of exposure is important. But, in contrast to tuberculosis, even patients exposed for less than 1 hour appear to be at significant risk. Third, the attack rate of influenza aboard a well-ventilated airliner appears to be higher than the general community attack rate during epidemics (10\% to 20\%) but less than the rate for boarding schools or nursing homes (>50\%).\textsuperscript{31}

**Measles**

Measles is one of the most contagious infectious diseases, with an attack rate of about 80\% among susceptible, casual contacts. Spread by droplet nuclei, virions can survive in the air for several hours. During the early 1980s, over 500 measles cases per year were either imported to the United States, or acquired from imported cases. Most of the imported cases were associated with air travel, and several secondary cases were acquired during flight.\textsuperscript{32}

An important aspect of measles transmission is that it may occur before the patient becomes symptomatic, a day or two before the end of the incubation period. In one report, eight passengers became infected on a single flight even though no ill or coughing passengers were observed during the flight.\textsuperscript{33}

**Smallpox**

During the Intensified Smallpox Eradication Program (1967 to 1980), concern was extremely high that smallpox would be reintroduced to Europe or the United States from endemic areas by air travel. Consequently, smallpox vaccinations and boosters were recommended for national and international flying personnel.\textsuperscript{34} From 1959 to 1973, 27 of the 29 known cases of smallpox imported to Europe were associated with air travel. None were acquired during flight, as all case patients traveled during the incubation period.\textsuperscript{35} There is one case of potential infection during air travel, but it is unclear whether transmission occurred in the air or in a terminal.\textsuperscript{36}

**Viral Hemorrhagic Fevers**

Viral hemorrhagic fevers (VHFs) are caused by a taxonomically diverse group of RNA viruses and feature a febrile syndrome with severe vascular abnormalities. In general, they are associated with high rates of morbidity and mortality.
With the exception of Lassa fever, little is known about their transmissibility during air transport.

The mortality and communicability of Lassa fever has engendered a cautious approach to these patients in the west from both the medical and aeromedical communities. As reported above, an infected patient transported from Lagos to Germany was the sole patient on a C-141, and the patient together with the aeromedical crew were quarantined from the flight crew. Perhaps the most unusual AE in history occurred when a CDC worker with Lassa fever and his wife were transported from Sierra Leone to the United States on a C-141. For lack of an isolation chamber, they were both sealed for the duration of the flight in an Apollo space capsule that had been flown from a US military warehouse in Germany.

Fortunately, the risk of transmission of Lassa fever, both on the ground and during commercial flight, appears to be low. There have been two reports of inadvertent exposure of large numbers of susceptible individuals to patients with Lassa fever in western hospitals without evidence of secondary transmission. On at least four occasions, passengers with Lassa fever have traveled on commercial overseas flights without a single secondary case occurring. This suggests that the apparently high transmission rate of Lassa fever in West African hospitals may be due to local infection control practices.

Based on these reassuring reports, it has been suggested that Lassa fever patients can be safely transported by AE using simple barrier infection control techniques. However, the World Health Organization (WHO) strongly discourages the transport of Lassa fever patients from endemic to nonendemic areas, stating that this should be undertaken only in exceptional circumstances and should be accomplished using special precautions including high-containment isolators.

### In-Flight Preventive Measures

Early diagnosis of communicable diseases is the key to prevent transmission. Only then can disease-specific, transmission-based precautions be promptly implemented. Attempts are currently underway to develop portable, rapid diagnostic tests, such as enzyme-linked immunosorbent assays and genetic typing, which can be used in the field. In the presence of a biologic warfare threat, patients will be screened for incubating infections (e.g., smallpox) prior to being transported for other indications to minimize the risks of evacuation related epidemics.

When a casualty is determined to be infectious, the most obvious preventive measure would be to defer AE until after the communicable period. However, such casualties might need evacuation sooner for tactical or other reasons. The use of restricted flights for transportation of cohorts with specific communicable diseases would obviate the risk of patient-to-patient transmission but offer little protection to either the aeromedical or flight crews.

When transporting any infectious patient, standard infection control practices are essential. Additional transmission-based precautions necessary for certain infections. CDC guidelines mandate the use of surgical masks for diseases transmitted by droplets (e.g., influenza) and fit-tested HEPA-filtered masks for diseases transmitted by droplet nuclei (e.g., tuberculosis) in hospitals. These guidelines can be adapted for use in aircraft. The USAF is currently developing a comprehensive regulation on infection control on aircraft.

Judicious patient placement should be used to minimize the transmission of disease by respiratory droplet or droplet nuclei based on the ventilation characteristics of the specific aircraft. For example, infectious patients are placed as far aft and as low as possible in the C-9A but as far aft and as high as possible in a C-141. The ventilation pattern of the C-17 transport remains to be characterized. The C-130 is potentially the most problematic from an infectious disease perspective because cabin air is vented out through the cockpit. In high-risk situations, the flow of cabin air can be reversed aftward by opening the safety valve located in the cargo door. Unfortunately, the aircraft cannot be pressurized in this configuration, necessitating an altitude restriction. As an additional protective
measure, the recirculation fan in the cargo com-
partment can be turned off to prevent recircu-
lolation of droplet nuclei.

The HEPA filtration used in most commercial
airliners may confer additional protection. This
may become an important factor in a large
conflict, where Boeing 767 passenger aircraft
will be converted into air ambulances as part of
the Civil Reserve Air Fleet (CRAF).

Airflow compartmentalization with plastic
partitions, neutral zones, contaminated zones,
and pressure gradients should be considered
only in exceptional cases.21 Because they have
yet to be proven effective in practice, no such
precautions are at present recommended for
use in US AE aircraft.

High-containment isolators can be used for
transporting patients with highly contagious,
potentially lethal diseases. Unfortunately, they
are limited in number and capability and
require specially trained teams of medical
personnel. These isolators are necessary for
the implementation of the extremely strict
CDC infection control guidelines for the care
and AE of patients with infections such as
Arenavirus, Filovirus, and Bunyavirus hemor-
rhagic fevers.32,48–51 They have been deployed for
evacuating patients with suspected or proven
VHF and active pulmonary tuberculosis.32,53
Although valuable for evacuating limited num-
bers of patients, they would not be suitable for
evacuating mass casualties.

The USAF has anticipated the possible
future challenge of operating in a chemically
contaminated environment by introducing the
Aircrew Eye/Respiratory Protection (AERP)
system.54 Transport aircraft have been equipped
with the AERP systems, and these could be
used to protect aeromedical crew members
from infection. The system consists of a
mask–hood assembly, a blower, and an inter-
communication unit. The C-9A is equipped
with eight AERP stations located throughout
the aircraft. There are fewer such stations on
the C-17, C-130, and C-141 aircraft. During
flight, regulated aircraft oxygen is passed
through the filter/manifold subassembly to the
mask for breathing while filtered ambient air is
used to provide visor defogging. On the ground,
filtered ambient air is used. The AERP blower
is powered by the aircraft electrical system or
by batteries. The AERP system is available in
most aircraft used for military AE, and all
aeromedical crew members routinely train
for its use during emergencies.55

US Military Policies for
Evacuating Contagious Patients
and Biologic Warfare Casualties

Historical Review

Aeromedical evacuation of US service
members with contagious diseases has been
routinely undertaken virtually since the estab-
ishment of a military AE service in 1942. During
World War II, C-46 Commandos, C-47
Skytrains, and C-54 Skymasters were reconfig-
ured to carry litters after unloading military
cargo, becoming air ambulances on their return
flights to the United States.56

Air transportation was soon determined to
be the most desirable method of evacuation
for all but the sickest of active tuberculosis
patients.57 Those with large tension cavities or
therapeutic pneumothoraces could not be
moved by air because intrapleural gas volume
would double as these unpressurized aircraft
ascended from sea level to 18,000 ft. In most
cases, patients were held at hospitals of
embarkation until a sufficient number accumu-
lated to fill a dedicated flight of tuberculosis
patients. A trained nurse was usually present,
and strict “sanitary precautions” and “proper
isolation” were practiced. However, the aero-
médical personnel were not screened with
tuberculosis skin tests.57 Consequently, the
number of new tuberculosis infections oc-
curring during these early air evacuations is
unknown.

In 1954, the first aircraft specifically designed
and dedicated to routine air medical transport,
the C-131A Samaritan, entered service. It could
carry specialized medical equipment and was
capable of cabin pressurization. In 1961, the
Boeing 707 jet was modified by the military to
become the C-135 Stratolifter and soon became
the mainstay of the first permanent interconti-

nental airlift system. Meanwhile, the C-130
Hercules began to see use for tactical AE. In
1965, the C-141 Starlifter began to replace the
C-135 for strategic (ie, overseas) AE. This jet aircraft represented a quantum increase in patient load, range, speed, and control of cabin environment. In Vietnam, helicopters moved wounded from the battlefield to medical treatment facilities in rear areas. From there, C-130 Hercules, C-123 Providers, and C-7 Caribous moved them to rear airfields, where C-141 Starlifters embarked on intercontinental routes. AE became so efficient that evacuees were sometimes received in a continental US medical facility within 24 hours of wounding. Large-scale actions in Vietnam in 1968 demonstrated the ability of the AE system to successfully respond to periodic surges of patients.

In 1968, the USAF received its first C-9A Nightingale, a military version of the McDonnell Douglas DC-9 specifically designed and dedicated for AE. New features included a special area for patient isolation and intensive care, a hydraulic ramp to facilitate enplaning of litter patients, integrated electrical and suction outlets, and medical supply and storage equipment cabinets.

The cornerstone of the current infection control program is adherence to the CDC guidelines for infection control. Any infections thought to have been acquired during AE are to be reported to the Air Mobility Command Surgeon’s Office, Scott AFB, Ill. To date, no cases have been reported.

Biologic Warfare Casualties

Military doctrine regarding all aspects of the medical management of biologic warfare casualties, including AE, is currently under development. Much of the existing joint and USAF doctrine relevant for the AE of nuclear, biologic, and chemical casualties does not clearly differentiate between these three groups. Clearly, there are significant differences among the diseases produced by these three weapons of mass destruction.

The USAF Surgeon General has developed interim guidelines for the AE of biologic warfare casualties. These guidelines are based on rational infection control procedures recommended for the infectious diseases caused by potential agents. Before these interim guidelines can be implemented locally, they must be approved by the appropriate theater commander-in-chief (a nonmedical general officer) and theater surgeon.

A key element of any successful approach to the treatment and transportation of biologic warfare casualties is early and rapid identification of exposure, clinical diagnosis, and laboratory confirmation using field diagnostic tests. To meet this need, the USAF is preparing to deploy multiple specialized teams and has developed a portable device that can quickly identify organisms by genetic typing. It is now projected that these teams will interface with the AE system as integral components of aeromedical staging facilities.

International Legal and Regulatory Aspects

In the 1970s, widely publicized outbreaks of Lassa and Ebola fevers in Africa spurred considerable interest among airline officials and public health authorities. In retrospect, inappropriate and unnecessary measures were instituted at airports in many countries to minimize the risk of disease importation. In commenting upon what he considered a deplorable state of affairs, Michel Perin of Air France’s Central Medical Service wrote:

Most airline companies refuse to admit aboard passengers known, or believed, to have contagious diseases. Such stringency can scarcely be justified by reference to laws or regulations, whether national or international. It introduces the risk of arbitrary, mistaken, or prejudiced conduct. It does not seem logical because airlines learn about only a small fraction of the contagious persons who travel, and public health is much more greatly endangered by unknown infectious persons. Normal hygienic conditions aboard planes usually suppress the risk of contagion of most diseases. The possibility of refusing admission should be given to airlines in certain cases, according to their doctor’s appreciation.

Perin suggested that exclusionary rules should be applied “only against someone who refuses to comply, or seems incapable of complying, with the conditions intended to make him harmless, or against someone who has such an infectious disease that it would be impossible to make him harmless to others.”
Insight into how the international community reacts to even rumors of highly contagious diseases among airline passengers can be gleaned from events of August and September 1994. An epidemic of plague in the Indian city of Surat resulted in panic and chaos. Many of the inhabitants including most physicians, evacuated themselves from the city. Panic spread rapidly to commercial air carriers, with all but two international airlines canceling flights to India. Indians deplaning at airports around the world were evaluated for signs of plague and, in Canada, airport workers donned gloves and masks. Eleven febrile Indian passengers were promptly quarantined when they deplaned in New York City. None had plague, but four were found to have malaria, one had dengue fever, and one had typhoid fever.

Health officials of any country can deny clearance for an aircraft to land or for the crew or passengers to disembark. There is a real possibility that an aircraft commander whose aircraft carries infectious patients or biologic warfare casualties might be denied permission to land in a foreign country or might find that his crew and aircraft are quarantined upon arrival.

The International Health Regulations of the WHO specify that permission to land can be denied for three quarantinable diseases: plague, cholera, and yellow fever (smallpox was removed from the list in 1981). In addition, the following diseases must be reported: louse-borne typhus, relapsing fever, poliomyelitis, influenza, and malaria. These International Health Regulations are being revised “in view of the growing global threat to public health posed by infectious diseases and the increase in emerging and re-emerging infectious disease.” The published draft requires reporting (and possible quarantine) of additional “diseases” of international importance, including “acute hemorrhagic fever syndrome, acute respiratory distress syndrome, acute diarrheal syndromes, acute jaundice syndrome, and acute neurological syndrome.” There is a potential for these revised regulations to have a considerable impact on international air travel and military AE.

### US Military Regulations

The US Military services have regulations that govern the transport of infected passengers. One the most relevant of these regulations for the AE of potentially contagious patients is USAF Regulation 161–4, which requires aircraft commanders to request an inspection by a quarantine official when an ill passenger has any of the following symptoms and signs: (1) a temperature of 100°F (38°C) or greater accompanied by a rash, lymphadenopathy, or jaundice or that has persisted for over 48 hours; (2) diarrhea defined as three or more loose stools or a greater than normal amount of loose stool for that person in a 24-hour period; (3) death due to illness other than physical injuries. The implications of this relatively imprecise and abstruse statement could be considerable. Medical planners must be aware of these regulations because failure to implement their provisions may have international repercussions.

### Unanswered Questions

Certain aspects of our current understanding of the AE of contagious patients remain unresolved. We offer the following questions about issues that may warrant future research:

1. Will additional smoke and simulant dispersal studies be done in various current AE aircraft to determine optimal aircraft type and patient configurations for AE of patients with contagious diseases?

2. Would the use of HEPA-filtered recirculated air reduce the risk of disease transmission in USAF aircraft that could potentially be used for tactical or strategic AE?

3. What is the utility of UV light in reducing transmission of airborne infections in aircraft?

4. Should the United States pursue international agreements regarding the entry of military aircraft carrying contagious disease patients into other countries under certain conditions?

5. Can a computer-based tracking system be developed for epidemiologic surveillance of AE patients, to enhance reporting of nosocomial infectious potentially acquired during AE?
Conclusions

Under normal conditions, the risks of transmitting infections in aircraft are probably equal to, or lower than, the risks in other crowded enclosures. This is most likely related to the excellent ventilation systems built into most modern aircraft. However, when the ventilation system is not functioning (as is often the case prior to take-off) the aircraft cabin environment increases the risk for transmission of airborne viruses such as measles and influenza.

The most effective method to minimize disease transmission is to defer AE of infectious patients until after the period of communicability. Unfortunately, there are many situations in which infectious patients must be evacuated, and AE planners must be ready to respond.

Most patients with infectious diseases, including biologic warfare casualties, can be safely evacuated using standard precautions. However, certain contagious diseases (ie, tuberculosis, pneumonic plague, VHF) require transmission-based precautions to protect the other patients, medical personnel, and aircrew. AE planning for these patients must take into account international public health regulations. Given adequate resources, foresight, and expertise, the AE of infected patients and biologic warfare casualties can be safely accomplished.

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References


22. Ritzinger FR. Aeromedical Review 4-65 Disease transmission by aircraft. USAF School of Aerospace Medicine: Brooks AFB, TX, May 1965.


12
In-Flight Emergencies: Capabilities and Limitations

R.T. Ross and M. Gage Ochsner, Jr.

The goal of aeromedical evacuation (AE) is the safe, efficient transport of all patients while maintaining adequate medical care with frequent reassessment. AE is often complicated and logistically demanding, requiring meticulous preplanning and flawless execution by a cohesive team composed of individuals with diverse skills. The need for AE was first recognized by military commanders who desired the rapid evacuation of seriously injured troops directly from the battlefield to skilled treatment facilities. Later, civilian hospitals adopted this military practice and developed a model of peacetime AE. The means by which AE is accomplished involves calculated risk because human flight is inherently dangerous. The purpose of this chapter is to familiarize the reader with common in-flight emergency situations, highlight clinical clues that facilitate rapid diagnosis using the Advanced Trauma Life Support (ATLS) primary survey as a model, and outline treatment options.

Definition

An in-flight emergency can be defined as any urgent condition or change in an existing condition that, during the course of aerial transportation, requires immediate evaluation and definitive intervention. Most of these emergencies are respiratory or circulatory in nature and can occur with little, if any, warning. Vigilant reevaluation of patients is crucial so that life-threatening changes in the patient’s condition can be recognized early and managed promptly.

Given a preliminary patient status report and a brief description of the mechanism of injury, astute aeromedical caregivers should be able to predict injury patterns and anticipate potential problems.

AE Environment

Caring for a patient in a moving aircraft is a complex challenge that requires a combination of resourceful evaluation and good tactile skills. Distractions, limited resources, and flight safety operational issues all impact the receipt, evaluation, transport, reassessment, and disembarkation of AE patients. Preflight preparation, communication, and teamwork are imperative for the safe and efficacious transport of seriously injured or ill patients. Medical personnel must anticipate the unique AE environment to minimize their influence upon the diagnosis and treatment of in-flight emergencies.

Stress Factors

There are numerous stress factors during AE. The gravitational forces associated with take-off, changing direction, and landing can alter equilibrium and affect blood flow. Air turbulence may induce motion sickness in both caregivers and patients. Reduced cabin pressure, common during most fixed-wing and some rotary-wing AE, promotes hypoxia and causes trapped gases to expand, sometimes painfully. In many aircraft, the cabin temperature may decrease because of the drop in ambient
temperature associated with altitude (approximately 2°C per 1000 ft). Aircraft noise and vibration can impede evaluation and communication, promote nausea and vertigo, and cause temporary and permanent hearing loss. Similarly, noise and vibration mildly stimulate the cardiovascular system. All of these factors lead to fatigue for both the aeromedical crew and patients.

Limitations
Restriction in cabin space and the standard safety practice of restraining personnel and equipment makes moving around the aircraft interior awkward, especially during emergency situations. Because aeromedical equipment must be light, durable, and field-hardened, it often sacrifices precision for ease of application and ruggedness. Although usually easy to use, the equipment itself is on occasion inaccurate and prone to malfunction.

Safety
Flight safety remains an important additional duty of the aeromedical crew. Caregivers must constantly maintain situational awareness and communicate significant patient care events (eg, defibrillation) to the aircraft commander. Conversely, the pilot must inform the aeromedical crew of weather issues, aircraft emergencies, and changes in the flight plan that could impact the ease, type, or duration of in-flight medical care. Unsafe practices adversely affect the mission and jeopardize the safety and well-being of both the crew and patients.

In-Flight Diagnosis and Treatment
Diagnosis and treatment of AE emergencies must be simultaneous rather than sequential because most such emergencies will require prompt definitive intervention to avoid catastrophe. The following simple, time-proven protocols can be applied in any situation, whether the patient is a trauma or medical casualty. These protocols are applicable whether the transport is from site of injury to medical facility or in between medical facilities.

Primary Survey
Seriously ill or injured patients must be monitored and re-evaluated in a timely, standardized fashion. The primary survey, as outlined in the ATLS Program for Physicians, serves as a template for a logical, sequential approach to patient assessment and surveillance. This primary survey quickly identifies, prioritizes, and simultaneously treats all life-threatening issues (Table 12.1).

The primary survey algorithm is universal and can be applied to all patient types and event scenarios. Patient care priorities remain constant whether the patient is civilian or military, trauma or medical, pediatric or adult, or pregnant. However, the differences in injury patterns and physiological status should always be taken into account. For example, military patients tend to be younger and in general healthier than the “at large” population. Elderly patients may have significant comorbid medical conditions that necessitate a more aggressive approach. Pregnancy is associated with marked anatomic and physiological changes that require early and aggressive resuscitation of the pregnant patient with parallel monitoring of the fetus. Despite these special considerations, the primary survey is the cornerstone for all patient evaluations that makes possible the rapid categorization and prioritization of life-threatening emergencies.

Airway
The first priority of medical management during AE involves maintaining or securing the

| A | Airway control with cervical spine immobilization |
| B | Breathing and ventilation |
| C | Circulation with hemorrhage control |
| D | Disability and neurological status |
| E | Exposure/environment |

Source: Adapted from American College of Surgeons Committee on Trauma.
airway while protecting the cervical spine. If the patient can speak, the airway is not immediately endangered but frequent reassessment is wise. If there is any question of an adequate airway, the first step is to inspect the oropharynx for potential obstructions and remove any secretions, loose teeth, dentures, or other foreign bodies.

The second step in securing an airway is to reposition the head. The chin lift, head tilt, and jaw thrust can serve as temporizing measures until a definitive airway is secured. However, in a trauma patient extreme care must be used to avoid any maneuver that applies force to the cervical spine, such as hyperextension, hyperflexion, or rotation of the neck, as this may result in iatrogenic spinal cord injury. Patients who have suffered multisystem trauma, especially involving the head, should be assumed to have cervical spine injuries. Even after thorough medical evaluation has ruled out such injuries (ie, a “cleared neck”), high-risk patients should wear a rigid cervical collar during transfer for in-line cervical spine immobilization.

**Signs and Symptoms of Airway Compromise**

A few patients will present with apnea as the first sign of airway compromise but, more commonly, the first signs will be subtle. Therefore, caregivers must keep alert with patients at risk for developing airway problems. Semiconscious and unconscious patients are at the highest risk and may suddenly lose their airways at any time. Narcotic analgesia may alter consciousness and thus increase the risk of airway compromise, especially for patients with multisystem trauma. Burn patients, in particular those with facial burns or whose injuries occurred in closed spaces, are especially susceptible to a compromised airway secondary to oropharyngeal edema.

**Treatment Options**

The first step is always positioning (as described above), followed by placement of an oropharyngeal or nasopharyngeal airway to optimize airway patency. If this is not sufficient, a decision should be made to secure an airway in the most appropriate manner. The esophageal obturator, once commonly employed as an airway option among emergency care personnel, is rarely used today. Instead, endotracheal intubation is the treatment of choice for airway compromise, and all medical personnel should be thoroughly trained in its indications and implementation.

**Intubation.** Intubation can be either nasotracheal or orotracheal. Nasotracheal intubation can be used in nonapneic patients without nasofacial trauma, but should not be used for more than 3 days. Ootracheal intubation under direct visualization with a laryngoscope remains the gold standard of securing an airway. This method is safe and effective although it may be difficult in some patients, such as those with laryngeotracheal trauma. Regardless of the method used, all intubations must be performed while maintaining cervical spine immobilization and ideally using the three-person technique. Specifically, one person maintains in-line cervical spine immobilization, one maintains cricoid pressure (ie, “Selinger maneuver”) to prevent aspiration of gastric contents, and the final person intubates the patient.

**Cricothyroidotomy.** Patients with maxillofacial trauma may be difficult to intubate and medical personnel should be ready to employ alternative methods of managing the airway. Needle or surgical cricothyroidotomy may be necessary, although these modalities are considered last or emergent use only and require a thorough knowledge of neck anatomy. Needle cricothyroidotomy is performed by identifying the anterior cricothyroid membrane between the thyroid and cricoid cartilages (Fig 12.1), immobilizing it with the thumb and finger, and inserting a 12- or 14-gauge over-the-needle catheter through the membrane at a 45° angle caudal. The needle is removed and high-flow oxygen administered through the catheter. A small hole in the tubing will allow intermittent ventilation: Occluding the hole for 1 second (usually with the thumb) results in lung insufflation with oxygen and leaving the hole open for 4 seconds allows for expiration.

A more definitive method of securing an airway is surgical cricothyroidotomy. It is accomplished by placing a vertical incision directly over the cricothyroid membrane,
inserting the scalpel handle through the incision to dilate the intended airway, and placing an appropriately sized endotracheal or tracheostomy tube in the trachea. This technique requires specialized equipment and training.

**Laryngeal Mask.** The laryngeal mask is an alternative method of maintaining a secure airway that is gaining popularity (Fig 12.2). Originally designed exclusively for surgical anesthesia, it is now considered an excellent alternative when direct endotracheal intubation is not possible. Easy and simple to insert, it can be applied blindly with ease in only a few seconds. However, it is not considered a primary or first-line technique at this time.

**Adjuncts for Maintaining a Secure Airway**

There are several important adjuncts for maintaining a secure airway in an emergency situation. The first is the use of paralytics for intubation, which should be considered during rapid-sequence induction in the conscious or semiconscious patient. Shorter-acting paralytic agents, such as succinylcholine, are preferred because they allow for earlier re-evaluation of the patient’s neurological status after intubation. The use of amnestic sedation is also recommended in these patients. Other important adjuncts are adequate suction and gastric decompression with a nasogastric or orogastric tube. Restraints should be available and used when deemed appropriate. Finally, all intubated patients should be monitored with end-tidal carbon dioxide devices if the devices are available because the absence of exhaled carbon dioxide implies inadvertent esophageal intubation or loss of a previously secured airway.

**Breathing**

The second priority of medical management during AE is adequate ventilation. Supplemental oxygen ($O_2$) should be administered during AE for any patient at risk of hypoxia. Methods for delivering $O_2$ include nasal cannula, non-re-breathing mask, bag-valve-mask, continuous positive airway pressure (CPAP), and mechanical ventilation. If hypoxia persists despite $O_2$ administration and a secured airway, other causes need to be discovered and treated.
Etiology of Ventilation Problems

Ventilation problems are in general categorized as either mechanical or neurological. Mechanical problems include airway obstruction or anything that restricts normal chest wall and lung movement. A partially or completely obstructed airway restricts or prevents adequate ventilation. The pain associated with chest trauma (e.g., rib fractures and flail chest segments) results in shallow breathing that impairs the bellows action of the thorax.

Anything that increases intra-abdominal pressure can impede diaphragmatic excursion. Any condition that results in intraperitoneal or retroperitoneal bleeding may hinder ventilation, as can pneumatic antishock garments. When the latter is suspected, the device should be deflated to determine if this improves ventilation.

Intrathoracic processes, such as simple pneumothorax, tension pneumothorax, and hemothorax, can seriously decrease ventilation by occupying intrapleural space and thus reducing vital lung capacity. This can be especially deleterious for patients with suboptimal pulmonary reserve prior to an injury, such as those with chronic obstructive or restrictive pulmonary disease.

Neurological problems that can lead to inadequate ventilation can be classified as either central or peripheral. Central neurological problems include intracranial injuries, which can suppress central respiratory drive, and spinal cord injuries, which can decrease either the intercostal or diaphragmatic contributions to respiration. An underappreciated central cause is the inappropriate use of analgesia, sedation, or paralytics. Peripheral neurological problems are less common and include isolated injuries to the nerves that supply the intercostal or diaphragmatic muscles.

In-Flight Emergencies

Regular re-evaluation to verify adequacy of ventilation is important during AE. In a noisy aircraft, observation of the symmetrical rise and fall of the chest is a more reliable indicator of adequate ventilation than is auscultation. Tachypnea or labored respiration may be the earliest signs of hypoxia. Clinical observation, the cornerstone of ventilatory surveillance, can be optimized by the use of technological monitoring devices, when available.

In high-risk patients, pulse oximetry and end-tidal carbon dioxide devices should be used to allow early detection of ventilation problems. Normal pulse oximetry assures peripheral oxygenation, but this monitoring device is of little use for patients with suboptimal peripheral perfusion and gives many false alarms. When the patient is intubated, the gold standard is the end-tidal carbon dioxide monitor because it will quickly and accurately alert medical personnel to inadvertent esophageal intubation or loss of a previously secured airway.

Medical Conditions. Any patient with chronic pulmonary disease should be monitored carefully throughout flight for signs of pulmonary compromise. All such patients should receive supplemental $O_2$ during AE, although this should be given cautiously in patients with chronic obstructive lung disease because hypoxia may be their only respiratory drive. Status
In-flight Emergencies: Capabilities and Limitations

Asthmaticus, a true emergency, should be treated aggressively with epinephrine, inhaled beta-agonists, corticosteroids, and antihistamines (Table 12.2). Acute respiratory decompensation with most other chronic medical conditions will usually require emergency intubation, as described above.

Pneumothorax. The most important potential respiratory complication for trauma patients is tension pneumothorax. On the ground, this condition evolves from a simple pneumothorax when air entering the pleural space through a defect in the lung or chest wall on inspiration is unable to escape. The resultant increasing intrathoracic pressure inhibits pulmonary perfusion, venous return to the right side of the heart, and eventually tracheal airflow. During flight a simple pneumothorax may develop into a tension pneumothorax as a result of expansion of the trapped air associate with decreased cabin pressure. For this reason, a thoracostomy tube should be placed prior to flight in any patients with known or suspected pneumothoraces and should be considered for any intubated patient with documented rib fractures.

Clinical clues associated with the development of a tension pneumothorax include dyspnea, ipsilateral absence of breath sounds (this will be difficult to detect in-flight), tracheal deviation, jugular venous distension, tachycardia, and hypotension. Immediate decompression of a tension pneumothorax can be lifesaving and is accomplished by inserting a large-bore needle into the second intercostal space in the midclavicular line (Fig 12.3). The simple pneumothorax that remains should be treated with a thoracostomy tube.

Another related condition is the open pneumothorax, where a defect in the chest wall allows air to enter the pleural space. Lack of a relative vacuum in the pleural space allows the lung to collapse, resulting in inefficacious ventilation with loss of functional residual capacity and ultimately hypoventilation and hypoxia. The open pneumothorax is treated with a

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Table 12.2. Emergency treatment of status asthmaticus.

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<td>1.</td>
<td>Ensure adequate humidified O₂</td>
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<td>2.</td>
<td>Inhaled beta-2 adrenergic agents</td>
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<td>3.</td>
<td>IV corticosteroids</td>
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<td>4.</td>
<td>Optimize theophylline</td>
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<td>5.</td>
<td>Consider anticholinergic agents</td>
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<tr>
<td>6.</td>
<td>Consider endotracheal intubation</td>
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Source: Adapted from Nowak and Tokarski.³

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**Figure 12.3.** Needle decompression of tension pneumothorax.
sterile, occlusive dressing applied over the open wound, but secured only on three sides so that accumulated air can escape via a Heimlich flap valve. It is critical that caregivers monitor respiration closely because an open pneumothorax can quickly evolve into a tension pneumothorax.

Flail Chest. Another trauma-related respiratory emergency is a flail chest segment, resulting from multiple fractures of contiguous ribs at two or more sites on each rib. This results in severe pain, loss of thoracic cage stability, and paradoxical respiratory motion of the chest wall. A concomitant pulmonary contusion can further exacerbate the resulting respiratory insufficiency. Initial therapy includes supplemental humidified O₂ and judicious application of intravenous (IV) fluids. These patients are at high risk of worsening respiratory insufficiency during AE and preparations should be made for emergency intubation and mechanical ventilation, if required.

Hemothorax. A life-threatening hemothorax results when 1500 mL or more of blood rapidly accumulates in the hemithorax. Patients with catastrophic intrathoracic vascular injury (eg, penetrating or blunt injuries to the great vessels or pulmonary hilar vessels) are unlikely to present during AE because these are quickly fatal. However, several types of patients, including postoperative patients, those with unrecognized injuries to the internal mammary or intercostal vessels, or those with lung parenchymal lacerations, may develop a massive hemothorax during flight.

The signs and symptoms associated with this injury include dyspnea, ipsilateral dullness to percussion, decreased breath sounds, and shock. General management includes immediate fluid resuscitation and placement of a thoracostomy tube. However, appropriate management of massive hemothorax is difficult, especially during AE. Continued drainage by thoracostomy tube may result in exsanguination. Alternatively, clamping the thoracostomy tube may result in tension hemothorax. Any time 1000 mL of blood is rapidly evacuated via thoracostomy tube, brief or intermittent clamping of the chest tube may help tamponade the bleeding until thoracotomy can be performed.

Circulation

The third priority of medical management during AE is to maintain adequate circulation by stopping hemorrhage, establishing adequate intravenous access, and instituting aggressive fluid resuscitation, if required. As with other life-threatening, in-flight emergencies, circulatory problems must be diagnosed quickly and treated immediately.

Shock

Shock is defined as hypotension associated with decreased tissue perfusion, cellular hypoxia, and metabolic acidosis. At the cellular level, inadequate oxygenation causes a shift from aerobic to anaerobic metabolism and results in lactic acidosis. Cellular swelling results from massive fluid shift from the intravascular to the intracellular space. Hypovolemia secondary to acute blood loss is quickly exacerbated by this secondary compensatory fluid shift.

Hemorrhagic Shock. The most common cause of shock is hypovolemia secondary to acute hemorrhage. Any trauma patient who has tachycardia and signs of peripheral vasoconstriction should be presumed to have hemorrhagic shock. The key management principle of shock is prompt recognition and stopping any ongoing hemorrhage. External hemorrhage resulting from soft-tissue laceration, amputation, or open fracture is usually obvious and should be treated with direct pressure, splints, and tourniquets, as required. Internal hemorrhage can occur into the thoracic cavity, peritoneal compartment, or retroperitoneal space and may be occult. If unrecognized, the initial signs of tachycardia and peripheral vasoconstriction can quickly progress to shock.

Basic management involves rapid administration of isotonic IV fluids. However, the massive amounts of fluid given to patients in the past may not be appropriate. The recent literature suggests that normalization of systemic blood pressure for patients with internal hemorrhage may negate the natural protective mechanism of relative hypotension. If the length of time between recognition of shock and landing at an airport where the patient can be taken to a hospital is great, then consid-
eration should be given to minimizing fluid resuscitation.

**Cardiogenic Shock.** Cardiogenic shock is a nonhypovolemic state in which hypoperfusion is caused by reduced cardiac output. Common causes are myocardial infarction or dysrrhythmia, cardiac tamponade, blunt cardiac trauma, tension pneumothorax, or massive pulmonary embolus. Signs of tamponade include “Beck’s triad” of muffled heart tones, hypotension with tachycardia, and jugular venous distension. Pulsus paradoxus (“Kussmaul’s sign”) is a more reliable sign for patients who are hypotensive.

Chest pain, dysrrhythmias, and myocardial infarction should be promptly treated using Advanced Cardiac Life Support (ACLS) protocols. If the patient’s hemodynamic status does not improve after routine resuscitation, cardiac tamponade should be assumed and immediate pericardiocentesis performed. A long 16- or 18-gauge needle should be directed percutaneously toward the ipsilateral tip of the scapula. Aspiration of as little as 15 to 20 mL of fluid will immediately improve cardiac output. If pericardiocentesis is successful, the patient should be transferred to a medical facility as soon as possible for creation of a pericardial window and possible thoracotomy.

**Neurogenic Shock.** Neurogenic shock is also nonhypovolemic in nature. Any head or spinal cord injury may diminish systemic vasomotor responses. Peripheral vasodilatation results in venous pooling of blood and hypotension. Decreased cardiac sympathetic innervation prevents a compensatory tachycardia. Aggressive fluid resuscitation is ineffective and may lead to fluid overload with pulmonary edema.

Once hypovolemia is excluded, neurogenic shock can be carefully treated with vasopressors. Atropine may be effective in alleviating bradycardia. Adrenergic compounds such as the alpha-agonist phenylephrine and the combined alpha/beta-agonist norepinephrine may play a role in the treatment of patients with spinal cord injuries.

**Septic and Anaphylactic Shock.** Shock related to massive infection is similar to the shock related to anaphylaxis, and thus they will be considered together. Neither of these types of shock are associated with acute trauma, but both can develop subsequent to trauma or resuscitation. Septic shock may result from infection after a grossly contaminated injury related to combat. Anaphylaxis can result from transfusion of blood products, especially if it has not been correctly cross-matched. In-flight treatment consists of stopping the infusing blood products, administering oxygen, aggressive fluid resuscitation, and a beta-2 adrenergic agent to relieve bronchospasm. If sepsis is suspected, broad-spectrum antibiotics should be started if not already in use.

**IV Therapy**

Venous access is crucial during the transport of patients, and large-bore (14-gauge) IV catheters should be readily available at all times. In high-risk patients, one or two IV lines should be established in the forearm or antecubital veins prior to transport. If this access is not possible, central venous access should be placed in these patients.

Medical personnel must be adept at quickly obtaining peripheral venous access in a noisy, unstable, and cramped environment. If the patient is in shock, placement of a large-bore device into a femoral vein may be required. In children less than 6 years of age, IV fluids can be quickly and reliably given in an emergency situation by placing an intraosseous needle through the anteromedial surface of the proximal tibia.

**Isotonic Solutions.** Isotonic crystalloid solutions, such as lactated Ringer’s solution or normal saline, are standard fluid therapy for in-flight emergencies. The use of lactated Ringer’s solution is slightly preferred if large volumes are required as it more physiologically approximates human plasma. If large amounts of normal saline are given, the patient must be evaluated for possible hypernatremia and hyperchloremia and acidosis. Colloids such as hetastarch and dextran are less commonly used because they have not been shown to improve patient outcome when compared with crystalloid infusion. Dextrose should never be used for fluid resuscitation as it promotes osmotic diuresis.
**Blood Products.** The administration of blood products, in particular packed red blood cells, is important for the treatment of hemorrhagic shock. However, before hypovolemic adults receive blood products, the clinical response to a 2-L challenge of crystalloid fluid should be evaluated. Hypovolemic children should receive two 20-mL/kg challenges of crystalloid solution, after which an infusion of 40 mL/kg of packed red blood cells should be given if necessary. When time and facilities permit, cross-matched blood should be used. In life-threatening emergencies, type-specific or type O Rh-negative blood may be required.

**Treatment of Coagulopathies**

Massive IV transfusions can result in dilutional coagulopathy. Delayed coagulopathies are uncommon during the first posttrauma hour, but it unfortunately becomes an issue several hours later.\(^5\)\(^,\)\(^6\) Warming the fluid may decrease this risk by minimizing hypothermia, whether crystalloids or blood products are given. Treatment consists of transfusion of fresh frozen plasma, cryoprecipitate, and platelets.

**Cardiac Defibrillation**

A portable defibrillator should be present and ready for use at all times. Paddles are not commonly used for defibrillation in an aircraft because of the increased risk of accidental shock to a caregiver secondary to the cramped quarters and unexpected movements common in aircraft. Instead, “hands-off” defibrillation is recommended using an external cable and adhesive gel pads. ACLS protocols remain the standard approach.

**Disability**

“Disability” refers to the patient’s neurological status. Patients with neurological injuries need to maintain optimal cardiopulmonary status to limit secondary neurological insult. Adequate supplemental oxygenation will also promote adequate cerebral oxygenation. Mild hyperventilation may be used during AE to reduce intracranial blood volume, limit intracranial acidosis, and increase cerebral metabolism. Finally, overhydration should be avoided because it may exacerbate cerebral edema.

During AE, neurological casualties must be closely monitored for potentially rapid deterioration. Clinical clues may include the development of unilateral or bilateral mydriasis, progression or development of lateralized neurological signs, unusual breathing, vomiting, combativeness, lethargy, increased confusion, or decreasing level of consciousness as determined by the Glasgow Coma Scale. Unfortunately, little more than supportive care can be done in-flight. Diversion to an appropriate medical facility may be required for the new onset of significant symptoms.

**Exposure/Environment**

The final step of the ATLS primary survey has a dual meaning. “Exposure” is a reminder that whenever a patient’s condition worsens it is important to examine the patient thoroughly for potential sources of hemorrhage, as well as other injuries that may have been missed in a field medical facility. “Environment” refers to factors in the patient’s environment that may adversely affect his or her health. Keeping the patient warm is especially important in large AE aircraft, which may have significant swings in cabin temperature during flight. In hot climates, hyperthermia may on occasion be a concern, in particular during evacuation of combat casualties. However, hypothermia is probably more common in trauma casualties, even in combat situations.

**Conclusions**

The flight environment places unique stresses on both patients and aeromedical personnel. Meticulous and periodic reassessment of patients and anticipation of potential problems is required for safe AE. Early recognition and treatment of complications that occur during AE requires well-trained aeromedical personnel and appropriate resources.

**References**


Timing is critical in the treatment sequence of both battlefield and civilian casualties. In both cases, rapid medical evacuation (MEDEVAC) from the site of injury to a medical facility has revolutionized trauma care. Likewise, aero-medical evacuation (AE) used for the transportation of casualties over long distances to access more sophisticated treatment has benefited the trauma casualty. AE is often employed for surgical casualties with apparently similar wounds but potentially different needs. During AE, the type of injury, mode of transportation, and duration of the process will influence treatment status and needs.

The focus of this chapter will be on AE considerations for casualties with abdominal, urogenital, and soft-tissue trauma and how they are managed, either surgically or nonsurgically. The history of these injuries will be followed by a discussion of the most common general surgical injuries to intra-abdominal and urogenital organs. Safe AE depends on an understanding of the injury, its treatment, and the distinctive complications that may occur.

Abdominal Trauma Care

Historical Perspective

During the Revolutionary War, the mortality rate for victims with abdominal trauma was quite high. Far more patients died from complications and sepsis than did from the actual penetrating abdominal trauma itself. Conservative management of penetrating trauma prevailed because the mortality rate of patients undergoing laparotomy was approximately 75% to 85%. Fortunately, military medicine and surgery continued to improve.

During World War I, the mortality rate for penetrating abdominal wounds dropped to approximately 50%. This has been attributed to the development of new and more reliable surgical techniques for performing laparotomy at frontline surgical facilities. This rate decreased to 25% in World War II with the advent of antibiotic therapy and the development of more capable forward surgical facilities. By the Korean conflict, the mortality rate for penetrating abdominal wounds had dropped to >12%. Although this was due in part to surgical advances and improved antibiotic therapy, the single greatest advance was the helicopter. This new form of casualty transportation, which saw limited use at the end of World War II, was used extensively during the Korean conflict for the rapid MEDEVAC of battlefield casualties to forward mobile army surgical hospitals. The Vietnam War saw even faster and more aggressive MEDEVAC of casualties from the battlefield, together with the first jet aircraft use in AE. As a result of this aggressive MEDEVAC and AE, the mortality rate for penetrating abdominal trauma has continued to decline to the present-day rate of 3%.

In the past, abdominal wounds encountered on the battlefield and those seen in the civilian sector were distinctively different. However, there has been substantial blurring of these differences, as pointed out by Norman Rich in his Hume Memorial Lecture in 1993.
High-velocity weapons are becoming more common in the street violence that plagues society today. Automatic weapons and explosives, whose use was once limited to acts of political terrorism, are now in use by common criminals and disturbed children. Suddenly, civilian trauma surgeons find themselves in “urban battlefields” applying lessons that have been learned from centuries of battlefield medicine. Compared to his military counterpart, the civilian trauma surgeon is at a disadvantage of having patients that may be aged or very young, in addition to young healthy adults.

Damage Control Surgery
The evolution of the modern trauma center has allowed patients to be cared for in a concise and rapid fashion, but many of these patients must be transported over long distances to access this definitive care. Thus, both MEDEVAC and AE have established permanent roles in the modern approach to surgical casualties.

A relatively new concept, termed “damage control surgery,” has taken on a particularly important role in both the initial treatment and AE of patients with abdominal trauma. Damage control surgery is essentially taking an unstable patient to the operating room with the sole purpose of providing hemostasis and drainage. This minimal but effective treatment of major injuries is used either to buy time until the patient can tolerate a prolonged surgical repair or transport the patient to a trauma center. Decisions to subject these stabilized patients to the potentially fatal stresses of long-distance AE must be made on a case-by-case basis (Table 13.1).

Unlike traditional definitive surgery, where reoperation is performed only for complications, damage control surgery is limited such that reoperation is a planned event for definitive repair at a later time. Damage control surgery is most often used for hemorrhage control of wounds associated with organ injury. This has created obvious new challenges for AE, as “stabilized” patients are transported after damage control surgery to a larger tertiary-care hospital thousands of miles away for the definitive repair (eg, Operation Just Cause in Panama). Maintaining and caring for stabilized patients in the dynamic AE environment requires a firm grasp of aerospace physiology, surgical anatomy, and the types of complications that may occur in these patients. In an effort to increase the knowledge base of surgical priorities for abdominal trauma, we will review several important aspects unique to these patients.

Surgical Approach
Surgical exposure is of paramount importance for abdomen exploration after traumatic injury. Adequate exposure of the abdomen allows the surgeon to determine which injury will take precedence and allows for better control of vascular and solid-organ hemorrhage. This is best accomplished with a midline abdominal incision that extends from the xyphoid to the pubic symphysis (Fig 13.1). Interestingly, this technique has remained relatively unchanged since the turn of the century, when George W. Crile, a pioneer in trauma surgery, determined this to be the incision of choice.8

The next step is careful exploration of the abdomen. Just as a pilot requires a routine for systematically checking the aircraft’s instruments, the surgeon also needs a systematic approach for exploring the abdomen. A reproducible, if not habitual, approach that explores the entire abdominal cavity will help minimize the risk for missed injuries.

Hollow-Organ Injuries and AE
Hollow-organ injuries are of particular importance to the aeromedical crew. Because of the
expansion of air that occurs at altitude, the injured gut is in particular vulnerable to complications due to AE. Expansion of trapped gas from a paralytic ileus or repaired gut can cause considerable pain or rupture of surgical anastomosis or retention sutures.

Altitude-associated decreases in pressure cause patients with gas trapped in hollow organs to potentially experience problems in unpressurized aircraft at altitudes above 5000 ft. This is important because even pressurized aircraft allow the cabin pressure to decrease to the equivalent of 8000 ft altitude. Unquestionably, gas expansion is a concern for postoperative patients during AE.

Because of gas expansion during flight, adequate drainage of both air and intestinal contents must be assured before, during, and after AE. It is extremely important that patients requiring AE have a nasogastric tube in place during or immediately after surgery. Both the surgical and aeromedical teams must be vigilant in the use of drainage devices in postoperative abdominal trauma patients.

Specific Injuries

Upper Gastrointestinal Injuries

Gastric Injuries

Injury of the stomach, although rare in blunt trauma, is relatively common in penetrating trauma (especially in knife wounds from right-handed assailants). During surgery, the finding of an anterior wall laceration is an indication to carefully examine the posterior wall for perforations as well. The laceration should be closed using two layers of interlocking sutures rather than a purse-string suture because the latter is not effective in controlling gastric wall bleeding. Asymmetrical tears should be converted to a linear closure. More extensive trauma to the stomach requiring gastric resection or vagotomy may require a reanastomosis procedure, such as a gastrojejunostomy or gastroduodenostomy.9–12

It is important to determine if there has been spillage of gastric contents. A simple gastric laceration without spillage requires minimal lavage and no subsequent drainage. When a gastric injury is associated with spillage of gastric contents into the peritoneal cavity, closure should be followed by copious lavage of the peritoneal cavity to avoid abscess formation, with special attention to the lesser sac. In addition, postoperative drains are usually required.

Duodenal Injuries

Whenever a blunt or penetrating injury of the upper abdomen occurs, duodenal injury should be considered. In the civilian venue, seat belt injuries are common causes of a duodenal injury, which is usually seen in conjunction with other organ injuries, including the pancreas, gastric, hepatic, or biliary system. During laparotomy, the duodenum should be mobilized using the Kocher maneuver to allow adequate examination of both the anterior and posterior duodenum and the adjacent organs.13–17
A retroperitoneal hematoma or bile-stained tissues should prompt an extensive search for pancreaticoduodenal injury.

Small penetrating injuries of the duodenum are closed in a simple two-layer fashion. The wound edges are debrided and all other surrounding structures are evaluated. A serosal patching for significant duodenal defects should be used only for damage control surgery, as a temporizing measure until the patient can be taken to more definitive surgery. More extensive surgery (eg, pancreaticoduodenectomy or Roux-en-Y anastomosis) is used as last resort for extensive damage to the duodenum, pancreas, and surrounding structures.

Small-Bowel Injuries

Small-bowel injury is almost always due to penetrating trauma, although blunt trauma can result in small-bowel injury at a point of relative fixation, such as the proximal jejunum. During exploratory laparotomy, the entire length of the small bowel should be inspected to rule out perforation or hematoma. The ligament of Treitz should be taken down to carefully evaluate each segment of the mesentery and its associated vessels. Injuries from knife wounds usually have clean edges and require much less debridement than high-velocity projectile wounds. Bowel resection is required for areas that are crushed, avulsed, ischemic, or torn. Drainage may be required for hematomas or contusions associated with blunt abdominal trauma.

Implications for AE

After damage control surgery, rather than using the standard layered abdominal closure, thought should be given to using a mass closure technique with retention sutures. This will allow for peritoneal expansion and will also allow the receiving surgeon to reinspect the bowel for vascular integrity if the mesentery has been involved.

Placing a nasogastric tube for drainage is absolutely necessary when transporting patients with gastrointestinal injuries by AE to avoid the pain and danger of breaking down of a repair because of overdilatation of expanding gas at altitude. The nasogastric tube should be connected to low intermittent suction throughout the flight.

Prolonged transports should be avoided in “stabilized” patients, who are at increased risk of lactic acidosis from ongoing bleeding or subacute hemorrhage. The aeromedical crew may have blood and lactated Ringer’s solution, but usually will not have platelets and fresh frozen plasma (FFP) if disseminated intravascular coagulopathy occurs as a result of the acidosis. If possible, acid/base balance should be monitored at 4-hour intervals during transport and more frequently in patients who have undergone damage control surgery. The aeromedical crew will need to keep a close eye on patients who have had mesenteric resection for signs of evolving ischemia, such as increased pain, lactic acidosis, and fluid sequestration into the gut.

Colorectal Injuries

Wartime wounds of the colon are more likely to be caused by shrapnel injuries than civilian wounds, which are often the result of the blunt forces associated with motor vehicle accidents. For most penetrating colon injuries, colostomy is commonly used to divert the fecal stream and thus decrease the risk of sepsis or abscess formation due to fecal contamination (Fig 13.2). Broad-spectrum antibiotic coverage is also important, especially for patients at high risk for subsequent infection such as those with open pelvic fractures, rectal injuries, or blunt colonic injury.18

Blunt colonic injuries may include serosal tears, contusions, mesenteric injuries, or frank rupture. Blunt injuries from motor vehicle crashes are more likely to involve the surrounding structures and tissues compared to penetrating injuries, which usually are more selective. Partial thickness contusions and serosal injuries can be left to heal on their own. Full thickness tears and mesenteric injuries with colonic involvement should be repaired in a primary fashion, with colostomy for large or complicated cases. Rupture of the colon should be treated with fully diverting colostomy and washout of the distal segment.

Rectal injuries are most commonly caused by penetrating trauma. Digital rectal examinations and/or proctosigmoidoscopy will identify most
Abdominal Wounds, Urogenital Trauma, and Soft-Tissue Injuries

rectal injuries, although abdominal computed tomography (CT) scan is sometimes required. Diverting colostomy is the most common surgical therapy for these injuries, although distal rectal washout and primary repair is used in some cases.

Implications for AE

Aeromedical crews must be trained in routine colostomy care because this operation is frequently used in both the civilian and military environments. In addition to care of the stoma, proper care of the colostomy bag is important. The bag must be periodically vented during ascent to avoid rupture of the colostomy bag secondary to gas expansion. The colostomy bag should not be filled with saline or water, as the fluid may be partially absorbed by the colonic segment or cause an enema-like catharsis, further complicating the in-flight care of the patient.

Solid-Organ Injuries

Spleen

The spleen is one of the most frequently injured organs in cases of blunt trauma. Abdominal pain and guarding are common for patients with acute splenic injury. Kehr's sign (referred left shoulder pain) may be present when intraperitoneal bleeding has caused diaphragmatic irritation. Leukocytosis is also common, but decreases in the hematocrit may be relatively delayed. The patient may have acute physical signs of hemorrhage (eg, pain, tachycardia, and hypotension) before the hematocrit has a chance to equilibrate. Thus, physical exam, physical signs, and radiological studies are used to diagnose splenic injury and laboratory findings are considered secondary. With the advent of spiral CT scanners and bedside ultrasound, splenic injuries can now be readily identified in a modern hospital setting.

Conservative management of splenic injuries has become more common in both pediatric and adult trauma centers because of the importance of the spleen in fighting infection. In the pediatric population, nonoperative management is successful in greater than 75% of cases of blunt traumatic injury. In adults with grade I or II splenic injuries with an intact capsule, conservative management is also possible. Total splenectomy is now reserved for those patients in which complete rupture, loss of the vascular stalk, or uncontrollable hemorrhage has taken place.

Damage control surgery for hemorrhage control can be performed in unstable patients by using a combination of electrocautery, gel foam, thrombin, and packing. But, this is reserved for splenic fractures that are deemed easily repairable when the patient is stable. Otherwise, splenectomy is indicated in unstable patients for hemostasis purposes. Treatment of moderate splenic injury differs between civilian and military practice. In civilian practice, the surgeon can take whatever time is needed to repair the injured spleen. However, in the combat arena of military medicine that time spent on an extensive, elaborate repair might be
better utilized on a rapid splenectomy of one patient to treat another.

Implications for AE. The aeromedical considerations in moving postsplenectomy patients, or those with splenic injury managed conservatively, mostly involve efforts to prevent bleeding. These patients should be carefully managed in the load plan, with litter placement in an area where the potential for trauma is minimized. It is also important that the AE crew have ready access to monitor vital signs and start intravenous fluids as required.

Pancreatic and Hepatic Injury

Treatment of hepatic injuries has changed somewhat over the past few years. Vascular embolization of bleeding hepatic vessels in the radiology suite has become a more common site. However, battlefield medicine frequently does not have this luxury. For this reason, we will review the management of penetrating trauma to the liver as it is performed in the field hospital, as these are the patients most likely to require AE. When managing superficial wounds to the solid organs, direct pressure is often all that is necessary. More severe arterial bleeding may necessitate the ligation of the right or left hepatic artery. Packing large wounds with hemostatic material (Surgicel, Gelfoam) for damage control and coadministration of FFP and platelets is often used as a two-fold assault on large lacerations and defects with uncontrolled hemorrhage. Direct pressure over the right and left arterial vessels is applied and then, dependent upon which one controlled the hemorrhage, the vessel is ligated. If the Pringle maneuver is used (application of a vascular clamp to the portal triad) and cessation of bleeding occurs, this strongly suggests the source of the hemorrhage is either hepatic artery or portal vein. If large defects or venous bleeding allows continued hemorrhage despite the previously applied techniques, direct ligation of venous bleeders is performed. This usually involves blunt dissection through the penetrating defect with ligation of the individual hepatic veins as they are encountered. The wound is then grossly packed with hemostatic agents or a transposing vascularized flap of omentum is sutured into the defect. Generous use of platelets and FFP should be given to this patient if AE anticipated.

Injuries to the pancreatic tail usually require simple resection. Care should be taken to spare the splenic artery. Injuries to the body and head may require either a Roux-en-Y or major resection of the duodenal segment. As stated previously, pancreaticoduodenectomy is a means of last resort, when the duodenum and pancreas have been so severely damaged as to leave no other alternative.

Implications for AE. Bleeding and latent disseminated intravascular coagulation (DIC) will be the nemesis of the aeromedical crew in this patient population. Although damage control surgery will not negate the need for AE for definitive surgery, this approach can be relatively effective in stabilizing patients prior to transport. Generous use of blood products, including platelets and FFP, prior to transport is paramount. Attempts should be made to correct all coagulopathies prior to consideration for transport. The aeromedical crew will not be able to adequately combat DIC while en route during transport, as they more than likely will not have all the blood products needed for this. Decompression of the gut is required by nasogastric tube for all patients with abdominal surgery. Ideally, a prothrombin time/partial thromboplastin time and hematocrit should be evaluated at each stop during transport in these patients.

Urogenital Injuries

Urogenital injuries are less likely to be life threatening than intra-abdominal visceral injuries. However, recognition and appropriate treatment is crucial to avoid untoward morbidity. Penetrating abdominal trauma is often associated with renal coinvolvement. In a combat situation, mine injuries are often associated with damage to external genitalia. The majority of urogenital injuries, whether internal or external, require some type of damage control surgery to prevent loss of viable organs and tissue, with a planned revision at a later date. AE of these patients must be done in such a way as to maintain adequate renal and uro-
genital function while attempting to avoid sepsis and other complications prior to definitive care.

Renal Injuries

Renal injuries are classified as minor or major or as nonpenetrating or penetrating (Fig 13.3). Most nonpenetrating renal injuries are considered minor (e.g., contusions and hematoma) and are usually managed without surgery because surgical manipulation of the kidney carries some risk. Even a nonfunctioning kidney may also be handled nonsurgically.

Major renal injuries include severe blunt renal trauma or penetrating injuries that result in uncontrolled internal hemorrhage or injury to the renal vascular stalk. Blunt injuries require surgical management if an expanding flank hematoma, continued frank hematuria, or drop in hematocrit accompany them or if significant vascular injury is demonstrated by arteriogram. Penetrating injuries require surgical exploration in almost every case to look for other injuries. Prior to surgery, normal function of the remaining kidney must be demonstrated by intravenous pyelogram (IVP) in case conservation of the damaged kidney is required. Even with a contralateral functioning kidney, nephrectomy is only performed if the pedicle is unreparable or has been torn away or more than 50% of the kidney has been obliterated.

Ureteral Injuries

Large ureteral injuries may require diversion of urinary flow to the skin by placement of a pyelostomy and ureterostomy tube. Intermediate injuries are treated surgically with ureteral repair, reanastomosis, or reimplantation, followed by placement of a stent. Smaller ureteral injuries can sometimes be treated by stenting alone. Stents and tubes present two challenges: First, stents usually cause painful ureteral spasms, requiring treatment with both antispasmodics and pain medication. The second problem with stents, and especially nephrostomy tubes, is that they are easy to dislodge and difficult to replace. Extreme care must be used when changing dressings or otherwise manipulating these devices.

Bladder and Urethral Injuries

Bladder injuries are usually repaired primarily and require continuous drainage afterward with either a large (24 French) suprapubic or urethral catheter. Bleeding can be a problem, as clots may prevent drainage. Although this can usually be remedied by irrigation, replacement of the tube of catheter may be required. Crush injuries of the pelvis often require the placement of percutaneous drains as well.

Penile and Scrotal Injuries

Penile lacerations may be closed primarily or secondarily, depending on the degree of contamination and debridement required. A dressing impregnated with antibiotic ointment or petroleum is used to avoid tissue disruption upon removal. A bladder catheter, either suprapubic or urethral, is usually required and must be carefully secured to avoid excessive wound manipulation. If the penis is closed primarily or sewn to a tissue or skin donor site, vascular integrity should be evaluated by checking for adequate capillary, especially in the presence of excessive edema.

Scrotal injuries often require debridement. Depending upon how much viable albuginea tissue remains, the scrotum may be closed or the testicle may be placed or buried in the abdomen or thigh. These wounds must be carefully evaluated for signs of infection or abscess developing. Using a pressure dressing to support the scrotum may significantly reduce pain. Antibiotic coverage and drainage may also be required.

Implications for AE

For all urogenital injuries, adequate urinary output is important for both treatment and management. Adequate urine output will verify patency of any catheter or nephrostomy tube and increase the ability of the kidneys (or kidney) to clear myoglobin related to the trauma. Hydration is perhaps the single best way to prevent obstruction by clots, debris, or encrustation while affording an adequate glomerular filtration rate to assure continued renal function. A good rule of thumb is to main-
tain a urine output of between 50 and 100 cc/hour in a 24-hour period. This may reduce the need for continuous irrigation, assures the patient is adequately hydrated, and is evidence of continued renal function. However, the first diagnostic step for decreased urinary output should be irrigation of the catheter because debris, blood, or mucous may have clogged the tubing.

For patients with stents, aeromedical crews should make sure they have adequate pain medication and antispasmodics (Table 13.2).
Care should be taken with nephrostomy tubes to ensure both patency and security because they are difficult to replace if dislodged and have a propensity toward obstruction. An unsecured tube should be resutured prior to AE.

For patients with bladder injuries, the crew should assure that the suprapubic or urethral catheter is ≥24 French so that clots can be irrigated from the bladder. Adequate irrigation fluid and syringes should be on-hand to manage an occluded catheter. A spare catheter should be available in case of persistent occlusion or dislodgment. Antispasmodics may be required for bladder spasm as well.

Foley catheters present special challenges. First, an air-filled balloon may expand and rupture at altitude. For this reason, air should be replaced with water or saline in all cases. For catheterized men, antibiotic ointment should be used to moisten the meatus to prevent friction between the catheter and urethra. The foreskin of uncircumcised males must be replaced after catheter insertion to prevent paraphimosis.

Finally, contaminated wounds that have not been closed primarily must be monitored closely for signs of infection. These patients are at increased risk of abscess and sepsis and are usually on broad-spectrum antibiotics.

### Soft-Tissue Wounds

Soft-tissue injury refers to damage to the skin, subcutaneous fat, and muscular tissue of the extremity or truncal wall. This section will outline management guidelines for soft-tissue injury, while associated vascular and orthopedic injuries are discussed in those respective chapters. Management of soft-tissue injury is divided into immediate care at the trauma scene and subsequent care during poststabilization evacuation.

### Immediate Care at the Trauma Scene

The immediate threats to life following a traumatic injury are in the areas of airway, breathing, and circulation. Unless a soft-tissue injury is the source of major blood loss, it should be addressed as part of the secondary survey. If ongoing extremity hemorrhage is contributing to hemorrhagic shock, it is best controlled by a properly placed compression dressing. This dressing should consist of a cotton trauma dressing that is firmly wrapped with elastic compression gauze. It is important to realize that excessive gauze can decrease the pressure on the site of hemorrhage and hide the blood loss from the evaluating physician.

If a pressure dressing does not stop the bleeding, the other treatment possibilities include a tourniquet, wound exploration, and vascular clamping. A tourniquet is rarely required except for complete amputations that cannot be controlled by a pressure dressing. There is no rote for wound exploration and direct clamping except for an amputated extremity. Vascular clamping in the field invariably results in crushing of the neurovascular bundle and the resultant nerve injury may be more damaging to the limb than the vascular injury. Direct compression is the modality of choice for bleeding control and vascular injury. Rarely, a mangled extremity (such as a landmine injury) will require a temporary tourniquet. This patient should be treated as a priority for evacuation so that a formal operative wound exploration can be performed for vascular control.

After hemorrhage has been controlled, the extremity should be stabilized. Motion increases bleeding and may compound any pre-existing vascular or nerve injury, especially in the presence of bone fracture. The limb may be secured to the backboard used for evacuation or splinted temporarily in the field. After stabilizing the limb, distal pulses must be checked.

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**Table 13.2. Supplies needed for in-flight care of urogenital casualties.**

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<thead>
<tr>
<th>Item</th>
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<tbody>
<tr>
<td>Ditropan</td>
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<tr>
<td>Saline irrigation</td>
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<tr>
<td>Toomey syringes</td>
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<td>Toradol 60 mg (intravenous or intramuscular use)</td>
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<td>Spare Foley catheter of same and one smaller size</td>
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<tr>
<td>Intravenous fluids (saline or lactated ringers)</td>
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<td>Viscous lidocaine</td>
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<td>Neosporin or suitable lubricating antibiotic ointment</td>
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<tr>
<td>Ciprofloxacin or other suitable broad-spectrum antibiotic with <em>Escherichia coli</em> coverage</td>
</tr>
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</table>
to ensure adequate circulation. If pulses are absent, the splint should be inspected and any binding that may be acting as a tourniquet should be adjusted. During MEDEVAC or AE, these patients should be placed in litter positions that minimize trauma to the injured part and give maximum accessibility for in-flight care.

If these stabilized patients are to be evacuated long distances (eg, transoceanic AE missions), broad-spectrum antibiotics should be administered prior to and during the flight. A first-generation cephalosporin is sufficient for most soft-tissue injuries. Extensively soiled wounds or crush injuries may benefit from the addition of antibiotics with Gram-negative anaerobic coverage. The key to infection prevention, however, remains rapid MEDEVAC to a medical facility where definitive wound debridement and washout can be done.

Myoglobinuria may complicate crushing soft-tissue injury. In the field, it will manifest as pigmented urine, which varies in appearance from grossly blood-like to the color of tea. Intravenous solutions should be administered to maintain a urine output of >100 to 150 mL/hour. Administration of adjuvants, such as mannitol and bicarbonate, should be deferred until a medical facility is reached because administration of mannitol to an acutely hypovolemic trauma victim may result in further fluid loss and hypotension.

Implications for AE

Following resuscitation and operative debridement of a soft-tissue injury, the patient may require urgent or contingency AE. After initial surgical treatment of soft-tissue injury, infection and sepsis are the primary complications. The risk of infection is increased by several variables: (1) initial contamination of the wound, (2) a large bacterial burden in the wound, (3) initial delay in debridement, and (4) inadequate debridement.

High-velocity wounds (military or hunting rifles) and wounds associated with high-energy transfers (landmines, shotguns) are associated with increased amounts of devitalized tissue and penetration of contaminants. Clothing and soil may be carried deep into the wound tract and spread by the cavitating effect of the projectile as it traverses the soft tissue. The presence of soil in a wound decreases the absolute number of bacteria required for an infection. Soil has been shown in animal models to: (1) interfere with normal leukocyte phagocytosis, (2) impair nonspecific bactericidal activity in serum, and (3) possibly inactivate antibiotics. Specific organisms present at the time of injury also influence the nature of any resultant infection. The heavily manured fields of Flanders in World War I gave rise to infections far different from those seen today in modern urban trauma centers. This effect of the local microbiology plays a major role in the virulence of any wound infection.

Delay in initial debridement will result in increased wound infection rates. The initial hematoma and devitalized tissue provides the media for bacterial growth while the compromised local circulation and resultant hypoxia inhibits any host response. Unfortunately, delay in immediate MEDEVAC may be unavoidable and patients entering the AE chain may be at increased risks for infection.

Prior to antibiotics, soft-tissue wound debridement involved radical debridement of all potentially contaminated tissue. The resultant deformity and disability may have been acceptable in the pre–anti-biotic era, where most wound infections would be fatal, but is an unacceptable outcome with modern surgical therapy. Serial wound explorations and debridement with appropriate antibiotic coverage is the current standard of care. In this manner, the maximum amount of soft tissue is preserved and the resulting muscular dysfunction minimized. However, stabilized patients must often be evacuated in the midst of this staged surgical therapy, and any delay during the evacuation process will increase the risk of infectious complications.

Thus, the flight crew taking care of patients during the urgent or contingency AE must be sensitive to the early signs and symptoms of wound infection, including fever, chills, increased thirst, decreased urine output, relative hypotension, increasing agitation or confusion, and change in drainage from the wound. Patients developing evidence of wound infections should be diverted to a medical facility.
for prompt surgical consultation. A delay in prompt surgical intervention may result in a necrotizing infection and possibly the loss of limb or life.

Conclusion

In addition to knowing what injuries their patients have sustained, the aeromedical transport crew must also know what therapies have been rendered in an attempt to stabilize the patient. This is in particular true in the trauma patient. The crew must understand modern techniques for surgical correction because they are likely to impact therapies needed for aeromedical transport. The evolution of aeromedical transport has allowed surgical facilities and definitive care to be moved farther from the front. In essence, advances in aeromedical transport and surgical techniques have extended the reach of advanced medical care from the tertiary-care centers to the field. This has placed a greater burden on the flight crew to be skilled and adept at critical care. Treatments and modalities previously rendered in hospitals are now routine for in-flight care. Patients previously thought to be unstable for transport are pushing the envelope and boundaries of conventional care, and military budget restraints are not allowing the massive medical units of the past. This is necessitating aeromedical crews to provide care farther, faster, and to more critical patients than they have ever done before.

References

The Air Evacuation System was first used in World War I by the USA Air Corps and was organized into a military patient airomedical evacuation (AE) system during the Korean conflict. Rapid transport by air with effective medical care en route has markedly changed the way in which head- and spine-injured patients can be managed and transported from the field to facilities that offer definitive neurosurgical care. In many metropolitan areas, helicopter transportation of patients with blunt or penetrating head trauma and spinal injury has become routine. Many studies have shown the benefits of rapid AE of critically ill patients.

Currently, the US military operates a state-of-the-art system for transporting personnel injured in the field to air transportable hospitals (ATKs) or regional hospital facilities for large-scale military operations. Due to the increasing frequency of contingency operations (eg, “military operations other than war”; MOOTW), a system is being developed whereby critically injured patients are transported long distances relatively soon after their injuries, often before they have received definitive care. One result has been an increased need for long-range transportation of critically ill neurosurgical patients. In response, the US military medical system is developing new standards for managing these critically injured patients in-flight while en route to definitive care facilities. This chapter will cover initial evaluation, stabilization, and in-flight management of the neurosurgical patient with intracranial and/or spinal injury.

Initial Evaluation of the Head Injury Patient

Once the patient’s airway is secured and they are hemodynamically stable, an initial neurological assessment should be performed. The Glasgow Coma Scale (GCS) is the most widely used and accepted method by which the physician and ancillary health-care personnel can rapidly assess the neurological status of a trauma patient. For an accurate GCS score, no paralytics, sedatives, or other medications that may blunt the patient’s ability to respond should be administered. The exam can be performed quickly and communicates vital information relative to the severity of the head injury to personnel at the receiving medical facility. The GCS is comprised of three parts: the best eye opening, verbal, and motor evaluation with a maximum combined point score of 15 and a minimum of 3. In general, mild head injury patients have a GCS of 13 to 15; moderate head injured patients a score of 9 to 12; and severe head-injured patients have scores of 8 or less.

The eye assessment determines whether the patient is able to open his eyes spontaneously (4 points), to voice (3 points), to pain (2 points), or unable to open eyes (1 point). Verbal evaluation determines whether the patient is oriented (5 points), confused (4 points), inappropriately verbal (3 points), incomprehensibly verbal (2 points), and nonverbal (1 point). The letter “T” after the verbal score indicates the patient is intubated. The best motor response deter-
mines whether the patient is able to obey commands (6 points), localize to pain (5 points), withdraw to pain (4 points), decorticate flexion (3 points), decerebrate extension (2 points), and has no response (1 point). It is important to recognize both decorticate flexion and decerebrate extension responses as these imply significant and severe head injury. The pupillary exam is extremely valuable as it can provide information as to the existence of an intracerebral hematoma and impending brain herniation. The examination should be performed with a pen- or flashlight shined directly into the eye to evaluate the size and reactivity of the pupil. A unilateral dilated pupil can be the result of a mass lesion within the brain, such as an epidural or subdural hematoma, which can result in irreversible brain damage and death without rapid medical and surgical intervention.

### Classification of Head Injury

Head injury can be classified by three methods: severity, mechanism, and morphology. There is no universally accepted guideline; however, this approach has proven useful in the diagnosis and management of head-injured patients.9,10

#### Severity

The GCS has been developed to provide objective uniformity to the evaluation of the head-injured patient. Those patients suffering from mild, moderate, and severe head injury have GCS scores of 13 to 15, 9 to 12, and 8 or less, respectively. In patients with severe head injury (GCS score of 8 or less), 90% were found to be in a coma (ie, unable to obey commands, utter words, or open their eyes).8,12

#### Mechanism

Head injury occurs by two basic mechanisms: blunt or penetrating trauma. Examples of blunt trauma include motor vehicle accidents where the head hits the windshield or a blunt object such as a baseball bat hits the head. Penetrating trauma results when a projectile enters the cranium, such as a bullet or knife. The primary distinction between the two is the presence or absence of dural penetration.

#### Morphology

When classifying injuries by morphology, the two broad categories are skull fractures and intracranial lesions.11

### Specific Types of Head Injuries

#### Skull Fractures

Skull fractures may be linear or stellate, depressed or nondepressed, and open or closed. Clinical signs that may indicate a skull fracture include large scalp abrasions or stellate lacerations. Scalp lacerations should be attended to promptly with irrigation, debridement, and closure because significant blood loss can occur. At the least, the patient’s head should be wrapped to prevent excessive blood loss. Gentle palpation of these areas with a gloved hand may reveal a bony step-off, or bone fragmentation. Battle’s sign (redness/bruising behind the ear) or raccoon’s eyes (bruising around the eyes) can indicate a basilar skull fracture. Other signs may include clear cerebrospinal fluid (CSF) leaking from the ears or nose or VII nerve palsy. Head computed tomography (CT) with bone windows clearly demonstrates skull fractures (Fig 14.1). In

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Response level</th>
<th>Score</th>
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<tbody>
<tr>
<td>Eye opening</td>
<td>Spontaneous</td>
<td>4</td>
</tr>
<tr>
<td>To verbal command</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>To pain</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>No response</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Best motor response</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obeys verbal command</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Localizes pain</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Flexion withdrawal to pain</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Flexion abnormal to pain</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>(Decorticate)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension to pain response</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>(Decerebrate response)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No response to pain</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Best verbal response</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oriented, converses</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Disoriented, converses</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Inappropriate words</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Incomprehensible sounds</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>No response</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
general, these fractures are repaired surgically if they are open, to reduce the risks of meningitis, or when the outer table of the skull is below the inner table of the skull on imaging studies.\textsuperscript{11}

Skull fractures can also be associated with an intracranial lesion such as a hematoma or contusion. Intracranial lesions can be further classified as focal or diffuse. Focal lesions include epidural and subdural hematomas, intracerebral hematomas, and contusions. Diffuse lesions include diffuse axonal injury (DAI), mild concussion, and classic concussion.\textsuperscript{11}

**Epidural hematoma**

An epidural hematoma is a blood clot located between the dura (the covering of the brain) and the undersurface of the skull, and has a lenticular shape because the clot is pushing the dura away from the undersurface of the skull (Fig 14.2). It is usually the result of a skull fracture and tearing of the middle meningeal artery, which runs on the inner surface of the skull, but venous bleeding can also cause an epidural hematoma. The patient may present with a “lucent interval” after which the patient may lapse into a coma.\textsuperscript{11} These injuries are uncommon, representing less than 1% of head injuries; however, early recognition and evacuation of the clot is important because outcome has been found to directly correlate with the clinical status of the patient before surgery. Mortality increases from 0%, to 9%, to 20% for patients not in coma, obtunded, and in deep coma before surgery, respectively.\textsuperscript{13} Optimal diagnosis and treatment within a few hours decreases overall mortality rates of 20% to 55% to 5% to 10%.\textsuperscript{14}

**Subdural Hematoma**

A subdural hematoma is a blood clot that occurs between the dura and the brain, and these have a convex appearance on CT (Fig 14.3). They are more common than epidural hematomas, occurring in 30% of head-injured patients. This injury is frequently caused by shearing of the bridging veins between the draining sinuses and brain or lacerations of the brain surface. In many series, mortality is about 60% and there is usually associated underlying brain damage. Rapid administration of medications to reduce intracranial pressure (ICP), such as mannitol, and expedient evacuation of

![Figure 14.1](image1.png) Bone-windowed axial head CT showing depressed skull fracture. Note the inner table of the skull is below the outer table.

![Figure 14.2](image2.png) Axial head CT showing right-sided frontal epidural hematoma.
the blood clot are the hallmarks of treatment. It was found in a series of 82 patients with acute subdural hematoma that patients operated on within 4 hours had a 30% mortality compared to 90% mortality if surgery was delayed more than 4 hours ("4-hour rule"). Therefore, rapid air evacuation of these patients is critical.

Intracerebral Hematoma

Intracerebral hematomas are blood clots within the brain substance (Fig 14.4). They can cause significant mass effect requiring evacuation, in particular when located near the brain stem in the temporal lobe.

Contusions

Contusions are frequently seen in head-injured patients and can be envisioned as “bruises” of the brain. They have the appearance of a “salt and pepper” pattern on head CT and are not as dense as intracerebral hematomas (Fig 14.5). They most commonly occur in the frontal or temporal poles of the brain, where during rapid deceleration, such as after the head hits a windshield, the brain is pushed up against the skull. Over a period of hours to days, these can evolve to intracerebral hematomas causing mass effect, increased ICP, and require surgical evacuation. The distinction between a contusion and intracerebral hematoma is not always clear, as contusions can evolve and enlarge to form an intracerebral hematoma.

Diffuse Axonal Injury (DAI)

DAI is felt to be a result of the shearing of axons during a rapid deceleration of the brain. It is the most common injury seen in head-injured patients. This term describes prolonged posttraumatic coma that is not due to mass lesions or ischemic insults. Patients with severe DAI, which comprises 36% of all head-injured patients, often present after motor vehicle accidents with decorticate or decerebrate posturing and often remaining severely disabled if they survive. CT imaging may reveal small punctate contusions throughout the brain and magnetic resonance imaging (MRI) may show white matter changes, in particular in the corpus callosum. Distinguishing between DAI and hypoxic brain injury is not easy in the clinical setting, and the two may coexist.
Avoiding Secondary Neurological Insults Upon Transport

Primary injury to the brain occurs at the time of impact and pertains to direct damage by trauma to the skull, brain, and surrounding tissues. Secondary injury occurs after the primary injury and includes the development of cerebral edema or brain swelling, intracranial hemorrhage, such as an epidural or subdural hematoma, and intracerebral brain hemorrhage. Hypoxemia and ischemia can be due to increased ICP and/or shock. Although medical personnel have no control over the primary injury, they can help to reduce the deleterious effects of secondary injury. To reduce the harm caused by secondary injury, the following principles should be followed:

- Rapid stabilization of airway, breathing, and circulation (ABCs of the Advanced Trauma Life Support [ATLS] protocol).
- Spinal stabilization with use of cervical collar and backboard.
- Rapid transportation to health-care facility.
- Optimizing patient’s hemodynamic status and oxygenation during transport.

Episodes of hypoxemia and hypovolemia must be avoided to improve outcomes of patients with head and/or spinal cord injury, and the significance of secondary injury on the outcome of head-injured patients has been well documented. Toward this end, specially trained personnel with appropriate equipment are required for the safe AE of patients with acute brain and spinal cord injuries (Table 14.2).

An analysis of outcomes from severe head injury from the Traumatic Coma Data Bank revealed that mortality increases from 30% in patients without hypoxia and hypotension at admission to 60% with those who were hypotensive and 75% in those who suffered both insults.

Figure 14.5. Axial head CT of right frontal contusion.

Table 14.2. Equipment required for AE of patients with acute brain and spinal cord injuries.

<table>
<thead>
<tr>
<th>Equipment required for AE of patients with acute brain and spinal cord injuries.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse oximeter</td>
</tr>
<tr>
<td>Face masks, nasal cannulas, endotracheal and tracheostomy tubes</td>
</tr>
<tr>
<td>Ambu bags with appropriate adapters for endotracheal and tracheostomy tubes</td>
</tr>
<tr>
<td>Laryngoscope and oropharyngeal blades</td>
</tr>
<tr>
<td>Surgical kit to perform cricothyroidotomy or tracheostomy</td>
</tr>
<tr>
<td>Suction apparatus and cannulas</td>
</tr>
<tr>
<td>Firm cervical collars of various sizes, halo vests</td>
</tr>
<tr>
<td>Sandbags or other means to immobilize the neck, backboard</td>
</tr>
<tr>
<td>Appropriate traction devices without weights (eg, cervical halters)</td>
</tr>
<tr>
<td>Turning bed (eg, Stryker frame) or improvised from two stretchers</td>
</tr>
<tr>
<td>Padding for pressure points</td>
</tr>
<tr>
<td>ICP monitoring equipment</td>
</tr>
<tr>
<td>Fluids and drugs</td>
</tr>
<tr>
<td>Mannitol, lasix</td>
</tr>
<tr>
<td>Sublingual nifedipine or nitroglycerin</td>
</tr>
<tr>
<td>Dilantin, ativan, phenobarbital</td>
</tr>
<tr>
<td>Methylprednisolone</td>
</tr>
<tr>
<td>Fentanyl, morphine, pancuronium</td>
</tr>
<tr>
<td>Antibiotics</td>
</tr>
<tr>
<td>Pressors (ie, dopamine)</td>
</tr>
<tr>
<td>Cystalloid IV Fluid</td>
</tr>
<tr>
<td>Collor IV Fluid</td>
</tr>
<tr>
<td>Blood Products</td>
</tr>
</tbody>
</table>
Hypoxia

Maintenance of the airway is the single most important management requirement in the unconscious patient. The most life-threatening aspect of unconsciousness is the loss of normal swallowing mechanisms, resulting in the inability to handle oropharyngeal secretions and keep the upper airway clear. In unconscious patients, unrecognized hypoxia or anoxia may result in severe, permanent brain dysfunction or death. Hypoxia and hypercarbia induce vasodilatation of blood vessels, which results in increased cerebral blood volume, increased ICP, and, potentially, cerebral herniation.16

Hypotension

Hypotension following brain trauma is another potentially avoidable cause of secondary brain injury. Every effort should be made to maintain normotensive blood pressure levels in brain-injured patients. Cerebral autoregulation is impaired after a head injury, resulting in cerebral hypoperfusion when systemic hypotension is present.16 When brain injury is accompanied by systemic injury, mortality is doubled. The effect of visceral or lower-extremity injury on mortality was found to result from hypovolemic hypoperfusion.20 On occasion, the scalp is a potential cause of hypovolemia, as it is a very vascular structure. Lacerations should be inspected, cleaned, and closed to prevent blood loss, as these can be a potential cause of hypovolemia. This is especially important if the AE is expected to take hours.

Increased ICP

There is a close relationship between increased ICP and brain damage from head injury.9,29–36 Increased ICP can result from a number of causes: expanding intracerebral hemorrhage, cerebral edema, poor venous drainage, and/or hydrocephalus. Normally, the ICP within the cranial vault is less than 20 mm Hg. Because the skull acts like a solid box with a fixed volume, a mass lesion within the brain can cause a rapid increase in the pressure within the skull. Sustained ICP elevations of >50 mm Hg are associated with a mortality rate approaching 100%.37

Increased ICP worsens outcome by two common mechanisms: decreased cerebral perfusion pressure (CPP) and brain herniation. CPP is the difference between mean arterial blood pressure (MAP) and ICP and represents the force pulsing blood through the brain (CPP = MAP – ICP). Normally, cerebral perfusion pressure is approximately 70 to 90 mm Hg. If it falls to less than 60 mm Hg, brain energy mechanisms begin to fail and neural cellular homeostatic mechanisms deteriorate. When it falls to 0, blood flow to the brain ceases, resulting in global ischemia and death. Although there are not set guidelines, attempts should be made to maintain the CPP above 70 mm Hg.28 This can be performed by increasing the MAP with fluids or vasopressors or by decreasing the ICP.

Intracranial hypertension, if left untreated, can have two effects on the injured brain: herniation and ischemia. Management of elevated ICP should begin early in the triage stages of resuscitation, as it is a significant contributing factor to irreversible brain injury.

Recognizing Increased ICP

Herniation Syndrome

Increased ICP, most commonly from either cerebral edema or a brain hemorrhage, may cause herniation of brain tissue out of its normal position in the cranium. The two most common types are temporal lobe and tonsillar herniation. Temporal lobe herniation, if unchecked, may permanently damage the brain stem, leading to death or permanent coma. Unilateral pupil dilation (ie, a “blown pupil”), caused by compression of the third nerve, may be the first indication of temporal lobe displacement. Tonsillar herniation compresses the medulla in which respiratory centers are contained, thus causing death by inhibiting respiratory drive.

Acute unilateral or bilateral pupillary dilation in a patient with brain injury is a neurosurgical emergency. The most widely accepted theory for the cause of the pupillary dilation is that an intracranial mass lesion (eg, hematoma or tumor) compresses the third cranial nerve as the uncus is herniated downward and medially. Continued compression of the medial temporal lobe into the brain stem results in loss of
consciousness, decerebrate posturing, and cardiovascular collapse. More recent data suggests that pupillary dilation is actually the result of compromised brain stem circulation.\textsuperscript{33}

Changes in blood pressure, pulse, and respiratory rates may also indicate elevated ICP. A Cushing’s triad can be seen with an increased ICP and includes hypertension, bradycardia, and respiratory irregularity. Another early sign of increased ICP is a change in respiratory pattern. The most common change in breathing can be confused with snoring. Because a clear airway and satisfactory oxygen exchange are paramount for brain function, patients should always be given supplemental oxygen and intubated if they are unable to protect their airway.

ICP Monitoring
The indications for placing an ICP monitor include severe head injury (GCS score of 3 to 8) when the patient is not following commands with an abnormal CT scan, or a normal CT scan and age over 40 years, unilateral or bilateral motor posturing, and systolic blood pressure <90 mm Hg. In this setting, the only way to tell whether the pressure inside the head is elevated is by placing an ICP monitor. ICP monitoring is not routinely indicated in patients with mild or moderate head injury. The most common devices used are the ventriculostomy catheter and intracranial parenchymal monitor. The ventriculostomy is a small catheter that can be passed through the brain with the tip lodging inside the ventricle of the brain (Fig 14.6). The advantage of this type of monitor is that it not only measures ICP but can also be used to treat increased ICP by draining CSF into a drainage system (Fig 14.7). The second type of monitor is placed directly into the brain substance just under the dura (Fig 14.8). The advantage to this monitor is that it is relatively easy to place, requiring only a small hole in the skull and tunneling the catheter under the scalp. However, no CSF can be drained and therefore its use is purely for monitoring purposes. ICP monitors should only be placed by experienced medical personnel because their placement, if not performed properly, can result in serious or life-threatening complications. However, once placed these devices can be transported with the patient to help record and manage ICP.
improve outcomes in patients suffering severe head injuries.

Elevate Head of Bed

One of the easiest methods of reducing ICP is to elevate the head of the bed. This improves the jugular venous drainage of the brain and thereby cerebral blood flow. The head should be raised approximately 30° and kept straight in the midline.

**Hyperventilation**

Hyperventilation reduces ICP by causing cerebral vasoconstriction and subsequent reduction in cerebral blood flow\(^3\); however, because of the presence of an increased risk of causing cerebral ischemia with aggressive hyperventilation\(^4\), because of the risk of ischemic injury with hyperventilation, the current recommendation is to avoid chronic prolonged hyperventilation therapy (PaCO\(_2\) of 25 mmHg or less) after severe traumatic brain injury in the absence of increased ICP. Nevertheless, hyperventilation therapy may be necessary for brief periods when there is acute neurological deterioration, such as on the way to the operative suite to evacuate an intracranial hemorrhage. More prolonged use may be necessary in the

**Management of Increased ICP**

Increased ICP can be treated by various means. However, before trying to treat increased ICP it is important that mass lesions such as intracranial hemorrhage that may require surgical evacuation are ruled out. A CT examination should be performed on patients with a history of loss of consciousness and certainly in any patient with a severe head injury. It is important to understand that a head CT can suggest, but not definitively determine, if increased ICP does in fact exist. At present, only invasive ICP monitors can determine if the ICP is actually elevated. Treatment of increased ICP should be started at a threshold of 20 to 25 mmHg. Although head CT is not always available for in-field use, appropriate medical management can be instituted during AE to improve outcomes in patients suffering severe head injuries.
setting of increased ICP refractory to sedation, paralysis, CSF drainage, and mannitol.

CSF Drainage

A ventriculostomy drain can be helpful in managing increased ICP by allowing drainage of CSF while also providing a measurement of the ICP. It can provide continuous drainage of CSF or intermittent drainage as needed by opening up a stopcock device (Fig 14.7). Continuous draining is in general used in the setting where hydrocephalus exists with the burritol bag being arbitrarily set at about 15 cm above the patient’s ear and left open to drainage. For treating increased ICP, 10 to 15 drops of CSF can be emptied as needed every 15 minutes to maintain the ICP below 20 mm Hg. The reason to avoid overdrainage is that it could result in ventricular collapse around the catheter tip, which could cause occlusion of the ventriculostomy or inaccurate ICP recordings.

Mannitol

Mannitol is an osmotic diuretic that is felt to be beneficial to severe head-injured patients with increased ICP in a number of ways, including the following: increases cerebral blood flow, increases cerebral oxygen delivery, reduces hematocrit, and reduces blood viscosity.41, 42 Acting as an osmotic agent, mannitol causes “opening” of the blood–brain barrier, which can contribute to cerebral edema; therefore, it should be administered as repeated boluses rather than continuous infusion.43 Mannitol should not be administered in the setting of low blood pressure because further loss of volume may lead to hypotension. The initial bolus dose is 1 g/kg body weight. Subsequent bolus usually range from 12.5 to 25 g every 4 to 6 hours as needed to keep the ICP below 20 mm Hg. Mannitol is stopped if the serum osmolarity exceeds 320 mOsm to prevent renal failure. Furosemide, a diuretic, can also be used to treat elevated ICP by reducing cerebral edema and CSF production.44 A Foley catheter is essential in these patients.

Pentobarbital Coma

Barbiturates appear to lower ICP through a number of different mechanisms: suppression of brain metabolism, inhibition of free radical-mediated lipid metabolism, and alterations in vascular tone. The most important is likely the lowering of cerebral metabolic requirements. Barbiturate therapy is usually used as a last resort after other methods such as sedation, paralysis, hyperventilation, CSF drainage, and mannitol have failed to bring the ICP below 20 mm Hg. Before initiating this therapy, other causes of increased ICP—such as an expanding mass lesion—must be ruled out, usually with a head CT. There are a number of therapeutic regimens that all require a loading dose followed by a maintenance dose. Because pentobarbitol can cause cardiac arrhythmias and hypotension, it is important that a Swan–Ganz catheter be inserted before initiating therapy. If the patient becomes hypotensive, the therapy must be stopped. A fairly easy regimen is the following:

- Loading dose: 10 mg/kg over 30 minutes; then 5 mg/kg every hour for 3 hours.
- Maintenance dose: 1 mg/kg per hour.

The goal is to reduce the ICP below 20 mm Hg and maintain a burst suppression pattern on electroencephalography (EEG).

Special Considerations Based on Level of Consciousness

The amount of care and the intensity of monitoring required for the patient with acute brain injury during AE are determined by the patient’s level of consciousness. In all cases, the patient will require close observation for changes in mental status, which will require frequent neurological assessments. Changes in mental status may indicate increased ICP.

Air Evacuation of Head Injured Patient

Once a severe head injury has been identified, neurosurgical treatment should be a priority. Institutions without this capability should establish early consultation with a neurosurgeon at a definitive care facility, and arrangements for transport should begin as soon as a severe traumatic brain injury has been iden-
tified. Transfer should not be delayed for unnecessary diagnostic procedures.45

Hypoxia, hypercarbia, anemia, and hypotension contribute to secondary injury, and early recognition and treatment of these problems will result in the best outcome.46 The task of the transport team is to recognize subtle changes from the time of initiation of transport to the time of arrival. The three most important measures are level of consciousness, pupillary function, and motion of the extremities. A decrease in the GCS of two points between examinations is usually an indicator of significant worsening in neurological status. Any pupillary asymmetry of over 1 mm should be regarded as secondary to intracranial pathology until proven otherwise. This is especially important to remember if there is concomitant facial or orbital injury. Lateralizing lesions often cause asymmetry of pupillary response and may manifest in decreased extremity motion on the opposite side.47

Once aboard the aircraft, airway maintenance becomes the most important aspect of care for the brain-injured patient. Unless the patient is ambulatory and fully alert, supplemental oxygen should be administered. Patients with endotracheal tubes or tracheostomies should receive humidified oxygen and scheduled suctioning of secretions. Changes in mental status, such as unconsciousness or not following commands, have a significant risk of increased ICP and require intubation. Stabilization of the airway may be difficult during transport, so it may be wise to intubate early to prevent hypoxia and hypercarbia.48 In many cases, neuromuscular blockade and sedation can prevent hypoxia, hypercarbia, and ICP spikes associated with coughing and “fighting the ventilator” during transport.49–51 It will also help to avoid accidental self-extubation en route, a potentially disastrous scenario.49, 52 The possibility of cervical spine injury must always be kept in mind because certain airway maneuvers may worsen a preexisting injury. Airway compromise from blood, secretions, or loss of mandibular tone accounts for a large percentage of unnecessary morbidity and mortality in patients with head injury and should be suspected immediately if there is deterioration in the patient’s status.48, 53

IV fluid management is an important aspect of care for brain-injured patients, with the goal of achieving both normal intravascular volume and adequate cerebral perfusion. In general, for acute severe head-injured patients a solution of normal saline plus 20 mEq KCl/L is given at a maintenance dose rate. Dextrose is not added to the solution because elevated levels of glucose in acute severe head-injured patients can cause further brain injury. Hyperglycemia aggravates cerebral edema54, 55 and may be exacerbated by steroids.15 An important point is that deliberate dehydration is no longer recommended for patients with acute brain injury to decrease the risk of brain edema. Sufficient hydration is required to assure the primary treatment goal of adequate CPP. Toward this end, urine output should be carefully monitored in critically ill patients with the aid of an indwelling Foley catheter.15

If ICP monitoring is performed, the guideline threshold is 20 to 25 mm Hg. Measures to lower ICP should be instituted if the ICP goes above the threshold. Maintaining a CPP greater than 70 mm Hg is given as a therapeutic option if ICP is elevated.38, 56, 57 Routine measures to lower ICP include elevating the head of the bed 30 to 45° to reduce edema by encouraging venous drainage. Keeping the head midline will prevent kinking jugular veins, which could also impair venous drainage. Avoid hypotension by normalizing intravascular volume and using pressor support if needed.

Early recognition of posttraumatic seizures can prevent secondary injury from hypoxia and increased ICP. In a pharmacologically paralyzed patient, the only indication may be tachycardia, hypertension, or pupillary changes (which could be misinterpreted as brain stem compression due to herniation).48, 58 Phenytoin is useful in preventing seizures in the acute posttraumatic period59 and a short-acting benzodiazepine is a reasonable initial treatment for seizures.48

Unique Problems of AE

AE has effectively reduced the time to transport patients from the field to hospital facilities. Nevertheless, questions arise from transport personnel and physicians regarding air medical
patient safety. The flight environment is physically different, and these implications deserve consideration when transporting a head-injured patient.

Acceleration and deceleration forces are important in aircraft transport, as well as in ground vehicles. For the supine patient, the landing and take-off forces are in the long axis of the body and may become significant. During ascent, the acceleration vector and steep climb angle create a sustained reverse Trendelenburg position. It has been suggested that patients be positioned with the head toward the front of an airplane to avoid blood pooling during accelerations and toward the rear of the plane on landing. This is obviously not always practical, but consideration of this with adjustment of the patient’s positioning during these times can assist with management of ICP by head elevation. The pilot should be requested to avoid the increased gravitational and centrifugal forces that may cause deterioration in an already compromised patient.

Pressurized cabins are maintained by controlling the flow of compressed air out of the cabin to the atmosphere. This flow also controls the thermal environment, so the control of pressure and temperature are closely related. The absolute pressure in an aircraft cabin is almost always stated in terms of pressure altitude. The maximum altitude consistent with flight safety in an unpressurized cabin is 5000 to 7000 ft. Some patients may be unable to maintain full oxygenation of tissues above 6000 ft. Hypoxia can affect not only the patients but the aircrew as well. The maximum cabin altitude of passenger and AE aircraft should be kept as low as possible (below 6000 ft). Cabin pressurization controls environmental changes due to ascent and descent of the aircraft. Flying at lower altitudes can put the aircraft into bad weather and turbulence that can otherwise be avoided by pressurized cabins. The USAF worldwide AE system currently restricts cabin altitude to 5500 to 6500 ft to ensure patient safety with a minimum impact on flight planning. This empirical limit also correlates with the British Royal Air Force Institute of Aviation Medicine.

In an unpressurized aircraft, breathing air at high altitudes can cause a marked reduction in oxygen tension, potentially contributing to secondary injury in the head-injured patient. Therefore, pulse oximetry and supplemental oxygenation should be in place to prevent cyanosis. Also, any reduction in hemoglobin can impair oxygen transport and affect the oxygen available to the brain. Even in a pressurized cabin, reduced PO₂ increases the potential to become hypoxic. Seizures may be precipitated by even mild hypoxia in the susceptible patient.

Barometric pressure decreases with increasing altitude. High rates of ascent are well tolerated, but rapid descent can cause expansion of gases in an enclosed air-filled body cavity. Medical devices such as cuffed endotracheal tubes, balloon bladder catheters, and aortic balloons can produce problems with fluctuations in gas volumes due to pressure changes. Damage to middle-ear structures, paranasal sinuses, lungs, and the gastrointestinal tract are fortunately rare in a pressurized cabin or an unpressurized aircraft at low altitude. Intracranial air (pneumocephalus), usually minimal in head trauma, can expand and cause neurological deterioration. Patients at particular risk include those having major sinus fractures or skull base fractures. Attempts should be made to maintain the cabin altitude at the ambient altitude of the point of origin.

Vibration can be a problem, especially in the transfer of patients by helicopter. The preflight assessment should take into account the effects of vibration and consider minimization of its effects on the head-injured patient. A patient lying on the floor of an aircraft is exposed to more vibration than one on a hanging stretcher or lying on an air mattress, which attenuates the vibrational forces.

Air Evacuation of Spinal Cord Injury Patients

General Principles

Spinal immobilization of patients with suspected spinal cord injuries is initiated at the scene of the accident with external bracing. A general inspection will indicate whether the patient is moving his hands or legs if conscious.
Inspection of the patient’s neck or back may show areas of abrasions or bruising suspicious for spinal injury. If the patient is able to talk and answer questions, a simple pinprick exam can indicate the level of spinal injury (Table 14.3). Like head injury, maintaining an adequate airway and circulation are paramount to preventing further neurological injury. If nasotracheal or orotracheal intubation is necessary, head and cervical manipulation should be minimized by performing a jaw thrust maneuver as described in ATLS protocol. Severe spinal cord injury may result in neurogenic spinal shock resulting in compromised sympathetic tone, causing a decline in peripheral vascular resistance. Clinical indications of spinal shock may include flaccid extremities, absent anal tone, priapism, and sensory loss. Unlike patients who are hypotensive from blood loss, patients in spinal shock may appear well perfused, with pink, warm extremities. These patients should be treated with fluids and vasopressors.

### Cervical Immobilization Devices

Spinal immobilization devices provide rigid fixation to prevent flexion, extension, and rotation of the spine when applied properly. The cervical collar is the most commonly used device for immobilization of suspected cervical spine injuries during transport (Fig 14.9). The collar is applied so that the chin rests snugly above the level of the collar (Fig 14.10). On short-necked persons, a small “short” collar has been developed to prevent head rotation. Once in a cervical collar, the patient can be transported properly secured on a backboard to minimize movement of the spine. It is important to keep in mind that lying on a backboard is extremely uncomfortable and can lead to sacral and scapular decubitus ulcer formation very quickly. Therefore, the backboard should be removed as soon as the patient is transferred to the definitive care facility or onto a stable stretcher. Once at the definitive care facility, the patient can be logrolled slowly off the backboard. This is done by having one individual at the head, another at the torso, and a third at the foot of the bed that supports the individual while the backboard is tilted and removed slowly. The patient is then slowly rolled in a logroll fashion onto the supine position.

More rigid cervical fixation devices include the SOMI brace and halo immobilization (Fig 14.11). The halo comes with a ring that is secured with pins into the skull of the patient (Fig 14.12). Before application of the halo, aseptic preparation of the pin site on the scalp needs to be performed and the skin anesthetized with local anesthetic as the application of the head frame can be painful. Once the halo is in place, adequate alignment of the spine

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**Table 14.3. Pinprick localization of key dermatomes to localize level of spinal injury.**

<table>
<thead>
<tr>
<th>Level</th>
<th>Dermatome</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4</td>
<td>Shoulder</td>
</tr>
<tr>
<td>C6</td>
<td>Thumb</td>
</tr>
<tr>
<td>C7</td>
<td>Middle finger</td>
</tr>
<tr>
<td>C8</td>
<td>Little finger</td>
</tr>
<tr>
<td>T4</td>
<td>Nipples</td>
</tr>
<tr>
<td>T6</td>
<td>Xiphoid</td>
</tr>
<tr>
<td>T10</td>
<td>Umbilicus</td>
</tr>
<tr>
<td>L3</td>
<td>Anterior thigh</td>
</tr>
<tr>
<td>L4</td>
<td>Medial malleolus</td>
</tr>
<tr>
<td>L5</td>
<td>Great toe</td>
</tr>
<tr>
<td>S1</td>
<td>Lateral foot</td>
</tr>
<tr>
<td>S4-5</td>
<td>Perianal</td>
</tr>
</tbody>
</table>

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**Figure 14.9. Cervical collar.**
needs to be assessed with a lateral, and anteroposterior plain radiograph. The patient can then be transported to a definitive care facility. Pin site care during transport includes washing the area two to three times per day with soap and water or a dilute hydrogen peroxide solution.

Reduction of an unstable or displaced cervical spinal column injury (ie, cervical subluxation) can be performed with Gardner–Wells
skull tongs and requires only local anesthesia and aseptic preparation of the scalp (Fig 14.13). Initial radiographic evaluation, which can be performed at an air transportable hospital equipped with plain radiographic imaging modalities, would include anterior–posterior, lateral, and odontoid cervical views. Patients with persistent neck pain and negative anterior–posterior, lateral, and odontoid views would undergo flexion and extension lateral views to rule out ligamentous instability. Cervical reduction should only be performed by an experienced physician, once adequate imaging radiographs have been performed. Although it may be impractical to reduce a patient during AE, patients can be reduced, immobilized in a halo vest, and then transferred to a definitive care facility. Placement of Gardner–Wells skull tongs is as follows: The pin insertion site is located 1 cm above the ear in-line with the tragus. The pins are tightened by hand until the spring-load pin indicator protrudes 1 mm. The pins may need to be retightened after 24 hours. The skull tongs are then attached to a pulley system, which supports weight behind the patient’s head. Small increments, 5 lb or less, are added to avoid overdistraction and possible neurological injury. If the patient reports any neurological deterioration, the weight must be reduced or removed. The weight is added slowly, up to a maximum of in general 5 lb per vertebral body level above the level of injury. Therefore a C5–6 subluxation may require up to 25 lb of weight to reduce. During the distraction period, the patient can be given muscle relaxants such as diazepam (Valium), which will help in the reduction process but must be administered judiciously because the drug can lead to overdistraction and neurological injury in the oversedated patient. Even gaining one functional level with traction can result in a significant improvement in rehabilitation potential. To gain a functional level from C6 to C7 often means the difference between being able to use a wheelchair and not. Once the cervical spine is reduced to its normal alignment, an external immobilization such as a halo can be applied for transport.

Thoracic and Lumbar Spinal Immobilization

The majority of spine fractures occur at the thoracolumbar junction, usually T12 to L1.
because this is a transition zone between the relatively stabilizing chest cavity and the lumbar spine. Most of these patients are without immediate neurological injury and can be initially managed with a thoracolumbar–sacral orthotic (TLSO). Patients can be transferred in the TLSO brace to a hospital facility where more definitive radiographic and surgical intervention can be performed.

**Methylprednisolone Administration**

Early administration of IV methylprednisolone is indicated for spinal cord injury patients.\(^6^9\) To be effective, the steroid needs to be administered within 8 hours from the time of injury, the dose being as follows:

- Loading dose: 30 mg/kg over 15 minutes.
- Forty-five minutes after initial dose: continuous infusion 5.4 mg/kg per hour for 23 hours.

An H2 blocker should also be given concurrently to prevent gastric ulcers. For paraplegic or quadriplegic patients, pneumatic compression hose or TED hose stockings should be in place to prevent venous pooling in the legs, which could lead to deep venous thrombosis and life-threatening pulmonary embolus. Patients with significant spinal cord injury will need placement of an in-dwelling Foley catheter acutely. Long-term management usually involves intermittent catheterization.

An important consideration for the care of paraplegic and quadriplegic patients is the

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**Figure 14.13.** Gardner–Wells skull tongs (A) with a close-up view of the pins that are inserted into the scalp (B).
prevention of decubitus ulcers. Patients with spinal cord injury cannot feel the discomfort of prolonged pressure, nor are they able to move because of paralysis. The loss of cutaneous spinal cord innervation results in an increased risk of skin breakdown at pressure points in as little as 2 hours. The resulting decubitus ulcers may take weeks or months to heal and greatly impair the rehabilitation of spinal cord-injured patients. Therefore, all pressure points, especially overlying bony prominences (ie, heels, hips, elbows, etc.), should be carefully padded to avoid decubitus ulcers. The patient should be turned every 2 hours during the entire evacuation process to check for and prevent decubitus ulcer formation.

In addition, spinal cord-injured patients are prone to constipation; therefore, they should receive stool softeners or suppositories as needed. Adequate blankets should also be provided because autonomic temperature control may be impaired. A final consideration for patients with acute spinal cord injuries is the increased risk of developing gastrointestinal complications, including paralytic ileus, gastric dilatation, the body cast syndrome, peptic ulcer disease, and pancreatitis. Because patients sometimes cannot feel pain related to these problems, the presence of intra-abdominal problems should be suspected in patients with other symptoms, including signs of autonomic dysreflexia, increased pulse rate, and shoulder pain.

Preparation for AE

All patients with acute spinal cord injuries should be thoroughly prepared for AE. This will usually include placement of an IV line for hydration, a Foley catheter into the bladder, and a nasogastric tube because of the paralytic ileus that often complicates this condition.

In-Flight Care

Airway maintenance remains the highest priority for patients being transported after spinal cord injury. Patients with high cervical lesions may often have some degree of respiratory compromise and may need to be intubated prior to AE. These patients will need careful attention to keep their airways clear of secretions.

Autonomic Dysreflexia

Autonomic dysreflexia is a life-threatening complication of spinal cord injury that occurs in patients whose injury is above the T6 level. It is an exaggerated autonomic response that can occur following a mildly noxious stimulus. The greatest time of occurrence is after the resolution of spinal shock injury and results from a disconnected feedback loop between the sympathetic and parasympathetic branches of the autonomic nervous system. The result is that any significant stimulation below the level of injury (eg, distended bowel or bladder) provokes an unopposed autonomic response, resulting most commonly in paroxysmal hypertension. Other symptoms include anxiety, diaphoresis, piloerection, headache, tachycardia, and erythema of face and chest. If untreated, autonomic dysreflexia can cause a cerebral hemorrhage, cardiac arrest, blindness, or even death. Treatment includes removal of the offending stimulus (ie, catheterize bladder or assure that the Foley catheter is not kinked) and elevation of the head of the bed (to decrease ICP). Antihypertensive drug therapy can include sublingual nifedipine, hydralazine, or nitroprusside.

Conclusion

Patients with brain and spinal cord injuries can be air evacuated safely and effectively acutely and after definitive neurosurgical care. An accurate evaluation of the patient’s neurological condition, acute stabilization, and in-transport medical management during AE can help improve patient outcomes and reduce secondary brain and spinal cord injury.

References


14. Air Evacuation of the Neurosurgical Patient


Otolaryngology has had a long and close relationship with aviation. The environment of flight posed many physiological challenges that were noted with the earliest human flights. The first ear block was described by J.A.C. Charles in 1783 when he experienced sharp ear pain upon descent in a balloon. A decade later, Benjamin Rush noted problems with epistaxis in a French balloonist.\(^1\) The first physician assigned as a “Flight Surgeon” to the US Army Signal Corps (1917) was an otolaryngologist from Philadelphia by the name of Robert J. Hunter.\(^2\) This close relationship has continued to this day. This chapter will begin with a discussion of specific otolaryngologic problems of flight. Next, it will address the aeromedical evacuation (AE) concerns regarding the movement of patients who have relevant otolaryngologic diseases, sustained trauma to the head and neck, and undergone recent otolaryngologic surgery.

Otolaryngologic Problems Associated with Flight

Middle-Ear Barotrauma

The most common otolaryngologic symptom associated with flight is the “ear block.” During ascent, most passengers do not experience problems as gas expansion in the middle ear forces open the normally closed Eustachian tube, thus releasing pressure. Upon descent, however, the Eustachian tube must be actively opened by chewing, swallowing, yawning, or performing the Valsalva maneuver. Passengers with upper-respiratory infections should avoid flying because their edematous Eustachian tubes and mucus membranes put them at increased risk for both ear and sinus barotrauma.

The Valsalva maneuver is performed by occluding both nares and exhaling against a closed mouth, thus forcing air into the nasopharynx to open the Eustachian tubes.\(^2\) If this is unsuccessful and the difference between ambient pressure and middle-ear pressure becomes $\geq 90 \text{ mm Hg}$, the Eustachian tube may become “locked” shut. If this pressure differential cannot be relieved, pressures inside the middle ear may range from 100 to 500 mm Hg and result in the rupture of the tympanic membrane.\(^3\)

Ear pain, presumably related to a locked Eustachian tube, can be experienced upon descent by $>20\%$ of adult air passengers and $>50\%$ of children.\(^4\) In this Danish study, 46% of adults and 33% of children who experienced pain were able to clear their ears using the Valsalva maneuver. A majority of the remaining adults and children who were unable to clear their ears were found to have signs of barotrauma (eg, tympanic membrane redness, retraction, clear fluid in the middle ear, or hemotympanum), but none had ruptured eardrums.

The risk of middle-ear barotrauma can be minimized through early and frequent attempts at ventilating the middle ear (eg, Valsalva maneuver, chewing gum, etc.) and the use of topical nasal decongestants prior to the flight.
and in anticipation of descent. Toward this end, sleeping passengers should be awakened before descent. Symptoms can also be controlled by returning the aircraft to an altitude above the point at which symptoms developed, although this is rarely practical in large commercial aircraft. Descent can then be attempted again at a slower rate while the person continues to equalize the pressure in the middle ear.

Treatment of middle-ear barotitis includes topical nasal and systemic decongestants. In severe cases, a Politzer bag can be used to apply pressure to the nasopharynx (Fig 15.1). To use this device, the mouth is closed along with one nostril, the Politzer tip is placed in the other nostril, and the patient is instructed to swallow while pressure is applied with the bag.

Perforation of the tympanic membrane related to barotrauma will usually heal spontaneously as long as infection does not occur and water is kept out of the ear. The patient with an acute tympanic membrane perforation will not experience further barotrauma in that ear as long as the perforation remains; however, repeated flying can delay closure of the perforation. The patient should not fly until the ear has returned to normal, which may take several weeks or more.

Alternobaric vertigo is another form of middle-ear barotrauma that results in vertigo thought to be induced by unequal pressure between the left and right middle ear. The vertigo is self-limiting and resolves with clearing of the pressure differential. Obviously, this can have disastrous consequences if it occurs in pilots while they are taking off or landing an aircraft.

Inner-Ear Barotrauma

Inner-ear barotrauma can occur from air travel, nose-blowing, diving, or any other phenomena that can cause a middle-ear overpressure. The most common damage to the inner ear is rupture of either the round or oval window membranes, which results in the loss of perilymph fluid from the otic capsule and injury to the hair cells of the auditory vestibular system. The clinical results can include sensorineural hearing loss and vertigo. Patients typically present with a “flat” hearing loss upon audiometric testing (all frequencies equally affected). In one study, only 15% of patients presented with vertigo or dizziness.

The effects of inner-ear barotrauma may be permanent. However, if patients present for treatment within 2 weeks of their injury approximately 70% will have marked or almost complete improvement. Treatment consists of bedrest with the head of the bed elevated. Patients who have no improvement or worsening of their auditory or vestibular symptoms after 2 weeks of treatment may have a perilymph fistula. Exploratory tympanotomy and repair of the fistula will usually improve their vertigo; however, in some patients hearing will not improve.

Inner-Ear Decompression Sickness

Decompression sickness (the “Bends”) occurs when nitrogen bubbles form in various tissues following a deep saturation underwater dive. If nitrogen gas bubbles localize to the inner ear, the patient will present with audiovestibular
symptoms. Individuals involved in special operations duty should be aware that flying within 24 hours of diving significantly increases their risk of developing decompression sickness.

**Sinus Barotrauma**

Sinus barotrauma results when pressure cannot equalize, most commonly in the frontal or maxillary sinuses, and can be severely painful, even potentially disabling. Symptoms can occur during either ascent or descent, although they are much more likely during descent. The most common cause is obstruction of a sinus opening by mucus membrane edema secondary to infection or allergic rhinitis. Polyps or tumors can obstruct the sinus openings by a “ball valve” phenomenon (Fig 15.2).

Immediate treatment consists of returning the aircraft or cabin pressure to the altitude where the symptoms began, if practical (Table 15.1). Topical nasal decongestants and analgesics should be given if available and the Valsalva maneuver should be performed in an attempt to clear the affected sinuses. Further changes in altitude should be done as gradually as possible. Recurrent sinus barotrauma may require surgical intervention, as described later in the chapter.

**Table 15.1. Conditions requiring altitude restrictions.**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Altitude Restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anemia less than 7 g of Hg</td>
<td></td>
</tr>
<tr>
<td>Frontal or maxillary sinus block unresponsive to medical therapy</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 15.2. Maxillary sinus ostia demonstrating ball valve action from a nasal polyp. At ground level (1), the sinus is equilibrated with ambient air. Upon descent (2), the polyp is displaced as air flows out of the sinus to equilibrate with the lower pressure. At altitude (3), the sinus equilibrates with the lower cabin pressure. Upon descent (4), the polyp is pushed into the ostia, blocking the sinus and preventing equilibration. The pressure within the sinus can only be reduced by hemorrhage and dehiscence of the lining. At the conclusion of the flight (5), sinus pressure reequilibrates with continued hemorrhage and lining dehiscence.](image)
Barodontalgia

Barodontalgia is an infrequent condition where dental pain is precipitated by altitude change. The differential diagnosis of tooth pain during flight includes sinus barotrauma because pain from this more common condition may be referred to the teeth. The etiology is uncertain but appears to involve diseased pulp tissue. The most commonly affected teeth are those of the posterior maxilla that have recently undergone an amalgam restoration. Definitive treatment usually requires removing diseased pulp and placing a new restoration.9

Otolaryngologic Trauma

Military and Civilian Injury Patterns

The types of maxillofacial traumas seen in warfare have changed throughout the years, based on the changes in types of combat. During World War II, the massive application of artillery and bombing resulted in 75% of facial injuries from shrapnel, while only 10% were from gunshot wounds.10 During the Vietnam War, close combat and in particular guerilla warfare were more common, and thus 58% of the maxillofacial trauma was secondary to bullet wounds, only 30% from artillery, with the remaining 12% resulting from accidents.11 More recently during combat in the former Yugoslavia, approximately 12% of all combat injuries were to the head and neck and approximately one half of these were from gunshot wounds and one half from explosive devices.12

Maxillofacial trauma also constitutes a significant proportion of the trauma treated in civilian trauma centers and may be initially overlooked in patients with multiple-organ system trauma. An Israeli study of prehospital diagnoses made by flight surgeons found that 10% of trauma patients had facial injury, 3% had soft-tissue neck trauma, and 22% had cranial head injuries.13 Approximately 26% of the potentially identifiable facial trauma diagnoses were missed, compared to only 8% of the soft-tissue neck trauma and 7% of the head trauma. An Australian study found that of head-injured patients seen in the emergency department 33% of facial injuries (primarily fractures) were missed.14

Airway Management

Airway control is crucial to victims of maxillofacial trauma, whether the trauma is to the face or neck, penetrating or blunt, and a bony injury or strictly a soft-tissue injury. Airway control is in particular important for unconscious patients and those with cranial vault trauma, facial trauma, or inhalation burns.

Any patient who is reasonably likely to need intubation should have an orotracheal or nasotracheal tube placed prior to AE. It is far better to intubate a patient in a controlled environment on the ground than in an emergency situation in the turbulent and cramped environment of an aircraft.

Orotracheal vs Nasotracheal Intubation

An airway can be secured by insertion of either an orotracheal or nasotracheal tube. Orotracheal intubation has the disadvantage of requiring cervical spine manipulation and direct visualization of the trachea, which can be difficult with massive trauma and bleeding of the lower face or oral cavity. Because victims of maxillofacial trauma are at increased risk of coexisting cervical spine trauma, orotracheal intubation should be performed cautiously with in-line cervical spine immobilization in these patients. The advantages of nasotracheal intubation are that it can be done blindly with a high degree of success and is better tolerated by conscious patients.15 However, nasotracheal intubation is contraindicated in apneic patients. It is also contraindicated in patients suspected of having a skull base fracture, as there is a risk that the endotracheal tube could pass through the cribiform plate into the cranial vault. Evidence of possible skull base fracture includes midface and cranial instability or deformity and hemotympanum.

Both orotracheal and nasotracheal intubation are relatively contraindicated for patients who have had blunt anterior neck trauma (eg, “clothesline” injuries) because laryngotracheal separation or severe laryngeal fracture
may have occurred. Instead, a tracheotomy should be done to stabilize the airway. Blunt passage of the endotracheal tube into a partially separated larynx and trachea could sever any remaining soft-tissue attachments, thus causing the trachea to partially retract into the chest with resultant loss of the airway.

Needle Cricothyrotomy

Needle cricothyrotomy is useful to rapidly provide limited and temporary airway access in any trauma scenario where the trachea cannot be readily intubated. A large-caliber angiocatheter is placed through the cricothyroid membrane into the trachea. This should be a 12- or 14-gauge catheter in an adult or a 16- or 18-gauge catheter in a child. The cannula should then be connected to oxygen at 15 L/minute at 40 to 50 psi via tubing with either a Y-connector or with a side hole cut in the tubing. Intermittent insufflation, 1 second on and 4 seconds off, can be achieved by placing a thumb over the Y-connector or hole in the tube. Patients can be maintained with this technique for 30 to 45 minutes, assuming they previously had normal pulmonary function and have no significant chest injury. Carbon dioxide will build up, which will limit the usefulness of this technique in head-injured patients. Caution must also be used if there is complete airway obstruction at the glottic level, and if such obstruction occurs the flow should be lowered to 5 to 7 L/minute.

Surgical Cricothyrotomy

Surgical cricothyrotomy is more dependable than needle cricothyrotomy and allows appropriate ventilation through a larger endotracheal tube. Multiple studies have demonstrated the efficacy and safety of this procedure in the hands of appropriately trained caregivers in field condition. The technique consists of making either a horizontal or preferably a vertical skin incision and then a horizontal incision through the cricothyroid membrane, dilating the opening with a curved hemostat or the blunt end of a scalpel, and inserting a 5- to 7-mm endotracheal tube or tracheostomy tube. Surgical cricothyrotomy should not be performed in children under the age of 12 due to the risk of damage to the cricoid cartilage. It also should not be performed in patients who have trauma to the larynx and trachea, with possible tracheal disruption. Both needle and surgical cricothyrotomy must be converted to tracheostomy when the patient has reached a surgical facility to minimize the long-term risk of subglottic stenosis.

Hemorrhage

Facial hemorrhage can be significant, but by itself is usually not life threatening. Direct pressure is usually adequate to achieve hemostasis. Penetrating wounds of the neck can cause rapid exsanguination or air embolism if the major vessels of the neck are involved. Surgical ligation may be necessary for emergent control.

Implications for AE with Specific Diagnoses

Epistaxis

Epistaxis may be controlled by a number of methods, including pinching the nose, cautery, anterior packing, and on occasion posterior packing for persistent bleeds. Rarely is ligation or embolization required. Posterior packing has by tradition been accomplished with placement of a bulb catheter, such as a Foley catheter, through the nares and inflated with saline after positioning in the nasopharynx. This is followed by placement of multiple layers of Vaseline-soaked gauze to form the anterior pack and then placement of a c-clamp, taking care not to put pressure on the nasal alae. Specially designed catheters with anterior and posterior bulbs are also readily available. If the bulb catheter is filled with air, the pressure fluctuations associated with flight may cause either increased pressure on the nasal mucosa or resumption of bleeding with decreased cuff pressure. For this reason, the bulb should be filled with water or normal saline instead. Because these patients are breathing predominantly through their mouths, they will need increased humidification and hydration during the flight. Usually blood has filled the lower sinuses (maxillary and sphenoid) and therefore sinuses are typically unaffected by pressure changes of flight. Patients with posterior packs must be closely monitored as the complication rate averages 17% with such things as alar necrosis, sepsis, aspiration, and even cardiac arrhythmias and death.
Midfacial Trauma

Facial fractures are often overlooked in the field, even in the presence of facial lacerations. Fortunately, fractures of the sinus cavities are unlikely to cause sinus barotrauma during flight because the sinus is no longer a fixed-wall cavity and thus allows expansion of gas into the nose or surrounding tissue.

Skull Base Fracture

If a skull base fracture is suspected in a patient, pneumocephalus must be considered and ruled out if possible prior to AE. A patient with an unrecognized pneumocephalus may suffer increased cerebral pressure or brain stem herniation due to expanding gases as the aircraft ascends. If a patient with a documented or suspected pneumocephalus must be transported (ie, urgent or contingency AE), the cabin should remain pressurized at the altitude of the departure facility. In helicopters and smaller transport aircraft where this is not possible, the lowest possible altitudes should be flown.

All head-injured patients should be placed headfirst in the aircraft (ie, head toward the front) to lessen the risk of increased cerebral pressures (pooling of blood in the head) during the take-off acceleration and climb. Drugs to manage potential cerebral complications should be available if possible, as discussed in chapter 15.

Temporal Bone Trauma

Temporal bone trauma may manifest as Battle’s sign (postauricular ecchymosis), tympanic membrane rupture, facial nerve paralysis, or hearing loss. If the middle ear is filled with blood, barotrauma during flight does not occur. In some cases, temporal bone fractures can breach the cranial vault, resulting in leakage of cerebrospinal fluid (CSF) and a potential pneumocephalus. A delayed complication is meningitis, as nasopharyngeal organisms contaminate the CSF.

Postoperative Otolaryngologic Patient

The AE of patients after otolaryngologic procedures poses unique challenges in maintaining the comfort and safety of these patients. This can be in particular disconcerting to the aeromedical flight crew if they are unfamiliar with the particular procedure performed or if written details of the operation are lacking. Familiarizing oneself with these procedures, as well as good communication with the otolaryngologist, should alleviate concerns.

Tracheostomy

There are many types of tracheostomy tubes, but the typical tube consists of an inner cannula with an outer sleeve (Fig 15.3). This inner cannula can be readily removed for cleaning, while the outer sleeve maintains the patency of the tracheostomy. The cuff is inflated to isolate the trachea from the larynx and secretions above and allow for a seal during ventilator use. When the patient is spontaneously breathing, this cuff may be deflated to allow passage of air through the mouth. The patient may be able to speak if the cuff is deflated and the tube is occluded on exhalation, thus allowing air to pass through the larynx.

Figure 15.3. The typical tracheostomy tube is made up of three parts: the outer sleeve (A), inner cannula (B), and obturator used to place the tracheostomy tube (C).
To facilitate speech, the patient may use a custom tube that is cuffless and typically is of a smaller size, or is fenestrated. Fenestrated tubes have a hole on the outer curve (posterior) of the tube to allow passage of air through the mouth. A fenestrated inner cannula must be used in conjunction with the fenestrated outer sleeve. The fenestrated tube has fallen into some disfavor because of possible irritation against the posterior trachea leading to subglottic stenosis.

Foam-filled cuffs are available that have a lower pressure against the tracheal mucosa. The foam cuff is collapsed through an external valve in the same fashion that air-filled cuffs are. Also commonly seen are customized and irregularly shaped tracheostomy tubes that may have only a single lumen.

Several principles apply to the use of all tracheostomy tubes. Tracheostomy tubes should be frequently cleaned and inspected. Spares should be available. Suction should also be readily available. Either air or oxygen, if required, should be humidified and applied to the tracheostomy tube rather than to the mouth or nose.

If a tracheostomy tube is dislodged, the inner cannula should be removed and replaced by an obturator that allows smooth reintroduction of the outer cannula of the tracheostomy tube into the airway passage. The obturator is then removed and the inner cannula is reinserted. The tracheostomy tube with obturator should be lubricated or moistened prior to introduction and this should be done with the patient’s neck extended under good lighting. For this reason, the obturator should be secured in an obvious place prior to AE, such as on the front of the patient’s chart or on the head of the bed.

**Implications for AE**

Patients who have tracheostomies are ready to fly as soon as they have recovered from their operation and preferably have undergone their first tracheostomy tube change, usually after the fifth postoperative day. This period could be compressed if surgical capability exists in the AE transport and final destination. The tube should be sutured into position when the tracheostomy is first performed and the sutures removed only when the tracheostomy tube is first changed. The tracheostomy provides an excellent airway and should be kept free of secretions and crusts. Humidification should be provided due to the low relative humidity of cabin air.

**Tracheostomy Cuff**

Conventional teaching on tracheostomy tubes has been to replace the air in the cuff with water or saline prior to take-off to avoid problems of changing cuff pressures in flight. The air-filled tracheostomy tube cuff pressure is normally between 20 to 60 torr, but in an unpressurized aircraft at 35,000 ft cuff pressure can reach 385 torr. An excessively high pressure of this magnitude can damage the tracheal mucosa. Alternatively, inappropriately low pressures upon descent can result in an inadequate seal, increasing the risks of aspiration or air leaks if the patient is on a ventilator.

The current recommendation, however, is to leave air in the tracheostomy tube cuff because the use of fluid causes difficulty in monitoring cuff pressure and leakage. It could also cause damage to the cuff valve, requiring premature changing of the tube, according to S. Derdak (personal communication, August 1998 and March 2000). In practice, the pressure changes during flight are slow and of relatively small magnitude because modern aircraft maintain a cabin pressure equivalent to approximately 8000 ft. It is a simple matter to check the cuff pressure with a cufflator upon reaching cruising altitude, every 30 minutes during the flight, and again during descent. Self-regulating cuffs are now also readily available. If the number of aeromedical personnel available is not sufficient to satisfactorily perform cuff pressure monitoring, replacement of the air with fluid remains a reasonable alternative.

**Specific Diagnoses**

**Tonsillectomy**

Patients who have undergone a tonsillectomy, with or without adenoidectomy or uvulopalatopharyngoplasty, are at risk of hemorrhage at two different times during the postoperative period. The time of greatest risk
is the first several hours after surgery. A postoperative tonsillectomy hemorrhage that can be controlled in an emergency department or operating room might be fatal in an aircraft.

The second period of increased risk of hemorrhage is approximately 7 to 14 days after surgery, when the eschar separates from the tonsillar fossa. For this reason, elective AE should be delayed until 2 weeks after tonsillectomy or after the eschars in the tonsillar fossae separate (Table 15.2).

If urgent or contingency AE is required sooner than 2 weeks, the risk of bleeding may be decreased by giving the patient humidified air and ensuring adequate fluid intake en route to counteract the dry atmosphere. If significant bleeding occurs, diversion to the nearest medical facility is required.

Rhinoplasty and Septoplasty

Patients who have undergone rhinoplasty or septoplasty are able to undergo AE after the nasal passage has been cleared of splints and packing, usually 24 hours after surgery. Splints may be left in place as long as 1 week. The majority of patients will be able to breathe better through their nose after septoplasty. However, for several weeks after surgery residual edema of the turbinates and mucosa may predispose the patient to sinus blockage. Patients should be treated with a nasal decongestant spray before and during flight if AE is required within the first few weeks postoperatively.

Endoscopic Sinus Surgery

Conditions that put patients at increased risk for sinus barotrauma are often treated surgically. Endoscopic sinus surgery is used to enlarge natural sinus openings for patients with chronic infections, tenacious mucus, or congenital bony abnormalities and remove obstructing pathology such as sinonasal polyps and tumors.

Aviators who have undergone this “functional endoscopic sinus surgery” have significantly fewer or no episodes of sinus barotrauma postoperatively. A study at Wilford Hall Medical Center of 54 aviators who had undergone this procedure found that 98% had returned to active flight duty. Aviators who have undergone endoscopic sinus surgery should be “preflight” tested in an altitude chamber prior to returning to flying status.

In general, patients who have undergone such surgery have few problems with air travel. However, elective AE should be delayed for at least 24 hours to allow resolution of any postoperative edema. Patients who require AE sooner should be treated with nasal decongestants and frequent Valsalva maneuvers to minimize the risk of sinus block. Patients should be cautioned that vigorous Valsalva maneuvers after some types of ethmoid surgeries (eg, involving the lamina papyracea, cribiform plate, or fovea ethmoidalis) may result in orbital emphysema or pneumocephalus.

If a sinus block occurs during flight in a patient post-sinus surgery, the aircraft should climb back to the altitude where the sinus block developed, if at all possible. Decongestants should be administered if available and descent then can be resumed at a more gradual rate with regular Valsalva maneuvers. Analgesics may be administered if the patient is not in control of the aircraft. Sinus barotrauma may result in an episode of epistaxis that is usually self-limiting and easily controlled.

Pressure Equalization Tubes

Patients with patent pressure equalization (PE) tubes in their tympanic membranes should have no difficulty with ear blocks. These patients may fly as soon as they are recovered from surgery. The patency of these tubes can usually be determined with direct otoscopy and insufflation or, if patency cannot be determined by direct visualization, then this can be readily determined by tympanography. A flat, high-volume tympanogram indicates a patent pressure equalization tube, whereas a flat, low-volume tym-
panogram indicates either a plugged PE tube with middle-ear effusion or one that has extruded and the tympanic membrane has since sealed, with the development of serous otitis media. A fluid-filled middle ear is not affected by altitude change because fluid does not expand and contract as gases do at altitude.

**Stapedotomy**

Otosclerosis is a disease that causes fixation of the stapes to surrounding bone, causing a conductive hearing loss. This can be treated with hearing aids or surgically corrected by stapedotomy. This procedure involves removing the stapes superstructure over the stapes footplate, drilling a small hole through the footplate, and placing a piston-like prosthesis into the hole, which is then directly connected to the incus. This restores ossicular mobility, resulting in improved hearing. A stapedectomy is a similar procedure; however, the entire footplate is removed and replaced with fascia/vein or perichondrium. Theoretically, these patients are at a higher risk of perilymph fistula. Patients who have undergone stapes surgery are allowed to fly in commercial aircraft after they have recovered from the anesthetic and are symptom free.

**Tympanoplasty**

Tympanoplasty encompasses a variety of operations that may involve the removal of middle-ear pathology, repair of ossicles, or reconstruction of the eardrum. A variety of materials may be used to repair the tympanic membrane and ossicles. A patient who has undergone recent tympanoplasty or even a tympanoplasty associated with some form of mastoid surgery should be able to fly as soon as recovered from the effects of the anesthetic and are symptom free. Movement of the tympanic membrane flap during pressure changes may dislodge grafts or prostheses. Prior to taking a flight after healing, these patients should begin performing frequent Eustachian tube clearing maneuvers, including gentle Valsalva maneuvers, chewing, if yawning, and swallowing.24

Placement of some types of ossicular prostheses creates a small but serious risk of perilymphatic fistula, regardless of the time since surgery. A prosthesis such as a total ossicular replacement prosthesis (TORP) lacks the natural lever action of the ossicle that it replaces. Excessive tympanic membrane motion transmitted directly to the footplate of the stapes may acutely create a perilymphatic fistula.25 This rarely can occur while the patient is trying to clear an earblock with forceful Valsalva maneuvers or during abrupt changes in cabin pressure (ie, explosive decompression). Symptoms can include sudden vertigo, nausea, vomiting, and a sensorineural hearing loss. Treatment is supportive, with immediate follow-up by a specialist after scheduled landing.

**Acoustic Neuroma and Cerebellar Pontine Angle Surgery**

Acoustic neuroma is the common name for a vestibular nerve schwannoma, a benign slow-growing lesion that causes compression of the contents of the internal auditory canal and ultimately grows into the cerebellopontine angle. These lesions can be treated with surgery, stereotactic radiation, or observation. The surgical accesses most commonly used include the translabyrinthine, retrosigmoid, and middle fossa approaches. Depending on the approach, the patient has a 9% to 29% risk of developing a CSF leak within the first few postoperative days.26

If a CSF leak develops after surgery, patients should not undergo elective AE for 2 weeks after any leakage has resolved. In the past, it was considered safe to fly immediately after a CSF leak resolved. However, there are reports of patients who flew immediately after the leakage resolved (following a translabyrinthine approach) and developed bacterial meningitis within hours of landing.26 The hypothesis is that, during descent, the relative negative
pressure that develops within the middle ear and Eustachian tube allows nasopharyngeal pathogens to reflux back into the middle ear and come into contact with CSF, resulting in meningitis.

Laryngectomy

Patients who have undergone a total laryngectomy have had their larynx removed and the trachea brought out through the anterior neck. They may have a short single lumen tube similar to that of a tracheostomy tube that fits within the trachea and helps prevent contracture at the tracheostoma site. Patients who have undergone a total laryngectomy may have a small one-way valve inserted on the posterior wall of their trachea and into the pharynx (such as the Blom-Singer® valve, International Healthcare Technologies, Carpinteria, Calif) that allows oral speech when the tracheostoma opening is occluded with their thumb. There are no problems associated with this condition during flight other than excessive drying. One pilot was reported to fly even after his total laryngectomy.27

Mandible Fractures

Patients with mandible fractures will usually require intermaxillary fixation (IMF, ie, their jaws are wired shut). For this type of fixation, arch bars are wired to the mandibular and maxillary teeth and then wired to each other, typically with four wire loops.

Patients with IMF are at risk of aspiration if they vomit with the wire fixation in place. If patients have a tendency toward motion sickness, they should be given antiemetics and placed on their side with the head down. In high-risk patients, the fixation wires should be removed and replaced with rubber bands.28 If wires are left in place, wire cutters should be worn around the neck for the rapid release from fixation in the case of vomiting (Fig 15.4). It is only necessary to cut and remove the wire loops spanning between the maxillary and mandibular bars (Fig 15.5).

Neck Dissection/Thyroidectomy/Free and Pedicled Flaps

Patients who have undergone neck dissection, thyroidectomy, or free or pedicled flaps should be able to be moved by elective AE after 2 weeks and after all drains have been removed, no fistula exists, and the flaps are viable. Earlier
movement may predispose patients to cutaneous emphysema or pneumopericardium.

**Conclusion**

The field of otolaryngology—head and neck surgery is strongly interwoven with the fields of flight medicine and AE. Successful flying requires the proper function of the middle-ear spaces and sinuses. An intact and functioning audiovestibular system is also highly desirable for passengers in aircraft and is required for those controlling aircraft. The transport of postoperative, wounded, or ill patients by AE introduces another level of complexity in the physical response to flight (Table 15.3). The anatomy and physiology of the head and neck is complex. When this anatomy is disrupted, the potential for troublesome or even disastrous complications is significant. An understanding of normal anatomy and function, and how this has been altered in the AE patient, is the key to safe and successful transport of these patients.

**References**


As the level of sophisticated weaponry has increased, the mortality rates associated with combat-related injuries in the field have decreased. This can be attributed to advances in medical and surgical capability, protective equipment ensembles, forward deployment of definitive medical treatment facilities, timely evacuation of wounded personnel from the field, and an extensive aeromedical evacuation (AE) system.

As overall mortality rates associated with combat have declined, combat-related ocular injuries have paradoxically come to represent an ever-increasing proportion of nonlethal combat-related injuries. It may also be said that the costs of prolonged medical care associated with ophthalmic injuries following cessation of hostilities represent an ever-increasing portion of postconflict expenditures. Some studies have indicated that the cost of postconflict ophthalmic care related to the Vietnam Conflict alone will likely exceed $4 billion.1 Nonlethal weapon technologies and interventive therapies of the future are certain to save lives but are almost equally as certain to increase these costs even further. Such statistics serve to emphasize the necessity to assure that adequate eye protection is worn in the field. Sadly, even during recent conflicts, the evidence shows eye protection is usually underutilized by troops in the field.

Ocular injuries likely to be encountered during modern military operations run the full gamut of potential ocular damage scenarios experienced with similar peacetime occupational and vocational threats. Ophthalmologists are trained and familiar with the nuances and medical/surgical management of this entire spectrum of potential resultant ocular damage. It is indeed likely, however, that high-speed ballistic particles and their associated damage will tend to represent the bulk of military-related ocular injuries. In addition, wartime-related eye injuries differ with respect to civilian situations in several other key areas: (1) longer time delays and restricted access to definitive ophthalmologic intervention; (2) risks associated with intra- and extratheater evacuation, in particular those involving AE; (3) laser-related ocular eye injuries; and (4) the sheer number of cases that will likely require intensive management at virtually the same time.

Unfortunately, an ophthalmologist is unlikely to be available at far-forward locations where ocular injuries may be most likely to occur. Most of those ocular casualties will depend on nonophthalmic medics for proper stabilization and movement to medical facilities for definitive ophthalmologic treatment. Depending on the intensity level of the military operation and the isolation of the area of operations, definitive ophthalmologic care will often be delayed. For this reason, it is important for nonophthalmologic medical practitioners to have a basic working knowledge of the principles of interim and emergency management of common ocular injuries. They must also have an effective understanding of the indications for AE, the potential modes of transport available, and the appropriate return to duty criteria. This approach applies not only to traditional war-related ocular injuries but also to
laser injuries, as this threat increases on the modern battlefield.

This chapter will briefly discuss the history of ocular casualties, the most common mechanisms of injury, and some specific ocular diseases and injuries, together with their AE implications.

**History**

Based on past military conflicts, medical managers and planners can anticipate that 8% to 10% of all combat-related injuries will likely involve the eye (Table 16.1). A significant percentage of these ocular injuries are likely to be complicated and severe. Penetrating and perforating eye injuries will occur 20% to 50% of the time. Of penetrating injuries, 30% to 85% will be associated with one or more intraocular foreign bodies, and 28% will involve both eyes.2

In addition to battlefield trauma-related injuries, other conditions that might require AE from the theater are related to sports and systemic diseases. In most military operations, disease and nonbattle injuries (DNBIs) exceeded those related to combat by considerable numbers. Fortunately, the majority of patients with nontraumatic opthalmic conditions will rarely require AE. Therefore, this chapter will focus on trauma-related opthalmologic injuries, many of which are significantly more likely to occur during combat.

The percentage of wartime-related ocular injuries has steadily increased and is perhaps a reflection of a parallel increase in overall survivability from other combat wounds. It should also be stated that, with the exception of the Gulf War, the threat of laser-based weapons was previously nonexistent. Although proper ballistic and laser eye protection may significantly reduce these ocular risks in the future, compliance with such protective devices, especially under the rigors of combat, is unpredictable and certainly not universal. It is also likely that the proliferation of laser-based weapons and the current focus on nonlethal weapon technologies may actually contribute to an even greater number of disabling, albeit nonlethal, eye injuries in the future.

During the Vietnam Conflict, only about 25% of combat-related ocular injuries were ever returned to duty.3 Fortunately, timely evacuation of ophthalmic causalities from the field has steadily improved, being reduced from an average of 36 to 48 hours from the time of injury during World War II to about 4 hours during the Gulf War.4–6 As the estimated costs of medical care associated with ocular injuries rises, defensive and interventive strategies that minimize the ocular risks and their sequelae also have other ramifications on society that go well beyond the immediate urgency of the moment.1,7

The risk for laser-related ocular injuries remains high on the modern battlefield despite an international treaty that bans the use of any laser weapon specifically designed to blind or damage the human eye. There are several reasons why this treaty is not a panacea and will not eliminate laser eye injuries. These include: (1) Not all countries are signatories to this treaty; (2) The “Bad Guys” have a habit of breaking all the rules; and most importantly, (3) the current treaty does not ban military weapon systems that employ lasers that will almost certainly cause injury when they accidentally strike the human eye.

**Mechanism of Injury**

The two most common mechanisms of ocular injury in combat will be ballistic and laser injuries. Ballistic injuries have been a part of warfare from the beginning, but lasers have only recently appeared on the battlefield. This

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**Table 16.1. Ocular casualty rates in military conflicts.**

<table>
<thead>
<tr>
<th>Conflict</th>
<th>Percentage of eye injuries</th>
<th>Mortality rates (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19th-Century wars</td>
<td>&lt;1</td>
<td>Unavailable</td>
</tr>
<tr>
<td>World War I</td>
<td>1.5–2.1</td>
<td>12.0</td>
</tr>
<tr>
<td>World War II</td>
<td>2.0–3.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Korean War</td>
<td>2.8–8.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Arab–Israeli wars</td>
<td>5.6–10.0</td>
<td>Unavailable</td>
</tr>
<tr>
<td>Vietnam Conflict</td>
<td>5.0–9.0</td>
<td>2.6</td>
</tr>
<tr>
<td>Gulf War</td>
<td>13.0</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Peacetime ocular injury rate: 1.7–2.4%.

*Source: Adapted with permission from Wong et al.2*
section will provide a summary of these dual threats, followed by discussions of the specific injuries that occur as a result of each. A schematic diagram of the eye is included to facilitate the following discussion (Fig 16.1).

Ballistic Injuries

The unprotected eye offers little innate tissue resistance to flying battlefield projectiles and concussive forces. This is true whether the projectile is kinetically enhanced by high speed and thus being of high energy or low speed, low mass and, therefore, of lower energy. Although the eye only represents a mere 0.27% of the total body surface, the incidence of eye injuries is surprisingly 20 to 50 times higher than expected based on proportional surface area representation.8

The inherent ballistic protection associated with wearing eye protection devices is well appreciated in both the operational military and peacetime environments. In most cases, any spectacle eyewear affords some degree of ocular protection for the eye. However, polycarbonate lenses offer the greatest degree of protection to a wide range of projectiles (including small-caliber bullets) when properly worn.

Compelling troops to properly and consistently wear eye protection remains a problem. There has been only moderate progress made in this regard since World War I, when post-conflict analyses indicated that 50% of all ocular injuries could have been avoided with proper eye protection.9 During the Yom Kippur War, only 27% of Israeli troops used their polycarbonate goggles and according to Heier et al only 3 of 92 US soldiers with field-related ocular complaints during the Gulf War acknowledged ever using goggles.9,10

The explanations for the inadequate use of eye protection are complex and multiple. In some cases, adequate eye protection may not be available. More often, the extreme range of environmental factors associated with the rigors of military operations discourages their use. Factors that tend to dissuade the individual from using such equipment even when the threat is high include the presence of particulates, smoke, heat, sweat, fogging, movement of the devices, glare, clarity, optical consequences, and ease of integration with other personal equipment. During the “heat of battle,” compliance is further compromised by the overpowering drive to optimize all visual input.

While ballistic injuries on the battlefield may be of such magnitude that ocular damage will be the least of the concerns, properly worn ballistic ocular protection will eliminate a considerable number of unnecessary war-related ocular injuries. Such protection undoubtedly avoids or mitigates many types of head trauma, perhaps even saving lives. Much the same can be said of current laser eye protection (LEP) devices, which consist most often of polycarbonate goggles or visors.

Laser Injuries

Accidental or deliberate laser-induced eye damage is becoming more likely with the proliferation of laser-based technology on the modern battlefield. Essentially, any laser-ranging weapon system can blind the human eye, whether intended or designed for that purpose or not. Further, military history supports the premise that, once at war, some adversaries may choose to disregard international treaty obligations or may not have been signatories of such a treaty in the first place. Consequently, the likelihood of combat-related laser eye injuries on the battlefields of tomorrow will

Figure 16.1. Anatomy of the eye.
continue to remain high. This means we will be faced with related dispositional decisions in such cases to include management, evacuation, and return to duty issues. Most laser-related eye injuries will not compromise the integrity of the ocular globe and will not usually involve any special medical AE criteria beyond routine ambulatory care.

The spectrum of laser eye injuries will run the gamut from temporary reversible effect, such as glare and flash blindness, to permanent damage from outright ocular burns and hemorrhages. Retinal damage can be caused by laser beams in both the visible and near infrared parts of the spectrum. These wavelengths are automatically focused by the cornea and lens through to the retina. This focus significantly increases the energy density and, therefore, the potential to reach thresholds for damage in retinal tissues increases dramatically.

Many of these injuries will leave individuals functionally disabled, either temporarily or permanently, thus presenting field commanders with additional casualty management considerations and problems. In this chapter, laser-induced eye injuries on the battlefield will remain confined to those that affect the ocular globe and surrounding ocular adnexa, although powerful laser systems of today and tomorrow are capable of causing even deeper and more widespread tissue destruction (Fig 16.1).

### Specific Ocular Injuries and Diseases

#### Corneal Injuries

**Corneal Abrasions**

Corneal abrasions are caused by a wide variety of insults, including contact lenses, flying projectiles, or direct contact by objects such as vegetation and fingers. Regardless of etiology, injuries to the cornea may vary from superficial epithelial defects to deeper corneal damage with the associated potential to develop a permanent corneal scar.

A related corneal injury is laser burns. Although focused laser energy can result in serious burns or penetrating injuries, certain lasers may result in an injury undistinguishable from a corneal abrasion. In addition, exposure to laser energy not strong enough to directly cause injury can result in reflex rubbing of the eyes, causing a secondary corneal abrasion. Whenever a laser injury of the cornea is suspected, a careful and comprehensive ophthalmic examination, to include a dilated retinal exam, must be accomplished to exclude other ocular tissue damage.

**Corneal Lacerations**

Tissue lacerations, such as in the cornea, are described as either penetrating (partial) or perforating (through and through), if for example, the cornea is completely violated (Fig 16.2). Although most types of corneal lacerations are treatable, perforating lacerations are more serious because they are more likely to result in permanent loss of vision. Further, perforating lacerations can introduce contaminated foreign material into the eye. Any resulting intraocular infection, referred to as an endophthalmitis, can be vision or life threatening.

**Implications for AE**

Because virtually all corneal abrasions will heal within a few days, such patients will usually not

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**Table 16.2. Duration of cycloplegic agent effects.**

<table>
<thead>
<tr>
<th>Cycloplegic agent</th>
<th>Percentage</th>
<th>Duration of effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropicamide</td>
<td>0.5–1.0</td>
<td>4–6h</td>
</tr>
<tr>
<td>Cyclopentolate</td>
<td>0.5–2.0</td>
<td>1 d</td>
</tr>
<tr>
<td>Scopolamine</td>
<td>0.25–0.50</td>
<td>2–3 d</td>
</tr>
<tr>
<td>Homatropine</td>
<td>2.0–5.0</td>
<td>3–5 d</td>
</tr>
<tr>
<td>Atropine</td>
<td>1.0–5.0</td>
<td>1–3 wk</td>
</tr>
</tbody>
</table>
require immediate AE. However, patients traveling in the AE system may have incidental corneal abrasions so AE crews should know how to treat them.

In most cases, urgent AE is required for serious corneal lacerations that occur in the field because immediate evaluation by an ophthalmologist in a surgically capable facility is always required. Evacuation can be delayed for a few days for less complicated nonpenetrating corneal lacerations, but contingency AE will still be required for ophthalmologic evaluation and treatment.

Statistically, open eye injuries do better when definitive ophthalmic care is not delayed. While some trapped air may be associated with penetrating lacerations, small amounts would not usually be expected to be a significant problem in an open eye. While it is possible that an expanding bubble of trapped air in such an eye could cause additional ocular damage, many specialists feel that these eyes can travel safely at routine AE altitudes and that the most expedient AE methods should be selected that will deliver the patient to more definitive care as quickly as possible, thereby making altitude restrictions of lesser concern, especially if such a restriction would result in a significant delay. However, the same cannot be said of intraocular gases in a closed eye, ie, following retinal detachment surgery, and will be discussed later in this chapter.

**Lens Injuries**

Isolated lens injuries are rare. Combat trauma or acute laser injury severe enough to cause a lens injury is almost always associated with other more serious ocular damage. For this reason, all lens injuries need assessment by an ophthalmologist as soon as possible, even though not all such injuries will require immediate intervention. Ophthalmologic assessment, including baseline visual acuity and slit lamp examination, is required to determine the extent of any associated lenticular damage.

Treatment for lens injuries will be necessary whenever there is dislocation, formation of a cataract, or lens capsule rupture. Lens capsular rupture often requires immediate surgical removal because exposure of the eye to lens proteins may result in a significant ocular inflammation.

**Implications for AE**

Injury to the lens requires immediate ophthalmologic evaluation for the reasons discussed above, and the patient should thus be classified as urgent AE. If ophthalmologic evaluation determines that the lens capsule is intact and no other eye injury is present, such individuals can usually return to duty. AE crews do not need to accomplish any specific actions in the management of these patients.

**Globe Rupture**

Globe rupture (ie, rupture of the eye) is a relatively common combat-related ocular injury (Fig 16.2). The most common form of globe rupture is a perforating laceration, usually
of the cornea or sclera. Less commonly, blunt trauma can cause rupture of the globe. Globe rupture must always be ruled out following significant blunt trauma, especially if one eye is “soft” compared to the other eye or there is obvious disruption of normal ocular architecture.

Any injury that perforates an entire layer or coat of the eye carries with it a high potential for intraocular infection (endophthalmitis). Infection can be expected in 2% to 7% of all perforating ocular injuries, with a slightly higher likelihood related to a perforating combat eye injury.\textsuperscript{12,13} Such injuries will require antibiotic intervention immediately. Intravenous fluoroquinolones would be an excellent first choice. Intravitreal antibiotics can also be used, but an ophthalmologist must administer these.

The visual consequences of globe perforation vary greatly, depending on the amount and location of tissue disrupted as well as the occurrence of any infection. However, today’s modern ophthalmologic equipment and techniques have dramatically improved our ability to save the globe.

\textbf{Implications for AE}

Regardless of etiology, a ruptured globe is an emergency that requires immediate surgical intervention by an ophthalmologist and should be classified as urgent AE. In most cases, the prognosis for the eye will be guarded, but statistically these eyes do better when definitive ophthalmic care occurs quickly after the injury. Regardless, every attempt must be made to save the eye.

Unfortunately, definitive care may be delayed for hours or even days for casualties whose injuries occur in remote locations. In these cases, appropriate field management and timely AE are of the utmost importance (Table 16.3) as discussed previously under corneal lacerations.

Probably the most important issue for patient transportation is \textit{position}. Throughout the transportation process, the patient with a ruptured globe should remain reclined, with the head elevated and face up. In no instance should the patient be positioned head-down.

\begin{table}[h!]
\centering
\begin{tabular}{|l|}
\hline
\textit{Implications for AE} Table 16.3. Field management for globe rupture. \\
\hline
\textit{Position} the patient supine, with the head elevated \\
\textit{Patch} injured eye to eliminate light and contamination; \textit{avoid direct pressure} \\
\textit{Shield} the injured eye with a metal or plastic shield to prevent direct pressure and additional damage \\
\textit{Minimize extraocular movements} by also covering the good eye with a pinhole patch \\
\textit{Prophylactic antibiotics} should be administered intravenously to all patients with globe rupture \\
\textit{Evacuation} should be by urgent AE to the nearest available ophthalmic care \\
\textit{Altitude restriction}: Usually none if the globe is open; if closed and containing intraocular air or gas, see restrictions under retinal detachment section \\
\hline
\end{tabular}
\end{table}

With a ruptured globe, an appropriate field dressing can sometimes make a dramatic difference in final outcome. The injured eye should be covered with a \textit{patch} to eliminate light and protect the eye from contamination. It is of critical importance that \textit{no direct pressure} be applied to the globe. To prevent direct pressure and additional damage to the eye, a metal or plastic \textit{shield} (eg, Foxx shield) should be properly secured over the patch for the injured eye. A Foxx shield is malleable and must be individually formed to the face so that its points of contact are clearly on the bony structures of the orbital rim and forehead and not on the patch or globe itself. To \textit{minimize extraocular movements}, the good eye should also be covered with a “pinhole” patch. A small hole in the center of the patch will give the patient some vision while minimizing eye movement. In addition, intravenous \textit{prophylactic antibiotics} (usually a fluoroquinolone) should be given to all patients with a ruptured globe.

Unless full-service ophthalmic care is readily available at the site of injury, \textit{evacuation} will be required for these patients. In general, this will be in form of urgent AE because the failure to receive timely specialized ophthalmic intervention will increase the risk of both permanent loss of vision and loss of the eye itself. Therefore, in an open globe rupture the benefits of expedient delivery of the patient to definitive care usually outweighs most of the altitude-induced effects. Thus, mandating an altitude restriction that significantly delays definitive care will prove problematic in most cases.
Chorio-Vitreoretinal Injuries

Chorioretinal injuries can be associated with any traumatic eye injury. They represent the most likely type of laser injury to be encountered. A complete ophthalmologic evaluation of both eyes is required.

Vitreoretinal Hemorrhages

Traumatic hemorrhages from any cause will in general fall into four basic categories based on location: subretinal, intraretinal, subvitreal, and intravitreal (vitreal). Laser-induced hemorrhage will vary in location and degree depending on the laser’s power, degree of focus (divergence), and wavelength, as well as which specific tissues are affected.

Regardless of the etiology of hemorrhage, visual acuity may be affected as a direct consequence of the bleeding or because of the primary location of the eye injury. Thus, a retinal hemorrhage may produce either an unrecognized and inconsequential small blink spot if the damage is in the periphery, or a less than best-corrected visual acuity, if central.

The treatment of vitreal hemorrhages is to remove blood that does not spontaneously reabsorb after a suitable period of time. However, treatment is required only when the remaining blood is functionally disabling. Although the emergency treatment of vitreoretinal hemorrhages is limited, several field management principles should be followed to minimize further damage (Table 16.4). Again, position is an important issue for patient transportation. The patient with a vitreoretinal hemorrhage should remain reclined with the head elevated. Field evaluation should include ophthalmoscopic and x-ray evaluation for intraocular foreign bodies with reexamination by an ophthalmologist as soon as possible. Patients should undergo evacuation as soon as possible for ophthalmologic evaluation. However, these patients do not need to be classified as urgent AE based on this type of injury and require no specific treatment en route.

Chorioretinal Burns

Chorioretinal burns are the most likely and most serious laser-related eye injuries that will occur on the modern battlefield. Management will depend on the site of the injury. A small burn in the fovea can result in significant visual impairment, whereas burns in the retinal periphery can be extensive and yet not affect vision. These injuries require immediate ophthalmologic assessment to determine the etiology, best management, and the potential for return to duty. Laser eye experts should be consulted immediately if a laser eye injury is suspected.

A laser injury of any significant degree in or near the macula will usually have serious permanent visual sequelae. Proper laser eye protection remains the best defense against laser eye injury.

Implications for AE

Immediate ophthalmologic evaluation is mandatory, so these patients should be moved by urgent AE if no ophthalmologist is available locally. Unfortunately, little can be done to restore vision after a serious macular burn, making return to duty unlikely. These patients require no specific treatment en route other than pain relief or possibly systemic steroids if recommended by the receiving ophthalmologist.

Chorioretinal Tears

Chorioretinal tears represent a true emergency and need immediate ophthalmologic evaluation and treatment. Consequently, patients with this injury must be evacuated at the earliest possible moment and should be classified as urgent AE. The treatment of chorioretinal tears is beyond the scope of this chapter and will need to be addressed on a case-by-case basis by ophthalmologists.
**Implications for AE**

These patients should remain as immobile as possible during AE to minimize the risk of retinal detachment or vitreal hemorrhage. Field and AE management is similar to those used for globe rupture with the exception of the requirement for antibiotics unless the tear is associated with a ruptured globe.

**Retinal Detachment**

Retinal detachment should always be considered following significant ocular trauma or when a patient complains of a loss of vision that is usually described as “a shade being pulled over the visual field.” Field and AE management are the same as for chorioretinal tears. The details of specific diagnosis and treatment are beyond the scope of this text. However, its treatment is significant to AE because of the intraocular gases used during ophthalmologic surgery.

Intraocular gases have been used to tamponade retinal tissue since Ohm introduced them in 1911. It was not until 1973 that gases other than air were used. Today, ophthalmologists use mixtures of air and other exotic gases such as sulfur hexafluoride and perfluorocarbon gases to help position or tamponade the retina against the underlying ocular tissues to facilitate retinal reattachment and healing. Exotic gas mixtures are used because of their weight, ability to expand after injection, and slower reabsorption times, all of which promote more prolonged positive effects in the eye compared to air alone. Nonetheless, all such gases are subject to the same gaseous laws as air and thus expand at altitude. However, the debate regarding the relationship between “safe and tolerable” amounts of intraocular gas and routine flight altitudes remains unresolved.

In general, if patients with residual intraocular gas must move for any reason cabin altitude should be limited to 2000 ft or lower or no higher than the altitude of the sending location, if higher than 2000 ft. If other more urgent patients require movement on the same mission as such “eye” patients, and an altitude restriction will significantly delay the mission and endanger lives, then the altitude restriction should not be requested.

**In-Flight Issues**

An eye problem may not always be readily apparent in an obtunded, unconscious, or heavily sedated patient, especially during contingency AE. If an otherwise conscious patient

<table>
<thead>
<tr>
<th>Types of gas</th>
<th>Weight (relative to air)</th>
<th>Reabsorption time (1 cc)</th>
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<tbody>
<tr>
<td>Air</td>
<td>Same</td>
<td>7 d</td>
</tr>
<tr>
<td>Sulphur hexafluoride</td>
<td>Heavier</td>
<td>10–14 d</td>
</tr>
<tr>
<td>Perfluorocarbon gases</td>
<td>Heavier</td>
<td>10–65 d</td>
</tr>
<tr>
<td>Xenon</td>
<td>Heavier</td>
<td>1–2 d</td>
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suddenly complained of pain, decreased vision, or increased drainage from the eye or orbit during aircraft ascent, this should draw immediate concern to the possibility of an expanding intraocular air bubble. Research has shown that the expansion of as little as 0.25 to 0.50 cc of air at altitude can significantly increase intraocular pressure to levels that threaten retinal perfusion. In the event of the acute onset of eye pain during AE, an attempt should be made to gently and carefully determine if gas is now visible in the anterior chamber. A dire sign of potential intraocular air is prolapse of intraocular contents.

If the presence of intraocular air creates problems during an unrestricted altitude AE flight, the flight crew should be alerted immediately and a request should be made to descend the aircraft such that the cabin altitude is 2000 ft above ground level or lower. Such a luxury may not always be operationally possible, especially in hostile territory, but once free of immediate danger an appropriate lower flight level should be flown as expeditiously as possible.

Resolution of the complaint upon descent would be reassuring. Although damage may have already been done, lowering cabin altitude may prevent further damage and restore adequate retinal blood flow. However, no attempt should be made to replace any expelled ocular contents back into the globe.

Finally, motion sickness associated with AE is a major concern with all open eye injuries or recent intraocular surgery. Such motion sickness may cause vomiting, leading to ocular or suture rupture. Appropriate antiemetics should be employed if evacuation and mental status conditions allow their use, but only after consideration of the potential impact on any other bodily injuries.

Conclusion

Rapid and appropriate AE of patients with serious eye injuries is an absolutely critical step in facilitating a favorable outcome when these injuries occur in locations where definitive ophthalmologic evaluation and treatment is not available. Therefore, expedient delivery of the patient to definitive care typically overrides any altitude restrictions. One exception is for patients who have had surgical introduction of intraocular gas in a closed globe. Further, there are no absolute contraindications for moving ocular injuries, and a decision regarding AE profiles must take into consideration other patients and factors related to the contingency situation. It is critical for medical triage personnel in the field to make the proper clinical and evacuation decisions early in the course of the injury.

Future providers will be challenged with new and expanding threats, such as the proliferation of lasers on the battlefields of tomorrow. Telemedicine communication in the future may facilitate field triage by extending ophthalmologic intervention and decisions directly to the scene. Certainly, every effort should be made to prevent eye injuries. However, when injuries do occur the modern combatant can take comfort that a modern AE system will help ensure that definitive medical care is obtained more quickly than before.

References

Until the 20th century, the acute surgical management of vascular injuries was solely directed at the control of hemorrhage. By the 1950s, a number of factors contributed to the successful application of vascular repair techniques. In military medicine, rapid casualty evacuation from the battlefield, using both helicopters and fixed-wing aircraft, often allowed surgical care to be rendered within 1 to 2 hours following injury, thus improving outcomes. In addition, better understanding of the importance of debridement, the use of delayed primary wound closure, and the availability of antibiotics decreased the hazards of infectious complications. The broader use of arterial repair preserved limb function and successfully lowered amputation rates following major vascular injury from approximately 50% in World War II to 13% during the Korean conflict. Aeromedical evacuation (AE) and surgical care further improved vascular outcomes during the Vietnam War. In Vietnam, Rich and colleagues reported an overall limb salvage rate of 86.5%. Repair of arterial injuries was the norm by that time, and only 15 of 1000 cases were treated with primary ligation. In addition to the availability of rapid casualty evacuation, better surgical training and new techniques (including the use of the Fogarty embolectomy catheter and external fixation of associated fractures) contributed to these improved results.

Further insight into vascular trauma can be gained from the paramilitary and terrorist activities in Northern Ireland. In his report on a decade of such trauma, Barros D’Sa documented an impressively low 5.1% lower-limb amputation rate. Ninety-five percent of patients were admitted to the hospital within 30 minutes of their injury and more than 80% had revascularization within 4 hours. In addition to rapid intervention, patch angioplasty arterial repair and the use of temporary shunts to maintain flow during treatment of associated fractures and soft-tissue injuries were felt to have contributed to these results.

In wars of the past century, vascular injuries were reported in 0.07 to 2.4% of the combat wounded. The incidence is higher, up to 10%, when considering only those seriously injured who are evacuated to a second- or third-echelon battlefield hospital. Vascular trauma can be expected to make up a significant portion of the injuries sustained in the modern combat environment because wounding patterns of high-velocity missiles or fragments often injure major vessels. In addition, the modern soldier’s body armor may protect him from otherwise fatal chest or abdominal injuries. Therefore, extremity wounds, often with major vascular injuries, can be expected to be a prominent part of the military surgeon’s experience in any future conflict.

Vascular injuries can occur from multiple types of penetrating or blunt trauma. Blood vessels can also be injured by stretch, blast, or cavitation effects or by direct physical disruption. Direct injury can result not only from penetrating trauma but also secondarily from fracture fragments lacerating the vessel. Minimal arterial injuries with nonocclusive intimal flaps may be asymptomatic and can
resolve over time without specific treatment. More extensive intimal disruption leads to thrombosis and occlusion.

Injuries to major blood vessels can pose an immediate threat to lives and limbs. While acute problems often require management within hours of onset, casualties may require urgent AE for further intervention or management of associated injuries. Elective AE for convalescence and rehabilitation can usually be accomplished at an optimal time.

Vascular disease alone may also necessitate AE. Patients with acute complications of peripheral vascular disease may need to be transferred to facilities with capabilities for complicated surgical procedures, angiography and endovascular therapy, and critical-care support. These patients are often elderly, have a history of tobacco use, may have diabetes, and frequently have concomitant cardiac, cerebrovascular, pulmonary, or renal disease.

This chapter will discuss the specific injuries and diseases likely to require AE, the special postoperative considerations, and the general transportation considerations for these vascular patients.

Specific Vascular Diseases and Injuries

Significant physiological disturbances can result from vascular disease or injury, and these disturbances can significantly affect a patient’s clinical status during AE. The most common injuries and diseases will be discussed, including the specific AE implications of each.

Ischemia

Major arterial injuries interrupt distal blood flow (Figs 17.1 and 17.2). The severity of resultant ischemic injury depends on several factors, including the adequacy of collateral arterial circulation, metabolic state, temperature, associated venous injury, soft-tissue injury, and muscle type. Collateral circulation may be well developed with chronic arterial occlusions in older patients with atherosclerosis, but healthy adults (such as trauma victims) may have severe distal ischemia with a single level of arterial occlusion. The result is a much higher rate of amputation after acute vascular occlusion in younger patients compared to older patients.

The “five Ps” describe clinical findings associated with acute ischemia: pulselessness, pallor, pain, paresthesia, and paralysis. Coolness, pallor, and the loss of palpable pulses distal to a site of injury usually indicate a significant arterial injury. These are not specific findings, however, because cool extremities without palpable pulses may also be the consequence of hypovolemic shock with marked peripheral vasoconstriction.

Other signs of vascular injury include empty veins, decreased capillary refill, penetrating injury in proximity to major artery, or peripheral neurological deficit.
Implications for AE

Patients with ischemic, or potentially ischemic, injuries should be positioned so the medical crew has the ability to monitor distal blood flow of the injured limb. Vasoconstriction due to cooling can affect tissue perfusion, a consideration during transport in large military airframes where significant hypothermic exposure is a constant risk.

Hemorrhage

The immediately life-threatening complication from vascular injuries is hemorrhage. Notably, 80% percent of civilian trauma deaths are from hemorrhage. Untreated major injuries to trunk or proximal extremity vessels can cause exsanguination in minutes. Pulsatile bleeding or the presence of an expanding hematoma indicate arterial injury.

Control of ongoing blood loss is always an immediate treatment priority that is accomplished using direct pressure or tourniquets. Direct manual pressure or pressure dressings can be applied to most extremity wounds but cannot be used for neck wounds and are of limited value for wounds to trunk vessels. There are few indications for tourniquet use, as this maneuver may result in permanent neurological injury and increase the likelihood of subsequent amputation. Extremity tourniquets should only be applied when other means fail to control bleeding and tourniquet application is necessary as a lifesaving measure in evacuating a casualty. Tourniquets, once applied, should be removed only when surgical means to arrest bleeding are available.

Vasospasm and tamponade by surrounding tissues are physiological hemostatic mechanisms that help limit blood loss from vascular injuries. Bleeding may also slow as hypotension and hypovolemic shock intercede. A completely divided vessel can retract and constrict, often with complete cessation of bleeding after an initial brisk hemorrhage. Blood loss can be more severe if the injured vessel is incompletely transected, as the lacerated segment may remain open. Further, bleeding that has stopped in a patient with hypovolemic shock may resume after resuscitation restores perfusion pressure.

Hemorrhage from an injured vein can actually be greater than that from an arterial injury, despite the fact that the arterial pressure is considerably higher. Veins have larger diameters and less capability for vasoconstriction because there is much less smooth muscle in the walls of veins. Although there is a difference between the arterial and venous pressures, the two sides of the circulation carry equal flow. Tears in vein walls can extend easily, and attempts to expose the bleeding site can exacerbate blood loss.

It is often difficult to accurately characterize the amount of blood lost. External losses can be deceptive, either appearing much greater or less than actual loss. Internal losses are occult and usually manifest only by the hemodynamic
consequences of the loss of intravascular (IV) volume.

Nevertheless, some clinical findings are pathognomonic for major vascular injury. For example, a systolic blood pressure less than 90 mm Hg in a patient with a penetrating lower-quadrant injury to the abdomen almost always indicates an iliac artery injury. Shock in a patient with trunk or extremity injuries, especially in cases of blunt trauma, can be due to blood loss unrelated to injury of a major vessel, eg, long bone or pelvis fractures.

**Implications for AE**

Patients must have hemorrhage under control prior to AE, whether urgent or elective. In extreme cases, the use of tourniquets might be required to achieve hemostasis. Patients who have had significant blood loss should be placed in litter positions where the medical crew can readily assess their hemodynamic status and assure that hemorrhage does not recur during transport.

**Shock**

Hypovolemia from acute blood loss is one of the most common causes of shock; the state is defined as inadequate perfusion to sustain the physiological needs of organ tissues. Drop in blood pressure may reflect the onset and severity of shock, but significant shock may occur before systolic hypotension is noted. Physiological compensation mechanisms for hemorrhage include peripheral and visceral vasoconstriction (thus shunting blood to the central circulation) and progressive tachycardia. Age, concomitant illness or injury, medications, and environmental factors all affect individual responses to hemorrhagic shock.

**Implications for AE**

The single most important resources required for AE of patients with hemorrhage are adequate fluids and blood products to continue resuscitation, should they be required. This is critical for missions longer than 5 hours, all overseas missions, and any other missions where emergency diversion may add hours to the transport time.

**Ischemia Reperfusion Injury**

Prolonged interruption of a limb’s blood supply results in cellular ischemia, which in turn leads to severe biochemical derangements. These derangements include energy loss from adenosine triphosphate breakdown to hypoxanthine, increased lactic acid production, and failure of membrane ion pumps. Normal membrane concentration gradients are lost, with increases in intracellular sodium (and water) and calcium, as well as extracellular potassium. Analysis of venous blood from ischemic limbs shows marked decreases in P<sub>O2</sub> and pH, with increases in P<sub>CO2</sub> and potassium.

Revascularization following prolonged limb ischemia does not completely prevent progression of tissue damage because microcirculatory failure and continued hypoxia are common. In addition, reoxygenation of previously ischemic tissue results in cytotoxic effects secondary to the generation of reactive oxygen intermediates and proinflammatory substances (including eicosanoids) and endothelial cell–polymorphonuclear leukocyte interactions. Revascularization of a severely ischemic limb also leads to increased compartment pressures, which causes muscle necrosis if not recognized and treated with fasciotomy (see discussion below).

Reperfusion injury can also have significant systemic effects. This is related to the high concentrations of lactic acid and potassium returning to the systemic circulation from a revascularized ischemic limb. If muscle necrosis has occurred, large amounts of myoglobin, creatine phosphokinase, and other toxic compounds are released. The resultant “myonephropathic metabolic syndrome” is characterized by metabolic acidosis and hyperkalemia, kidney failure from myoglobin precipitation in the renal tubules, a reperfusion-induced renal medullary perfusion defect, pulmonary failure caused by inflammatory mediators, and depressed cardiac function. In severe cases, reperfusion injury can lead to limb loss or even death.

Ischemic reperfusion injury is diagnosed on the basis of systemic signs and symptoms. Metabolic acidosis, hyperkalemia, and fluid sequestration can manifest as increased
postoperative fluid resuscitation requirements. Dark, tea-colored urine may indicate myoglobinuria. Oliguria may indicate intravascular volume depletion or renal failure from acute tubular necrosis, which may ensue in the first several days after injury or operation.

Management principles include complete early revascularization, anticoagulation, liberal use of fasciotomies, and intensive medical support postoperatively. In trauma, early revascularization of an acutely ischemic limb should be given priority because the longer the duration of limb ischemia the greater the chance of reperfusion injury. If immediate, definitive revascularization is precluded by orthopedic or soft-tissue injuries, a temporary in-dwelling shunt can be used. When systemic anticoagulation with heparin is contraindicated, eg, because of risks of increased bleeding from associated injuries, regional heparin can be employed in the affected limb after vascular control is obtained. Early fasciotomy (prior to revascularization) should be considered if ischemia has been prolonged or if severe soft-tissue or combined arterial and venous injury is present.

Postoperatively, intensive medical support is often required. To decrease the risk of myoglobin precipitation in the renal tubules and ameliorate the medullary perfusion defect, urine can be alkalinized with bicarbonate infusions. An osmotic diuresis should also be established by the administration of mannitol. Mannitol can also attenuate local and systemic effects of free radical-mediated tissue damage by acting as an hydroxyl radical scavenger, although its effects are limited to the extracellular space. If available, hyperbaric oxygen therapy may also be useful in decreasing edema and muscle necrosis after reperfusion.

Implications for AE

It is crucial that AE medical crew members have an accurate history of which patients have undergone revascularization procedures. A diagram from the surgeon can be a particularly useful contribution to the medical record. Extra fluids must be available to assure a urine output large enough to preclude the kidney damage described above. Fasciotomies should be accomplished prior to AE when indicated (see below).

Compartment Syndrome

Compartment syndrome occurs when interstitial pressure within a confined anatomic compartment exceeds the capillary perfusion pressure (30 to 50 mm Hg), thus resulting in microvascular compromise and ultimately cell death. All four extremities, in particular the legs, contain osseofascial compartments that are surrounded by a relatively inelastic fascial covering. Important risk factors for compartment syndrome in the trauma victim include crush injuries, severe closed fractures of the extremities, combined arterial and venous injuries, prolonged ischemia with reperfusion, and circumferential full thickness burns. In addition, iatrogenic compartment syndromes can be caused by extravasation of fluids administered using pressure infusers and tight dressings.

Unrecognized compartment syndrome continues to plague trauma victims. The diagnosis may not be obvious and can be excluded only in the presence of an open extremity wound. Palpable peripheral pulses do not rule out this diagnosis because capillary perfusion can cease at pressures well below the systolic arterial pressure.

Signs and symptoms that suggest compartment syndrome include pain (especially pain out of proportion to the injury or pain with stretching or contraction of the muscles in the compartment), swollen or tense compartments, and tenderness. Sensory loss and paresthesia are early signs of compromised peripheral nerve function. Loss of motor function occurs later and may be irreversible.

Measurement of Compartment Pressure

Compartment pressure can be measured if invasive pressure monitoring capability is available. One of the simplest techniques is the “continuous infusion technique,” where a hypodermic needle or intravenous catheter is inserted into the tissue and patency is maintained by the slow but continuous infusion of saline. The pressure of the fluid within the needle or
The catheter is continuously monitored with a standard blood pressure transducer. Measured compartment pressures <15 mm Hg reliably exclude the diagnosis of compartment syndrome.

**Implications for AE**

The possibility of compartment syndrome should be considered when examining any patient after vascular surgery, even after fasciotomy. This is usually related to fasciotomies that have been performed through limited incisions or have failed to release all potentially effected compartments.

Development of a compartment syndrome during transport can result in irreversible nerve and muscle injury, leading to permanent disability or even limb loss. The cornerstone of effective management of compartment syndrome remains the preflight recognition of patients at risk. Extensive surgical fasciotomies to decompress compartmental hypertension are the best way to treat or prevent compartment syndrome and should be done prior to air transport any time the condition is suspected. In high-risk patients, prophylactic fasciotomies are often appropriate prior to AE because monitoring for changes in the status of the limb is usually difficult during flight. If a Critical Care Air Transport (CCAT) Team is available, fasciotomies can be performed during flight for those patients who unexpectedly develop compartment syndrome.

**Venous Thrombosis**

Patients with conditions that require AE often possess Virchow’s classic triad of factors predisposing to venous thrombosis, ie, local vessel wall injury, hypercoagulability, and stasis. Clinical conditions associated with these risk factors include: surgery (especially orthopedic, thoracic, abdominal, and genitourinary procedures), trauma (especially with pelvic, femur, or tibia fractures or with any neurological injury), malignancy, pregnancy, postpartum state, immobilization, and in-dwelling venous catheter use.

Thrombosis of pelvic or lower-extremity deep veins (eg, iliac, femoral, or popliteal veins) most often presents with unilateral extremity swelling and mild discomfort. Increased tissue turgor, distension of superficial veins, and prominent venous collaterals may all be evident.

Examination with a hand-held continuous-wave Doppler ultrasound can screen for deep-venous thrombosis (Fig 17.3). In the exam, asymmetry of the limb compared to the contralateral limb, diminished spontaneous venous flow, and loss of the normal phasic variation with ventilation are signs suggesting occlusive venous thrombosis. Small Doppler devices can be used prior to transport in emergency department or field settings, but the fairly subtle findings of the extremity venous examination may not be detectable in a noisy aircraft environment.

The best noninvasive test to diagnose deep-venous thrombosis is duplex venous ultrasonography: 2D gray-scale B-mode imaging combined with pulsed-wave Doppler flow evaluation. A venous thrombosis can be either directly visualized or inferred by the absence of vein wall collapse with extrinsic compression. Contrast venography is rarely, if ever, indicated.
Complications affecting the limb associated with venous thrombosis almost always develop months or years later in the form of chronic venous insufficiency of an extremity. However, acute limb-threatening complications can occur in rare cases. If there is concomitant obstruction of both the deep and superficial collateral veins, marked impairment of venous outflow of the limb will occur. The result is a cyanotic hue and dramatic swelling of the limb, termed “phlegmasia cerulea dolens.” In severe cases, interstitial tissue pressure may exceed the capillary perfusion pressure, causing arterial hypoperfusion and ischemia, termed “phlegmasia alba dolens.”

**Pulmonary Thromboembolism**

Pulmonary thromboembolism is the most serious acute risk associated with lower-extremity or pelvic venous thrombosis. Although as many as one half of patients with pelvic vein thrombosis or proximal leg deep venous thrombosis have pulmonary embolism, most are asymptomatic. In the presence of large or multiple emboli, the acute signs and symptoms are often dramatic and include:

- Increased pulmonary vascular resistance.
- Impaired gas exchange.
- Alveolar hyperventilation due to reflex stimulation of irritant receptors.
- Bronchoconstriction and increased airway resistance.
- Loss of pulmonary compliance from lung edema, lung hemorrhage, and loss of surfactant.
- Circulatory collapse and death may result from acute right ventricular dysfunction.

The clinical diagnosis of pulmonary embolism can be challenging. Dyspnea and tachypnea are frequent but nonspecific. Associated syncope, hypotension, or cyanosis may indicate a massive embolism. Small, distally lodged emboli may cause pleuritic pain, cough, or hemoptysis. Chest radiographs can help exclude other causes of acute pulmonary compromise but rarely yield signs of pulmonary embolism.

The diagnosis of pulmonary embolism should be suspected in the setting of any severe illness or injury, especially if there is leg swelling or an established diagnosis of lower-extremity deep vein thrombosis. Blood gas abnormalities may be seen but are insufficient to diagnose pulmonary embolism.

Electrocardiographic (ECG) abnormalities may be noted in field settings or during transport if multilead capabilities are available. Associated ECG findings include: sinus tachycardia; atrial fibrillation or flutter; and an S wave in lead I, a Q wave in lead V3, and an inverted T wave in lead V3. A rightward axis shift and T wave inversion in lateral leads may indicate right ventricular strain. An initial management plan can be made before arrival at a definitive care site with lung scintigraphy or pulmonary angiography capability.

**Implications for AE**

Patients with known or suspected pulmonary thromboembolism should be stabilized and treated before transport whenever possible. If the patient has remained normotensive with normal right ventricular function, pulmonary embolism is in general managed with anticoagulation. IV heparin infusion (5000 to 10,000 U heparin bolus, followed by an infusion of 1000 to 1500 U/hour) remains the standard therapeutic choice in acute and subacute settings. An activated partial thromboplastin time (PTT) twice the control value confirms therapeutic heparin dosing. Recent studies suggest fixed-dose, subcutaneous low-molecular-weight heparin may be as effective and safe as adjusted-dose, IV unfractionated heparin for the initial management of pulmonary embolism.

Adjunctive measures include pain relief and supplemental oxygen, especially during flights with cabin altitudes of approximately 8000 ft. For patients with contraindications to anticoagulation, or those with recurrent pulmonary embolism despite adequate anticoagulation, an inferior vena cava filter should be placed. Cavafilter placement, when available, should be considered prior to elective transfer of patients with pulmonary embolism who cannot be maintained on heparin.

Transthoracic echocardiography, if available, should be considered prior to interhospital transports to distinguish between different
etiology of cardiovascular instability that may present with some features similar to pulmonary embolism. These include acute myocardial infarction, pericardial tamponade, thoracic aortic dissection, and right heart failure.

AE is contraindicated in those patients with untreated pulmonary embolism associated with hypotension or right ventricular hypokinesis because the mortality risk is high (Table 17.1). Right heart failure and cardiogenic shock is treated with fluid restriction and the beta-adrenergic agonist dobutamine (a positive inotropic agent with pulmonary vasodilating effects). In cases of refractory hypotension, thrombolytic therapy may be required in addition to anticoagulation. In extreme cases, catheter extraction or surgical embolectomy may be needed.

Nontraumatic Vascular Disease

Patients with nontraumatic vascular disease are typically older and are likely to have many comorbid conditions. Detailed medical histories should be obtained prior to transport whenever possible. Peripheral arterial disease is frequently associated with atherosclerosis in other vascular beds, including the coronary and carotid arteries. Patients with concomitant heart disease may experience perioperative myocardial infarction, dysrhythmias, or heart failure.

Risk of complications during AE in these patients is minimized by continuous monitoring, avoiding volume overload, attention to blood pressure control, appropriate analgesia, supplemental oxygen, and consideration of beta-blocker use. Because concomitant diabetes is also common, blood glucose levels should be checked regularly.

Surgical Considerations

Soft-Tissue Coverage

All vessels, vascular repairs, and vascular grafts require adequate soft-tissue coverage to minimize the risk of desiccation and infection. Exposed vein grafts and arterial suture lines tend to break down, with resultant delayed hemorrhage. Although vessel coverage by skin and subcutaneous tissue is important, coverage by fascia and/or muscles is critical. In some cases, muscle flaps may be employed and skin left open. In cases of extensive soft-tissue injury (eg, high-velocity missile injuries), grafts may be routed around the zone of injury. Nonanatomic positioning of grafts, either subcutaneous or deep to fascia, may be necessary. When used, this positioning should be clearly communicated to the accepting medical team.

Shunts

Placement of a temporary shunt to bridge a segment of damaged artery can be used to stabilize patients, thus allowing urgent AE to a referral center for management by a vascular specialist. Shunt placement is not technically demanding and can be rapidly performed (Fig 17.4). Shunt placement for management of limb ischemia is not prioritized above control of hemorrhage. It is unlikely to affect the outcome of patients who have an uncorrected source of hemorrhage or uncorrectable low cardiac output. Fasciotomies are required anytime a shunt is being used to maintain limb perfusion during prolonged air transport.

Shunts can be left in place for hours but need to be monitored. One case has been reported that described the use of a shunt that was inserted into the cut ends of a lacerated superficial femoral artery prior to a 950-mile air evacuation. The shunt functioned well for 16 hours. Animal models of traumatic arterial injury have demonstrated that non-

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<th><strong>Table 17.1. Vascular contraindication to AE.</strong></th>
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<tr>
<td><strong>Absolute (contraindications to elective, urgent, and contingency AE)</strong></td>
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<tr>
<td>Pulmonary thromboembolism associated with hypotension or acute right ventricular dysfunction</td>
</tr>
<tr>
<td>Uncontrolled bleeding</td>
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<tr>
<td>Acute ischemia if resources are locally available for revascularization</td>
</tr>
<tr>
<td><strong>Relative (contraindications to elective AE)</strong></td>
</tr>
<tr>
<td>Thrombolytic therapy</td>
</tr>
<tr>
<td>Within 24h of hyperbaric oxygen therapy*</td>
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<tr>
<td>Associated cardiac complications (myocardial ischemia or heart failure)</td>
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<td>* Unless the cabin altitude pressure can be maintained at the equivalent of sea level or the altitude (mean sea level) of the sending facility.</td>
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heparin-bonded shunts can provide adequate limb blood flow to prevent acidosis, myocyte ischemic necrosis, or systemic complications, even when shunts are in place for up to 24 hours. Continued shunt patency can be assessed with a Doppler, either directly or by serially assessing the distal arterial perfusion. In a contingency setting or in deployed military operations, general and orthopedic surgeons should consider shunt use and fasciotomy for initial surgical management of an ischemic limb if rapid AE with CCAT Teams are available.

Postoperative Considerations

Arterial Patency

The result of the revascularization should be objectively demonstrated with continuous-wave Doppler or operative angiography. Reparable technical problems potentially compromising the success of revascularization should be corrected before transport. Examples include anastomotic narrowing from poor suture technique, distal embolization or thrombosis, elevation of intimal flaps, graft twisting or entrapment, and spasm.

Arterial spasm is a greater problem in young patients than in older patients with atherosclerotic arteries. Spasm can be treated with direct infusion of a vasodilator (eg, intra-arterial nitroglycerin infusion or injection of 60 to 120mg of intra-arterial papaverine) or postoperative treatment with a calcium channel blocker (eg, nifedipine 10 to 40mg orally every 4 hours). Postoperative thrombosis is an indication for reoperation.

Continuous-Wave Doppler

Continuous-wave Doppler is the most common method used to objectively monitor peripheral arterial circulation and is much more sensitive than palpation of pulses. The only equipment required is a pocket or portable continuous-wave Doppler flow detector (Fig 17.3), acoustic gel, a sphygmomanometer, and pressure cuffs. A useful measure of perfusion of an injured lower extremity can be obtained by determining the ratio of the Doppler-derived systolic arterial pressure of the arm to that measured at the level of the ankle on the injured side. This is the “ankle/brachial index” (ABI). For each lower extremity, the ankle pressure is determined as the highest measured systolic pressure obtained by comparing the anterior tibial,
posterior tibial, and in some cases the peroneal arteries. The systemic pressure is determined as the higher of the two brachial pressures. An analogous arterial pressure index can be obtained for an injured upper extremity by comparing the pressure from the injured arm to that of the uninvolved arm. The use of ratios corrects for some of the effects of systemic pressure variations that occur over the course of transport and allows comparison of perfusion measurements between individuals.

A measured pressure gradient (with an index of <0.90) indicates the presence of arterial obstruction secondary to occlusion or stenosis that narrows the lumen diameter by >50%. Serial assessments can detect changes in lower-extremity arterial circulation and are used to monitor the patency of arterial reconstructions. The normal ABI is 1.0. However, a value ≥0.9 after acute injury indicates a low likelihood of a significant arterial injury requiring urgent evaluation. The ABI may also be low due to chronic arterial occlusive disease. This may be suspected in the elderly or in patients with a history of claudication or other peripheral arterial disease manifestations. An ABI <0.30 indicates severe ischemia. These patients will in general have severe pain and face the threat of limb loss without revascularization. Absent ankle signals indicate severe acute or far advanced chronic occlusive disease. Differences in serial ABI determinations of <0.10 in general are not significant.

Another helpful way to evaluate arterial flow is by the audible characteristics of the Doppler flow signal. Normal peripheral arterial flow is triphasic, with three distinct sounds or phases during each cardiac cycle. With decreased peripheral resistance, the flow reversal will disappear and the arterial Doppler signal becomes biphasic. Severe proximal stenosis or proximal occlusion with reconstitution via collateral vessels will produce a low-velocity (low-pitched), monophasic signal.

Vascular Imaging in the Field

Until recently, diagnostic imaging capabilities in environments encountered by deployed personnel have been limited to large field hospitals. Weight and volume constraints limit deployability of conventional radiology equipment, as does the need for darkrooms, fresh water, steady power, etc. While radiographic assessment during transport is impractical, there are commercially available portable ultrasound systems that can be used for vascular imaging. Compact, medium-resolution units that weigh under 10lb can provide gray-scale images adequate for a large number of ultrasound exams, such as detecting the presence of an abdominal aortic aneurysm, venous thrombosis, or other vascular conditions.

Duplex scanning combines real-time 2D B-mode imaging of vessels and surrounding structures with pulsed Doppler ultrasound evaluation of blood flow. Duplex scanning, by combining sonographically derived imaging and hemodynamic information, takes advantage of the strengths of each modality and avoids many of the problems inherent with the use of imaging or flow studies alone. The two greatest problems with duplex scanning are that it requires a skilled operator and advanced ultrasound capabilities are not in general available in the smaller units. Newer capabilities can be expected from future portable systems, including power Doppler, color flow Doppler, spectral Doppler, and 3D volumetric rendering. The usefulness of technologies such as 3D ultrasound remains to be proven, but some distinct advantages may be found in field environments where minimally trained users might be able to perform meaningful examinations that they otherwise would not be able to accomplish.

Anticoagulation and Antiplatelet Therapy

Systemic anticoagulation is contraindicated in those patients with multisystem trauma or other bleeding risks. Patients with thrombotic or ischemic syndromes, however, may be transferred on heparin infusions. Pre- and in-flight monitoring of coagulation function and careful surveillance are critical to minimize bleeding risks. Heparin should be discontinued if there is evidence of bleeding. In addition, protamine sulfate quickly reverses the anticoagulant effects of heparin. One milligram of protamine sulfate reverses 100 U of heparin.
Patients who have undergone complex revascularizations may be on other antithrombotic or antiplatelet therapy. Recent administration of low-molecular-weight dextran may result in volume expansion and risk for heart failure. Conventional antiplatelet regimens rarely cause bleeding problems, but patients who have received combinations of antiplatelet therapies, especially GIIIb2a inhibitors, may be at increased risk for spontaneous bleeding or bleeding from recent puncture sites, injuries, or surgical wounds.

Secondary Infection

After vascular compromise, the patient is at risk for both local infection and systemic sepsis. Bacteria may be introduced by contamination at the time of initial injury or may translocate from the intestinal tract after ischemic injury or shock. Tissues subjected to severe or prolonged ischemia are immunologically compromised and thus at higher risk for subsequent infection. Patients who develop signs of systemic infection, such as fever, tachycardia, hyperemia, or pain, may progress quickly to septic shock in the presence of ischemic or infarcted tissue. For this reason, early administration of antibiotics is indicated in the presence of open fractures, grossly contaminated wounds, or an established infection.

Because of the risk of infection, continuous broad-spectrum antibiotics should be started for all patients with significant vascular injuries who require long-distance AE, eg, from Europe back to the United States.

Special AE Considerations

Aircraft Configuration

Movement of vascular patients by AE requires an aircraft configuration and patient positioning that assures the aeromedical crew can adequately evaluate the patient for both ischemia and hemorrhage. For elective AE, a flight crew comprised of flight nurses and technicians is adequate. For urgent evacuations, a CCAT Team should be considered, especially if any patient has not yet had definitive surgical treatment. All patients with recent injuries or vascular repairs should have IV access. Patients with recent injuries should also receive in-flight supplemental oxygen.

Dressings and Drainage

All wounds should be evaluated and dressings replaced immediately prior to AE. The potential for limb swelling should be anticipated, and all circumferential dressings should be repeatedly checked to ensure they do not become constricting, especially if they overlay superficially routed grafts. Likewise, all casts must be bivalved.

Dressings over open wounds, including fasciotomy incisions, need to be kept moist to avoid tissue desiccation, especially in the dry AE environment. If dressings show evidence of continued blood loss, they should be removed and the wounds examined.

Closed-suction drains are often used during vascular surgery. If such drains have been placed, they will need venting during ascent to avoid gas expansion in the wound.

Cabin Altitude

There are no cabin altitude restrictions for most vascular surgery patients. However, patients might have undergone recent hyperbaric oxygen therapy in the course of treatment for associated conditions, such as acute crush injuries, Clostridial gangrene, and chronic wound management. It is well appreciated that these patients are at risk for decompression sickness during air transport. Therefore, if such patients require AE <24 hours after a hyperbaric treatment, a cabin altitude restriction to sea level (or the altitude of the sending location) will be required.

Medications and Treatment Supplies

Patients with recent vascular injuries or surgery often require nonstandard items for in-flight use. These can include heparin for infusions, insulin and glucose, mannitol, antibiotics, blood products and infusion sets, splints, and dressing supplies. If patients are anticoagulated with heparin, protamine sulfate should be available
to reverse heparin anticoagulation in the event of uncontrollable hemorrhage.

Early thrombolytic therapy is often used for ischemic disease and can be continued during rotary-wing casualty medical evacuation (MEDEVAC). However, thrombolytic therapy should not be used during long-distance fixed-wing AE because of the difficulties and risks associated with its prolonged use.

Deployable Diagnostic Equipment and Monitoring

All patients with vascular diseases or injuries should be evaluated during AE with routine hemodynamic and physiological monitoring. In addition, efforts to detect changes in limb perfusion should be made by serial evaluations of peripheral pulses, neurological function, and skin color and capillary return. Unfortunately, aircraft noise, vibration, low lighting, and patient restraints may limit the accuracy of these evaluations.

Continuous-Wave Doppler

Continuous-wave Doppler is useful in a field or contingency setting to provide an objective assessment of peripheral arterial circulation (see above). Many Doppler units can be used with headsets, which can facilitate use in a noisy aircraft environment. During AE of patients in the first week after vascular surgery, vessel patency should be documented by evaluating the ABI preflight, postflight, and in-flight if there is any clinical indication of a change in limb perfusion status.

Laboratory Evaluation

The ability to perform basic blood and urine tests immediately preflight or in-flight is extremely useful when severely ill or injured patients are transferred over longer distances. Early detection of adverse effects of tissue necrosis or ischemia reperfusion injury can permit immediate treatment.

Hand-held portable clinical blood analyzers provide rapid, simultaneous quantitative determination of whole blood electrolytes, glucose, hematocrit, and blood gases. These values can help guide fluid administration and permit early detection of systemic effects of tissue ischemia and infarction, such as hyperkalemia and metabolic acidosis. Monitoring the PTT should be considered if the transport team is responsible for managing heparin infusions for more than 12 hours.

A simple urinalysis by dipstick is extremely important in the trauma patient to detect the presence of free myoglobin or hemoglobin in the urine. However, because the dipstick cannot differentiate myoglobin from hemoglobin both rhabdomyolysis and hemolysis will manifest on urine dipstick as positive for blood. In either case, the risk of subsequent renal injury can be minimized by fluid loading with Ringer’s lactate, urine alkalinization with IV bicarbonate, and perhaps mannitol use.

Specific Care Plans for Vascular Casualty AE

Unique aspects of care, criteria for urgent and elective AE, and checklists for major categories of vascular casualties are summarized in Tables 17.2, 17.3, and 17.4.

Trauma patients are perhaps the most frequent consideration for military AE (Table 17.2). Control of life-threatening hemorrhage is prioritized before limb salvage, but with limb ischemia the best long-term functional outcomes result from rapid restoration of blood flow.

AE is less commonly required for nontraumatic acute ischemia or complications of chronic peripheral artery disease (PAD), but PAD is common in the elderly. PAD complications can be presenting problems or can result from iatrogenic injury (such as arterial cannulation for cardiac catheterization or other reasons). These patients often have multisystem problems (Table 17.3).

Venous thromboembolism can be a complication in trauma patients or a concomitant process with acute or chronic illnesses. While patients rarely require AE for venous thromboembolic disease, the risk of pulmonary embolism may be significant in many AE patients (Table 17.4).
**Table 17.2. Extremity vascular trauma.**

<table>
<thead>
<tr>
<th>Related medical conditions</th>
<th>Skeletal injury, bony instability, open fracture; soft-tissue injury, crush, compartment syndrome; peripheral nerve injury; multisystem trauma, shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Care and management prior to AE</td>
<td>Assessment, resuscitation, stabilization (ABCs of trauma management); hemorrhage control; IV access; revascularization for ischemia (surgical, endovascular, or by placement of temporizing shunt) if surgical care available; fracture care (irrigation of open fractures, antibiotics, stabilization); soft-tissue injury management (irrigation, debridement of devitalized tissue)</td>
</tr>
<tr>
<td>Preparation for AE</td>
<td>Monitoring, including ECG, blood pressure, pulse oximeter, and Foley catheter; document perfusion status (careful pulse examination, ABI measurement); document neurological status (motor and sensory); evaluate for compartment syndrome (consider fasciotomies); evaluate dressings, wound check if appropriate</td>
</tr>
<tr>
<td>Indications for return to medical facility prior to evacuation</td>
<td>Active bleeding; arterial, graft, or shunt occlusion (drop in ABI &gt;0.15) or evidence of critical ischemia; new sensory or motor deficit</td>
</tr>
<tr>
<td><strong>Urgent AE:</strong></td>
<td></td>
</tr>
<tr>
<td>Minimal conditions that must be met</td>
<td>Airway protection; bleeding controlled; adequate immobilization of skeletal injuries; spinal and cervical immobilization if stability not demonstrated; wounds debrided and dressed</td>
</tr>
<tr>
<td>Specific concerns, supplies, and needs of patients</td>
<td>Supplemental oxygen; Doppler flow detector; transport monitor; IV fluids and infusion pumps; dressing supplies; consider blood products and infusion sets, heparin, intermittent pneumatic compression devices for prophylaxis of deep-vein thrombosis, mannitol, portable laboratory</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Possible in-flight emergencies</th>
<th>Consequences and risks</th>
<th>In-flight treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recurrent bleeding</td>
<td>Hypovolemic shock</td>
<td>Direct digital or manual pressure; hemostatic dressings; tourniquet (only when all other measures fail); discontinue use of anticoagulants; IV lactated Ringer’s solution and/or transfusion; monitor vital signs and urine output</td>
</tr>
<tr>
<td>Arterial, graft, or shunt thrombosis</td>
<td>Acute limb ischemia</td>
<td>Consider diverting for immediate surgical care</td>
</tr>
<tr>
<td>Compartment syndrome</td>
<td>Progressive loss of peripheral nerve function</td>
<td>Compartment pressure measurement; compartment release (fasciotomy); consider diverting for immediate surgical care</td>
</tr>
<tr>
<td>Metabolic complications (hyperkalemia, acidosis, etc)</td>
<td>Cardiac dysfunction or dysrhythmia</td>
<td>Monitor blood gases and chemistries</td>
</tr>
<tr>
<td></td>
<td>Renal failure</td>
<td>Adequate IV fluid resuscitation (as needed) to augment resuscitation; correct electrolyte abnormalities</td>
</tr>
</tbody>
</table>

**Elective AE:**

**Ideal timing of AE**

**Conditions that should be met prior to transportation**

**Possible in-flight emergencies**

<table>
<thead>
<tr>
<th>Graft or arterial thrombosis</th>
<th>Distal ischemia</th>
<th>Heparin anticoagulation (if not contraindicated); consider diversion for progressive signs of acute ischemia or development of motor deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary thromboembolism</td>
<td>Hypoxemia; tachycardia; hypotension</td>
<td>Heparin anticoagulation (see Table 17.4 for additional information)</td>
</tr>
</tbody>
</table>
**Table 17.3. Peripheral artery disease.**

<table>
<thead>
<tr>
<th>Related medical conditions</th>
<th>Coronary artery disease; cerebrovascular disease; renal insufficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Care and management prior to AE</td>
<td>Supplemental oxygen; IV access; revascularization for ischemia if available (surgical, endovascular, or catheter-directed thrombolytic therapy); wound debridement and dressing care</td>
</tr>
<tr>
<td>Preparation for AE</td>
<td>Monitoring, including ECG, blood pressure, pulse oximeter, and Foley catheter; full heparin anticoagulation for acute ischemia if not revascularized; evaluate for significant systemic disease or acute problems (include baseline ECG); check laboratory tests, including hemoglobin, platelet count, serum electrolytes, coagulation status, and urinalysis; document perfusion status (careful pulse examination, ABI measurement); document neurological status (motor and sensory); evaluate for compartment syndrome if revascularized for acute ischemia (consider fasciotomies); evaluate dressings, wound check if appropriate</td>
</tr>
<tr>
<td>Indications for return to medical facility prior to evacuation</td>
<td>Active bleeding; postprocedure arterial, graft, or shunt occlusion (drop in ABI &gt;0.15 or evidence of critical ischemia); new sensory or motor deficit</td>
</tr>
<tr>
<td>Urgent AE:</td>
<td>Hemodynamic stability; evaluate for myocardial ischemia; pain control</td>
</tr>
<tr>
<td>Minimal conditions that must be met</td>
<td>Supplemental oxygen; Doppler flow detector; transport monitor; IV fluids and infusion pumps; dressing supplies; Consider heparin, narcotics for ischemic pain, intermittent pneumatic compression devices for prophylaxis of deep-vein thrombosis, mannitol, portable laboratory</td>
</tr>
<tr>
<td>Specific concerns, supplies, and needs of patients</td>
<td></td>
</tr>
<tr>
<td>Possible in-flight emergencies</td>
<td>Consequences and risks</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>Dysrhythmias</td>
</tr>
<tr>
<td></td>
<td>Heart failure</td>
</tr>
<tr>
<td>Bleeding from arterial puncture sites or disruption of recent graft or anastomosis</td>
<td>Hypovolemic shock</td>
</tr>
<tr>
<td>Arterial, graft, or shunt thrombosis</td>
<td>Acute limb ischemia</td>
</tr>
<tr>
<td>Compartment syndrome</td>
<td>Progressive loss of peripheral nerve function</td>
</tr>
<tr>
<td>Metabolic complications (hyperkalemia, acidosis, etc)</td>
<td>Cardiac dysfunction or dysrhythmia</td>
</tr>
<tr>
<td></td>
<td>Renal failure</td>
</tr>
<tr>
<td>Elective AE:</td>
<td>Usually dictated by associated medical conditions</td>
</tr>
<tr>
<td>Ideal timing of AE</td>
<td>Soft-tissue coverage of grafts and anastomoses; nonviable or infected tissue debrided, wounds dressed; invasive monitoring and continuous infusions no longer required</td>
</tr>
<tr>
<td>Conditions that should be met prior to transportation</td>
<td></td>
</tr>
<tr>
<td>Possible in-flight emergencies</td>
<td>Consequences and risks</td>
</tr>
<tr>
<td>Same as above</td>
<td>Pulmonary thromboembolism</td>
</tr>
</tbody>
</table>
Conclusion

Specific considerations in the AE of peripheral vascular casualties include risks of both local and systemic complications. Serial evaluation of perfusion is indicated. Vascular injuries are often associated with skeletal or other injuries that must be considered. Concomitant medical problems of patients with PAD may be primary concerns during transport.

References


Cardiothoracic casualties occurring during armed combat, natural disaster, and peacetime may have different mechanisms but the resulting pathophysiology can be similar due to the effects of such injuries on the cardiopulmonary system. The distinct nature of each type of injury will determine specific care requirements. This, in turn, will dictate the expertise and equipment requirements of the aeromedical evacuation (AE) transport team. This chapter will address common cardiothoracic injuries, their sequelae, and management during elective, urgent, and contingency AE.

General Considerations

In both the civilian and military domains, severe thoracic injuries are particularly lethal, especially when combined with head trauma. The mechanisms and resultant pathology of these injuries determine their physiological effects and clinical courses. The most important factors influencing the patient are blood loss, direct destruction of organ tissue (such as myocardial contusion), secondary effects of tissue injury or sepsis on thoracic organ function (such as adult respiratory distress syndrome [ARDS]), and tension effects (such as pericardial tamponade). Blood loss obviously affects ultimate prognosis. Intravascular depletion results in shock and decreased tissue perfusion, and the obligatory fluid resuscitation creates its own complications. Local and remote tissue injury can cause significant interstitial fluid losses (ie, “third spacing”) and thereby increase the amount of fluid required for intravascular repletion.

Massive fluid resuscitation has detrimental effects on many organ systems and thus it is not surprising that greater fluid resuscitation volumes are associated both with greater trauma and poorer prognosis. Common sequelae of massive fluid resuscitation include pulmonary edema, decreased pulmonary compliance, decreased thoracic compliance, increased ventilator pressures, pulmonary parenchymal barotrauma, pulmonary hypertension, right-sided heart failure, increased abdominal compartment pressures, and diaphragmatic elevation from visceral edema (Fig 18.1). The volume of fluid required for resuscitation in the first 48 hours after injury is a crude marker of the overall trauma to the patient and ultimate prognosis.

Cardiothoracic injuries are often critical. However, the true severity of the injury is not always initially apparent. The patient can transiently compensate for severe injuries with tachycardia, arterial and venous vasoconstriction, and anaerobic metabolism. Each of these compensatory mechanisms will eventually be exhausted, sometimes resulting in the rapid deterioration of an apparently stable patient. For this reason, safe AE requires that the aeromedical crew have an accurate understanding of the injury, its variants, natural history, associated risk, and predictable complications. This is especially important when patients are transported early in the course of their recovery.
Complications of Cardiothoracic Injuries

Pneumothorax

Pneumothorax is defined as free air in the pleural space. In a combat or mass-casualty situation, this will be secondary to trauma to the lung, trachea, or chest wall. However, pneumothorax may also occur spontaneously in tall, thin, young men with pre-existing apical blebs or patients with emphysema and parenchymal degeneration. Pneumothorax can also occur after relatively minor pulmonary barotrauma, which creates alveolar overpressurization and rupture. Common causes of barotrauma include a sudden blow to the chest during breath-holding, uncontrolled depressurization during flight or diving, severe bronchospasm, and iatrogenic overpressurization of the intubated patient.

Traumatic pneumothorax can arise from penetrating or blunt chest injuries. With penetrating injuries, air can be sucked into the pleural space through the chest wall defect, forced from the lung into the pleural space through a puncture wound, or both. In blunt trauma, the air leak usually results from focal rupture of the pulmonary parenchyma, puncture of the lung by a fractured rib, or leak from a large parenchymal tear.

Free air within the pleural space can create either simple or tension pneumothorax. Simple pneumothorax occurs when a relatively stable amount of intrapleural air compromises lung expansion in the affected hemithorax. Tension pneumothorax occurs when a lung defect acts as a one-way valve and air entering the pleural space during inspiration cannot escape during expiration. This creates an expanding pocket of intrapleural air that can completely collapse the ipsilateral lung and shift the mediastinal contents toward the opposite hemithorax. As this process progresses, the rising intrathoracic pressure decreases venous return to the heart. Inadequate atrial filling renders the patient functionally hypovolemic and can lead to cardiovascular collapse.

Chest Tube Management

A chest tube is commonly required for patients with cardiothoracic injuries. Medical providers taking care of these patients need a complete understanding of chest tube design, placement, management, and troubleshooting approaches. A tube that is malpositioned, obstructed, too small for the job, or not connected to suction properly can create a critical in-flight situation (Fig 18.2).

Verification that the chest tube is adequately positioned is the foremost concern during placement. A misplaced chest tube (eg, in the subpulmonic space, lung fissure, or extrathoracic location) will not drain an apical pneumothorax (Fig 18.3). Proper location is confirmed by chest radiograph immediately after placement and whenever the tube is manipulated.

Once placed, a chest tube must be connected to a three-stage vacuum–collection system prior to AE (Fig 18.4). The first stage is a reservoir for the fluids that drain from the pleural cavity. The second stage is a one-way valve. This may be in the form of a Heimlich-type valve or a water seal chamber that prevents the backward flow of air into the pleural space. A water seal chamber has the added advantage of displaying an active air leak as the continuous passage of bubbles. The final stage is a regulator or relief valve to prevent excessive suction from being applied to the pleural space and potentially injuring the lung by sucking it into the chest tube. Although newer designs replace some of these components with water-free mechanical devices, these three essential functions of the device remain the same.
Figure 18.2. A diligent aeromedical crew prepared with the appropriate skills and equipment is necessary for safe AE of intubated patients.

Chest tube management includes wound and dressing care to prevent wound infection. Dry dressings are preferable, as salves and ointments do not seal the air leak around an inadequately secured tube but do create a slimy anaerobic environment that can encourage wound infection. Intravenous (IV) antibiotic administration is optional but favored in trauma to help prevent wound infection or empyema via ascending wound colonization. A first-generation cephalosporin is adequate for this task. If Gram-negative colonization or fecal contamination is possible, a second- or third-generation drug with anaerobic coverage should be added. Careful monitoring to assure continued tube function is mandatory. The chest tube system may malfunction due to chest tube occlusion (e.g., kinks in the tubes, external occlusion, internal clots), detached or leaky connections, or malfunction of the suction sources. Each of the three-system stages must be methodically monitored and restored to working order as required.

Implications for AE

An untreated pneumothorax is a contraindication to AE (Table 18.1). Left untreated, a pneumothorax can severely compromise patient oxygenation and circulation during AE by three methods: (1) The pneumothorax may enlarge due to ongoing air leak from the
injured lung or bronchus; (2) the decreased cabin pressure associated with flight may cause the volume of a stable pneumothorax to increase; and (3) the partially collapsed lung on the side of the pneumothorax may cause arterial desaturation from shunting, in addition to altitude-related hypoxia.\(^2,3\)

Elective AE should be delayed until there is radiographic evidence that the pneumothorax has spontaneously resolved or until a chest tube has been inserted. The pneumothorax preferably will have completely resolved, although a small residual pneumothorax is both common and tolerable (e.g., a \(< 1\)-cm apical pneumothorax). Patients with a residual pneumothorax may be transported by urgent or contingency AE after a chest tube has been placed and is verified to be functioning properly. Patient oxygenation must be adequate, in general defined as above 90% in a patient without significant cerebrovascular or coronary vascular disease.

All chest tubes must be connected at a minimum to a one-way valve system (e.g., Heimlich valve), and preferably a three-stage suction–collection apparatus, prior to AE. Additional aspects of in-flight management include connection of the chest tube to continuous suction, administration of supplemental oxygen and first-generation cephalosporin prophylactic antibiotics, and verification of adequate oxygenation by pulse oximetry (Table 18.2).

Prophylactic chest tube placement in patients at high risk of developing a pneumothorax (e.g, Figure 18.4. Three-stage vacuum–collection system for chest tube drainage during AE.

<table>
<thead>
<tr>
<th>Table 18.1. Contraindications to AE.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Within 48h of cardiothoracic surgery if cardiac tamponade is a risk</td>
</tr>
<tr>
<td>Within 24h of repair of ruptured diaphragm</td>
</tr>
<tr>
<td>Untreated pneumothorax</td>
</tr>
<tr>
<td>Untreated pneumomediastinum or pneumopericardium</td>
</tr>
<tr>
<td>Ruptured diaphragm with herniation into the chest</td>
</tr>
<tr>
<td>Active endobronchial bleeding</td>
</tr>
<tr>
<td>New or unstable arrhythmias</td>
</tr>
<tr>
<td>Deteriorating hemodynamics</td>
</tr>
<tr>
<td>Deteriorating respiratory status</td>
</tr>
<tr>
<td>Relative (contraindication to elective AE)</td>
</tr>
<tr>
<td>Within 14d of most cardiothoracic surgery</td>
</tr>
<tr>
<td>Within 7d of repair of ruptured diaphragm</td>
</tr>
<tr>
<td>Within 48h of significant chest wall trauma</td>
</tr>
<tr>
<td>Hemothorax with continued chest tube bleeding</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 18.2. AE checklist for chest tube management.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preflight</td>
</tr>
<tr>
<td>Proper placement has been verified radiographically</td>
</tr>
<tr>
<td>Tube is connected to a one-way valve or drainage apparatus</td>
</tr>
<tr>
<td>Adequate oxygenation verified</td>
</tr>
<tr>
<td>Tube insertion site inspected for air leaks and secure tube anchor</td>
</tr>
<tr>
<td>Need for suction and suction capability of airframe assessed</td>
</tr>
<tr>
<td>Supplies for emergent tube replacement verified</td>
</tr>
<tr>
<td>Pain control plan prepared and drugs available</td>
</tr>
<tr>
<td>In-flight</td>
</tr>
<tr>
<td>Tube connected to continuous suction or one-way valve</td>
</tr>
<tr>
<td>Prophylactic antibiotics</td>
</tr>
<tr>
<td>Supplemental oxygen</td>
</tr>
<tr>
<td>Pulse oximetry</td>
</tr>
</tbody>
</table>
patients with existing blebs or bullous disease) is rarely indicated. The risk of bleb rupture during a flight in a pressurized aircraft is low, and tube placement itself may injure the lung, resulting in an air leak. Because pneumothorax can occur suddenly in any patient, the aero-medical crew should be prepared to treat a tension pneumothorax during any AE flight. In most cases, a needle thoracostomy will be adequate, with results comparable to placement of a tube thoracostomy. If the patient has an active air leak into the pleural space, the chest tube or needle thoracostomy must be connected to suction.

Pleural Effusion

A pleural effusion is any collection of fluid other than blood, chyle, or pus in the pleural space and is common in trauma patients. Effusions are designated as either transudative or exudative based on the relative concentrations of protein and lactate dehydrogenase in the fluid. Exudative effusions usually have a pleural fluid to serum protein ratio >0.5 and a lactate dehydrogenase ratio >0.6. Transudates are less common in the acute trauma patient and are usually due to pre-existing heart failure, cirrhosis, or accumulated third-space fluid losses.

Exudative effusions have a wide variety of causes (eg, pneumonia, malignancy, mediastinal or subphrenic abscesses) or injuries to adjacent organs (eg, pancreas, esophagus, chest wall). Conditions that mimic pleural effusion include collections of blood (hemothorax) or lymph (chylothorax), and these can be differentiated by diagnostic thoracentesis.

Therapy consists of placement of a chest tube for diagnosis and drainage. Coexisting injuries must be treated as appropriate. Otherwise, AE management of a chest tube placed for a pleural effusion is identical to that for pneumothorax.

Hemothorax

Hemothorax is a potentially life-threatening complication of a pulmonary parenchymal, chest wall, mediastinal, or thoracic vascular injury (Fig 18.5). Hemothorax may also occur postoperatively as a complication of thoracic wall and lung, laceration and contusion of the lung, hemothorax, pneumothorax, and hemorrhagic shock.

Figure 18.5. Blast wound to the chest. Prior to AE, the patient must be evaluated and treated for multiple injuries, including laceration of the chest.
surgery (e.g., thoracotomy or lung resection). Hemothoraces must be assiduously sought and vigilantly monitored because of several unique characteristics that create the potential for rapid deterioration. First, a significant amount of concealed bleeding can occur with minimal symptoms. Each pleural cavity can hold several liters of blood, collapsing the lung as the chest fills with blood. Second, in contrast to internal bleeding in confined locations, tamponade occurs relatively late. Finally, the volume of blood in the pleural cavity causes a corresponding decrease in functional lung tissue. This combination of pulmonary parenchymal loss with major blood loss contributes to the high mortality of this condition.

The cornerstone of diagnosis and treatment for hemothorax is chest tube drainage. A chest tube alone will be adequate therapy for the vast majority of intrapleural bleeding. However, if the initial amount of blood drained by the chest tube is >1000 to 1500 cc, or if the continued blood loss is >500 cc/hour, emergency thoracotomy is indicated to stop the bleeding. The objective of therapy is to stop the bleeding and decrease the chance of empyema or fibrothorax developing from undrained blood. No rigid criteria exist, but when the fluid drainage becomes serosanguineous and is less then 200 to 300 cc per day it is reasonable to consider removing the chest tube. If the chest radiograph reveals a residual clotted hemothorax, it must be evacuated, either surgically or by instilling fibrinolytic agents into the pleural space.

**Implications for AE**

Active bleeding from a hemothorax placement is a contraindication to elective AE. A residual clotted hemothorax is temporarily acceptable as long as bleeding has been stopped for 48 hours (i.e., residual drainage is serosanguineous) and the patient has adequate respiratory reserve. The patient’s hemoglobin should be 10 g/dL or greater and the chest tube should be managed as described above.

During armed conflict or mass-casualty situations, urgent or contingency AE may be required despite continued intrapleural bleeding. Patients can be moved with a reasonable degree of safety if the chest tube blood loss is <100 cc/hour. Greater rates of blood loss put the patient at considerable risk of progressive anemia, hypotension, hypoxia, and dilutional coagulopathy during flight. Urgent AE of these precarious patients will require a Critical Care Air Transport (CCAT) team equipped with appropriate blood products, transfusion supplies, and autotransfusion equipment.

For all patients, the amount and type of chest tube output must be closely monitored during AE. Routine chest tube management, as described for pneumothorax, will also be required (Table 18.2).

**In-Flight Complications**

Patients with hemothorax and continued bleeding are at risk for chest tube obstruction by clotted blood. Signs of hemodynamic instability with ineffective chest tube drainage should make the aeromedical crew suspicious of undetected intrapleural bleeding or an occluded tube. In this situation, every effort should be made to clear the tube or replace it if necessary. Disconnecting the chest tube and steriley sucking out the obstructing clot with an endotracheal tube suction catheter or extracting the clot with a Fogarty balloon embolectomy catheter are simple and effective techniques. These can be successfully accomplished even in the most austere AE environment. Resuscitation with fluids and blood products should be instituted until diversion to the nearest medical facility is possible.

**Pneumomediastinum**

A bronchial air leak can sometimes result in air leakage proximally into the mediastinal space instead of peripherally into the pleural space. The result is pneumomediastinum or pneumopericardium (Fig 18.6). There is frequently associated subcutaneous emphysema, and if the air dissected across the diaphragm via the mediastinum or retroperitoneum pneumoperitoneum will develop.

In the trauma patient, the presence of pneumomediastinum or related conditions should prompt a search for a central airway rupture or esophageal injury. A large central airway injury will require surgical repair. Otherwise, no
specific treatment is necessary for stable patients who do not require air transportation. However, the patient should be observed for the development of pneumothorax because even a small leak could extend into the pleural space. Similarly, although subcutaneous emphysema may create an alarming appearance, it poses no immediate threat to the patient so long as the pleural cavity is decompressed. If it is unclear whether a pneumothorax is or is not present, it is safest to place bilateral chest tubes before evacuating the patient. Rarely, placement of a chest tube via the subxiphoid route into the pericardial space is necessary for decompression of tension pneumopericardium.

**Implications for AE**

Untreated pneumomediastinum and related conditions are a contraindication to AE.
because of the risk of subsequent pneumothorax in these patients (Table 18.1). Prior to AE, these patients should have prophylactic chest tubes placed.

Untreated pneumopericardium is a contraindication to AE because expansion of air in the pericardium during flight can result in cardiac tamponade. Although tension pneumopericardium is rare, the results can be disastrous. For this reason, these patients must have adequate pericardial drainage prior to AE, using either a subxiphoid pericardial drainage tube or a pericardial window (Fig 18.6).

Tracheobronchial Bleeding

Airway bleeding may be the result of a penetrating lung injury, massive blunt chest trauma, inflammation, burns, infection, pulmonary hypertension, foreign bodies, or malignancy. Significant endobronchial bleeding is associated with a high mortality rate. Emergency treatment consists of endotracheal intubation to secure the airway. The patient should be positioned with the bleeding side (if this is known) down. Oxygen should be administered and aggressive respiratory care implemented to clear the airway of blood. Coagulopathy should be identified and corrected. If the airway cannot be cleared due to voluminous bleeding, proceed with advancement of the tube into the mainstem bronchus contralateral to the site of bleeding. This temporizing maneuver permits “one-lung” ventilation and prevents entry of blood into the ventilated lung. Definitive non-surgical treatment involves placement of a double-lumen endotracheal tube. Angiographic embolization can be helpful if available, as the bleeding source is frequently a bronchial branch of the aorta. Bronchoscopic occlusion of the bleeding bronchial orifice with a balloon catheter (eg, a Fogarty or small Foley catheter) is on occasion successful.

Uncontrolled tracheobronchial bleeding will usually necessitate emergency thoracotomy with resection of the bleeding lung segment or the entire affected lung (ie, pneumonectomy). These procedures have a significant mortality rate, even in a fully equipped operating room. Radiographic selective embolization of the bronchial or pulmonary artery may be reasonable options in selected situations.

Implications for AE

Endobronchial bleeding is always a contraindication to AE. Medical evacuation (MEDEVAC) to the nearest appropriate medical facility should be undertaken only after the bleeding has been controlled by mainstem bronchus intubation and any coagulopathy has been corrected.

Air Embolism

Lung injury is a major risk factor for air embolism. Air can pass from injured alveoli into the pulmonary venous circulation, where it is transported to the left atrium and quickly ejected by the left ventricle into the aortic root. Air naturally rises to the highest spot, which in the supine patient is the anterior aortic root, near the ostium of the right coronary artery. The bubbles pass down the right coronary artery until they eventually lodge in the small vessels or myocardium. This creates ischemia of the right ventricle, inferior left ventricle, and septum, which quickly become dysfunctional. The result is rapid, profound hypotension, right ventricular failure, bradycardia, and cardiac arrest. (If the patient is in the 10% to 15% of the population with strongly left-dominant coronary circulation, the ventricular depression will be limited to the right ventricle and thus be better tolerated.)

The most important treatment approach is increasing coronary perfusion pressure by administration of epinephrine or other alpha-adrenergic agonists and fluids in an effort to flush the bubbles out of the coronary circulation and restore coronary capillary perfusion pressure. Further measures include changing the patient’s position to the left lateral decubitus, Trendelenburg position to direct aortic root air away from the coronary arteries and allow the air to aggregate in the ventricular apex. Halting further entrance of air into the circulation requires an emergency thoracotomy for pulmonary hilar control, repair or resection of the injured lung, and aspiration of the air pockets in the ventricles and great vessels.

The most effective approach to air embolism is prevention. In high-risk patients with parenchymal pulmonary injuries, prophylactic measures include maintenance of low airway
pressures and relatively high atrial filling pressures as reflected by central venous pressure and pulmonary capillary wedge pressure.

Air entering the circulation through IV lines can also be dangerous because right-sided air embolization can be fatal. A massive amount of air (tens to hundreds of ccs of air) can cause right ventricular cavitation and immediate cardiogenic shock. Less commonly, air bubbles in the venous circulation can pass through a patent foramen ovale or atrial septal defect, thereby becoming a left-sided air embolus. These latter two entities are more likely in conditions that increase right-sided cardiac chamber pressures, such as hypoxia, volume overload, acidosis, pulmonary hypertension, or tamponade.

Emergency management of venous air embolism includes halting the ingress of air, fluid resuscitation, inotropic support, and repositioning the patient in the left lateral decubitus, Trendelenburg position to allow the air to accumulate in the apex of the right ventricle. A pulmonary artery balloon catheter (eg, Swan–Ganz) can be floated into the right ventricular outflow tract to aspirate the bubbles and foam creating the obstruction.

Postoperative Cardiothoracic Patients

Early postoperative complications in cardiothoracic patients can provoke rapid deterioration due to compromise of the circulatory and respiratory systems. For these reasons, elective AE should be delayed until patients are in the convalescent phase of their recovery from thoracotomy. This is usually 7 to 14 days after surgery, when patients have had chest tubes removed, are tolerating regular diets, and are ambulatory. For comparison, in the civilian environment such patients will be at home, self-sufficient in their activities of daily living, accomplishing their own pulmonary hygiene, and ready to begin cardiopulmonary rehabilitation.

Urgent or contingency AE may be required much sooner after surgery. However, the patient should be allowed to stabilize for at least 12 hours after thoracotomy prior to AE. This will almost always require the assistance of a well-equipped CCAT team experienced in the diagnosis and treatment of postoperative complications in these high-risk patients. Postoperative problems associated with various conditions are discussed below.

General Considerations for AE

Safe AE of the cardiothoracic patient depends on an adequate understanding of the unique aspects of their injuries and the associated postoperative risks. Although pain control, respiratory hygiene, and fluid management are required for all postoperative patients, post-thoracotomy patients have special concerns that must be recognized.

Pain Control

Effective pain management is essential for optimizing respiratory function in the post-thoracotomy patient. Intermittent morphine is effective but has the disadvantage of being a respiratory depressant. Ketorolac (given by either intramuscular or IV injection) is an extremely effective adjunct but should not be used for patients with renal insufficiency, coagulopathy, or a history of gastrointestinal bleeding. When available, a thoracic epidural catheter is an excellent method for providing pain relief without depressing the sensorium. However, they do place additional monitoring burdens on the AE crew and can be somewhat variable in their efficacy. Periodic intercostal blocks are an effective adjunct that can help tide the patient over during critical intervals.

Respiratory Hygiene

It is critical to minimize atelectasis in post-thoracotomy patients. The cornerstone of this effort is effective pain management to allow deep inspiration. Other methods include incentive spirometry, chest physiotherapy, and bronchodilators to loosen secretions. All of these methods must be continued throughout the AE process. Aggressive baseline therapy when the patient appears to be stable can prevent the sudden hypoxia and respiratory distress that occur when occult atelectasis or mucous retention reaches a critical level.
Aeromedical Evacuation of Cardiothoracic Casualties

Fluid Management
Cardiothoracic trauma is often associated with massive blood loss, which creates a need for disproportionate fluid resuscitation to restore equilibrium. In addition, pulmonary injury and cardiac failure are both associated with “third spacing” of fluids, but for different reasons. The complex relationship between intravascular fluid balance and both increased and decreased cardiac output makes appropriate fluid management critical in the postthoracotomy patient. Further, in the presence of cardiac dysfunction it is critical to discriminate between left- and right-sided heart failure. Central venous and capillary wedge pressure monitoring is invaluable in managing critically ill patients.

Venous Thrombosis Prophylaxis
Postthoracotomy patients are at increased risk of pulmonary embolus due to immobility and hypercoagulability. In addition, their compromised respiratory physiology increases the physiological impact of subsequent pulmonary thromboembolism. For this reason, all such patients should be treated on the ground with sequential compression devices on their lower extremities. During flight, these must be replaced with elastic compression hose because sequential compression devices are not approved for use in the hypobaric AE environment. In addition, all postoperative patients who have not achieved full ambulation and do not have active bleeding or risk thereof should be treated with heparin prophylaxis. The advent of low-molecular-weight heparin prophylaxis has increased the safety and reliability of this therapy.

Chest Tubes
Chest tubes are a ubiquitous component of postoperative thoracic surgical management. Details of chest tube placement, design, and management have been discussed above. The design and essential components of the standard three-chamber suction–collection apparatus are shown diagrammatically in Figure 18.2.

Specific Injuries

Flail Chest and Pulmonary Contusion
Flail chest refers to chest wall trauma in which one or more ribs is fractured in at least two places, mobilizing a plate of chest wall from the remainder of the thorax. It can be the result of blunt trauma, projectile, or blast shock wave. The paroxysmal, painful inward movement of this plate limits respiratory excursion and efficiency. Flail chest is almost universally accompanied by pulmonary contusion and commonly by pleural effusion or hemothorax as well.

Pulmonary contusion is characterized by interstitial and alveolar hemorrhage with architectural disruption resulting in decreased gas exchange across capillary–alveolar interfaces. Severe cases may develop regions of lung necrosis and hemothysis. Radiographically, pulmonary contusion is usually evident at the time of injury as an area of consolidation and will often progress in size over the next 24 to 96 hours. The lung injury can be aggravated by the massive fluid administration often required for trauma resuscitation.

Respiratory insufficiency after significant chest wall trauma has several potential causes, including pulmonary contusion, splinting secondary to rib fractures, hemothorax, atelectasis, pneumonia, and deranged respiratory mechanics due to flail chest. These complications are most likely to manifest in the first 48 hours postinjury. During this time, the patient should be treated with pain medications, bronchodilators, and active pulmonary hygiene (eg, incentive spirometry, chest percussive therapy) and observed closely for signs of deterioration. Although these steps will maximize chest wall compliance and respiratory function, endotracheal intubation will often be required in patients with significant pulmonary contusions.

Implications for AE
The first 48 hours after significant chest wall trauma is the critical period during which deterioration of pulmonary function may occur. For this reason, patients with fractured ribs and pulmonary contusion should not be transported by elective AE for the first 48 hours postinjury (Table 18.1). Patients transported by AE within
7 days of pulmonary contusion should be given supplemental oxygen.
During a military operation or mass-casualty situations, or if appropriate medical care is not available locally, movement of these patients by urgent or contingency AE may be required after little more than medical stabilization. The presence of a pneumothorax will require placement of a chest tube with a one-way valve, as discussed above. The presence of hemothorax is especially dangerous, as discussed above. Pain relief can be provided with parenteral narcotic and nonnarcotic drugs, local injection (ie, intercostal block), or regional anesthesia (ie, epidural block). If the patient continues to have a severely abnormal PaO2 on room air (ie, 50mmHg or 88% SaO2), endotracheal intubation should be considered prior to AE.

Tracheobronchial Injuries
Intrathoracic tracheobronchial injuries are usually the result of penetrating chest injuries, although they can result from severe deceleration or crush mechanism. They are associated with significant morbidity and mortality. These injuries affect multiple critical systems, and can simultaneously create airway obstruction, pneumothorax or pneumomediastinum, and significant blood loss. Emergency care is primarily supportive, and immediate surgery is usually required. The surgery itself can be technically challenging for both the surgeon and anesthetist. Associated injuries can cause substantial blood loss and a fatality rate approaching 25% at tertiary-care centers. Surgical tracheobronchial repair leaves an anastomotic suture line that is delicate, slow to heal, and vulnerable to barotrauma, tension ischemia, and infection. Postoperatively, early extubation is indicated to minimize airway pressure and avoid anastomotic erosion from airway catheters.

Implications for AE
Elective AE should be deferred until the convalescent period, usually at least 14 days after surgery. The patient should no longer require chest tubes and be substantially recovered from coexisting injuries.

In an emergency situation, urgent or contingency AE should be delayed for 12 hours after definitive surgery to observe for early operative complications (anastomotic disruption or pneumothorax) and fluid resuscitation. These patients will be relatively unstable and require the special expertise of a CCAT team for safe transport so soon after surgery. Prior to AE, the patient should be afebrile and the chest tube output should be <50cc/hour. Thoracic air leaks often continue for the first 2 to 5 days postoperatively, and thus AE prior to this time will require effective drainage with chest tubes connected to continuous suction. Muscular paralysis may be required to prevent bucking and maximize thoracic compliance.

Patients who have undergone emergency lung resections must be observed for postoperative air leaks. These patients may undergo urgent or contingency AE 12 hours postoperatively if the air leaks are adequately treated by a chest tube connected to continuous suction.

Patients with profound injury to one lung will have asymmetrical pulmonary compliance. If this is severe enough to cause hypoxia and hypoventilation from shunting through the injured lung and overventilation of the compliant lung, two ventilators will be needed to provide differential lung ventilation during transport. In addition to pulse oximetry, the patient will usually require central venous and arterial pressure monitoring.

In-Flight Emergencies
Anastomotic dehiscence, although uncommon, can be fatal unless the condition is quickly recognized and lung isolation achieved. The cardinal signs are massive air leak through one or both chest tubes (depending on the level of anastomosis), sudden intractable hypoxia, and pneumothorax. Lung isolation is achieved with a single-lumen endotracheal tube by advancing the tube beyond a tracheal anastomosis or into the mainstem bronchus contralateral to the lung with a bronchial anastomosis. If the expertise and equipment is available, a double-lumen endotracheal tube can be placed and positioned to isolate the leaking lung. If a CCAT team or
an appropriately trained specialist accompanies the patient, ancillary equipment should include a flexible bronchoscope in addition to endobronchial suction catheters, a light source, and endotracheal tubes of a variety of sizes and styles.

Cardiac Trauma

Cardiac trauma may be either blunt or penetrating. Cardiac contusions clinically resemble acute myocardial infarctions in many ways. However, the area of tissue damage is more likely to conform to regions of impact than anatomic boundaries of coronary perfusion. These patients usually will not require specific medical intervention unless they develop arrhythmias or heart failure. Implications for AE after such an injury are covered in more depth in chapter 24.

Penetrating cardiac injuries must be treated surgically. Unfortunately, military trauma patients with penetrating cardiac injuries rarely survive to the point of requiring AE unless the injuries are trivially small or they are injured very near a surgical unit. Patients with more limited injuries may survive their injury after surgical repair via sternotomy, thoracotomy, or clamshell incision. Their postoperative course will be similar to that of the postthoracotomy patient, as described below.

Implications for AE

Like most postoperative cardiothoracic patients, elective AE should be delayed until well into the convalescent phase of recovery, approximately 14 days after surgery. The difficulties encountered when attempting to perform emergency surgery in-flight are enormous, and thus every effort should be made to delay AE until the patient is stable.

Urgent and contingency AE can be performed 12 hours after surgery but will require the assistance of a fully equipped CCAT team. The patient must be hemodynamically stable with coagulation parameters in the normal range. It is imperative that mediastinal chest tube output is <100 to 150cc/hour because patients with greater rates of output are at significant risk of anemia, coagulopathy, and cardiac tamponade, a potentially fatal complication requiring emergency re-exploration.

In-flight care should include monitoring of central venous and arterial pressure, as well as pulse oximetry. Blood pressure must be rigorously controlled because excessive hypertension can result in the failure of an otherwise secure arterial or cardiac suture line.

Complications are common in the first 72 hours after surgery and require immediate treatment. Inotropic, vasoregulatory, and antiarrhythmic drugs should be available. Because cardiac arrhythmias are common postoperatively, a defibrillator with internal and external paddles and a pacing device compatible with both surgically placed and transvenous wires should be available. An open-chest instrument tray and skilled personnel should be present for the emergency treatment of cardiac tamponade, should it occur. Blood and clotting factors should be available if significant bleeding is a problem. Warming devices are mandatory if the patient is hypothermic.

Blunt Aortic Trauma

Blunt aortic trauma resulting in transection is highly lethal. In peacetime, almost 90% die at the accident site and many more die before diagnostic studies are completed. The diagnosis should be suspected in any patient in hemorrhagic shock after significant blunt chest trauma, especially after sudden deceleration.

Emergency care is limited to airway management and vascular volume expansion with fluids and blood products. In surviving patients, exsanguination is usually prevented by the formation of an adventitial hematoma. The single most important aspect of care is to prevent hypertension, which could disrupt this hematoma. Hypertension can be minimized by the adequate treatment of pain and hypoxia, avoidance of fluid overload, pharmacological muscular paralysis, and beta-adrenergic antagonist therapy.

Implications for AE

Patients with aortic trauma who are still alive when they reach a medical facility will often
require further MEDEVAC to a higher level of care because cardiopulmonary bypass is commonly required for surgical repair of this injury. Although the injury can be repaired without cardiopulmonary bypass, the surgeon is without resort if the lesion extends into the proximal aortic arch or ascending aorta, and protection of the spinal cord and viscera during the cross-clamp interval is suboptimal. The referring surgeon must decide if the urgency of the situation warrants undertaking these risks.

Like all postoperative cardiothoracic patients, elective AE should be delayed approximately 14 days, until the patient is well into the convalescent phase of their recovery and complications are unlikely.

Urgent or contingency AE will require the assistance of a well-equipped CCAT team and may be initiated approximately 12 hours after surgery, when the patient is hemodynamically stable and coagulation parameters have returned to the normal range.

A distinctive problem related to aortic disruption is visceral ischemia secondary to intraoperative aortic cross-clamping. Within the first 72 hours after surgery, bowel edema and massive third-space fluid loss will often increase intra-abdominal pressure. If abdominal compartment syndrome is suspected in-flight, diversion to a medical facility for decompressive laparotomy is indicated. Measurement of a decompressed bladder pressure of greater than 40 cm H$_2$O is suggestive of this diagnosis. Delayed spinal cord ischemia can also occur after aortic cross-clamping and aortic surgery. If this occurs, intrathecal decompression by lumbar drainage of cerebrospinal fluid can be beneficial. Although the patient stable enough for AE will be outside of the usual time window for this complication, the well-prepared AE crew will have the necessary supplies to react if it does develop.

Esophageal Perforation

Esophageal perforation may result from penetrating trauma, blunt trauma, caustic ingestion, barotrauma, or impaction of sharp objects, food, or pills. Penetrating injury to the thoracic esophagus is seen less often because the accompanying injuries to the great vessels or heart are usually fatal. Penetrating injury to the cervical esophagus should be suspected with any deep neck injury, especially in the presence of subcutaneous air. Treatment of associated vascular or tracheal injuries must take precedence over esophageal repair.

Barotrauma to the esophagus usually results from violent emesis (Boerhaave’s syndrome). The most common site of perforation is near the hiatus at the left lateral wall, where the esophagus lies adjacent to the negative pressure of the pleural space.

The primary risk of esophageal rupture is pleural or mediastinal contamination with oral or gastric contents and secondary sepsis. Pleural or mediastinal contamination will require surgical drainage, repair of the primary injury, generous chest tube drainage, and antibiotic therapy.

Implications for AE

Time from injury to surgical repair is critical for esophageal perforation because necrotizing mediastinitis may force esophageal diversion or esophagectomy, a morbid and potentially fatal intervention under these circumstances. Urgent AE should be undertaken as soon as the diagnosis of esophageal perforation is made, assuming the patient is stable in respect to other concurrent injuries. Prior to AE, these patients should have nasoesophageal or nasogastric drains placed and receive continuous broad-spectrum antibiotics.

Postoperative patients should be allowed to recover for 14 days prior to elective AE. After esophageal repair, oral alimentation is in general withheld for 7 days, until a swallowing study verifies the integrity of the repair site. Prior to elective AE, the patient should be able to swallow normally and be adequately recovered from any coexisting injuries.

Urgent or contingency AE can be carried out after the patient has been allowed to recover for 12 hours postoperatively, assuming the patient is stable in respect to other injuries. The patient will usually require up to three large chest tubes (eg, >32 to 36 French) and neck drainage with Penrose drains. Broad-spectrum antibiotics with good anaerobic coverage are mandatory.
Diaphragmatic Rupture

Diaphragmatic rupture is common in trauma patients and can be difficult to diagnose, especially if the defect is small. At surgery, 19% of patients with penetrating lower thoracic trauma, but without preoperative evidence of visceral herniation, can be found to have diaphragmatic perforation. In blunt trauma, the left hemidiaphragm is more likely to be injured, apparently because of a protective effect of the liver on the right. This is the presumed explanation for why 85% of diaphragmatic injuries involve the left hemidiaphragm and fewer than 15% involve exclusively the right.

**Implications for AE**

A ruptured diaphragm with herniation of abdominal contents into the chest is a contraindication to AE (Table 18.1). Visceral ischemia and respiratory compromise may worsen as the intestinal gas expands during flight. Rupture of the stomach, colon, or small intestine into the pleural space can lead to sepsis and death. Surgical repair of the hernia and nasogastric decompression is mandatory before transport.

Elective AE implications for patients after surgical repair of a ruptured diaphragm should be delayed for 7 days to minimize the risk of in-flight complications. Urgent or contingency AE may be undertaken as soon as 6 hours postoperatively if hemodynamic and respiratory stability have been demonstrated.

**Conclusion**

Cardiothoracic trauma carries a high mortality rate and often requires emergency surgery for survival. Injuries to the lungs and heart and massive blood loss are common. As a result, these patients have many unique aspects to their care, both before and after surgery. For this reason, elective AE should be delayed until the patient is well into the convalescent phase of recovery. Urgent or contingency AE can be done within hours of most thoracotomies, but the expertise and equipment of a CCAT team will usually be required.

**References**

In the modern era of technology-dependent medicine and sophisticated methods for high-speed transportation, it has become increasingly necessary to move relatively ill patients from areas with insufficient medical care to medical centers with a full range of specialty care. Aeromedical evacuation (AE) of pulmonary patients can be safely accomplished, but having an appropriate medical team, equipment, and supplies is essential. Inherent in this concept are a high level of clinical competency and a thorough understanding of the effects of altitude and flight on the pathophysiology of disease. This chapter will begin with a review of the most important aspects of AE for pulmonary patients. It will also describe the indications for and operations of flight ventilators, including the potential complications caused by them.

Effects of Altitude on Pulmonary Patients

Changes in altitude can dramatically affect patients with pulmonary disease secondary to changes in oxygenation, atmospheric moisture, and changes in the partial pressure and volume of gases within the lung. Changes in airway moisture may induce airway irritation and bronchospasm and changes in gas volumes may result in barotrauma within the lung or other organ systems.

Probably the most dramatic effect of altitude is on gas exchange, potentially resulting in both hypoxia and hypercapnia. Most aircraft are pressurized to an altitude of approximately 8000 ft above sea level. This decreased barometric pressure reduces the inspired partial pressure of oxygen. Using standard tables for atmospheric pressure, it can be determined that a \( P_{aO_2} \) on room air at sea level of 60 mm Hg can be expected to decrease to approximately 41 mm Hg at an altitude of 8000 ft. For this reason, patients with diseases that affect oxygenation at sea level will often decompensate at altitude.

A dramatic example of the effect of altitude on hypoxia was illustrated by a study examining the arterial blood gases of military patients without pulmonary conditions who were transported by air from Vietnam to Japan. Those flown at low cabin altitude (3000 to 3800 ft above sea level) rarely had a \( P_{aO_2} \) < 60 mm Hg. In contrast, patients transported at higher cabin altitudes (6700 to 7500 ft above sea level) had a \( P_{aO_2} \) in the 34 to 50-mm Hg range 48% of the time.

It comes as no surprise that any patients with evidence of hypoxia at sea level will experience a worsening in their \( P_{aO_2} \) with altitude. There are elaborate equations to predict \( F_iO_2 \) requirements at altitude. Practically speaking, most patients require an additional oxygen supplementation of at least 2 L per minute more than their requirements at sea level. It is in general recommended that if a patient has an underlying respiratory condition they should undergo arterial blood gas testing and appropriate oxygen supplementation should be added before they are entered into the aeromedical system (Table 19.1). This is true for all pul-
monary diseases regardless of the pathophysiology of their disease.

The effect of altitude on hypercapnia has been less well studied. It is known that supplemented oxygen can be dangerous for a patient with chronic CO₂ retention and must be used judiciously. However, it is unlikely that a patient with chronic CO₂ retention will experience increased respiratory distress at altitude due to worsening hypercapnia if the PaO₂ is kept in the range of 60 to 75 mm Hg. If cabin pressure cannot be maintained at or near sea level, an oxygen saturation of 90% to 95% by pulse oximeter should be maintained with supplemental oxygen to avoid both oxygenation and ventilation problems. Pulse oximeters are standard pieces of equipment in most aeromedical inventories and are included in the equipment carried by USAF Critical Care Air Transport (CCAT) Teams.

### Acute Respiratory Failure

Acute respiratory failure is especially dangerous when it occurs unexpectedly in-flight. Respiratory failure is typically classified as being one of three types: (1) hypoxic, (2) hypercapnic, or (3) mechanical failure. Most commonly, respiratory failure is due to intrinsic lung disease resulting in inadequate gas exchange. However, respiratory failure can also result from the increased work of breathing and respiratory fatigue associated with overwhelming metabolic acidosis that occurs with an acute myocardial infarction or sepsis. The latter is much akin to running a marathon without the required prerequisite training.

Rapid identification and treatment is critical to minimize mortality, which has been reported to be as high as 40% in some series. Subtle clinical signs of impending respiratory failure include confusion (suggestive of hypoxemia), somnolence (common with hypercapnia), and increased work of breathing. The definitive diagnosis is determined by arterial blood gas results showing a PaO₂ < 60 mm Hg and/or PaCO₂ > 50 mm Hg.

When evidence of increasing respiratory compromise is noted, an immediate search for reversible causes of acute respiratory failure should be initiated. Early treatment of altitude-induced exacerbations of chronic pulmonary conditions (eg, obstructive lung disease) may avoid acute pulmonary arrest (Table 19.2). Early recognition and treatment of acute conditions (eg, anaphylactic shock, drug overdose with altered mental status, acute pulmonary edema) may avoid the need for mechanical ventilation in these situations as well.

### Emergency Treatment of Acute Respiratory Failure

Treatment of acute respiratory failure requires a two-pronged approach: (1) support of
ventilation and (2) identification and treatment of the underlying cause. Initial support of ventilation can be as simple as airway stabilization and supplemental oxygen. However, most patients with acute respiratory failure will ultimately require a combination of intubation and mechanical ventilatory support.

Basic Life Support

When one encounters a patient with acute respiratory failure, the first steps are to stabilize the airway, ensure that the airway is patent, and summon help. If the patient has stopped breathing, ventilatory support should be provided with a bag–valve–mask apparatus and supplemental FlO₂ when available. The next step is to determine if the patient has a pulse and initiate cardiopulmonary resuscitation if required. Once the proper equipment is available, endotracheal intubation should be performed as soon as possible to minimize the risk of both inadequate ventilation and aspiration.

It is imperative that an experienced physician ossess the patient’s respiratory status before placing that patient on AE and makes the appropriate interventions before flight.

When acute respiratory failure occurs during AE, it is unlikely that a mechanical ventilator will be available. Fortunately, manual assistance with a bag–valve–mask apparatus will usually be effective in maintaining adequate oxygenation until an emergency landing can be made. However, it is often difficult to monitor the patient during flight because of increased noise and suboptimal lighting, limited equipment, and space constraints. When available, a pulse oximeter is the ideal way to verify adequate oxygenation in an austere AE environment. In the absence of sophisticated monitoring equipment, the patient must be carefully observed for clinical signs of inadequate oxygenation, eg, using accessory muscles or exhibiting paradoxical respiratory efforts. In these cases, a rapid survey should be accomplished to identify treatable conditions such as right mainstem bronchus intubation or pulmonary edema resulting from fluid overload.

Patients on Mechanical Ventilators

Principles of Mechanical Ventilation

Mechanical ventilation is a method of supporting patients during illness and is never curative or therapeutic. A primary physiological objective is to normalize alveolar ventilation, thus achieving and maintaining an acceptable arterial blood oxygenation level using an acceptable inspired oxygen concentration. A secondary physiological objective is to reduce the patient’s work of breathing until specific therapies can reverse the condition leading to the increased workload.

The clinical objectives of mechanical ventilation are to relieve potentially life-threatening hypoxia, correct life-threatening respiratory acidosis, and relieve respiratory distress and patient discomfort while the primary disease process reverses or improves. In some cases (eg, flail chest), the primary objective is to stabilize the chest wall to provide adequate ventilation.

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<td>Albuterol, terbutaline, metaproterenol</td>
</tr>
<tr>
<td>Long-acting</td>
<td>Primarily inhaled</td>
<td>Salmeterol</td>
</tr>
<tr>
<td>Anticholinergics</td>
<td>Primarily inhaled</td>
<td>Ipratropium bromide</td>
</tr>
<tr>
<td>Methylxanthines</td>
<td>Oral</td>
<td>Theophylline</td>
</tr>
<tr>
<td>Anti-inflammatories</td>
<td>Inhaled, PO, IV</td>
<td>Beclomethasone, triamcinolone, flunisolide, fluticasone, budesonide, prednisone, methylprednisolone</td>
</tr>
<tr>
<td>Corticosteroids</td>
<td>Inhaled</td>
<td>Cromolyn, nedocromil</td>
</tr>
<tr>
<td>Nonsteroidal</td>
<td>Inhaled</td>
<td>Zafirlukast, montelukast</td>
</tr>
<tr>
<td>Leukotriene modifiers</td>
<td>Oral</td>
<td></td>
</tr>
<tr>
<td>Expectorants/mucolytics</td>
<td>Oral</td>
<td>Guanefesin, acetylcysteine (not FDA approved)</td>
</tr>
</tbody>
</table>

Abbreviations: PO, by month; IV, intravenous.
and lung expansion. In all cases, an equally important clinical objective must be to avoid iatrogenic lung injury and other complications.

Ventilators operate almost exclusively on one of five modes (Table 19.3). Assist-control ventilation is a volume-cycled mode where the tidal volume and minimum ventilatory rate are preset. Each time the patient initiates a breath, the preset tidal volume is delivered. This mode is the best way to allow the patient to rest by significantly decreasing the work of breathing for the patient.

Synchronized intermittent mandatory ventilation is another volume-cycled mode where there is a preset tidal volume and a set number of breaths delivered per minute. Any breaths over the preset number will have a tidal volume delivered based on the patient’s ability to generate that tidal volume and not the preset volume. Patients who are “more awake” can tolerate this mode better.

Pressure-support ventilation has a preset pressure for each breath that helps overcome the resistance in the system but may have a variable tidal volume with each breath. The patient controls respiratory rate, duration of inspiration, gas flow rate, and tidal volume. This mode is often coupled with synchronized intermittent mandatory ventilation.

Pressure-controlled ventilation is a time-cycled mode that limits the peak inspiratory pressures set by the clinician. This theoretically limits both barotrauma and volutrauma. It has been found to be especially useful in patients with pulmonary burn. This mode requires considerable experience because there is no set tidal volume and minute ventilation will vary. For this reason, it may be the least commonly used mode of ventilation for aeromedical transport.

Finally, continuous positive airway pressure is not a true mode of ventilation but allows patient breathing to occur at an elevated pressure baseline that decreases atelectasis in the airway.

Each ventilation mode has relative advantages and disadvantages. For this reason, the mode of ventilation should not be changed immediately prior to AE unless some significant problem has rendered the original mode unsafe for the patient.

Although there are many ventilators in the commercial market, only three are at present approved for use in the USAF AE system. These are the Bear 33 (Fig 19.1) and the Impact 750 and 754. The Impact Uni-Vent Eagle Model 754 is the ventilator currently used by the USAF CCAT Teams (Fig 19.2). It is important to note that, at present, these approved ventilators have only three modes: assist-control, synchronized intermittent, and continuous positive airway pressure. When possible, the ideal ventilation mode for long-distance AE will be assist-control ventilation.

### Steps to Institute Mechanical Ventilation

There are several important steps involved for instituting mechanical ventilation prior to AE (Table 19.4). The first is to select the ventilation mode, depending on the patient’s condition and the experience of the clinician. In our experience, assist-control ventilation, when practicable, is ideal for AE. For burn patients, pressure control ventilation is often required. A second standard step is to begin ventilation with a 100% fraction of inspired oxygen (FiO2). The patient is then weaned to the lowest possible oxygen level required to maintain adequate oxygenation (to avoid oxygen toxicity).

The third step is to set the initial tidal volumes at 5 to 8 cc/kg. Historically, tidal volumes of 10 to 15 cc/kg were used. However, recent data from the National Institutes of Health and others have suggested that lower tidal volumes in the range of 5 to 8 cc/kg may significantly lessen the risk of volutrauma. Patients with neuromuscular disorders will be more comfortable with an even larger tidal volume (10 to 12 cc/kg).

The fourth step is to evaluate arterial blood gas pH to determine the ideal tidal volume and

<table>
<thead>
<tr>
<th>Table 19.3. Modes of mechanical ventilator operation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assist-control ventilation</td>
</tr>
<tr>
<td>Synchronized intermittent mandatory ventilation</td>
</tr>
<tr>
<td>Pressure-support ventilation</td>
</tr>
<tr>
<td>Pressure-controlled ventilation</td>
</tr>
<tr>
<td>Continuous positive airway pressure</td>
</tr>
</tbody>
</table>
respiratory rate. Although some medical conditions warrant the use of permissive hypercapnea, this situation should be avoided while in-flight if possible. The fifth step is to add a minimal amount of positive end-expiratory pressure (PEEP) to assist oxygenation. PEEP is usually started at 5 cm H2O and increased by increments of 2 to 3 cm H2O as needed. It is uncommon for patients to require more than 15 cm H2O of PEEP.

The sixth step prior to AE is to verify that the patient is adequately sedated (using paralysis if necessary) to assure adequate patient–ventilator synchrony (Table 19.5). It is imperative that the patient be appropriately sedated and restrained to protect the airway and prevent the patient “fighting the ventilator.” The loss of the airway in air travel is catastrophic and resecuring the airway can be difficult in-flight.

The final step is to allow the patient to stabilize on the ventilator for hours or days to allow fine adjustments of PEEP, respiratory rate, tidal volume, and oxygen. A steady state should be achieved prior to transport. There are portable, miniaturized devices that can perform arterial blood gas analysis in-flight, but they are not yet widely available. Even with the benefit of pulse oximeters and CO2 monitors, adjusting ventilation can be difficult during flight.
When dealing with a patient requiring high PEEP pressures (20 cm H2O PEEP or greater), strong consideration should be given to the use of bilateral chest tubes for prophylaxis. This is necessary because barotrauma can result in the sudden and unpredictable development of unilateral or bilateral pneumothoraces. A second reason for considering prophylactic chest tubes is the fact that both bronchospasm and pneumothorax are extremely difficult to detect in the noisy AE environment.

### Pediatric Issues

Pediatric patients frequently require transportation in the AE system. To meet their needs, a skilled pediatric critical-care team is essential to guarantee appropriate care of infants and children with pulmonary disease during transport. It is not unusual for these patients to develop conditions during AE that will require the team to intervene.

The key to success in pediatric patients is careful assessment for impending or existing respiratory failure, with obvious attention to and stabilization of the patient’s airway, breathing, and circulation. The airway must be stabilized and secured, with appropriate tube placement confirmed. The size of the endotracheal tube must be based on the age of the child (Table 19.6). The depth of the tube is three times the tube size. If the tube is cuffed (not recommended for very young children), only minimal air should be inflated in the cuff with frequent reassessment as the cabin altitude increases (Boyle’s law). This holds true for all cuffed tubes, adult or child.

Even in the controlled environment of an ICU, up to 14% of intubated pediatric patients will have an accidental extubation. Therefore, sedation and/or paralysis may be crucial to prevent this catastrophe during AE. Dosages of commonly used medications must be adjusted as indicated in pediatric references.

### Table 19.4. Important steps for instituting mechanical ventilation prior to AE.

1. Select the ventilation mode
2. Begin ventilation with 100% fraction of inspired oxygen (FiO2)
3. Set the initial tidal volumes at 5–8 cc/kg
4. Evaluate arterial blood gas pH
5. Add a minimal amount of PEEP
6. Verify that the patient is adequately sedated (including paralysis, if necessary)
7. Allow the patient to stabilize on the ventilator

### Table 19.5. Medications commonly used for adult patients on mechanical ventilation.

<table>
<thead>
<tr>
<th>Drug</th>
<th>Route</th>
<th>Onset</th>
<th>Peak effect</th>
<th>Starting dose*</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haloperidol</td>
<td>IV, IM</td>
<td>5–20 min</td>
<td>15–45 min</td>
<td>0.5–2.0 mg</td>
<td>Agitation</td>
</tr>
<tr>
<td></td>
<td>PO</td>
<td>30–60 min</td>
<td>120–240 min</td>
<td>5–10 mg</td>
<td></td>
</tr>
<tr>
<td>Droperidol</td>
<td>IV, IM</td>
<td>3–10 min</td>
<td>15–45 min</td>
<td>2.5–10 mg</td>
<td>Agitation</td>
</tr>
<tr>
<td>Chlorpromazine</td>
<td>IM</td>
<td>5–40 min</td>
<td>10–30 min</td>
<td>25 mg</td>
<td>Agitation</td>
</tr>
<tr>
<td></td>
<td>PO</td>
<td>30–60 min</td>
<td>120–240 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diazepam</td>
<td>IV</td>
<td>2–5 min</td>
<td>2–30 min</td>
<td>2–5 mg</td>
<td>Sedation, agitation</td>
</tr>
<tr>
<td></td>
<td>PO</td>
<td>10–60 min</td>
<td>30–180 min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lorazepam</td>
<td>IV, IM</td>
<td>2–20 min</td>
<td>60–120 min</td>
<td>1–2 mg</td>
<td>Sedation, agitation</td>
</tr>
<tr>
<td></td>
<td>SL</td>
<td>2–20 min</td>
<td>60–120 min</td>
<td>0.5–1.0 mg</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PO</td>
<td>20–60 min</td>
<td>20–120 min</td>
<td>0.5–1.0 mg</td>
<td></td>
</tr>
<tr>
<td>Morphine sulfate</td>
<td>IV</td>
<td>1–2 min</td>
<td>20 min</td>
<td>4–10 mg</td>
<td>Analgesia</td>
</tr>
<tr>
<td></td>
<td>IM</td>
<td></td>
<td></td>
<td>10 mg</td>
<td></td>
</tr>
<tr>
<td>Propofol</td>
<td>IV</td>
<td>40s</td>
<td>Continuous</td>
<td>10–80 µg/kg per min</td>
<td>Sedation</td>
</tr>
<tr>
<td>Midazolam</td>
<td>IV</td>
<td>2–3 min</td>
<td>Continuous</td>
<td>2–8 mg/h</td>
<td>Sedation</td>
</tr>
<tr>
<td>Pancuronium</td>
<td>IV</td>
<td></td>
<td></td>
<td>LD 0.1 mg/kg</td>
<td>Paralysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MD 0.05–0.1 mg/kg per h</td>
<td></td>
</tr>
<tr>
<td>Vecuronium</td>
<td>IV</td>
<td></td>
<td></td>
<td>LD 0.1 mg/kg</td>
<td>Paralysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MD 0.05–0.1 mg/kg per h</td>
<td></td>
</tr>
<tr>
<td>Atracurium</td>
<td>IV</td>
<td></td>
<td></td>
<td>LD 0.5 mg/kg</td>
<td>Paralysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MD 0.5–1.0 mg/kg per h</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: IV, intravenous; IM, intramuscular; PO, by mouth; SL, sublingual; LD, loading dose; MD, maintenance dose.
* Dosages need to be individualized for each patient taking into account routes of elimination and other potential drug interactions that may exist.
Because of the inherent risks associated with the use of paralytics, only clinicians familiar with their use should use these drugs.

Infants less than 5 kg are usually placed on time-cycled pressure-limited ventilation with peak inspiratory pressures started at low levels of 18 to 20 cm H₂O and then adjusted clinically based on adequate chest movement and pH stabilization (Fig 19.3). A tidal volume of 10 to 15 cc/kg is usually achieved in this manner.

In children, synchronous intermittent mandatory ventilation is the most frequent mode used. Suggested settings are a tidal volume 10 cc/kg, with a flow rate resulting in an inspiratory time of 0.6 to 0.7 seconds for babies, 0.8 seconds for toddlers, and 0.9 to 1.0 seconds for school-aged or older children. Rates may need to be higher than the rates used for adults to maintain a normal pH, and a PEEP of 2 to 4 cm H₂O is usually adequate.¹⁰

### Complications of Mechanical Ventilation

#### Pulmonary Barotrauma

Pulmonary barotrauma most commonly manifests as the triad of acute pneumothorax, interstitial emphysema (pneumomediastinum), and subcutaneous emphysema. Of these conditions, only pneumothorax requires immediate attention because it can progress rapidly to tension pneumothorax and death. Immediate treatment is needle decompression until a chest tube can be placed for definitive treatment. Neither interstitial nor subcutaneous emphysema require any specific therapy. However, any patient who develops these conditions while on a mechanical ventilator must be closely monitored for development of a pneumothorax.

### Table 19.6. Size of the endotracheal tube for pediatric patients.

<table>
<thead>
<tr>
<th>Age</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn to 6mo</td>
<td>3–3.5 French</td>
</tr>
<tr>
<td>6–12mo</td>
<td>3.5–4.0 French</td>
</tr>
<tr>
<td>&gt;18mo</td>
<td>(age + 16)/4</td>
</tr>
</tbody>
</table>

### Table 19.7. Medications commonly used for pediatric patients on mechanical ventilation.

<table>
<thead>
<tr>
<th>Drug</th>
<th>Dose</th>
<th>Route</th>
<th>Effect</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Midazolam</td>
<td>0.15–0.40 mg/kg</td>
<td>IV or IM</td>
<td>Sedation, amnesia</td>
<td>Avoid if already hypotensive</td>
</tr>
<tr>
<td>Diazepam</td>
<td>0.1–0.6 mg/kg</td>
<td>IV</td>
<td>Sedation, amnesia</td>
<td></td>
</tr>
<tr>
<td>Lorazepam</td>
<td>50–100 μg/kg</td>
<td>IV</td>
<td>Sedation, amnesia</td>
<td></td>
</tr>
<tr>
<td>Morphine</td>
<td>50–200 μg/kg</td>
<td>IV</td>
<td>Analgesia, sedation</td>
<td></td>
</tr>
<tr>
<td>Fentanyl</td>
<td>1.0–5.0 μg/kg</td>
<td>IV</td>
<td>Analgesia or sedation</td>
<td>May cause histamine release; avoid if hypotensive</td>
</tr>
<tr>
<td>Ketamine</td>
<td>0.5–1.5 mg/kg</td>
<td>IV</td>
<td>Analgesia or amnesia</td>
<td>May increase intracranial pressure; hallucinations</td>
</tr>
<tr>
<td>Etomidate</td>
<td>0.2–0.4 mg/kg</td>
<td>IV</td>
<td>Amnesia</td>
<td>May activate seizure foci</td>
</tr>
<tr>
<td>Flumezanil</td>
<td>2.0–4.0 μg/kg</td>
<td>IV over 15–30s</td>
<td>Reverses benzodiazepines</td>
<td></td>
</tr>
<tr>
<td>Naloxone</td>
<td>10 μg/kg (maximum total dose of 100 μg/kg)</td>
<td>IV</td>
<td>Opioid antagonist</td>
<td></td>
</tr>
<tr>
<td>Succinylcholine</td>
<td>1–2 mg/kg</td>
<td>IV</td>
<td>Paralysis (for initial intubation)</td>
<td>Associated with dysrrhythmia, hyperkalemia, myoglobinuria, and malignant hyperthermia</td>
</tr>
<tr>
<td>Pancuronium</td>
<td>0.1 mg/kg</td>
<td>IV</td>
<td>Paralysis</td>
<td>Vagolytic and sympathomimetic; may cause tachycardia</td>
</tr>
<tr>
<td>Vecuronium</td>
<td>0.1–0.3 mg/kg</td>
<td>IV</td>
<td>Paralysis</td>
<td>Rapid, stable cardiovascular effect</td>
</tr>
</tbody>
</table>

Abbreviations: IV, intravenous; IM, intramuscular.
Endotracheal Intubation Complications

Common complications related to endotracheal intubation include the risk of right mainstem intubation and inadvertent self-extubation. Right mainstem intubation can result in hypoventilation, atelectasis, and pneumothorax. It is imperative to verify bilateral breath sound immediately after intubation and at regular intervals thereafter.

Inadvertent self-extubation can be catastrophic during AE because of the increased difficulty that may be encountered when attempting to reintubate the patient. Therefore, airway security must be reassessed immediately prior to AE and all patients on mechanical ventilation must be adequately sedated and restrained.

Despite appropriate care and monitoring of mechanically ventilated patients, airway problems can occur during AE. When they do, the situation should be calmly and methodically assessed and treated. If the patient has self-extubated, the patient should first be reassessed to determine if mechanical ventilation is still necessary. If so, the patient should be ventilated manually with a bag–valve–mask apparatus and supplemental oxygen until adequate help and equipment for reintubation becomes available. The patient should then be adequately sedated, restrained, and reintubated as quickly as possible.

If the patient develops signs of inadequate ventilation despite proper placement of a patent endotracheal tube, the cuff balloon should be reinflated and checked for leaking. If the leaking continues, it can be managed either by intermittently instilling additional air into the cuff or replacing the endotracheal tube. If the endotracheal tube requires changing, it should be changed using either a tube exchanger technique or direct laryngoscopy.

Cardiac Complications of Mechanic Ventilation

Cardiac complications of mechanic ventilation can be the result of either positive pressure within the chest or inadequate oxygenation. Both of these may result in hypotension, decreased cardiac output, and arrhythmias.

Arrhythmias may be the result of inadequate oxygenation secondary to intrinsic pulmonary disease or as a result of inadequate ventilation. In the case of arrhythmias, always re-evaluate...
the adequacy of your ventilatory support and treat the arrhythmia as outlined by Advanced Cardiac Life Support clinical guidelines.11

Auto-PEEP is a phenomenon in which not all of a volume of air or oxygen is exhaled with each breath. The volume that is not exhaled may continue to increase until it causes extra pressure within the alveoli. When there is enough pressure, increasing intrathoracic pressure can cause barotrauma or significant hypotension by impeding venous return.

Auto-PEEP can be due to either suboptimal ventilator settings or the patient’s disease process. Another cause is patient–ventilator dysynchrony, ie, when an inadequately sedated patient fights the ventilator.

Once auto-PEEP is recognized, it can be treated by allowing a longer exhalation time (by adjusting the inspiratory to expiratory ratio) or adding PEEP to maintain the integrity of the airways so less gas is trapped. If patient–ventilator dysynchrony appears to be the cause, the patient can either be removed from the ventilator or more effectively sedated.

Conclusion

The need to transport critically ill patients by air has dramatically increased in the last 20 years, and many patients requiring such transport are ventilator-dependent. In response to this need for critical-care air transport, a better understanding of the implications of flight on pulmonary patients has developed, and both the personnel and equipment have progressed to the point that an AE airframe can now be converted into a mobile intensive-care unit. Central to the modern AE mission is a thorough understanding of the effects of flight and altitude on pulmonary patients, especially those requiring ventilatory support.

References

Orthopedic trauma comprises a significant percentage of all injuries, either by themselves or in combination with other injuries. This holds for both the civilian world and during military operations. The use of modern protective equipment by both civilians and military members reduces the overall rate of injury or wounding yet paradoxically increases the percentage of orthopedic injuries.1–4 This is because both civilian restraints (eg, airbags and safety harnesses) and military body armor protect vital central nervous system and visceral structures but do little to protect the extremities, which remain exposed.

Orthopedic injuries include not only fractures and dislocations but also soft-tissue injuries, including tendon and nerve injuries, loss of tissue, and vascular injuries. This constellation of trauma can be treated by several different surgeons including orthopedic, trauma, general, and plastic surgeons or a team of surgeons. The exact composition of the surgical team depends upon several factors including the setting of the injury, the training of the individuals involved, and the inclination of the medical system where they are treated. This chapter will cover these multitissue injuries as well as fractures and dislocations.

This chapter will begin with a brief description of the pathophysiology of orthopedic injuries followed by a discussion of treatment and implications for the aeromedical evacuation (AE) of these patients. It will end with a discussion of the preparation for and contraindications of AE.

Pathophysiology of Orthopedic Injuries

Bone fractures result in three immediate and distinctive pathologic responses that can have grave sequella: pain, bleeding, and the release of “injury amines.” Pain is related to both the interruption of the sensitive periosteum and the damage the jagged edge of a compound fracture can inflict on adjacent nerves, vessels, and soft tissue. Pain can be adequately treated only with a combination of immobilization of the fracture, elevation of the limb, and pain medication, as discussed below.

Likewise, potentially massive bleeding originates from both the fracture itself and the associated soft-tissue and vessel injuries. The formation of a fracture hematoma usually controls the bleeding. If left undisturbed, the hematoma will become fibrous and stable. Limb movement related to inadequate splintage can result in hematoma disruption and renewed bleeding. This has obvious implications for AE both in terms of movement techniques and patient monitoring.

The final pathologic response to fracture is the local release of injury amines and other substances. These include histamine, bradykinin, various prostaglandins, and others—with more substances being elucidated on a regular basis. The predictable consequence is substantial tissue edema that results from local changes in capillary permeability. This can be minimized by both elevation and splintage of
the fractured limb. Unfortunately, edema can worsen during an AE flight (ie, “flight edema”) because of fluid shift caused by reduced cabin pressure.5–9

Fat Embolism Syndrome
A unique and potentially fatal condition that can occur after any significant fraction is fat embolism syndrome. It has long been attributed to the release of marrow fat into the circulation but may actually result from the release of injury amines into the systemic circulation, which then induce changes in systemic fat metabolism. As the fracture hematoma forms, the risk of fat embolism decreases, but can occur if the fracture hematoma is disrupted as a result of either surgical manipulation or inadequate splintage.

The Danger Zone
The “danger zone” for immediate orthopedic complications is the first 72 hours after fracture or any major bone surgeries, especially long-bone manipulation. During this period, injury-related edema becomes maximal. In addition, during this period patients are at greatest risk for fat embolism syndrome, manifesting most commonly by acute respiratory distress.3,10

Treatment of Orthopedic Casualties
There are several important considerations for the care of orthopedic casualties and recognition of complications in a timely fashion as they occur. Key among these are adequate splintage and elevation of the injured limb, monitoring of general vital signs, and frequent checks of the neurovascular status of the affected limb.

Splintage
Splintage is the single most crucial aspect of orthopedic casualty treatment.11–15 Adequate splintage of orthopedic injuries reduces pain and edema and prevents further damage to the limb by preventing sharp bone ends from lacerating soft-tissue structures. In addition, splintage reduces bleeding by allowing clotting to occur and the fracture hematoma to stabilize. Given the significant bleeding that can occur from long-bone and pelvic fractures, this is an important consideration.

Splintage can be anything from a rifle strapped around a leg to a complex internal fixation device. It also includes casts, traction, and external fixators. For medical evacuation (MEDEVAC), orthopedic injuries with fracture or dislocation need to be splinted using whatever is available, including the soldier’s rifle. Although the details of splintage are beyond the scope of this chapter, it is important to realize that many orthopedic devices that work well in a hospital setting are incompatible with AE, as discussed below.

Elevation of the Injured Limbs
An important aspect of care of the orthopedic casualty is elevation of the injured limb. This deceptively simple maneuver decreases pain, bleeding, and edema, probably as a result of decreasing venous capillary pressure. Maintaining elevation during transportation is well worth the small effort required.

Monitoring of Vital Signs
Once the fracture is reduced and the patient’s pain is well controlled, the risk of serious complications appears to be decreased. However, the risk of complications remains significant for the first 72 hours. Many of the most serious complications discussed below start with subtle signs and symptoms. Because effective treatment depends on early recognition, careful monitoring of vital signs in the apparently stable orthopedic casualty is essential.

Neurovascular Status Checks
Continued reassessment of limb status is vital during the 72-hours danger zone after fracture, when patients are at the greatest risk of limb edema and other causes of neurovascular compromise. The standard of care requires thorough documentation of normal neurovascular function before, during, and after AE.
Implications for AE

Orthopedic casualties possess both positive and negative characteristics that influence AE. On the positive side, orthopedic injuries are rarely life-threatening and, after initial stabilization, complications are uncommon. Notable exceptions to this are patients with significant pelvic fractures (especially posterior) or multiple long-bone fractures. On the negative side, the most common complications that may develop in orthopedic casualties during AE are in general beyond the capability of the aeromedical crew to treat and usually require expedient surgical treatment. An understanding of the potential complications and when they might occur will help avoid elective AE of orthopedic casualties during the periods when they are at highest risk for devastating complications. Appropriate planning is crucial to achieve an ideal outcome for all patients.

Orthopedic Contraindications for Elective AE

There are several orthopedic conditions that are contraindications to elective AE (Table 20.1). After major orthopedic trauma or surgery, elective AE should be delayed for 3 days (72 hours) to avoid the danger zone. If the injury required microvascular reattachment of a limb or digit, AE should be delayed until 7 days after surgery. Because of the risk of further damage to surrounding tissue, AE should be delayed until fractures are reduced and, if necessary, fixed. This is especially important if the patient is anticoagulated. Patients with compartment syndrome should be treated prior to AE because the occurrence of any flight edema will only worsen the problem. Finally, elective AE should be avoided when possible for patients with gas gangrene because any reduction in oxygen tension will worsen this condition.

If urgent or contingency AE is required relatively soon after major orthopedic injury or surgery, several important precautions should be taken. First, the aeromedical crew should be advised of the increased risk patients are at during the 72-hour danger zone following orthopedic injury or surgery. For any patient who has undergone microvascular reattachment of a limb or digit, or who is suspected or known to have gas gangrene, the flight altitude should be restricted to maintain sea-level cabin pressure. There are no altitude or cabin pressure restrictions for patients with compartment syndrome, but reasonable attempts should be made to maintain the cabin pressure as close as possible to sea level to minimize additional edema. The greatest possible care must be taken when moving patients with unreduced or unstable fractures to minimize damage to surrounding tissue and the associated pain (Fig 20.1). Careful monitoring of the neurovascular status of the affected limb is required for early detection of developing problems.

Preparation of the Orthopedic Patient for AE

Splintage

The most important consideration for AE is selection and preparation of splintage. Some splints are difficult or impossible to use during AE and others have potential complications. Free weight traction should not be used during AE, even in a sophisticated air ambulance, because of the adverse affect of movement and G-forces on these systems. Both US and NATO doctrines specifically forbid free weight traction. MAST trousers, a type of splintage sometimes used for pelvic fractures, is

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Table 20.1. Contraindications to elective AE.

<table>
<thead>
<tr>
<th>Contraindication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 72 h following major orthopedic trauma or surgery</td>
</tr>
<tr>
<td>Less than 7 d following microvascular reattachment of a limb or digit</td>
</tr>
<tr>
<td>Unreduced long-bone fractures or major joint dislocations</td>
</tr>
<tr>
<td>Unstable long-bone or pelvic fractures</td>
</tr>
<tr>
<td>An anticoagulated patient prior to definitive fracture fixation</td>
</tr>
<tr>
<td>Untreated compartment syndrome</td>
</tr>
<tr>
<td>Gas gangrene</td>
</tr>
</tbody>
</table>
also inappropriate for AE. The amount of pressure exerted by these inflatable trousers will vary with cabin pressure. The resultant excess pressure on the lower extremities can be dangerous when MAST trousers are used for prolonged periods during an AE flight. Likewise, air splints are relatively contraindicated for AE because splint expansion related to reduced cabin pressure can constrict circulation to the limb. Air splints are acceptable for MEDEVAC, as the altitudes flown will not induce significant expansion of a properly inflated air splint. All splints, whether inflatable or attached with elastic bandages, must be checked to ensure they are not too tight before and during any MEDEVAC or AE flight.

Casts present several unique challenges to AE. A rigid cast that fit well on the ground may become dangerously tight during flight because of flight edema or other changes in the patient’s condition. For this reason, all casts must be bivalved down both sides prior to AE (Fig. 20.2). The underlying cast padding should be divided as well, and the cast held together with an elastic bandage. In some cases, windows must be cut to allow adequate monitoring of neurovascular status. These windows must have plaster covers that can be replaced after every check. If a windowed area is left uncovered, soft-tissue swelling can result in an artificial “hernia.”

Preflight Checklists

There are several steps that should be taken prior to AE to minimize the chance of complications during flight (Table 20.2). Above all, it should be ensured that the medical records are complete and appropriate radiographs accompany the patient. If possible, the fracture should be drawn on the cast, as well as a list of any procedure done. This will guarantee that this important information is available to both the caregivers during the flight and the accepting physicians. If AE is required within the 72-hour danger zone following injury or surgery, the aeromedical crew must be made aware of higher risks for this patient. A flow sheet should be provided to record continuing neurovascular monitoring of the patient during flight. If the patient has undergone microvascular reattachment of a limb or digit within 7 days or has gas gangrene, flight altitude should be restricted to maintain sea-level cabin pressure.

Clinically, the most important preparation for AE involves careful examination of any cast or traction devices (Table 20.3). First, it must be verified that no free weight traction, MAST trousers, or air splints are being used. Next, all casts should be examined to ensure they are in good condition and both the plaster and underlying cast padding have been completely bivalved. The entire cast should be held...
together with an elastic bandage. All windowed areas that have been cut in the cast should have corresponding plaster covers in place to avoid localized soft-tissue swelling. Finally, all spring traction device settings should be checked.

Prior to take-off, it should be confirmed that all required equipment is on-board. This should include a spare blanket or pillow to elevate the injured limb during flight, a large paramedic-type scissors capable of cutting cast padding, a cast saw, extra elastic bandages, and standard dressings. The final clinical step prior to AE is to assure that normal neurovascular status of any fractured limb is present and has been clearly documented.

In-Flight Care

General nursing care for orthopedic patients during AE is straightforward. Adequate patient monitoring and documenting of vital signs and limb neurovascular status should be carried out at regular intervals. This interval may vary from every 1 to 4 hours, and needs to be specified by the referring physician in the preflight orders.
If a cast or dressings impedes the caregiver’s ability to palpate distal pulses, capillary refill of fingernails/toenails should be evaluated to verify adequate limb perfusion. If motor testing of distal extremities is difficult to evaluate because of pain, the response to touch can be used as a simple guide. The results of each exam should be recorded with the dates and times.

### Potential In-Flight Emergencies

Patients with orthopedic injuries may suffer from all of the problems common to other trauma patients, including infection and external hemorrhage. However, there are several complications that are relatively unique to orthopedic injuries, many of which are often “hidden.” Vascular and neurological complications, especially common with military orthopedic injuries, can be obvious and thus repaired prior to entrance to the AE system. Alternatively, more subtle neurovascular compromise can subsequently occur as a result of progressive intimal tears or the failure of a vascular repair. Concealed hemorrhage, significant enough to result in shock, is a risk for any patient with long-bone or pelvic fractures. Two complications relatively unique to orthopedic injuries are compartment syndrome and fat embolism syndrome. Two other complications for which a patient is at increased risk after orthopedic injuries are gangrene and crush syndrome.

Each of these complications is considered below.

### Neurovascular Compromise

Neurovascular compromise is always at the top of the list of problems associated with orthopedic injuries. Injuries to nerves or blood vessels can be on the same basis as the fracture (eg, projectile or crushing injury). A partial vessel injury, such as an intimal tear, can be completely asymptomatic immediately after injury but progress to complete vessel occlusion during transport. The jagged end of unstable fractures can create new nerve or vessel injuries as a result of inadequate splintage. Partially impeded circulation can become further compromised due to edema or the pressure of compartment syndrome.

Vascular compromise from any cause (including compartment syndrome, discussed below) present with acute loss of distal pulses, a cold extremity, or bleeding through dressings or casts due to the failure of a vascular repair. Management of acute vascular compromise of a limb is limited to supportive measures such as

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**Table 20.2. Administrative preflight checklist.**

<table>
<thead>
<tr>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ensure complete medical records and radiographs accompany the patient</td>
</tr>
<tr>
<td>If urgent or contingency AE is required during the 72-h danger zone following injury or surgery, alert the aeromedical crew to increased risk</td>
</tr>
<tr>
<td>Restrict the flight altitude to maintain sea-level cabin pressure for any patient who has undergone microvascular reattachment of a limb or digit within 7d or who has gas gangrene</td>
</tr>
<tr>
<td>Provide a neurovascular monitoring flow sheet for the patient</td>
</tr>
<tr>
<td>Draw on the cast the patient’s fracture and a list of any procedures done; in the event that paperwork becomes unavailable, this information will be invaluable to both the in-flight caregivers and the receiving physician</td>
</tr>
</tbody>
</table>

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**Table 20.3. Clinical preflight checklist.**

<table>
<thead>
<tr>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verify that no free weight traction, MAST trousers, or air splints are being used</td>
</tr>
<tr>
<td>Ensure all casts have been completely bivalved (not just split down one side); even the underlying cast padding should be cut, and the entire cast held together with an elastic bandage</td>
</tr>
<tr>
<td>Ensure all windowed areas cut in the cast have corresponding plaster covers; an uncovered window area will result in localized soft-tissue swelling forming a hernia</td>
</tr>
<tr>
<td>Ensure all casts are in good condition; soft, or soggy, or otherwise “beat-up” casts should be replaced or reinforced</td>
</tr>
<tr>
<td>Ensure the availability of a spare blanket or pillow to elevate the injured limb during flight</td>
</tr>
<tr>
<td>Check all spring traction device settings</td>
</tr>
<tr>
<td>Ensure that normal neurovascular status of any fractured limb has been clearly documented</td>
</tr>
<tr>
<td>Ensure the following supplies are available on the aircraft</td>
</tr>
<tr>
<td>Extra elastic bandages</td>
</tr>
<tr>
<td>Large paramedic-type scissors capable of cutting cast padding</td>
</tr>
<tr>
<td>Cast saw</td>
</tr>
<tr>
<td>Standard dressings</td>
</tr>
</tbody>
</table>
oxygen supplementation and diversion to an appropriate medical facility.

**Shock**

Shock is both an acute and delayed risk in an apparently stable orthopedic casualty. Absence of external bleeding can lead to a false sense of security in a patient with long-bone or pelvic fractures. The risk of continued bleeding is especially great in patients with unreduced or unstable fractures. These casualties can lose significant amounts of blood into a thigh or pelvis with none of the dramatic distension associated with intra-abdominal bleeding. Transfusion coagulopathy also becomes a risk if large amounts of blood replacement are required.

**Compartment Syndrome**

A compartment is an anatomic area of the body that is incapable of significant expansion due to rigid bony or fascial boundaries. With increasing edema or bleeding in a rigid compartment, the pressure in the compartment rises. Once the pressure in the compartment exceeds capillary perfusion pressure, approximately 30 to 35 mm Hg, blood flow at the cellular level to the tissues in the compartment ceases. This is most important to the skeletal muscle because it is the most metabolically active tissue.\(^\text{10,17,18}\) The resultant ischemic muscle swells further and becomes extremely painful in what is known as compartment syndrome.

Compartments most at risk for this syndrome with an orthopedic injury are the anterior, posterior, and lateral leg compartments and the volar compartment of the forearm. An artificial “compartment” is created whenever a rigid cast is placed around an extremity. If a cast is not bivalved properly so that it does not allow adequate room for edema, iatrogenic compartment syndrome can result.

It is important to note that the compartment pressure at which capillary perfusion of the muscle ceases is well below mean arterial pressure. Therefore, full-blown compartment syndrome can occur even in the presence of an excellent palpable distal pulse. Once compartment syndrome develops, the problem must be treated (ie, fasciotomy) within 4 hours or permanent damage, including limb loss, is likely to occur.\(^\text{10,15,17,18}\) Swelling of a limb inside an improperly bivalved cast over a prolonged flight has necessitated subsequent amputation.\(^\text{15}\)

During flight, the diagnosis of possible compartment syndrome is made on clinical grounds in patients at high risk. Both increasing limb pain and pain upon passive stretch of the compartment (elicited by extending the fingers or toes) indicates compartment syndrome until proven otherwise. Loss of distal pulses or neurological changes can be late signs.

For patients with diminished capacity to respond to a clinical exam for compartment syndrome (eg, decreased consciousness due to central nervous system injury), direct measurement of compartment pressure may be necessary. However, only experienced personnel should place in-dwelling monitoring devices. Commercially available compartment measuring devices not much larger than a hypodermic syringe can be utilized, even in the noisiest AE environment. On the ground or in the relatively quiet environment of modern dedicated AE aircraft, compartment pressure can also be measured with a simple in-dwelling catheter hooked to an arterial pressure monitor.

The first step in the treatment of evolving compartment syndrome is loosening of a properly bivalved cast. However, continued symptoms will require diversion to the nearest medical facility because definitive treatment, surgical fasciotomy, should be performed within 4 hours.\(^\text{10,17,19}\)

**Fat Embolism Syndrome**

Another complication unique to orthopedic injuries is fat embolism syndrome. This is most typically seen in long-bone fractures, such as femur fractures, but can be seen in patients with pelvic fractures or multiple fractures of smaller bones. This complication is most common in the 12 to 72 hours after orthopedic injury or surgery. Probably the highest-risk surgery for this complication is the placement of an intramedullary rod into the femur with reaming. Postmortem examination of patients who die from this syndrome reveals widespread fat emboli in alveolar blood vessels of the lung.
The clinical presentation of fat embolism syndrome is the rapid development of progressive respiratory distress syndrome in a patient at risk. Severity ranges from a mild hypoxia with a mild tachypnea to a profound respiratory distress requiring intubation and mechanical ventilatory support. Other clinical signs include progressive tachypnea, confusion secondary to hypoxia, and a distinctive petechial rash on the chest and neck, which is pathognomonic when present.\textsuperscript{3,10} In-flight treatment of fat embolism syndrome consists of supplemental oxygen and diversion to a medical facility if symptoms warrant. Intubation and assisted ventilation assistance may be required in severe cases.

**Pulmonary Thromboembolism**

The one relatively common complication of orthopedic injury which is not limited to the first few days following injury, is thromboembolism.\textsuperscript{10} The symptoms, while respiratory in nature, differ from those of fat embolism in two key ways. First, pulmonary thromboembolism usually presents with acute onset, as opposed to the frequently more insidious onset of fat embolism. This can vary from moderate respiratory distress and pleuritic chest pain to cardiac arrest. Second, jugular venous distension is commonly noted.

In-flight treatment of pulmonary thromboembolism consists of supplementary oxygen and ventilatory support as needed. Depending on the severity of symptoms, diversion to a facility that can initiate immediate anticoagulation, thrombectomy, and/or insertion of a vena cava filter may be necessary.

**Gas Gangrene**

A particular complication of a dirty extremity injury, especially with delayed or inadequate debridement, is clostridial (gas) gangrene. Patients with gas gangrene may require urgent AE to a facility with a hyperbaric chamber to assist in the treatment of this condition. The single most important AE-specific management action for these patients is altitude restriction to maintain the aircraft at sea-level air pressure because any reduction in oxygen tension will result in a worsening of this condition.\textsuperscript{9,15}

**Crush Syndrome**

One final complication that is seen in orthopedic casualties is “crush syndrome.” Casualties who have crushing injuries of an extremity associated with a significant period of limb hypoxia may develop crush syndrome. The etiology of this syndrome is muscle ischemia resulting in necrosis. The elements of crush syndrome include compartment syndrome symptoms (which may be delayed) and myoglobinuria, sometimes severe enough to result in renal failure. Casualties who have been pinned for any length of time in a structure or vehicle are at risk for this syndrome, even in the face of a relatively benign looking limb. If symptoms of crush syndrome develop during AE, the treatment is limited to supplemental oxygen, hydration to treat the myoglobinuria, and diversion for emergency surgical treatment of compartment syndrome.

**Conclusion**

Orthopedic casualties present specific challenges to both the civilian and military AE system. While usually not critically ill from their orthopedic injuries, these patients frequently represent a difficult nursing and transport challenge due to lack of mobility and potentially bulky and heavy splintage and traction devices. While orthopedic emergencies that threaten life or limb are rare during AE, there is relatively little the aeromedical crew can do to treat them in-flight. For this reason, the cornerstone of the safe AE of orthopedic casualties is adequate preparation and stabilization, together with delaying AE until 72 hours after injury or surgery if possible.

**References**

An estimated 1.4 to 2 million people are burned every year in the United States, resulting in 500,000 emergency department visits, 75,000 hospital admissions (including 20,000 admissions to burn centers), and 6500 deaths.\textsuperscript{1,2} In the civilian sector, burn care is delivered in 138 self-designated burn treatment centers in the United States and in 21 centers in Canada for a total of 1951 specialty-care beds.\textsuperscript{1} In the military health care system, the USA Burn Center (USA Institute of Surgical Research) functions as the international burn center for all branches of the US military, retirees, and dependents and as the national burn center for the Department of Veterans Affairs. The Institute of Surgical Research/Army Burn Center is a tenant agency at Brooke Army Medical Center, Fort Sam Houston, Tex, and has a normal capacity of 40 burn beds, all of which are configured to provide intensive care. By utilizing other wards at Brooke Army Medical Center, the burn center is capable of expansion to an 80-bed unit on short notice or a 200-bed unit in time of war.

Military service poses unique burn risks. Sailors live and work in close proximity to superheated steam, aviation fuel, and munitions. Soldiers handle demolition devices, tank rounds, and artillery shells and depend upon gasoline-fueled cooking stoves and tent heaters while in the field. Aviators operate rotary-wing and fixed-wing aircraft at design extremes and under adverse weather conditions.

Historically, burn injury has comprised 3% of all battle casualties. In recent conflicts, the incidence of burn injury is higher, possibly related to increased lethality of contemporary munitions. Based upon the Vietnam War experience, the Wound Data and Munitions Effectiveness Team suggests that, for planning purposes, thermal injury or other major soft-tissue injury requiring operative debridement will be present in 10% of combat casualties.\textsuperscript{3} In actual conflict, thermal injury was seen in 8.1% of casualties from the Yom Kippur War and 18% of British casualties from the Falklands War.\textsuperscript{4,5} Conflicts involving chemical weapons (blister agents) or tank warfare may be expected to produce even greater numbers of burn casualties.

Full-thickness burn injury requires surgical excision and grafting, with attendant blood loss. The average burn patient may require transfusion of up to 19.7 U of blood products during acute hospitalization,\textsuperscript{6} making in-theater burn surgery impractical. For this reason, the aeromedical evacuation (AE) system will have significant exposure to burn victims during future conflicts, as definitive care will likely be provided in the communication zone (COMMZ) or the continental United States (CONUS).

Overview of Military
Burn Casualties

Burn injury may be caused by contact with steam or hot liquids, flame, electrical current, or chemicals. Patients injured in closed spaces such as buildings or vehicles may have smoke inhalation injury to the lungs, which significantly complicates management. Combat-
related burns may be complicated by blast injury, open fractures, or other trauma. The presence of associated traumatic injury must always be considered and visceral injury ruled out prior to long-range transfer. The preflight work-up and preparation of burn patients in general is presented below. Subsequent sections present information specific to chemical or electrical injuries.

Acute Thermal Burn Injury (With or Without Smoke Inhalation)

General Considerations

Determining who Should Be Transferred and How Transfer Should Be Carried Out

The American Burn Association has established criteria for the referral of patients with thermal injury to special-care facilities (Table 21.1). These criteria, endorsed by the Advanced Trauma Life Support and Advanced Burn Life Support programs, represent a national civilian standard of care and are the criteria utilized by the USA Burn Center for accepting patients. In combat, triage may become necessary when treatment or evacuation assets are limited. In such situations, transfer priority is given to victims with second- and third-degree burns of >20% and <70% body surface area (BSA). For triage purposes, burn size is increased by 10% for the presence of inhalation injury or other major trauma. When medical assets are unable to accommodate patients within this range, the maximum burn size to receive treatment may be decreased in 10% increments until assets are adequate.

Transport guidelines for civilian practice recommend the use of ground ambulances for transport distances less than 30 miles, rotary-wing aircraft for distances of 30 to 150 miles, and fixed-wing aircraft for distances over 150 miles. In battle, rotary-wing aircraft would be used for tactical distances and fixed-wing aircraft used for strategic transfer.

Determining the Optimal Time for Transfer

Two factors, hemodynamic stability and pulmonary insufficiency from smoke inhalation injury, determine the optimal time for aeromedical transfer. Burn injury has profound effects on the circulation. Capillary permeability is increased both at the site of the burn and throughout the systemic circulation, resulting in hypovolemia, shock, and the need for fluid resuscitation. With resuscitation, capillary permeability is restored at 24 hours postinjury. Cardiac output is depressed in the first hours following thermal injury and then becomes elevated to levels of 2 to 2.5 times normal in the second 24 hours postinjury. This hypermetabolism persists until the burn wounds are healed or surgically closed. Patients with limited cardiac reserve may suffer myocardial infarction, usually at the peak of hypermetabolic response approximately 1 week postburn. If sepsis occurs, the hypermetabolic response may be further exaggerated. From a hemodynamic standpoint, the ideal time to transfer a patient is after a patient begins to respond to resuscitation but before sepsis occurs or hypermetabolism becomes severe.

Smoke inhalation injury may be present when fires occur indoors or within a vehicle. Approximately 400 toxic compounds can be identified in smoke from an ordinary house fire. Pulmonary insufficiency may result from a number of mechanisms including asphyxia,
carbon monoxide poisoning, thermal burns to the upper airway from breathing superheated air, tracheal injury, or parenchyma injury. Because the heat-carrying capacity of air is minimal, true thermal injury below the epiglottis is unusual; rather, such injuries represent tracheitis or pneumonitis from chemical irritation. An exception is the inhalation of steam, which can produce a true thermal pulmonary injury. The presence of smoke inhalation increases the mortality associated with a given sized burn by up to 20%. If pneumonia develops as a complication of inhalation injury, mortality is increased by up to 60%. 12

Airway loss or pulmonary failure can rapidly occur in previously asymptomatic patients with smoke inhalation injury. Initial physical examination, chest radiograph, and arterial blood gas determination are usually normal. Carbon monoxide, present in all fires, binds to hemoglobin and produces carboxyhemoglobin, which rapidly decreases oxygen carrying capacity. Carboxyhemoglobin produces false elevation of oxygen saturation values on both blood gas analysis and on pulse oximetry. Unless the carboxyhemoglobin level is known, high PO2 or saturation values upon arterial blood gas analysis cannot be relied on to indicate proper oxygenation.

The diagnosis of smoke inhalation is best suggested by the combined history of loss of consciousness and exposure to fire in enclosed spaces. Signs such as the presence of soot in the oropharynx, facial burns, or singed nasal hairs are nonspecific. Diagnosis is confirmed by laryngoscopic evaluation of the upper airway, followed by fiber optic bronchoscopy. As these maneuvers are impractical on the battlefield, elective endotracheal intubation is indicated in situations where inhalation injury is likely. The mainstay of treatment is oxygen ministration and mechanical ventilation. Neither steroid nor antibiotics are indicated in smoke inhalation injury. 13

Our criteria for safe transfer of patients with inhalation injury is the presence of a secure airway, a minute ventilation of 25L or less, and an adequate arterial blood gas measured at ground level on a FiO2 of 0.5 or less. When patients do not meet these criteria, frequent communication between the referring physician and the burn center determines the optimum time to send the burn flight team for transfer.

Determining Who and What Should Accompany the Patient

Optimal transport of the burn patient considers that the patient is being moved from one intensive-care area (emergency department or ICU) to another intensive-care area (burn center). Transport should not be attempted unless an ICU level of care can be maintained in-flight. 11

For urgent evacuation, our preference is to send a burn flight team to stabilize and accompany the patient. The Army Burn Flight Team, operational since the 1950s, consists of a general surgeon or burn center general medical officer, a burn ICU nurse, a licensed vocational nurse (MOS 91C), and a respiratory therapist (MOS 91V). In a recent 16-year period, the burn flight team managed the care of 1196 patients over a distance of approximately 850,000 miles without in-flight fatality or major mishap. 11

The flight team carries sufficient supplies to stabilize and transport burn patients independent of the referring facility (Table 21.2), including a transport ventilator designed for military use (TXP ventilator, Percussionaire Corp, Sandpoint, Idaho). 14 The transport ventilator is oxygen powered, weighs 1.5lb (0.68 kg), and can accommodate tidal volumes between 5 and 1500cc and respiratory rates between 6 and 250 breaths per minute (Fig 21.1). The ventilator system operates for several hours on a composite Kevlar/aluminum oxygen cylinder weighing 7.3kg, which is carried on the back of the respiratory therapist.

Care and Management Immediately Prior to AE

Preparation for AE

Where possible, the patient should be evaluated at the referring medical facility rather than on the flight line or in the aircraft. We follow the sequence advocated by the Advanced Trauma Life Support and Advanced Burn Life Support curricula, 7,8 including primary and secondary surveys.
Table 21.2. Equipment carried by the USA Burn Flight Team.

<table>
<thead>
<tr>
<th>Medical capability</th>
<th>Monitoring capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resuscitation fluids</td>
<td>ECG</td>
</tr>
<tr>
<td>ACLS drugs</td>
<td>Pulse oximetry</td>
</tr>
<tr>
<td>Pain and anxiety control</td>
<td>Core temperature</td>
</tr>
<tr>
<td>Stress ulcer prophylaxis</td>
<td>Automated blood pressure</td>
</tr>
<tr>
<td>Burn care</td>
<td>Pressures: CVP, arterial line, Swan–Ganz catheter</td>
</tr>
<tr>
<td>Nasogastric tubes</td>
<td>End-tidal carbon dioxide</td>
</tr>
<tr>
<td>Foley catheters</td>
<td>Portable arterial blood gas analyzer</td>
</tr>
<tr>
<td>Topical agents</td>
<td>Defibrillator</td>
</tr>
<tr>
<td>Burn dressings</td>
<td>Monitoring capability</td>
</tr>
<tr>
<td>Sheets, blankets, and Mylar rescue blankets</td>
<td>Surgical capability</td>
</tr>
<tr>
<td>Communications</td>
<td>Tracheostomy</td>
</tr>
<tr>
<td>Cellular/digital telephones (within the CONUS)</td>
<td>Venous access—central or cutdown</td>
</tr>
<tr>
<td>Satellite communications (extended missions outside the CONUS)</td>
<td>Tube thoracostomy</td>
</tr>
<tr>
<td>Secure, portable FM radios</td>
<td>Transvenous pacing</td>
</tr>
<tr>
<td>Respiratory support</td>
<td>Surgical capability</td>
</tr>
<tr>
<td>Endotracheal intubation/tracheostomy supplies</td>
<td>Surgical capability</td>
</tr>
<tr>
<td>Transport ventilator/oxygen supply</td>
<td>Venous access—central or cutdown</td>
</tr>
<tr>
<td>Battery-operated suction</td>
<td>Tube thoracostomy</td>
</tr>
<tr>
<td>Battery-operated fiber optic bronchoscope</td>
<td>Respiratory support</td>
</tr>
<tr>
<td>Adapters/connectors</td>
<td>Endotracheal intubation/tracheostomy supplies</td>
</tr>
<tr>
<td></td>
<td>Transport ventilator/oxygen supply</td>
</tr>
<tr>
<td></td>
<td>Battery-operated suction</td>
</tr>
<tr>
<td></td>
<td>Battery-operated fiber optic bronchoscope</td>
</tr>
<tr>
<td></td>
<td>Adapters/connectors</td>
</tr>
</tbody>
</table>

Figure 21.1. Portable pressure-controlled time-cycled transport ventilators used for the long-range aeromedical transport of patients with burns. The Duotron System (A; the black cylinder apparatus) utilizes two controllers to provide pressure-cycled and high-frequency ventilation. The controller for the TXP system (B; photo courtesy of Percussionaire Corp, Sandpoint, Idaho) provides pressure-cycled ventilation alone.14
The primary survey is a 1-minute, head-to-toe survey for life-threatening conditions, following the algorithm of ABCDEF (Airway, Breathing, Circulation, Disability, Exposure, and Fluid resuscitation). The airway should be secured by nasotracheal intubation if there is any question of inadequate patency, smoke inhalation injury, or if the massive resuscitation necessary for a large BSA burn would cause facial and airway edema. Nasotracheal intubation is preferred over the orotracheal route, as a nasotracheal tube can be easily secured by using multiple tracheostomy ties around the patient’s head. Facial burns preclude the use of adhesive tape to secure an orotracheal tube, which, in any case, is easier to dislodge in-flight than a nasotracheal tube. Anticipating the need for fiber optic bronchoscopy, the nasotracheal tube should be at least 7.0 to 7.5 mm inner diameter. Breathing is next assessed by observation and auscultation. Circulation is assessed by capillary refill and palpation of pulses in each extremity. Disability evaluation documents level of consciousness and ability to move extremities to command or noxious stimuli. Any suspected spinal trauma is immobilized at this point if not already done. The patient is then exposed and examined to determine extent of burn injury. Clothing is removed from any area where burn injury is a possibility and any rings, watches, or jewelry are removed to avoid constriction as edema forms during resuscitation. Posterior skin surfaces are evaluated by logrolling if other traumatic injury is suspected. The burn surface area is then estimated using “the rule of 9s” (Fig 21.2). In the adult, the surface area of the head, each extremity, and the anterior and posterior trunk can be divided by nine, providing a convenient estimate. Children have a similar system except that

![Figure 21.2](image.jpg) Figure 21.2. The rule of 9s for determining the total surface area of a burn.
the head is proportionally larger and each lower extremity is 14% BSA. The palm of the patient represents 1% BSA and can be used to estimate irregular surfaces. Only second- and third-degree burns are included in calculations. Second-degree burns (partial thickness injury) are typically supple, red or pink in color, weeping, painful to the touch, and may have blister formation (Fig 21.3). Third-degree burns (full-thickness injury) are cold, inelastic, leathery, pale, brown or charred, and insensate, as the cutaneous nerve endings have been damaged (Fig 21.4). Once the burn size is known, intravenous (IV) lines are placed and fluid resuscitation is started according to the Modified Brooke formula. At least two large-bore (16 gauge or bigger) peripheral IV cannula should be placed. The upper extremities are preferred over the lower extremities. IV lines may be placed through burned skin if necessary. The IV catheters are easily dislodged and should be sewn in place prior to flight.

Rarely, peripheral access is unobtainable and central venous access must be performed. We prefer to cannulate the femoral vein using the Seldinger wire technique rather than the subclavian vessels, as a delayed pneumothorax following chest line placement would be difficult to later detect in-flight.

For the first 24 hours, estimated fluid needs in milliliters are two times the percentage BSA of second- and third-degree burn times the patient’s weight in kilograms (2 cc/kg per percent burn). Children (under 30 kg body weight) should receive lactated Ringer’s solution at 3 cc/kg per percent burn, in addition to maintenance fluids of 5% dextrose in half-normal saline.15 One half of the calculated fluids
should be infused in the first 8 hours postburn, with the remainder given over the next 16 hours. Infusion should be calculated from the time that the burn occurred: If treatment is delayed, it is necessary to attempt to “make up” initial fluid requirements within the first 8 hours. Resuscitation formulae provide only an estimate of fluid need, and IV fluid rates should be adjusted hourly to obtain 30 to 50 cc of urine per hour in the adult and 1 cc/kg body weight in infants under 30 kg body weight. When urine output is inadequate or excessive, rate of fluid administration should be changed in 20% to 30% increments. Inadequate urine output in the first 24 hours is nearly always hypovolemia rather than renal failure. In the second 24 hours postburn, capillary permeability is restored and resuscitation fluids are changed to colloid and free water. Albumin, 5%, is given at a rate of 0.3 mL/kg/% burn for burns between 30% and 50% BSA, at 0.4 mL/kg/% burn for burns between 50% and 70% BSA, and at 0.5 mL/kg/% burn for burns >70% BSA. Free water as D5W is given to maintain adequate urine output. Beyond the second postburn day, albumin is discontinued and fluids adjusted to gradually return the patient to preburn weight by postburn day 10.

Circumferential burns of the chest or extremities may restrict breathing or circulation as resuscitation proceeds and the patient becomes edematous. The treatment is escharotomy or incision through the burn eschar. Escharotomy is a bedside procedure performed with a knife or electrocautery. Incision is made only to the level of the dermis–fat interface: Once the dermis is completely divided, there is no advantage to cutting deeper into fat. Escharotomy of the chest is performed in the shape of a shield (Fig 21.5). Escharotomy of an extremity is performed along the midmedial or midlateral line (Fig 21.6). The incision should extend along the entire length of the full thickness burn. If escharotomy on one side of an extremity does not restore circulation, then a second escharotomy on the second side should be performed. Because the tissue being divided is insensate third-degree burn, general anesthesia is both unnecessary and undesirable.

Bleeding at escharotomy sites is controlled with electrocautery or absorbable suture. As the compression is relieved and extremity blood flow is restored, delayed bleeding may occur, which may go undiagnosed if the extremity is wrapped in bulky dressings. Hypotension during flight should prompt removal of dressings over escharotomy sites to rule out bleeding. To avoid this complication, we recommend serial examination of escharotomy sites for 30 to 60 minutes following performance of the procedure or reexamination of the sites prior to leaving the medical facility for the flight line.

Adjuncts to resuscitation include placement of a nasogastric tube, a Foley catheter, and monitoring of pulse oximetry and electrocardiogram. Patients with burns over 20% BSA often develop gastric atony, making nasogastric decompression essential.

Following initial stabilization, a complete history is taken and a secondary survey performed to rule out associated injury. Tetanus immunization should be given if the patient has not been immunized within the last 5 years. Hyperimmune globulin is also given if the history of tetanus immunization cannot be obtained or if adult patients have had less than three tetanus immunizations in their lifetime. The burn wound should be washed with a surgical disinfectant and loose necrotic material should be debrided. Blisters that would burst in-transit should be unroofed and debrided. Whether or not to apply a topical antimicrobial cream will depend on the circumstances of transport. In civilian practice, use of topical antimicrobial agents are discouraged prior to burn center arrival, as these creams will have to be removed by the burn team to assess the wounds. Instead, covering the burn surface with a clean (nonsterile), dry sheet is advocated. When the Army Burn Flight team transports a patient, the wounds are placed in silver sulfadiazine cream prior to transport with the rationale that the burn physician and nurse on the flight team have already performed wound assessment. In battle, wound care is deferred until the patient arrives at the level of a combat support hospital, at which time silver sulfadiazine is applied after wound debridement. In combat situations, penicillin may be given for the first 5 days postinjury to prevent beta-hemolytic streptococcal burn wound infection, the onset of which may be missed during evacuation. Systemic antibiotics are otherwise not indicated in the acute phase of burn care.
In all circumstances, the patient must be protected from heat loss and tight dressings must be avoided. The burn wound should be inspected at least daily during the transport process.

The transport team should obtain records of treatment performed, IV fluids given, urine output, and results of any laboratory studies to carry with the patient. The chest radiograph should be reviewed and a copy obtained.

**Indications for Return to Medical Facilities Prior to Evacuation**

Immediately prior to the flight, a preflight checklist should be used to verify that the patient is ready for AE (Table 21.3). The most common reasons for return to the medical facility preflight are hemodynamic instability, loss of the airway, loss of peripheral pulses, or continued bleeding from escharotomy sites.

**Urgent AE**

**Minimal Conditions That Must Be Met**

Contraindications to aeromedical transfer of burn patients are listed in Table 21.4. In the absence of these conditions, a burn patient is ready for urgent AE when the airway is patent, successful resuscitation is underway or completed, appropriate lines are in place (see checklist), adequate arterial blood gases have been obtained on the transport ventilator, the chest radiograph has been reviewed, and wounds are dressed.

**Specific Concerns, Supplies, and Needs of Patients**

The noise and vibration present during flight make auscultation difficult and changes in airway or breathing status are easily missed. Assurance of adequate airway and breathing preflight is important. In-flight, adequacy of airway and breathing are assessed with continuous pulse oximetry and, if available, end-tidal capnography.

In rotary-wing aircraft, vibration-induced motion artifact often precludes use of a continuous electrocardiogram (ECG) monitor. When this happens, heart rate can be monitored by using the pulse oximetry waveform displayed on a multifunction monitor such as the ProPaq Encore system.

Patients with large BSA burns are unable to regulate body temperature and can rapidly become hypothermic at normal ambient temperatures. The cold associated with increasing altitude accentuates this problem. Preflight, we normally wrap the patient in a clean sheet, covered with a wool blanket, followed by a Mylar rescue blanket. Core temperature should be frequently assessed with rectal probe or ear tympanic membrane thermometer. In fixed-wing aircraft, the cabin temperature should be raised.
Burn patients require repeated administration of IV narcotics and anxiolytics at doses much higher than used for other patients. Chemical paralysis may also become necessary to facilitate mechanical ventilation. All pain and antianxiety medications should be given in small, frequent, IV doses. Flight planning must consider this increased need for analgesic and anxiolytic drugs.

**In-flight Emergencies**

Restlessness or anxiety are signs of hypovolemia or hypoxia. When present, the adequacy of oxygenation, ventilation, and resuscitation must be reassessed before leaving the medical treatment facility.

**Table 21.3. Preflight checklist: Items that should be reassessed before leaving the medical treatment facility.**

<table>
<thead>
<tr>
<th>Category</th>
<th>Checkpoints</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airway</td>
<td>Airway is patient, Endotracheal or tracheostomy tubes are secured</td>
</tr>
<tr>
<td>Breathing</td>
<td>Presence of bilateral breath sounds, Chest radiograph has been examined, Adequate arterial blood gas after 20–30 min on the transport ventilator, Pulse oximeter is functioning</td>
</tr>
<tr>
<td>Circulation</td>
<td>IV lines are functioning and sewn in place, Peripheral pulses are present, Foley catheter functional/urine output is adequate, ECG is functioning, Escharotomy sites are not bleeding</td>
</tr>
<tr>
<td>Other</td>
<td>Nasogastric tube functional, Wound dressings are not constrictive, Transport team has copy of hospital chart, results of any tests performed, and intake and output records, Patient protected against heat loss</td>
</tr>
</tbody>
</table>

**Table 21.4. Contraindications to the aeromedical transfer of burn patients.**

<table>
<thead>
<tr>
<th>Contraindication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marginal respiratory reserve</td>
</tr>
<tr>
<td>Inadequate arterial blood gas at ground level on FiO₂ of 0.5</td>
</tr>
<tr>
<td>Minute ventilation &gt;25 L</td>
</tr>
<tr>
<td>Uncontrolled bleeding, GI or otherwise</td>
</tr>
<tr>
<td>Body temperature &gt;39.5°C not controllable with antipyretics</td>
</tr>
<tr>
<td>Uncontrolled cardiac dysrhythmia</td>
</tr>
<tr>
<td>Intraocular or intracranial air or recent intraocular or intracranial surgical procedure</td>
</tr>
<tr>
<td>Relative contraindication</td>
</tr>
<tr>
<td>Intra-abdominal or intrathoracic surgical procedure within 24–48h of flight</td>
</tr>
</tbody>
</table>
should be reassessed. Hemodynamic instability may result if escharotomy sites start to bleed. With bulky dressings, this blood loss may not be readily apparent and removal of dressings and direct inspection of the wound is necessary. Electrocauterization and blood transfusion are impractical in-flight. When bleeding sites are identified, the best treatment is to oversew the bleeding vessels with absorbable suture (3-0 chromic or Vicryl).

Physiological consequences of change in barometric pressure during ascent or descent are familiar to the aeromedical team. Burn-specific problems include the need to monitor endotracheal tube cuff pressure (or the use of saline to inflate the cuff), the need to monitor inflation of air splints if used to stabilize concurrent trauma, and the need to ensure that burn dressings do not become constrictive. Change or loss of peripheral pulses should first be treated by elevation of the extremity and loosening of the dressings. Any possible need for escharotomy or fasciotomy should be anticipated preflight, as in-flight surgical procedures are difficult.

**Elective AE**

A number of patients will meet American Burn Association criteria for burn center care, but do not require urgent evacuation. This group would include patients with small BSA burns being transferred for functional or cosmetic considerations (burns of the hands, feet, and face), small full thickness burns, or small chemical burns. A second group considered for elective AE are patients nearing the conclusion of acute care that are being transferred for rehabilitation. The need for urgent rather than elective AE cannot be determined on burn size alone and should consider the patency of the airway, the need for mechanical ventilation in-flight, and the presence of preexisting medical conditions or associated traumatic injury. Consultation with the receiving burn facility is useful when the need for urgent versus elective transport is unclear.

During armed conflict, triage decisions in general afford the highest transport priority to patients with burns between 20% and 70% BSA. Patients with burns outside of this range would then be selectively transported as space becomes available.

**Electrical Injury**

Electrical injury, including lightning contact, meets American Burn Association criteria for treatment in a burn center. While overall management is similar to thermal injury, pathology and complications specific to electrical injury must be identified and addressed prior to evacuation.

Electrical injury may be caused by contact with alternating or direct current. Alternating current produces more severe injury and is more likely to cause muscle tetany or cardiac arrhythmias. Tetany may prevent the victim from releasing hold of a current source. On occasion, tetany of paraspinal muscles produces compression fractures of the thoracic or lumbar vertebrae.

Cardiac arrhythmias are seen in up to 37% of patients with electrical injury. Cardiac arrest may be present at the time that the victim is removed from the current source. Other arrhythmias include ventricular fibrillation, ventricular tachycardia, sinus tachycardia, or nonspecific ST-T changes. Arrhythmias, when present, usually occur prehospital or in the emergency department and rarely present after the first postburn day. Selective ECG monitoring of electrical injury patients for 24 to 48 hours is advocated when current may have passed across the chest and in patients with cardiac symptoms or a history of cardiac risk factors. It would be prudent to monitor the ECG of electrical patients while in-flight, in particular within the first 24 to 48 hours of injury.

As current passes through the extremities, blood vessels and nerves may be injured. Muscle and bone resist current flow and, like resistance wires in a toaster, become heated. This heat continues to radiate internally after the current is stopped, resulting in muscle necrosis, edema, and compartment syndromes. Skin may be spared from thermal injury because the external location allows heat dissipation. It cannot be overemphasized that
necrotic muscle may be present underneath intact skin and that the absence of burned skin does not rule out deep injury from electricity.

Lysis of myocytes or erythrocytes may release myoglobin, hemoglobin, or potassium. Life-threatening hyperkalemia may result, requiring treatment with bicarbonate, insulin, and glucose infusion or binding resins. Radical excision of dead tissue is on occasion required to control hyperkalemia. Free myoglobin or hemoglobin are excreted in the urine as dark pigment and can precipitate in renal tubules, causing renal failure when the urine is acidic. When dark pigment is present in urine, resuscitation fluids should be increased to provide urine outputs in the 75 to 100 mL/hour range and 50 mEq of sodium bicarbonate should be added to each liter of resuscitation fluid. As urine color returns to normal, fluids should be readjusted to provide 30 to 50 cc/hour of urine output. If urine pigments fail to clear, mannitol can be given with the understanding that this osmotic diuretic will render urine output inaccurate as a resuscitation indicator.

Frequent neurovascular assessment of extremities is indicated in electrical injury. Change in pulse or neurovascular status indicates the need for escharotomy of circumferential extremity burns. If the skin is not burned, or if escharotomy does not restore pulses, formal surgical exploration and fasciotomy or even amputation is required. Patients should not be accepted for flight until neurovascular status has been determined and surgery performed or the need for surgery ruled out. Change of neurovascular status or loss of pulse is an indication to return to the medical facility prior to flight.

Associated trauma should be ruled out prior to transportation. A history of electrical contact on a power pole should prompt consideration of a fall with possible cervical spine or internal organ injury. We routinely obtain radiographs of the thoracic and LS spine in cases where compression fractures are a possibility.

### Chemical Burn Injury

Chemical burn injury can be caused by skin contact with acids, alkalis, or organic compounds. Acid burns produce coagulation necrosis of the skin and are less severe than alkali burn, which produce liquefaction necrosis with disruption of tissue planes. Organic compounds such as gasoline produce burn injury by skin contact and, in addition, may be absorbed, causing systemic toxicity. Renal or hepatic insufficiency or failure may result. The fumes of organic compounds may cause unconsciousness or pulmonary injury.

Chemical burns meet American Burn Association criteria for treatment in a burn center. Compared to thermal injury, chemical burns are usually of a smaller surface area but more likely to be full thickness or third-degree injury. Full thickness chemical burns may initially mimic second-degree or partial thickness burns, presenting as erythematous areas of blister formation. The true depth becomes apparent in the next few days as the burn becomes blanched and leathery.

The treatment of all types of chemical injury is to flush the burned area with water until the pain significantly decreases or stops. Chemicals that are dry powders should be brushed off of the wound prior to irrigation. Acid burns typically require 30 minutes to 1 hour of irrigation. Alkali burns may require several hours of irrigation. Irrigation has the added advantage of providing some decontamination of hazardous chemical exposure by dilution. Many hazardous chemicals, including chemical warfare agents, require specific decontamination methods that are beyond the scope of this chapter.

For evacuation purposes, chemical burns are treated identically to thermal injuries with several exceptions. The smaller size of the injury usually places these patients into a routine rather than an urgent transport status and simplifies in-flight management, as patients are usually ambulatory. The transport team must verify that wound irrigation and decontamination has been performed prior to arrival of the team. Transportation of a patient prior to decontamination will place the flight crew at risk and will remove the aircraft from service until aircraft decontamination has been performed. In civilian practice, we likewise advise against the use of rotary-wing aircraft to transport patients from the scene of hazardous materials incidents. The prop wash generated at
take-off and landing will spread chemical contamination, and any accidental contamination of the aircraft by an incompletely decontaminated patient will place an expensive asset out of service.11

Contingency AE

The complex pathophysiology of acute burn injury superimposed upon the physiological stresses associated with flight make the aeromedical transport of burn patients difficult. Specialized burn transport teams have been available in peacetime and in war since the Vietnam War era and are likely to play a significant role in the next armed conflict. In nearly all situations, the long-range transport of burn patients should be performed by burn or critical-care specialty teams.

In some wartime situations, transport of burn patients without a specialized team may become necessary. While it is not possible to cover all contingencies in a textbook chapter, general planning guidelines should include consideration of triage and the increased needs for IV fluids and other medications unique to the burn patient.

As previously mentioned, wartime triage may require restriction of transportation to patients with burns between 20% and 70% total BSA. In theory, patients with burns in the 10% to 20% BSA range can be resuscitated with oral fluids and transported as “walking wounded.” In practice, the gastric atony associated with burn injury, coupled with distension and contraction of hollow organs secondary to changes in barometric pressure, may make oral resuscitation impractical. For this patient population, IV fluids must be available in-flight if vomiting precludes oral resuscitation. Alternatively, evacuation can be delayed 24 to 48 hours until oral resuscitation is completed.

For planning purposes, the availability of sufficient quantities of IV fluid, narcotics, sedatives, and paralytics must be anticipated. In contemporary civilian practice, burn patients are resuscitated on the Modified Brooke formula (2cc) or on the Parkland formula (4cc), and should require between 2 to 4cc of Ringer’s lactate per kilogram body weight per percent BSA second- and third-degree burn during the first 24 hours. In practice, such formulae are only guidelines and fluid administration is adjusted hourly based upon urine output. Certain situations, such as inhalation injury, delayed resuscitation, associated traumatic injuries, or very large burn size increase the need for resuscitative fluids. Twenty-four hour IV fluid requirements of 6 to 8cc/kg per percent burn are not uncommon. To provide a margin of safety, sufficient Ringer’s lactate to provide flow rates of at least 10cc/kg per percent BSA burn for the duration of the flight should be available for each burn patient transported.

Burn patients normally require narcotic medications for pain control and usually benefit from simultaneous administration of benzodiazepines. Neuromuscular blockade may be required to facilitate mechanical ventilation. To avoid hypotension, these medications should be started in small doses and given intravenously at frequent intervals. If hypotension occurs with administration of 2 to 5mg of morphine, the adequacy of resuscitation should be reassessed.

After the initial administration of small doses of narcotics, benzodiazepines, and paralytics, it usually becomes apparent that the need for all three classes of medication in burn patients far exceeds dosages normally encountered in critical-care practice. The authors have treated burn patients who have required the simultaneous administration of 15 to 20mg of morphine, 15 to 20mg of benzodiazepine, and 10 to 15mg of vecuronium per hour for several days at a time. When expedient transfer of burn patients is attempted, the need for very large doses of narcotics, benzodiazepines, and neuromuscular blocking agents must be anticipated.

A final point to consider is that the present standard of care permits the morbidity and mortality-free transport of seriously burned patients over long distances when a properly trained and equipped team is available. The expedient transfer of burn patients without the benefit of specialized assets will be expected to increase in-flight mortality and morbidity. In wartime, the possibility of death in-flight must be balanced against other possibilities, including death on-scene for lack of medical assets or
tactical considerations such as the possibility that a forward medical facility will be captured or overrun by aggressor forces.

**Conclusion**

Thermal injury will be a likely consequence of the next armed conflict. Surgical management of thermal injury is resource intensive and impractical in the far-forward arena; rather, burn casualties will require evacuation out of theater for definitive care. The experience of the USA Burn Flight Team over the past 40 years demonstrates that long-range aeromedical transport of the massively injured can be safely performed when the patient is properly stabilized and the transport team is both experienced and well equipped.

**References**

It is noteworthy that obstetric and gynecological diagnoses are the most common reasons for hospital admissions in the United States. This is related in part to the fact that childbirth occurs almost exclusively in a hospital setting. In addition, problems related to the female reproductive tract are relatively common in women of all ages, but especially in women of reproductive age. Together, childbirth and hysterectomy account for more than 30% of all surgical procedures performed annually in the United States. The implications for long-distance civilian aeromedical evacuation (AE) are obvious.

Obstetrics and gynecology has taken on increased importance in military medicine as well. The active-duty military population is now made up of more than 15% women, who are almost exclusively of reproductive age. In addition, the majority of active-duty and retired men have wives who often utilize the military medical care system. This is especially true overseas, where civilian medical care might not be available or adequate. With more than 200,000 active-duty troops and 400,000 dependents stationed overseas, large portions of the personnel who utilize overseas the military medical system are female. The AE implications related to the significant number of obstetric and gynecological patients treated in military medical facilities should not be underestimated, and contingency plans should be immediately available.

Even during armed conflict, gynecological considerations remain surprisingly important. Although active-duty dependents are no longer a major consideration, many of the medical problems experienced by women living under field conditions are gynecological in nature. A recent example is the Persian Gulf War. Prior to and during the offensive actions in Kuwait and Iraq, more than 600,000 US military personnel were billeted under field conditions, many for more than 6 months. Women made up 7% of the active-duty personnel in the theater. However, more than 17% of the sick call visits were by women, and more than 25% of these visits were for gynecological problems. Although most problems were treated locally, many gynecological patients eventually required AE for medical or administrative reasons.

One unanticipated result of billeting a large number of men and women together under field conditions for an extended period was inadvertent pregnancy. Because pregnancy is an administrative indication for reassignment outside of the theater of operations, pregnancy became the single most common reason for AE of women during Operations Desert Shield and Desert Storm.

This chapter will explore both the obstetric and gynecological implications for AE. Uncomplicated and complicated pregnancies will be examined at all stages, including the first, second, and third trimesters and the postpartum period. Information on emergency delivery is also included. Chronic and acute gynecological conditions and considerations for AE of the postoperative gynecological patient will be discussed.
Ob/Gyn Emergency Equipment

An important consideration for AE of the obstetric and gynecological patient is the availability of equipment specific to these problems. Because many specialized instruments are not routinely available without preplanning, an ob/gyn emergency kit should be made available. This is composed of instruments that are commonly used for both obstetric and gynecological problems. In addition, the kit should include instruments specific to emergency vaginal delivery (Table 22.1).

The kit should include instruments for evaluation and prepared for vaginal lacerations or vaginal bleeding including speculums, suturing instruments and materials, and scissors. Instruments and equipment specific for delivery of infants include cord clamps, suction bulbs, and towels. A relatively important piece of equipment for an emergency vaginal delivery in a confined area is a bedpan. This is used to elevate the buttocks during emergency delivery, as described below. Various types of gauze and padding are also essential. This includes gauze for packing a vaginal laceration or the vagina in the event of uterine hemorrhage.

Obstetric menstrual pads are included for both for gynecological vaginal bleeding and normal postpartum bleeding. In addition, specific medication might be required when transporting high-risk pregnant patients (see specific diagnoses below).

Table 22.1. Emergency ob/gyn kit.

<table>
<thead>
<tr>
<th>Sterile preassembled ob/gyn kit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Instruments</strong></td>
</tr>
<tr>
<td>Vaginal speculum (Graves &amp; Pederson)</td>
</tr>
<tr>
<td>Needle holder</td>
</tr>
<tr>
<td>Suture scissors</td>
</tr>
<tr>
<td>Thumb forceps</td>
</tr>
<tr>
<td>Large (Russian)</td>
</tr>
<tr>
<td>Small (Allis)</td>
</tr>
<tr>
<td>Ring forceps (2)</td>
</tr>
<tr>
<td>Single-tooth tenaculum</td>
</tr>
<tr>
<td>Vascular clamps</td>
</tr>
<tr>
<td>Large (Kelly) hemostat (2)</td>
</tr>
<tr>
<td>Small (Crile) hemostat (2)</td>
</tr>
<tr>
<td>Bandage scissors</td>
</tr>
<tr>
<td>Cord clamp</td>
</tr>
<tr>
<td>Suction bulb</td>
</tr>
<tr>
<td>Towels</td>
</tr>
<tr>
<td>Gauze, 4 x 4&quot; (40)</td>
</tr>
<tr>
<td>Gauze 2&quot; tape, 10 ft (for packing)</td>
</tr>
<tr>
<td>Sterile gloves</td>
</tr>
<tr>
<td>Thermal absorbent blanket and head cover (for newborn infant)</td>
</tr>
<tr>
<td>Bedpan (to elevate buttocks)</td>
</tr>
</tbody>
</table>

Obstetric Patients

Uncomplicated Pregnancy

Flight imposes little risk to the healthy pregnant woman or her fetus. Pregnant women have flown millions of hours in commercial aircraft at all stages of gestation without a documented increased in the risk of any pathologic or physiological events associated with pregnancy. This is not to say that there are no medical implications related to flying during pregnancy. Sudden, potentially catastrophic events might occur at any time in pregnancy and are more common near term. The space constraints and the relative isolation from immediate medical care that often occurs during flight must be taken into account both by potential pregnant passengers and the flight crew.

Effects of Altitude

During routine commercial flights, the maximum cabin pressure is equal to an altitude of approximately 8000 ft. This results in a 25% decrease in PO₂ in a healthy pregnant adult breathing ambient air from 80 mm Hg to 60 mm Hg. Fortunately, this drop has no appreciable effect on a healthy pregnant woman or her fetus. However, in pathologic conditions where the fetus might suffer from decreased oxygenation supplemental oxygen should be given as a matter of course.

Immobilization

Prolonged immobilization is probably the most significant medical consideration for the pregnant patient during a long flight. Pregnant women have increased coagulability for hormonal reasons, leading to an increase risk of venous thrombosis. In late pregnancy, increased intra-abdominal pressure from the pregnancy decreases venous return from the
lower extremities, thus increasing the risk of venous thrombosis further. The risk of lower-extremity venous stasis might be increased even further in a sitting position with the knees flexed. For these reasons, it is recommended that women flying late in pregnancy in a seated position should ambulate at frequent intervals throughout the flight. A semirecumbent position afforded by reclining the seat back might also help with venous return. High-risk pregnant women should be transported in a lateral recumbent position by litter, preferably keeping the patient on the left side.

Effects of G-Forces
Pregnant patients might be more susceptible to the effects of increased G-force. During take-off and landing, both commercial and military passengers experience a slight increase in G-forces. For most people, this G-force effect is virtually undetectable. However, there is an increased susceptibility to orthostatic hypotension during the second half of pregnancy as a result of increased venous pooling in the lower extremities. This might also explain an apparent increased sensitivity to G-forces in late pregnancy. In one study, two of three patients transported by military AE after 34 weeks experienced “dizziness and shadowing of vision” during descent that responded to supplemental oxygen. Although the exact mechanism of these symptoms remains uncertain, orthostatic hypotension related to a combination of venous pooling and increased G-forces is a likely explanation.

Onset of Labor During Flight
A potentially more pressing concern in late pregnancy is the onset of labor or any one of the normal or pathologic processes associated with labor during a prolonged flight. Each year, the sudden onset of labor, rupture of the amniotic membranes, or bleeding in pregnancy during flight requires emergency diversion of commercial airlines. Because of the significant implications of this, the International Air Transportation Association has recommended that pregnant women should not fly on commercial aircraft after the 36th week of pregnancy (the 35th week for overseas flights) to minimize the risk of such an event occurring during flight. USAF regulations recommend against routine air transfer of patients beyond the 34th week of pregnancy (including AE) for the same reason.

Fortunately, there are usually a matter of hours between the onset of labor and delivery of the infant in most women. At term, labor lasts an average of 8 to 12 hours. However, some women deliver less than 2 hours after the onset of painful contractions. For this reason, the onset of obvious labor during a commercial flight is best treated by diversion to the nearest large airport and evaluation of the laboring patient in a hospital setting. If AE is required during the last month of an uncomplicated pregnancy, the availability of obstetric emergency supplies and an attendant who is trained in emergency vaginal delivery is a wise precaution.

A related concern is that the risk of spontaneous ruptured membranes might be increased by the changes in pressure associated with flight. It has long been suspected that subtle changes in atmospheric pressure might increase the risk of spontaneous rupture of membranes. Anecdotal evidence suggests that the rapid increase in pressure associated with landing of commercially pressurized aircraft might increase the risk of membrane rupture near term.

Problems During the First Half of Pregnancy

First-Trimester Bleeding: Miscarriages
The first trimester is defined as the first 13 weeks of pregnancy after the last menstrual period. During this time, bleeding is extremely common. It has been estimated that more than one third of pregnant women experience some bleeding in early pregnancy. At least 20% of all clinical pregnancies will end in spontaneous abortion, commonly referred to as a “miscarriage.”

In any case of bleeding in the first trimester, consideration should always be given to the possibility that the patient actually has an ectopic pregnancy, discussed in more detail.
The importance of making this diagnosis lies in the fact that minimal external vaginal bleeding can be associated with life-threatening intra-abdominal hemorrhage from an ectopic pregnancy. For this reason, ultrasound should be used to verify that the pregnancy is intrauterine in any patient with first-trimester bleeding.12

Once an ectopic pregnancy has been ruled out, the spontaneous abortion can be further classified according to stage of progression. A “threatened” abortion describes a pregnancy in which any spotting or bleeding is occurring. Fortunately, the first sign of a spontaneous abortion, relatively light bleeding, almost always occurs days to weeks before progression to the heavy bleeding and cramping.12 The most critical stages of a spontaneous abortion are accompanied by heavy bleeding and are termed “inevitable” abortion if the cervix is open but no tissue has been passed or “incomplete abortion” if some, but not all, tissue has been passed vaginally. In some cases, the bleeding can be heavy enough to constitute a medical emergency. The final stage of most spontaneous abortions, termed “complete” abortion, is when all tissue has been passed and is usually associated with minimal residual bleeding. This diagnosis is usually verified by ultrasound.

A less common condition, termed a “septic” abortion, is when an intrauterine infection complicates a spontaneous or induced abortion. In the past, septic abortions were the common sequelae of illegal abortions. The implications of a septic abortion for AE are similar to a uterine infection related to other causes, and are discussed below. Another uncommon condition is a “missed” abortion, defined as a pregnancy in which the fetus is no longer viable but no bleeding or cramping has occurred. This condition can be treated the same as a threatened abortion for the purposes of AE.

**Implications for AE**

Active bleeding in the first trimester of pregnancy is a contraindication to elective AE (Table 22.2). Emergency transportation to the nearest appropriate medical facility (ie, medical evacuation [MEDEVAC]) should be considered only if the facilities for definitive treatment are not available locally. Patients with minimal spotting might be moved short distances relatively safely if there is no significant cramping and the cervix is closed (eg, an early threatened abortion) (Table 22.3). Fortunately, few patients will experience heavy bleeding within the first week after the onset of spotting.12

During contingency operations (eg, natural disaster or armed conflict), it might be necessary to move pregnant patients who are experiencing more than minimal spotting by AE. Before AE is considered, several conditions should be met to minimize the chance that a threatened abortion will progress to heavy bleeding. The most valuable tool is ultrasound. In a patient with bleeding, the presence of cardiac activity indicates that the chance of

<table>
<thead>
<tr>
<th>Table 22.2. Contraindications for AE of obstetric and gynecological patients.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Obstetric patients</strong></td>
</tr>
<tr>
<td>First trimester</td>
</tr>
<tr>
<td>Uterine bleeding (especially with cramping)</td>
</tr>
<tr>
<td>Suspected ruptured ectopic pregnancy</td>
</tr>
<tr>
<td>Second and third trimesters</td>
</tr>
<tr>
<td>Active labor</td>
</tr>
<tr>
<td>Uterine bleeding</td>
</tr>
<tr>
<td>Cervix &gt;4 cm dilated</td>
</tr>
<tr>
<td>Incompetent cervix, untreated</td>
</tr>
<tr>
<td>Severe preeclampsia</td>
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<tr>
<td><strong>Postpartum</strong></td>
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<tr>
<td>Heavy vaginal bleeding</td>
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<tr>
<td><strong>Gynecological patients</strong></td>
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<tr>
<td>PID with peritonitis</td>
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<tr>
<td>Ruptured tubo-ovarian abscess</td>
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<td>Heavy vaginal bleeding</td>
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<table>
<thead>
<tr>
<th>Table 22.3. Criteria for AE: First-trimester bleeding.</th>
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</thead>
<tbody>
<tr>
<td><strong>Elective AE</strong></td>
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<tr>
<td>No bleeding for 48h with ultrasound evidence of a viable fetus</td>
</tr>
<tr>
<td>After fetal nonviability is verified by ultrasound, perform D&amp;C prior to transport</td>
</tr>
<tr>
<td>Convalescent period: 24h after D&amp;C</td>
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<tr>
<td><strong>Urgent AE</strong></td>
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<tr>
<td>Bleeding &lt;normal menstruation</td>
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<tr>
<td>Minimal or no uterine cramping</td>
</tr>
<tr>
<td>No signs of intra-abdominal bleeding (eg, ectopic pregnancy)</td>
</tr>
<tr>
<td>Convalescent period: 12h after D&amp;C</td>
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miscarriage is less than 5% and thus heavy bleeding is unlikely. If fetal heart tones are observed by ultrasound and no bleeding has occurred for >48 hours, AE is relatively safe. In contrast, the absence of cardiac activity with an intrauterine sac >10 mm in diameter 7 or more weeks from the last menstrual period is associated with an increased risk of miscarriage and heavy bleeding.\textsuperscript{12}

Regardless of the ultrasound findings, the most important clinical consideration is the amount of bleeding and uterine cramping. If the bleeding is less than a menstrual period and there is minimal or no uterine cramping, then urgent AE is reasonable in a contingency situation. However, if the patient is bleeding more than a normal menstrual period or having significant cramping she should not undergo AE (Table 22.3). In these emergency situations, MEDEVAC to the nearest medical facility for cervical dilation and curettage (D&C) might be lifesaving.

\textit{Preparation for AE}

If AE is required for a patient with a threatened abortion, certain steps should be taken to minimize the risk to the patient during flight. First, it should be verified that the patient’s hemoglobin is >12 g/dL so that she will have an adequate reserve should heavy bleeding occur. If the patient is found to be anemic, transfusion prior to transportation might be needed to increase the margin for safety.

In any pregnant patient who is bleeding, an intravenous (IV) catheter should be placed prior to flight because placing it during flight might be difficult. The amount of bleeding will determine whether the patient will require ongoing IV hydration or only a heparin lock. However, in all cases, the ability to quickly start IV fluids is imperative. In addition, the patient needs an adequate supply of obstetric pads to last throughout the flight or longer, should a delay occur.

\textit{Potential In-Flight Emergencies}

The vaginal bleeding that can be associated with a spontaneous abortion can be massive, resulting in hypovolemic shock. The first step of in-flight treatment of heavy bleeding is a pelvic examination using the equipment in an ob/gyn emergency kit (Table 22.1). With the patient in a supine “frog-leg” position (with heels together), a vaginal speculum and concentrated light source are used to inspect the cervix. If tissue is seen protruding through the cervical os, the tissue should be removed by gentle traction with ring forceps. This might result in completion of the spontaneous abortion process and decrease bleeding. However, if significant bleeding continues emergency treatment consists of tightly packing the vagina with gauze and diversion of the flight to an airfield near a medical facility.

Another, less common, complication of spontaneous abortion is intrauterine infection, termed septic abortion. If a patient with a diagnosis of spontaneous abortion develops a fever, with or without chills, emergency therapy consists of IV hydration and broad-spectrum antibiotics. In most cases, definitive surgical treatment (D&C) can be delayed for several hours with little risk to the patient.

\textbf{Ectopic Pregnancy}

An ectopic pregnancy, usually located in the fallopian tube rather than the uterus, occurs in approximately 1% to 2% of all pregnancies. In patients at increased risk of tubal pregnancies because of previous pelvic infection or tubal surgery, the ectopic rate can be as high as 15% to 25% of pregnancies.

A patient with an ectopic pregnancy most commonly presents with vaginal bleeding and unilateral pain 6 to 8 weeks after her last menstrual period. However, this presentation is neither specific nor sensitive for ectopic pregnancy. A threatened spontaneous abortion can often present with these symptoms. Alternatively, some patients present with atypical symptoms that can range from painless bleeding to severe abdominal pain with hemorrhagic shock.

With modern ultrasound and serum betahuman chorionic gonadotropin (hCG) determination, the diagnosis of ectopic pregnancy is often made well before tubal rupture and intrauterine hemorrhage. The result is that many ectopic pregnancies might be diagnosed days or weeks prior to the need for definitive
surgery. In some patients, the tubal pregnancy resolves spontaneously or can be treated medically and surgery avoided.

**Implications for AE**

A diagnosis of ectopic pregnancy is a contraindication for elective AE. Although the chance of sudden tubal rupture and intra-abdominal hemorrhage is small, the inability to treat this emergency by means other than immediate surgery makes AE relatively risky. Once the ectopic pregnancy has been surgically removed, AE is delayed until the patient has recovered from surgery, as discussed below for the postoperative gynecology patient.

A nonsurgical approach for the treatment of ectopic pregnancies has become more popular in the last few years. This involves the use of methotrexate, a chemotherapeutic agent that destroys placental tissue and results in resorption of the ectopic pregnancy. Although this approach is safe in selected patients, there is an approximately 5% risk of tubal rupture requiring emergency surgery. For this reason, patients being treated nonsurgically for ectopic pregnancy should not be transported by elective AE until their serum beta-hCG levels are undetectable.

In contingency operations, or when definitive treatment is not available locally, it might be necessary to transport patients with an ectopic pregnancy. If required, patients with a diagnosis of an unruptured ectopic pregnancy should be transported at the earliest opportunity.

**Preparation for AE**

When AE is required, certain criteria should be met prior to transportation. First, the patient should be hemodynamically stable. Second, there should be no evidence of intra-abdominal bleeding such as peritoneal signs or free intraperitoneal fluid on ultrasound. Finally, the patient should have a sufficient hematologic reserve (Hgb >12 g/dL) in case of rupture during transport. An important point to remember is that a vigorous pelvic exam should be avoided in patients suspected of having an ectopic pregnancy to avoid iatrogenic tubal rupture.

Because sudden rupture is always a possibility, IV access should be established prior to flight. This can be either a functioning IV line or a heparin lock. Transportation as a litter patient is imperative.

**In-Flight Emergencies**

Sudden rupture of an ectopic pregnancy is uncommon prior to 6 weeks’ gestation as determined by the last menstrual period. However, the patient might have already been pregnant at the time of the apparent “last menses,” making the gestational age 2 to 4 weeks greater than calculated using this “menses.” For this reason, the onset of severe unilateral pain in a patient with a tentative diagnosis of ectopic pregnancy constitutes a medical emergency, with or without signs of peritoneal irritation and hemodynamic instability.

Emergency in-flight treatments include IV hydration and Trendelenburg position. Transfusion with type-specific packed red cells or whole blood is indicated for signs of hypovolemic shock. Because the only definitive treatment for a ruptured ectopic pregnancy is surgical, any sudden changes in the patient’s condition is an indication for emergency flight diversion to an airfield with a nearby medical facility.

Lesser degrees of unilateral pelvic pain are common with an ectopic pregnancy. However, it is difficult to differentiate pain related to tubal distension from catastrophic tubal rupture. For this reason, any change in the nature or degree of pelvic pain in a patient with an ectopic pregnancy should be treated as a likely “ruptured ectopic” and considered life-threatening.

Vaginal bleeding is a common occurrence in patients with ectopic pregnancies. For this reason, several days’ supply of menstrual pads should be sent with the patient. Heavy vaginal bleeding with a diagnosis of ectopic pregnancy suggests that the patient might actually be having a spontaneous abortion (see above).

**Hyperemesis of Pregnancy**

Another common problem encountered in the first trimester is hyperemesis. This excessive
nausea and vomiting can lead to dehydration and electrolyte imbalances. Treatment consists of supportive measures including IV hydration with electrolyte replacement and antiemetic therapy. No other special considerations are needed for AE.

Problems During the Second Half of Pregnancy

With the exception of spontaneous abortion, the incidence and implications of problems continues to increase until term. Because of this, any pregnant patient considering long-distance flight, including AE, should first have a thorough obstetric evaluation (Table 22.4). This should include verification of fetal viability by auscultation of fetal heart activity (by fetoscope, Doppler, or ultrasound) and a pelvic examination to verify that the cervix is closed and accurately estimate the gestational age.

Incompetent Cervix

Approximately 5% of pregnancies are complicated by painless dilation of the cervix, almost exclusively in the middle third of pregnancy. The treatment for an incompetent cervix is strict bedrest until a suture (cerclage) can be placed around the cervix. These patients are at risk for premature rupture of membranes and premature labor and delivery.

Fetal Demise

Intrauterine fetal demise might occur at any time. During the second or third trimester, the earliest sign of this is usually a cessation of fetal movement noticed by the patient. The diagnosis can be suspected by absence of fetal heart tones by auscultation but is verified by ultrasound. After fetal demise, the patient will usually remain asymptomatic for days to weeks. Some patients will experience bleeding, resulting in a second-trimester spontaneous abortion. Later in pregnancy, premature labor might occur. In extreme cases, the patient can experience a disseminated intravascular coagulation. However, this complication is rare in a patient in whom the fetus has been dead for less than 4 weeks.

Premature Labor

The single most common complication of the third trimester is premature labor, which occurs in approximately 20% of all pregnancies. Premature labor is defined as painful, regular contractions associated with progressive dilatation before 37 weeks’ gestation. In some cases, underlying causes can be determined, such as abruptio placenta (see below) or intrauterine infection. However, the vast majority of cases are idiopathic.

The initial treatment for premature labor is bedrest, IV hydration, and medications to decrease uterine contractility, referred to as tocolytics. Intramuscular (IM) steroids are commonly given to accelerate fetal lung maturity. In many cases, prolonged treatment with subcutaneous or oral tocolytics is required to decrease the chance of premature delivery.

Premature Rupture of Membranes

Premature rupture of membranes is another relatively common condition. In general, the fetal membranes rupture during labor as a part of the normal delivery process. However, in approximately 5% of patients ruptured membranes occur prior to the onset of labor and often prior to term. The latency period is defined as the time interval between the rupture of membranes and the initiation of labor. The length of this period is inversely proportional to the gestational age at the time of rupture. In over half of these patients at term, spontaneous labor begins within 12 to
48 hours. If membranes rupture prior to labor, these patients are at increasing risk of intrauterine infections as the interval between membrane rupture and delivery increases. Care should be taken to avoid unnecessary digital examination of the cervix after rupture of membranes.

Third-Trimester Uterine Bleeding

Bleeding from the uterus in the third trimester is a potentially life-threatening problem for both the fetus and mother. These patients can be divided into two major categories: abruptio placenta and placenta previa.

Abruptio Placenta

The most common serious cause of bleeding in the third trimester is abruptio placenta, which occurs in 1% to 2% of all deliveries. In this situation, the placenta partially or completely detaches prematurely. The result is vaginal bleeding associated with premature labor. This can also result in massive hemorrhage, which can be fatal to the unborn child and potentially to the mother as well. In extreme cases, this can also be associated with disseminated intravascular coagulopathy. Most often in these cases, there will not be enough time to transport the patient before delivery except by short-distance MEDEVAC to the nearest medical facility.

Placenta Previa

The painless bleeding associated with placenta previa occurs in approximately 1% of all pregnancies. In this condition, the placenta is implanted abnormally low in the uterus, such that it partially or completely covers the cervical opening. As uterine contractile activity becomes more common near term, the risk of bleeding increases. Digital cervical examination is contraindicated because this might incite bleeding. This condition can result in massive hemorrhage that can be fatal for both the mother and fetus.

Pregnancy-Induced Hypertension

Another relatively common complication in the third trimester is pregnancy-induced hypertension, or preeclampsia, which occurs in approximately 5% of all pregnancies. The hypertension of preeclampsia is usually accompanied by proteinuria and edema of the hands and face. This condition puts the fetus at risk for abruptio placenta and intrauterine demise and the mother at risk for grand mal seizures, referred to as eclampsia.

The ultimate treatment is delivery of the fetus. However, if the woman is remote from delivery the treatment often consists of bedrest for mild cases. More serious cases are treated with IV magnesium sulfate to prevent seizures, antihypertensive medication, and induction of labor, regardless of gestational age.

Implications for AE

Women with the complications listed above in the second and third trimesters of pregnancy constitute a group of extremely high-risk patients for AE. Contraindications to AE include untreated incompetent cervix, labor (premature or term) that cannot be stopped with tocolytics, any degree of uterine bleeding, and severe preeclampsia (Table 22.2). If facilities are not available locally to treat these conditions, the patient should be transported to the nearest appropriate medical facility by MEDEVAC.

Patients with intrauterine fetal demise can undergo AE as long as their clotting factors (as reflected by prothrombin time, partial thromboplastin time, fibrinogen, and platelets) are within the normal range. Because disseminated intravascular coagulation is uncommon and usually occurs after the fetus has been dead for more than 4 weeks, transportation as soon as possible is advisable.

Patients with the remainder of these complications can be transported by AE if their condition can be stabilized. A patient with a history of premature labor can be transported if she has been without uterine contractions for >48 hours. The fetal position should be verified to be vertex (head down) because unexpected delivery from a breech position can be dangerous for the infant. Tocolytic therapy should be continued throughout the flight to minimize the risk of recurrent labor. Finally, an individual...
trained to perform a vaginal delivery and the necessary equipment should accompany the patient.

Patients with premature rupture of membranes are at significant risk for premature labor. If labor has not started within 12 hours of rupture, AE might be considered. However, tocolytic therapy should be available in case labor starts during the flight. As with premature labor patients, the fetus should be vertex and both trained personnel and equipment for delivery should be available.

Patients with a diagnosis of placenta previa or chronic abruptio placenta should be free of bleeding for at least 24 hours prior to AE and should remain at bedrest throughout transport. Patients with the other conditions listed can be moved by AE but should be accompanied by a physician trained in the management of spontaneous vaginal delivery and obstetric complications that might occur. In most cases, urgent AE should be carried out as soon as practical after the diagnosis and the need for transportation is determined and the patient’s medical condition is determined to be stable.

Patients with mild preeclampsia can be transported by AE but should be treated in-flight with antiseizure medicine as a precautionary measure. The most common of these is magnesium sulfate given as a continuous IV infusion (Table 22.3).

**Preparation for AE**

Prior to AE, the patient should be ascertained to have (1) cervical dilation <4 cm (by visual inspection only in patients with placenta previa), (2) no bleeding or premature labor for 24 hours prior to transportation, and (3) adequate hematologic reserve (Hgb >12 g/dL). All patients should be transported by litter in the left lateral decubitus position and must have a functioning IV line in place. Supplemental oxygen (4 L/minute by nasal prongs) should also be routinely administered. Continuous fetal monitoring is not required because all conservative treatment for fetal distress (position, hydration, and oxygen) are already in place and definitive treatment (operative delivery) is not possible in-flight. Patients with mild preeclampsia should be treated with antiseizure medicine as well.

**Potential In-Flight Emergencies**

In the third trimester, most in-flight emergencies can be treated only with supportive measures inflight, whereas definitive treatment will require emergency flight diversion to an airfield near a medical facility with obstetric capabilities. Because emergency delivery is a significant risk for many of these patients, they should be accompanied by medical personnel trained in emergency vaginal delivery and an ob/gyn equipment kit (Table 22.1).

**Hemorrhage**

Treatment of obstetric hemorrhage during flight is limited to supportive measures, including IV fluids, transfusion of whole blood or packed red blood cells, Trendelenburg and left-lateral decubitus position, and supplemental oxygen (4 L/minute by nasal prongs). Emergency flight diversion with immediate transfer to a medical facility equipped with an operating room might be lifesaving for the mother and child.

After emergency delivery, postpartum hemorrhage can be a problem in as many as 5% of cases. The treatment of this is discussed below in the section on emergency delivery.

**Seizure**

Eclampsia is the most common cause of seizure during pregnancy and is usually associated with hypertension and proteinuria, as described above. Emergency treatment consists of maintaining the maternal airway, control of convulsions, and lowering of the blood pressure if the diastolic blood pressure is >100 mm Hg.7 Seizures are most commonly treated with parenteral magnesium sulfate (MgSO4). An initial bolus of 4 g MgSO4 is given intravenously as a 20% solution at a rate of 1 g/minute. Maintenance MgSO4 should be given until delivery, usually at a dose of 2 g/hour. The patient must be observed closely for respiratory depression related to MgSO4 toxicity. The treatment is calcium gluconate (1 g intravenously administered slowly), which should always be readily available when MgSO4 is used.
If the patient was diagnosed as having pre-eclampsia prior to AE, she might be already receiving MgSO₄. If she is having a seizure despite MgSO₄ therapy, the emergency treatment is IV diazepam (10mg). Although this is an expedient way to treat seizures, there is a risk of respiratory depression that might require respiratory support. In addition, the infant will show signs of respiratory depression if born within 1 hour of this treatment.

**Fever**

When transporting a patient with premature labor or premature rupture of membranes, the development of an elevated temperature is most likely a sign of intrauterine infection (chorioamnionitis). Another common source of infection is pyelonephritis. The fetal heart rate will almost always be elevated with maternal fever. In all cases of maternal fever, treatment consists of IV antibiotics and acetaminophen as an antipyretic. Aspirin and nonsteroidal anti-inflammatory drugs should be avoided in late pregnancy. If the patient is not already on oxygen supplementation, this also should be started (4L/minute by nasal cannula). Transfer to a medical facility within 1 to 2 hours is important.

**Labor**

Regular, painful contractions can occur in any pregnant patient during flight but is most likely to occur in patients previously diagnosed with premature labor or premature rupture of the membranes. The initial treatment is bedrest in a left lateral recumbent position and IV hydration (lactated Ringer’s solution at 175cc/hour). If the patient is being given a tocolytic agent, the dose can be increased. Careful monitoring must be done for signs and symptoms of toxicity. Flight diversion and transfer to an obstetric unit will be required if the labor cannot be stopped. In the absence of placenta previa, cervical examination by someone with obstetric experience can give the crew an estimation of how imminent delivery might be. Should the patient experience the urge to push, preparation for vaginal delivery should be made.

**Emergency Vaginal Delivery**

In-flight vaginal delivery is fortunately an uncommon event. This might be because women in late pregnancy avoid prolonged flights. In addition, there is normally a matter of hours between the onset of labor and the actual delivery in most patients. However, AE flight crews, especially on long overseas flights, should be familiar with the signs of labor and know how to best assist a woman during delivery should this become necessary.

**Signs of Labor**

In general, labor is a relatively prolonged course of events that begins with regular painful contractions and/or a spontaneous rupture of membranes and ends with vaginal delivery. Labor is usually a long process, averaging 12 hours for the first child and 8 hours for subsequent deliveries. However, labor can be unexpectedly quick in some cases, especially with premature labor and women who have had several previous children. Once the patient has an urge to push, delivery usually occurs in less than 2 hours and sometimes in a matter of minutes, especially in multiparous women. Because of this, an emergency ob/gyn kit and personnel trained to assist with a vaginal delivery should be available any time a pregnant patient is transported in the late second or third trimester of pregnancy.

**Stages of Labor**

Labor progresses in a predictable manner divided into three stages. The first stage is the regular painful contractions that result in gradual dilation of the cervix. After an average of 8 to 10 hours, the complete dilation of the cervix is coupled with an often irresistible urge to push. The second stage of labor is the descent of the presenting part through the open cervix and ends with delivery of the infant. This usually takes 1 to 2 hours of active pushing, although it can take less than 10 minutes in some cases. The third stage of labor is the delivery of the placenta, which can be the most dangerous stage for the mother if hemorrhage occurs.
Vaginal Delivery with a Vertex Presentation

In approximately 96% of all deliveries, the fetus descends through the birth canal with the top of the head proceeding first. This vertex presentation is the simplest and safest mode of delivery. Several steps are involved in assisting a vertex vaginal delivery (Fig 22.1).

When the perineum begins to bulge, or the presenting part becomes visible, the patient should be placed in an appropriate position for delivery. This is usually in a semirecumbent position, with the back elevated approximately 45° from horizontal. Adequate lateral room should be made to allow the patient to abduct her thighs such that the angle between her thighs is at or near 90°. In this position, the patient’s buttocks must be elevated at the time of delivery to allow for the delivery of the anterior shoulder of the infant (see below). A padded, inverted bedpan under the buttocks works well for this purpose.

The delivery process itself involves assisting the patient and minimizing the risk of vaginal and peritoneal trauma. Having the patient grasp her knees or behind her knees and pull backward often assists in delivery. As the vertex is seen bulging from the vaginal opening, general pressure is placed on the head so as to avoid explosive delivery. A gentle, slow delivery will minimize the risk of trauma to the perineum, whereas explosive delivery often results in significant vulvar and vaginal lacerations. The hemorrhage associated with severe vulvar and vaginal lacerations can be life-threatening.

Once the infant’s face is within view, the head should be gently turned either facing to the right or left thigh and both mouth and nose suctioned with bulb suction. During this time, the mother can be instructed to try to avoid pushing, although this is often not possible for her to do.

The next step is delivery of the infant’s shoulders. As the mother pushes, gentle downward traction on the infant’s head will aid in delivery of the anterior shoulder. Significant traction should be avoided because this can injure the brachial nerves that extend from the infant’s neck vertebrae to the upper arm. The inability to deliver the shoulders (shoulder dystocia) is discussed below. Once the anterior shoulder is delivered, general upward traction will assist in the delivery of the posterior shoulder. The remainder of the infant’s delivery proceeds relatively quickly because the largest part is the head and the shoulders.

The umbilical cord is clamped twice and cut between the clamps. The infant is then rubbed briskly and dried to stimulate breathing and minimize loss of core temperature. The infant should be wrapped in a warm blanket. A full-term infant might be left in the mother’s arms or on her bare chest, then covered during the remainder of the delivery as long as the infant is breathing without difficulty. If the infant is making inadequate respiratory efforts, neonatal resuscitation might be required.

Delivery of the Placenta

The third stage of labor is delivery of the placenta. After delivery of the infant, the cord protrudes from the vagina. If there is minimal bleeding, the vagina and perineum can be evaluated for lacerations while waiting for the placenta to separate. Usually, placentas will deliver spontaneously within 30 minutes. If significant vaginal bleeding occurs prior to the placental delivery, gentle downward traction on the umbilical cord and uterine massage might expedite this. Every effort must be made to avoid excessive traction on the umbilical cord, which can result in inversion of the uterus.

Once the placenta is delivered, the uterus should be massaged and the patient administered oxytocin 20IU/L intravenously at a rate of 200mL/hour until the uterus remains contracted and vaginal bleeding slows. Maternal breast-feeding might also help expedite delivery of the placenta or decrease postpartum bleeding.

Once uterine contracture and hemostasis is assured, any resulting vaginal or perineal lacerations should be repaired with suture under local anesthesia. If no other individual trained in this procedure is available, then closure of lacerations that are not actively bleeding can be delayed until transportation to a medical facility. However, if hemorrhage from the
Figure 22.1. Emergency vaginal delivery, vertex presentation. (a) The perineum is supported as the head emerges. (b) A nuchal cord is reduced (if present) by lifting it from the posterior neck over the head. (c) The mouth and nose are suctioned. (d) The anterior shoulder is delivered by maternal pushing and gentle downward traction on the head. (e) The posterior shoulder is delivered by continued maternal pushing and gentle upward traction on the head. (f) The infant’s body is delivered by gentle outward traction.
lacerations is a significant problem. Temporary hemostatic control can usually be achieved by direct pressure. In extreme cases, tight vaginal packing might be required. The risk of hemorrhage from vaginal and cervical lacerations should not be underestimated because they can potentially lead to hemorrhagic shock in untreated cases. The perineum should be routinely examined in the immediate postpartum period to evaluate for excessive blood loss.

Delivery Complications

**Breech Presentation**

Approximately 4% of infants are delivered from a breech presentation. Ideally, the presentation of the infant should be determined by ultrasound prior to AE. However, in many cases ultrasound is not available or the infant changes position between the ultrasound and the flight. For this reason, patients at high risk for delivery should be accompanied by a medical attendant who is experienced in assisting in delivery regardless of the presentation. The steps for assisting a vaginal breech delivery are listed in Figure 22.2.

**Other Abnormal Presentations**

Rather than a presentation of a head or breech, an arm or a shoulder might present. This situation is often associated with rupture of membranes and is more common prior to term. In a medical facility, this complication is an indication for cesarean delivery. In any other situation, immediate transportation to a medical facility with an obstetrician and surgical capabilities is the only acceptable approach.

**Shoulder Dystocia**

Difficulty in delivering the shoulders after the head has been delivered occurs in <1% of all vaginal deliveries. If the shoulders do not deliver with the expulsive efforts of the mother coupled with gentle downward traction on the head, several simple techniques might assist in this delivery (Fig 22.3). An extremely effective procedure is McRobert’s maneuver. Two assistants help the mother press her thighs back against her abdomen, while continuing to push. This changes the angle of the pelvis and often results in delivery of the anterior shoulder with gentle downward traction on the infant.

Another effective approach is suprapubic pressure (Fig 22.3b). An assistant pushes firmly downward with the heel of their hand immediately above the symphysis pubis. This will often push the anterior shoulder beneath the symphysis pubis and allow delivery to proceed.

If a medical attendant experienced in obstetrics is available, cutting a large episiotomy will also aid in delivery of the shoulders. However, because of the risk of hemorrhage and injury to the infant or mother in inexperienced hands, an episiotomy should only be used by someone with obstetric expertise.

A final procedure, which takes a significant amount of obstetric skill, is delivery of the posterior arm of the infant (Figs 22.3c and 22.3d). This involves reaching into the vagina, finding the posterior arm, which is pinned against the infant’s body, and delivering the entire arm. Once the posterior arm and shoulder are delivered, a hand is placed on the infant’s back and on the abdomen and the infant is then rotated such that the previously anterior is shoulder is now posterior and this arm is likewise delivered. This difficult maneuver might result in significant vaginal lacerations and might fracture the arm of the infant. However, if all other methods for delivering the shoulders have failed this maneuver can be lifesaving for the infant.

**Cord Prolapse**

In some patients, spontaneous rupture of the membranes results in prolapse of the cord prior to the delivery of the infant. This is much more common in infants who are not presenting in the vertex (head-down) position. If cord prolapse occurs during the late first stage or early second stage, voluntary maternal pushing by someone who has had children before can result in the delivery of the baby quickly enough to avoid problems. However, if the cervix is not completely open, or if this is the patient’s first child, pushing usually takes 1 hour or more. The situation can be temporarily mediated by placing a hand in the vagina to keep the presenting part from compressing the
Figure 22.2. Emergency vaginal delivery, breech presentation. (a) The feet are guided out during maternal pushing. (b) The infant is delivered to the level of the umbilicus by maternal pushing alone and rotated such that the back is upward. (c) The infant is rotated 90° to visualize the left arm (or alternatively the right arm). (d) The anterior arm is delivered with a single finger. (e) The infant is rotated 180° and the opposite arm is delivered with a single finger. (f) The infant’s head is delivered using maternal expulsion and suprapubic pressure. A finger should be placed over the maxillary process and the body kept parallel to the floor.
cord and cutting off the circulation to the infant. However, unless an emergency cesarean section is carried out in a matter of minutes prolapse of the cord is usually fatal to the infant.

**Postpartum Hemorrhage**

Life-threatening hemorrhage after delivery of the infant occurs in approximately 5% of all vaginal deliveries. For this reason, those involved in caring for women who deliver outside of a hospital setting must be familiar with the treatment of postpartum hemorrhage.

Once the infant is delivered, there is usually a period of time when little bleeding occurs prior to delivery of the placenta (see above). As the placenta begins to separate, a significant amount of bleeding often occurs, usually in the range of several hundred milliliters of blood. At this point, the placenta must be delivered so that the uterus can fully contract because the only way the uterus can achieve hemostasis after delivery is by significant uterine contraction. For this reason, the next step after delivery of the placenta is vigorous transabdominal uterine massage. An experienced operator will often place a hand in the vagina below the uterus to assist in the massage. The patient should be given IM or IV oxytocin at this time to expedite uterine contractions. The natural way to release oxytocin is by breast stimulation associated with breast-feeding. A combination of natural or exogenous oxytocin and uterine massage will result in adequate hemostasis in most cases. However, it should be kept in mind...
that the average blood loss for a vaginal delivery is approximately 500mL and thus what might appear to a nonobstetrician to be excessive hemorrhage during and immediately after delivery of the placenta is to be expected.

**Uterine Inversion**

An uncommon but important complication of a normal vaginal delivery is uterine inversion. This is usually a result of too aggressive traction on the umbilical cord. If the placenta is implanted in the top of the uterus (fundus), excess traction on the cord can result in the uterus turning inside out. In this configuration, the uterus can no longer achieve hemostasis by contraction. In this situation, the fundus of the uterus must be pushed back up to return the uterus to its natural configuration. This should be done with the placenta still in place. The final step is vigorous bimanual massage and oxytocin therapy. If replacement of the uterine fundus is not possible, then the patient should be aggressively hydrated as she is transported as quickly as possible to a medical facility.

**The Postpartum Patient**

The immediate postpartum period is a time of dramatic change in the physiology for both the mother and newborn infant. This is more obvious for the newborn child than for the mother, but these changes have significant implications for AE for both. After either vaginal delivery or cesarean section, the patient has to deal with significant physiological changes. After cesarean section, the patient must also deal with the expected sequela of major abdominal surgery.

**Implications for AE**

Elective AE of the postpartum patient and her newborn infant should be delayed for at least 1 week after vaginal delivery. This assures adequate uterine involution, such that postpartum hemorrhage is unlikely to occur. This 1-week recovery time also allows for the complete physiological readjustment and the almost complete healing of any laceration or episiotomy associated with delivery. In addition, most normal newborn infants will also be ready for transportation 1 week after delivery. If either the mother or infant is not ready for transportation, AE should be delayed so that they can be transported together. An exception to this would be if the infant were extremely premature or will require prolonged hospitalization related to another medical condition.

After cesarean delivery, elective AE should be delayed for at least 2 weeks. This is usually more than enough time for the mother to become medically stable from a postpartum perspective, as described above. However, she needs to recover from major abdominal surgery as well. Prior to elective AE, she should be tolerating a regular diet and be fully ambulatory so that she can travel in a seat rather than a litter. By this time, most women will be able to perform all activities other than heavy lifting.

In a contingency situation, the earliest time the patient should be transported by AE is 24 hours after delivery. The mother and child need this period of physiological adjustment immediately after delivery. In addition, postpartum hemorrhage is most likely to occur in the first day after delivery. During this time, many patients will receive IV hydration and a dilute solution of oxytocin until uterine contraction and adequate hemostasis is assured.

Likewise, the newborn infant is carefully observed during the first 24 hours for early signs of circulatory or breathing problems. If the infant develops signs of decompensation during AE, this might be difficult to recognize in the flight environment. In addition, expert pediatric care is unlikely to be available.

The mother and newborn infant should be transported together, with rare exception. Thus, if one is taking more time to stabilize after birth transportation of the other should be delayed. One possible exception would be when the infant has serious medical problems or is extremely premature. If the infant will need to remain hospitalized for weeks to months, the mother might need to be transported separately. If expedient AE of the premature infant is absolutely required, a Critical Care Air Transport Team will need to be involved.
Prerequisites for AE

After either vaginal delivery or cesarean section, the most important requirement for AE is that the patient’s postpartum bleeding (lochia) has slowed sufficiently. The bleeding should be <1 obstetric pad per hour with no episodes of “flooding,” and the uterus should remain firmly contracted. Continued heavy postpartum bleeding might be due to inadequate uterine contracture, retained intrauterine placenta, or infection and is a contraindication to AE. Because of the risk of sudden bleeding after delivery, the patient should have adequate hematologic reserve with a Hgb >10 g/mL.

Appropriate wound healing should be assured prior to AE. After a vaginal delivery, any vaginal lacerations or episiotomy should also be healing appropriately. After cesarean section, the abdominal incision should be healing normally.

Preparation for AE

The length of time since delivery and any complications the patient had with her pregnancy will dictate preflight preparation. If AE is required in the immediate postpartum period, appropriate pain and nausea medicines should be available. In all cases, the patient should be given a several days’ supply of obstetric pads for vaginal bleeding. If the patient developed a uterine infection (endometritis) during or after delivery, continuation of IV antibiotics is usually required until the patient has been afebrile for 4 hours. If the patient remains hypertensive after delivery, antihypertensive medication might be required.

All patients, both vaginal delivery and cesarean section, who are transported within 1 week of delivery should be transported in the supine position as litter patients because prolonged sitting might increase the risk of deep-vein thrombosis (DVT). Women who have had cesarean sections will sometimes require continued IV hydration for up to 3 days after delivery until bowel function has returned. Women within 72 hours of vaginal delivery should be transported with a heparin lock in place in the event that unexpected hemorrhage should occur.

AE transportation of a newborn infant will take special arrangements. Because a litter is too narrow to accommodate both mother and infant, a separate temperature-controlled islet will be required (see chapter 24). The infant will need frequent feedings, and many mothers will be breast-feeding. In general, the most appropriate position for infant feeding by the mother will be in a sitting position. For this reason, the mother will need to be in a stretcher low enough to the deck that she will be able to get up to attend to the infant. She will also need a seat in which to feed or nurse the baby. If the mother is unable to feed and care for the infant, a separate attendant will be required.

Potential In-Flight Complications

Hemorrhage

By far, the greatest risk in the immediate postpartum period (24 to 72 hours after delivery) is postpartum hemorrhage. Heavy bleeding can occur any time within the first month after delivery but is much less frequent after the first week. Later bleeding may be due to subinvolution, which is often associated with subclinical infection. Another cause of postpartum hemorrhage is the undiagnosed presence of retained placenta.

The treatment of postpartum hemorrhage during flight is primarily supportive with IV hydration. If the patient is within 72 hours of delivery, lack of uterine contracture might be the cause. In these cases, treatment consists of uterine massage and IV oxytocin (10 U over 2 minutes) or increasing circulating endogenous oxytocin by breast-feeding. If an obstetrician is available, uterine packing might be attempted. Emergency flight diversion to a facility with obstetric care is required for definitive treatment of postpartum hemorrhage.

A less common source of serious postpartum bleeding is a vaginal laceration or episiotomy. Should moderate vaginal bleeding occur in a patient with vaginal lacerations, evaluation of the perineum and vagina is important to determine if the bleeding is from this area. This type of bleeding will usually stop with direct
pressure over the bleeding site. If the laceration is higher in the vagina, vaginal packing should be attempted whenever the bleeding does not abate with the above-mentioned methods.

**Abdominal Pain**

Patients might experience severe abdominal pain within the first week after delivery as a result of nonmechanical (paralytic ileus) or mechanical bowel obstruction. Paralytic ileus is usually caused by bowel irritation related to the intra-abdominal blood or infection associated with cesarean section. The risk is greatest within the first 48 hours of surgery and is uncommon after vaginal delivery. Decreased pressure associated with altitude can result in expansion of trapped gas in the gastrointestinal tract and exacerbate postoperative pain, nausea, and vomiting.

Mild symptoms might be treated with parenteral pain medication and antiemetics. More serious nausea or vomiting is an indication to pass a nasogastric tube. In extreme cases of pain, a decrease in altitude might be helpful.

**Postpartum Seizure**

Patients who had preeclampsia during pregnancy are at a small risk for a grand mal seizure for the first week after delivery. The risk is highest for the first 24 hours after delivery and decreases after this time. For this reason, most patients with a diagnosis of moderate to severe preeclampsia are treated with IV magnesium sulfate for 24 hours after delivery. A full 25% of eclamptic seizures occurs in the postpartum period, and therefore any woman with a seizure after delivery should be treated as an eclamptic.

The treatment for seizures is IV or IM antiseizure medication. This can be diazepam (10 mg) given every 30 minutes for a total of 30 mg until the seizures have stopped. Following the cessation of seizure, the treatment is supportive and includes IV hydration, a lateral position to avoid aspiration, oxygen supplementation (4 L/minute by nasal prongs), and close observation for signs of respiratory suppression. Should this patient have problems with respiration, temporary bag-mask ventilatory assistance might be required.

**Infection**

Infection is a relatively common postpartum complication. In most cases, this will follow an infection during pregnancy. However, even in some patients without intrapartum infection endometritis will manifest within the first 4 weeks after delivery. The primary symptom of endometritis is uterine tenderness with increased vaginal bleeding. A more advanced infection usually presents with fevers, chills, and purulent vaginal discharge.

The primary treatment is IV hydration and oral antipyretics. If antibiotics are available, a broad-spectrum antibiotic can be started intravenously or orally as a first line of therapy until a medical facility can be reached. Flight diversion will rarely be necessary unless the patient appears to be getting septic.

**Breast Engorgement**

Although engorgement is not truly a medical emergency, this common postpartum problem can be distressing to the patient. Breast engorgement commonly occurs 2 or 3 days after delivery and is usually less dramatic in women who are breast-feeding. However, it can occur both in those patients who choose breast-feeding and those who do not.

The treatment for breast-feeding patients is to increase the frequency of nursing the infant. The treatment for non-breast-feeding patient is exactly the opposite. Breast stimulation should be minimized. Breast binding, by wrapping the upper thorax with an elastic bandage, will decrease engorgement and the discomfort. Engorgement can sometimes be associated with significant temperature elevation. Antipyretics and analgesics will help with both the discomfort and the fever associated with engorgement.

**The Gynecological Patient**

**Chronic Gynecological Conditions**

Patients with chronic gynecological conditions might require AE (Table 22.5). These conditions include such diverse conditions such as endometriosis, gynecological malignancies, and
intractable menstrual abnormalities. The symptoms vary with the diagnosis. However, the three most common gynecological symptoms these patients might have are vaginal bleeding, nausea, and lower abdominal pain.

**Implications for AE**

The risk of in-flight problems for patients with chronic gynecological conditions is low. Asymptomatic patients might be transported at any time. The risk of symptoms with gynecological malignancies increases over time, so these patients should be transported as soon as possible after the diagnosis is made.

Patients with advanced gynecological malignancies are at risk for vaginal bleeding, anemia, and gastrointestinal symptoms. A supply of gynecological pads should always be available. If the patient has experienced any abnormal vaginal bleeding, preparations should be made for the possibility of vaginal hemorrhage during flight. Significant hemorrhage is treated with IV fluid expansion and flight diversion. In extreme cases, tight packing of the vagina might be required to slow the bleeding until transfer to a medical facility can be arranged. Patients with significant gastrointestinal symptoms, including nausea, vomiting, and abdominal pain, should be transported with an IV line in place for hydration. Significant vomiting and abdominal distension might require a nasogastric tube. Finally, abdominal pain might require treatment with parenteral pain medications or antiemetics. The onset of severe colicky abdominal pain at altitude suggests expanding trapped intestinal gas. If the pain does not respond to standard doses of pain medication or gastric intubation, decreasing altitude might help.

**Genital Trauma, Including Sexual Assault**

Trauma to the external female genitalia can be significant enough to impair functionality for days or weeks. These injuries are most commonly straddle-type injuries where the patient has fallen forcefully on an object such as a beam or cross-bar of a bicycle. These types of blunt traumas to the external genitalia might result in nothing more than bruising. However, significant vulvar and vulvo–vaginal hematomas are possible.

When a patient is found to have significant genital trauma, the possibility of rape should be considered. In these cases, psychological considerations are important because many rape victims might suffer from significant post-traumatic distress. Even with minimal physical trauma, rape victims might have to be evacuated from the theater if they are unable to carry out their military function.

Medical treatment of blunt genital trauma most commonly involves observation with decreased activity until the signs and symptoms resolve. Symptomatic pain relief includes ice packs acutely, followed by heat and oral pain medication.

Lacerations, even those that are relatively superficial, might bleed significantly because this is a relatively vascular area. Direct pressure is usually all that is required to stop the bleeding. In severe cases, vaginal packing might be required. Surgical repair might be required to stop arterial bleeding or close clean, deep lacerations. Prophylactic antibiotic coverage is recommended because vulvar and vaginal lacerations are prone to infection.

Penetrating peritoneal injuries might involve not only the vagina and external genitalia but

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**Table 22.5. Criteria for AE: High-risk gynecological conditions.**

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<tr>
<th>Elective AE</th>
<th>Urgent AE</th>
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<tr>
<td>Pelvic infections</td>
<td>Pelvic infections</td>
</tr>
<tr>
<td>Afebrile for 48h after cessation of parenteral antibiotics</td>
<td>No evidence of abscess rupture</td>
</tr>
<tr>
<td>Abnormal uterine bleeding</td>
<td>Abnormal uterine bleeding</td>
</tr>
<tr>
<td>Bleeding etiology has been diagnosed and treated Bleeding &lt; normal menstrual flow</td>
<td>No heavy vaginal bleeding for 12h</td>
</tr>
<tr>
<td>Postoperative 1 wk after minor surgery or laparoscopy 4 wk after major surgery</td>
<td>Postoperative 12h after minor surgery or laparoscopy 24h after major surgery</td>
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<td>Hgb &gt;12g/dL</td>
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also the rectum and bladder. In extreme cases, surgical exploration might be required to rule out injury to the intra-abdominal organs.

**Implications for AE**

Patients with serious genital injuries should be allowed to recover for 7 days after definitive surgical treatment before elective AE. This will decrease the risk of bleeding or infection developing during the flight and dramatically reduce the amount of pain the patient will experience. In contingency situations, urgent AE might be carried out as soon as 12 hours after vulvo-vaginal surgery if the patient is otherwise medically stable. However, the risk of in-flight complications will subsequently be increased.

As with any condition with a possibility of significant blood loss, the patient should have an adequate hematologic reserve (Hgb >12 g/mL) in case of hemorrhage during transport. If the patient has significant vulvar edema, or is transported by litter, a bladder catheter is also required. In addition to any required antibiotics, the patient should have an adequate supply of menstrual pads.

Psychological support prior to and during AE is especially important in the case of sexual assault. The relatively prolonged periods of isolation and removal from normal psychosocial support inherent in long-distance AE will increase the stress on the patient. Agitated patients might benefit from the short-term use of a sedative or hypnotic during the flight (eg, zolpidem 10mg PO).

The mode of AE will depend on the severity of the injury and the length of recovery before AE. If the injury makes prolonged sitting uncomfortable, the patient should be transported by litter. Patients transported in a seated position might require analgesics during flight.

Potential in-flight complications include increased vaginal bleeding and infection. These problems are discussed below under postoperative gynecological care. The sexual assault victim might suffer from a panic attack as part of a posttraumatic stress syndrome. This will usually respond to the acute administration of an anxiolytic (eg, diazepam 5 to 10mg PO, IM, or IV).

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**Gynecological Pelvic Infections**

Pelvic infections, most commonly in the form of pelvic inflammatory disease (PID), are relatively frequent in the reproductive-aged population. The most common presenting symptoms are the triad of pelvic pain, vaginal discharge, and fever. However, PID can have an indolent onset and might be confused with gastroenteritis or appendicitis. Gynecological examination usually reveals a purulent cervical discharge and tenderness of the cervix, uterine fundus, and adnexa. Leukocytosis is common. The differential diagnosis includes appendicitis, ectopic pregnancy, ruptured ovarian cyst, and ovarian torsion.

When a diagnosis of PID is made early in the course of the disease, the patient can be treated as an outpatient with a combination of IM and oral antibiotics (eg, ceftriaxone 150mg IM plus doxycycline 100mg PO bid × 10 days). For more serious cases of PID, indicated by fever, leukocytosis, significant nausea, peritoneal signs, or a pelvic mass, the patient should be treated as an inpatient.

The most serious sequelae of PID are pelvic abscesses, which occur in 5% to 10% of patients. Pelvic abscesses are suggested by palpable adnexal masses. Once PID has advanced to this stage, effective treatment consists of prolonged bedrest and high-dose antibiotics. Surgical drainage is frequently required. Rupture of a pelvic abscess is a medical emergency that has a presentation similar to a ruptured appendix. Immediate laparotomy is indicated and might be lifesaving.

**Implications for AE**

A ruptured tubo-ovarian abscess is a contraindication to AE. For this reason, patients with PID and signs of peritoneal irritation, such as rebound tenderness, decreased bowel sounds, shoulder pain, or nausea and vomiting, should not be transported by AE. Although these signs could be the result of PID alone, they might also be the result of a ruptured or leaking pelvic abscess. A ruptured tubo-ovarian abscess has a significant mortality rate, even with immediate surgical treatment.14

Patients with mild PID (no leukocytosis, fever, or abscess) might be transported by AE.
at any time. Elective AE of patients with more serious cases of PID should be delayed until the convalescent phase of their illness. These patients should be treated as inpatients with parenteral and oral antibiotics. AE should be delayed until the patient has been afebrile for at least 24 hours and is able to tolerate oral hydration and feeding. She should be ambulatory with minimal or no pelvic pain.

During a contingency situation, urgent AE might be required prior to this point. If the patient has a pelvic abscess, it should be surgically drained prior to AE when possible. Vaginal drainage might be possible if the abscess is bulging into the posterior cul-de-sac. Alternatively, the abscess can be drained using an ultrasound-guided needle transvaginally or using a laparoscopic approach. If drainage is not possible, the patient can be transported by air after she has remained afebrile for 48 hours, but only if there is no sign of peritoneal irritation suggestive of a leaking abscess. Forceful pelvic exams should be avoided because this might increase the risk of abscess rupture. These patients should be transported on a litter with continuous IV hydration and parenteral antibiotics.

**Preparation for AE**

For elective AE, the patient should be recovered to the point that she is fully ambulatory, tolerating a regular diet, and taking only oral antibiotics. She might be transported in a sitting position. If she is known to have a resolving tubo-ovarian abscess, establishment of a heparin lock is a reasonable precaution in case of in-flight abscess rupture.

When urgent AE is required during the acute phase of more serious PID, the patient will require continuous IV hydration and IV antibiotics. These patients might not yet be tolerating a regular diet and should be transported by litter. Many patients will require pain and antinausea medication during flight.

**Potential In-Flight Complications**

The most serious complication that can occur with PID is the sudden rupture of a tubo-ovarian abscess. The movement required for AE might increase this risk. It is unknown if changes in cabin pressure during AE increase this risk.

The primary symptom of a ruptured tubo-ovarian abscess is an acute increase in abdominal pain with signs of peritonitis. This might be accompanied by signs of sepsis and progress to shock if untreated. In-flight treatment is supportive and consists of IV hydration and supplemental oxygen. If the patient is no longer taking IV antibiotics, coverage with a broad-spectrum antibiotic (eg, a second- or third-generation cephalosporin) is appropriate. Any rapid deterioration of a patient’s condition with a known tubo-ovarian abscess is an indication to divert to the nearest airfield with a nearby medical facility.

A less serious complication is the recurrence of fever and/or pelvic pain in a patient recovering from PID. If the patient has no history of a pelvic abscess, and otherwise appears stable, treatment should consist of recumbence, oral pain medication, antipyretics, and antibiotics. If possible, the patient should be given IV fluids and antibiotics. Flight diversion might be required if the patient becomes unstable.

**Abnormal Uterine Bleeding**

Excessively heavy or frequent bleeding is a common occurrence among reproductive-aged women. The differential diagnosis includes pregnancy (see spontaneous abortion and ectopic pregnancy, above), anovulatory bleeding, infection, and malignancies. In postmenopausal-aged women (usually >51 years of age), any uterine bleeding is abnormal and uterine cancer is more common. Clinical evaluation includes a pregnancy test (in premenopausal women), complete blood count, Pap smear, and physical examination. Endometrial biopsy is commonly performed in women >40 years of age with abnormal bleeding.

The treatment for gynecological bleeding depends on the diagnosis. Anovulatory bleeding is usually treated with hormones, whereas infection is treated with antibiotics. D&C might be required for definitive diagnosis and treatment.

In cases of cervical or endometrial malignancy, hemorrhage is usually related to neovascularity of the tumor itself. Lesser degrees of
bleeding might be treated with vaginal packing until definitive treatment with surgery or radiation can be carried out. Extreme cases of bleeding might require emergency hysterectomy. If the necessary expertise is available, radiographic selective cauterization and embolization of the bleeding vessel might be used.

**Implications for AE**

Uncontrolled, heavy vaginal bleeding from any cause is a contraindication to AE. Definitive diagnosis and treatment (most commonly by D&C) is required prior to AE.

Patients with limited bleeding resulting from anovulation or endometritis might be safely transported by elective AE. Likewise, those with light bleeding after definitive treatment with D&C can safely undergo AE. If abnormal bleeding is treated nonsurgically with hormones or antibiotics, elective AE should be delayed until 1 week after the last episode of heavy bleeding to minimize the risk of recurrent hemorrhage during flight.

Patient with significant vaginal bleeding resulting from endometrial or cervical cancer should be definitively treated prior to elective AE. After radiation therapy or selective embolization, the patient should be observed for at least 1 week to minimize the risk of recurrent hemorrhage. If the definitive treatment includes hysterectomy, AE should be delayed as discussed below for postoperative gynecological patients.

In a contingency situation, urgent AE might be required for patients with continuous or recent episodes of heavy vaginal bleeding. The only appropriate approach is transportation of these unstable patients to the nearest appropriate medical facility (ie, MEDEVAC). The patient will require a functioning large-bore IV line and readily available blood products.

**Preparation for AE**

Evaluation prior to AE includes a pregnancy test (for women of reproductive age), complete blood cell count, and physical examination. The patient’s Hgb should be >12 g/dL so she will have an adequate reserve should she begin hemorrhaging during AE. An adequate supply of menstrual pads to last several days should be available. An ob/gyn emergency kit should be available (Table 22.1).

After definitive treatment, patients need no special preparation and might be transported as ambulatory. If a patient is at high risk for recurrent heavy bleeding during flight, she should have a functioning IV line in place, type-specific blood products available, and must be a litter patient.

**Potential In-Flight Complications**

The obvious risk is recurrent heavy vaginal bleeding. This risk is not increased by cabin pressure changes but might be increased by patient movement, in particular in cases of gynecological malignancy. Vaginal bleeding of any etiology might be massive enough to result in hypovolemic shock.

The in-flight treatment of vaginal bleeding includes IV hydration and supplemental oxygen. Vaginal inspection with a speculum, followed by tight vaginal packing with gauze, might temporarily slow the bleeding. Diversion of the flight to the nearest airfield and emergency transportation to the nearest medical facility will usually be required.

**Postoperative Gynecological Patients**

Many gynecological conditions require surgery for definitive therapy. Because gynecological procedures are some of the most common major operations performed, an understanding of these patients is important for AE.

Gynecological procedures are often divided into three general categories: major, minor, and laparoscopic. The majority of laparoscopic procedures are minor in nature. However, because the peritoneal cavity is entered, and because there is a <1% incidence of major complications, postlaparoscopy patients should be considered separately from those undergoing other minor surgery.

The most common nonlaparoscopic minor procedure is cervical D&C. This procedure is often performed in conjunction with hysteroscopy. Another common minor procedure is a cone biopsy of the cervix, where a relatively large center portion of the cervix is removed.
using a scalpel, laser, or electrocautery. The latter of these techniques is referred to as a “loop electrosurgical excision procedure (LEEP).” Mini-laparotomy (<6 cm) for tubal ligation or removal of an ovarian cyst is also considered minor surgery. Vulvar and vaginal biopsies also fit into this category.

The most common major gynecological procedure is hysterectomy. This is most often performed through an abdominal incision (total abdominal hysterectomy; TAH) but is sometimes performed exclusively through a vaginal incision (total vaginal hysterectomy; TVH). Either might be performed with or without the removal of the ovaries (bilateral salpingooophorectomy; BS&O). A recent innovation is termed “laparoscopically assisted vaginal hysterectomy” (LAVH). This carries all the risks of both TVH and laparoscopy. Other major gynecological procedures include vaginal surgical repairs, bladder suspensions, and laparotomy for removal of pelvic masses.

Laparoscopy (other than LAVH) was first used almost exclusively to diagnose pelvic pathology or perform a tubal ligation. In the last decade, the types of laparoscopic procedures have increased dramatically. It is now common for more intricate or involved procedures to be performed laparoscopically, including removal of ectopic pregnancies, ovaries, and uterine fibroids.

Laparoscopic complications are most often related to introduction of sharp instruments through small incisions, and include injury to intestines, bladder, and blood vessels. These most often are discovered at the time of surgery, but the diagnosis might be delayed for several days after surgery. Later complications of laparoscopy include infection, delayed bleeding, and occult injury of the bowel or urinary tract.

**Implications for AE**

Prior to elective AE, the postoperative gynecological patient should be allowed to recover to the point that she is ambulatory, tolerating regular diets, and her pain has decreased to the point that she is able to tolerate the rigors of long-distance flight in a sitting position. After minor or laparoscopic gynecological surgery, the patient will usually be ready for AE after a 1-week recovery time. After uncomplicated major surgery, elective AE should be delayed for 3 or 4 weeks, depending on the patient’s rate of recovery.

If earlier urgent AE is required during a contingency situation, the risk to the patient increases. The sooner a patient undergoes transportation after surgery, the greater the risk of in-flight complications. For this reason, AE should be delayed for a minimum of 24 hours after major gynecological surgery or 12 hours after minor gynecological surgery. This will allow the healing process to begin and reduction of the surgical hemorrhage risk. In addition, it will allow the patient to recover from the effects of anesthesia. Finally, the measured Hgb level will more accurately reflect the patient’s hemodynamic state because equilibration takes several hours after the acute blood loss associated with surgery.

**Preparation for AE**

Patients who are almost completely recovered from gynecological surgery need little preparation. They should ready for transport in a sitting position but might still require oral pain medication. Some patients might still be experiencing vaginal bleeding and thus will need menstrual pads.

If the patient is transported within 1 week of major surgery, probably the most important consideration is the Hgb level. Postoperative patients should have a Hgb ≥12 mg/dL prior to AE. Most patients will need to be transported by litter. Adequate medication for pain and nausea should be available.

If AE is required within 72 hours of major gynecological surgery, the patient should have a functioning IV line. Patients without return of normal bowel function should be actively hydrated. These patients should be transported by litter and have parenteral pain and anti-nausea medications available. Patients should be routinely fitted with elastic stockings for leg compression to decrease the risk of deep-vein thrombosis.

**Potential In-Flight Complications**

The risk of postoperative complications decreases with time after surgery. For this reason,
complications will be relatively uncommon during elective AE in the convalescent period. If AE is required prior to recovery, complications that rarely occur outside the hospital setting might occur during flight.

**Intra-Abdominal Hemorrhage**

Perhaps the most common early postoperative complication is intra-abdominal hemorrhage. This complication almost always occurs within the first 24 hours of surgery and thus will be unlikely to occur in patients transported after this initial recovery period. However, the movement to which the patient is subjected during AE might result in hemorrhage in the days immediately following surgery.

The signs of intra-abdominal hemorrhage include increased abdominal discomfort and hemodynamic instability. Late signs are abdominal distention and hypovolemic shock. If intra-abdominal hemorrhage is suspected in flight, supportive measures include intravascular volume expansion and supplemental oxygen. Emergency diversion of the flight to an airfield near a medical facility might be lifesaving.

**Pulmonary Embolism**

A potential early complication of major gynecological surgery is pulmonary embolism, which accounts for almost half of all deaths after gynecological surgery. It is also the second most common cause of death after nonmedical abortion and the most frequent cause of postoperative death in patients with uterine or cervical cancer. The risk is increased in patients who are over 40 years of age, obese, or have a history of DVT.

The clinical presentation of pulmonary embolism is sudden onset of shortness of breath, chest pain, tachypnea, and tachycardia. The patient might have symptoms of DVT of the leg, such as unilateral leg edema, pain, or erythema.

As with many postoperative complications, the primary approach is preventive. After major gynecological surgery, most patients are treated with leg compression devices (elastic stockings or intermittent pneumatic compression devices) until fully ambulatory. Because of decreased cabin pressure at altitude, the pneumatic devices cannot be used during AE but elastic stockings should be continued.

Patients at high risk for DVT are also treated with prophylactic heparin in the perioperative period. A standard approach is subcutaneous unfractionated heparin (5000 U/12 hours) or low-molecular-weight heparin (30 mg/12 hours) until the patient is ambulatory. For patients being transported by AE with 72 hours of surgery, the use of either elastic stockings or heparin is important.

Emergency in-flight management of pulmonary embolism is limited to supportive therapy, including IV hydration and oxygen. If the symptoms warrant, flight diversion and transportation to the closest medical facility might be required. Modern management of pulmonary embolism consists of full anticoagulation. In severe cases, clot lysis with streptokinase or urokinase might be required. Surgery might be required for recurrent emboli and massive emboli resulting in cardiovascular collapse.

**Abdominal Pain**

Some postoperative patients might experience increased abdominal pain during AE. If the pain is acute, intra-abdominal hemorrhage should be considered, as discussed above. However, a more common cause of postoperative abdominal pain is related to gas trapped in the bowel. It is not uncommon for postoperative patients to have a temporary obstruction related to bowel irritation, referred to as paralytic ileus. It usually spontaneously resolves within 1 week of surgery. Bowel obstruction that does not resolve is more likely to be mechanical in nature, related to intra-abdominal adhesions, or an errant suture.

Even in the hospital, bowel obstruction condition can lead to abdominal distension and colicky pain usually associated with nausea and vomiting. The pain might be worsened by expansion of bowel gas associated with decreased cabin pressure in-flight. Treatment is gastric decompression with a naso- or orogastric tube, IV hydration, and supportive therapy with pain and antinausea medicine. It is unlikely for this complication to require emergency flight diversion. However, complete
medical reevaluation of the patient at the next scheduled stopover is mandatory.

**Postoperative Infection**

One of the most common postoperative complications in the first week after surgery is infection. Even with the use of prophylactic antibiotics, clinically significant infection occurs in 5% of hysterectomies. One of the most common sites of postoperative infection is the abdominal incision. The clinical presentation is redness and induration around the incision, with or without purulent discharge. Other sources of infection in a postoperative patient with a fever or signs of sepsis might be more difficult to determine. Infection at the vaginal cuff after hysterectomy or infections of the urinary or pulmonary tract are difficult to diagnose during flight.

If a postoperative patient develops fever or signs of sepsis in-flight, the primary treatment consists of IV hydration and oral antipyretics. If available, broad-spectrum antibiotics can be instituted. Flight diversion is necessary if the patient exhibits signs of advanced sepsis, such as tachycardia or hypotension.

**Wound Complications Other Than Infection**

**Bleeding**

A relatively common postoperative complication is bleeding from the operative site. Although hemostasis in the subcutaneous tissue is achieved prior to enclosure, patient movement and the normal healing process can sometimes result in significant bleeding. In general, this will occur in the first 48 hours after surgery. Later bleeding from the wound might represent infection. After most gynecological procedures, the bleeding will come from an abdominal incision. After hysterectomy and vaginal procedures, the bleeding might come from the vaginal incision.

Treatment for in-flight bleeding from an abdominal incision consists of direct pressure over the bleeding site and placement of an overdressing over the original dressing. When possible, the dressing should be removed to evaluate the wound. In most cases, the wound will remain intact and a pressure dressing will minimize further bleeding. Uncontrollable bleeding will require further evaluation at a medical facility.

Heavy vaginal bleeding in the postoperative patient is a more difficult problem. If a physician with gynecological experience is available, the vaginal cuff can be evaluated using a speculum and focused light source. A discrete bleeding site might be selectively clamped and ligated. Vaginal packing might be most helpful in controlling postoperative bleeding.

**Dehiscence**

A serious, but fortunately uncommon, wound complication is dehiscence. This is defined as disruption of all layers of the abdominal incision, including skin, subcutaneous, fascia, muscle, and peritoneum. The most serious variant of wound dehiscence is evisceration, where peritoneal cavity contents spill out. Dehiscence is usually related to sudden increases in abdominal pressure from coughing or patient movement. Obesity, wound infections, diabetes, and malignancies increase the risk of wound dehiscence.

The treatment for wound dehiscence in-flight is support of the wound with a pressure dressing and an abdominal binder. A binder can be made by wrapping an elastic bandage around the abdomen over a thick dressing. If evisceration occurs, the bowel should be covered with a moist, sterile towel or dressing. If available, this dressing should be covered with a layer of plastic (eg, trash bag) to limit loss of body heat and moisture. Every effort should be made to avoid compromising the blood supply to the bowel because bowel hypoxia might cause necrosis and necessitate bowel resection. Emergency flight diversion for emergency medical care is mandatory.

**Conclusion**

Long-distance AE of obstetric and gynecological patients present many unique challenges. An understanding of the common diagnoses and their related complications might help minimize the risk of these complications during
AE. This knowledge might also help the medical flight crew develop a rational approach to emergency in-flight treatment.

References

The transport of critically ill patients from one location to another is inherently perilous. Although this is true even for in-hospital conveyances (eg, down the hall to accomplish a computed tomography scan), the risk is considerably greater during long-distance aeromedical evacuation (AE) because the only expertise and medical equipment available is that which was enplaned with the patient. For this reason, AE of medical casualties (especially those needing intensive care) requires extensive preplanning and careful preparation for both predictable and unanticipated problems.

Unfortunately, the ability to prepare for AE is limited by the amount of personnel, equipment, and supplies that will fit on a rotary-wing or fixed-wing aircraft. Therefore, successful transport of medical casualties depends on (1) an accurate understanding of the diseases that afflict the patient; (2) knowledge of potential or likely complications; and (3) a clear appreciation of how the AE process can aggravate disease. Simply put, you can take only what is necessary but you must ensure you have what you need!

**Definition of Terms**

**Medical Evacuation vs AE**

The first important distinction to be made is between medical evacuation (MEDEVAC) and AE, two clearly different processes that are often confused because they have much in common. MEDEVAC is defined as transportation of casualties from the site of injury to a medical facility or between relatively nearby medical facilities. This includes both ground transportation and air transportation, most commonly by rotary-wing aircraft. In the civilian sphere, MEDEVAC is the majority of air transportation, and the most common scenario is transportation of trauma patients from the site of a motor vehicle accident to an emergency department. In the military, the MEDEVAC system is designed to transport combat and noncombat casualties to the closest field medical facility or between medical facilities within the theater.

On the other end of the spectrum, AE is defined as the long-distance (usually >300 miles) air transportation of casualties between medical facilities. In the civilian sphere, this is likely to be a shorter distance between an emergency department and an ICU to a higher level of care at another facility. It is usually performed using rotary-wing aircraft. However, it has also been clearly demonstrated that transportation of patients over distances greater than 800 miles is safe. For military AE, the distance of transport is often measured in thousands of miles and fixed-wing aircraft are almost exclusively used. The similarities between AE and MEDEVAC are obvious, especially when transporting critically ill patients by air.

**Elective vs Urgent or Contingency AE**

**Elective AE**

Elective AE is characterized by virtually unlimited time for planning prior to transportation.
In most cases, elective AE takes place well after definitive therapy, when the rigors of air travel are unlikely to result in medical decompensation. Although these patients are stable and convalescing, some may be critically ill and require high levels of in-flight medical care and support requirements. In addition, even the most stable patients may experience complications and become unstable when exposed to the sometimes-rigorous AE environment.

For the critically ill patient, the goal of elective AE is seamless critical care from the point of transfer through arrival at the accepting facility. The most significant determination of the quality of transport care is the training and expertise of the medical attendants. To this end, medical attendants should be knowledgeable in the environment of flight as well as the provision of critical care.

Elective AE of a medical casualty is most commonly performed to transport a patient to a facility capable of a higher level of care. It is also used to transport a patient from a foreign environment where the culture, language, and medical capabilities are significantly different. In every case, the decision to transfer a patient should be made with consideration of (1) the risks to the patient of not being transferred; (2) the risks inherent to AE; and (3) the expected benefits of the transfer. Regardless of the reason, elective AE patients should be stable with a secure airway and have demonstrated an appropriate response to therapy, including stable vital signs prior to transport.

**Urgent and Contingency AE**

Medical casualties may sometimes have to be transported by AE after having received only enough therapy to “stabilize” their disease process (Fig 23.1). Common reasons for urgent or contingency AE include:

1. Transportation to a facility capable of a higher level of care when appropriate care is not available locally.
2. Removal from a military theater of operations.
3. Removal from a disaster area where local medical facilities are saturated.

There are a number of medical diseases and conditions that commonly require urgent AE to a higher level of care (Table 23.1). These seemingly disparate conditions are similar in that they all possess an increased risk for en route deterioration. Aggregate experience from the USAF Critical Care Air Transport (CCAT) Teams suggest that a preponderance of these risks relate to acute airway compromise. In some patients, rapid airway deterioration can require immediate recognition and definitive intervention to avoid loss of life. Continuous and comprehensive physiological monitoring is essential in these patients to recognize impending disasters and permit preemptive intervention.

A surprisingly large number of previously healthy patients develop life-threatening cardiac syndromes (eg, infarction, pump failure, or uncontrolled hypertension) in relatively austere locations, necessitating transfer to higher levels of care. Because of lack of appropriate medical facilities locally, these patients often require transfer during the most unstable phases of their diseases. Complete evaluation and definitive treatment is often unfeasible prior to AE. This results in reliance on state-of-the-art monitoring throughout AE for timely detection of complications that may develop during the natural progression of the disease.

### Table 23.1. Medical conditions that often require urgent AE to a higher level of care.

<table>
<thead>
<tr>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory conditions</td>
</tr>
<tr>
<td>ARDS: Acute respiratory failure requiring mechanical ventilation</td>
</tr>
<tr>
<td>Pulmonary embolism, with or without shock</td>
</tr>
<tr>
<td>Toxic gas inhalation with respiratory injury</td>
</tr>
<tr>
<td>Respiratory failure secondary to sepsis or cardiac causes</td>
</tr>
<tr>
<td>Cardiovascular conditions</td>
</tr>
<tr>
<td>MI: Myocardial infarction</td>
</tr>
<tr>
<td>Unstable angina</td>
</tr>
<tr>
<td>Congestive heart failure</td>
</tr>
<tr>
<td>Recurrent ventricular tachycardia</td>
</tr>
<tr>
<td>Septic shock</td>
</tr>
</tbody>
</table>

### Description of Patient Condition

Another important area to consider is the use of precise terms to describe a patient’s medical condition. A patient who is described as “critically ill” by one provider may be depicted as “stable” by another. For example, a patient with primary respiratory failure on a mechanical ventilator requiring adjustment once or twice daily is critically ill, but is also stable. This is in contrast to a patient with respiratory failure secondary to evolving adult respiratory distress syndrome (ARDS), who is both critically ill and unstable. The relative risk involved in moving these two patients on ventilators is drastically different and is influenced by the patient’s medical condition, the equipment available, and the experience level of the providers caring for the patient.

Safe AE is dependant on reliable communication between all involved physicians to ensure that the right personnel and equipment are available. Using the same terminology to express the difference in acuity of illness is one of the most fundamental requirements of critical-care–related casualty transport. While this is vital for critically ill patients, it is also true for medical casualties of lesser acuity.

### Stable vs Stabilized vs Unstable Patients

Patients who require AE can be divided into three basic groups: stable, stabilized, and unstable. Stable patients are those patients who are extremely unlikely to medically decompensate during a prolonged flight either because their medical condition is not life-threatening or because they are in the convalescent stage of their illness or injury. For the purposes of this book, these are the patients transported by elective AE and are classified as “routine” using the standard AE patient nomenclature (see chapter 7).

The second group are stabilized patients: those who have received just enough medical care to allow them to be transported by AE but are at significant risk of becoming unstable during the flight. These include patients transported by urgent AE (when a patient’s serious condition cannot be adequately treated locally) and what we termed in this book contingency AE (when patients are moved for nonmedical
reasons, including armed combat or natural disaster). These patients are termed “special” by standard AE patient classification because they require special equipment or expertise for AE.

The final AE group is made up of unstable patients. These patients require continued intensive care throughout AE for survival. These patients are also classified as both urgent and special and may be more common during contingency AE. In response to US military doctrinal changes, AE of both stabilized and unstable patients is becoming increasingly common. For this reason, the AE system now includes CCAT Teams made up of intensive-care providers trained to use sophisticated air-transportable intensive-care equipment (see chapter 9).

Variables Influencing Long-Distance AE

Stressors of Flight

Successful AE of medical casualties requires a clear understanding and insight of the stressors of flight on a patient. These stressors can be considered in three broad categories: (1) physical, (2) mechanical, and (3) environmental.

The most important physical stressors are the consequence of altitude-induced changes in cabin pressure on the patient and the adjunctive medical devices used en route. The physiological implications of these effects will be discussed in the respiratory and cardiovascular sections below.

Mechanical stressors include aircraft-specific factors, such as vibration, noise saturation, and poor lighting. Noise and vibration render auditory diagnostic assessment difficult or impossible. For this reason, medical equipment must provide ample visual cues, especially for alarms on devices such as mechanical ventilators and cardiac monitors. In a contingency situation, this problem may be compounded by a high patient-to-provider ratio (Fig 23.2). In this potentially low-light environment, visual alarms must reliably attract the caregivers’ attention (eg, by blinking incessantly).

Finally, the most important environmental stressors include those related to extremes of temperature and low humidity. Failure to
account for these variables can significantly complicate patient management.

Decreased Pressure

At the altitude flown during routine fixed-wing AE, the cabin pressure in a pressurized aircraft is equivalent to an altitude of approximately 8000 ft. This lower pressure significantly decreases the amount and rate of oxygen that diffuses across alveolar–capillary membrane surfaces. For this reason, the flight altitude must be restricted for patients with severe lung disease and unresolvable hypoxemia at the normal cabin altitude. Even with a partial altitude restriction (ie, 3000 to 7500 ft) during fixed-wing AE, the PaO₂ in a majority of casualties may be compromised to < 60 mm Hg.4

Altitude restriction for AE aircraft creates a significant cost in terms of speed and fuel efficiency; thus, it should only be used when essential. The obvious result is increased duration of the flight, related both to decreased air speed and increased refueling stops. This, in turn, increases the overall risk to the patient transport and must be carefully accounted for during the AE planning phase.

Oxygen Therapy

All AE patients should receive the same amount of oxygen equal to that received prior to transport to minimize complications of hypoxia. This requires maintenance of the same inspired oxygen partial pressure (PiO₂). Even though the inspired fraction of oxygen is constant at all altitudes, the reduction of barometric pressure with ascent to altitude decreases the ambient PiO₂ according to the following formula:

\[
\text{PiO}_2 = (\text{PB} - \text{PH}_2\text{O})\text{FiO}_2
\]

where PB is ambient barometric pressure and PH₂O is the partial pressure of water vapor that is dependent on the patient’s temperature. At 37°C, body temperature, PH₂O is 47 mmHg. Although PH₂O will vary with patient temperature, for practical purposes it can be assumed to be constant over the range of temperatures present in patients. Thus, the required FiO₂ to maintain PiO₂ constant during exposure to a lower barometric pressure can be calculated as follows:

\[
\text{Required } \text{FiO}_2 = \frac{\text{FiO}_2 \times (\text{PB}_1 - 47)}{\text{PB}_2 - 47}
\]

where FiO₂ is the current FiO₂, PB₁ the current barometric pressure and PB₂ the barometric pressure at the new altitude (Table 23.2).

For example, if a patient is located in a city 1000 feet above sea level and is receiving an FiO₂ of 0.50, but will be transported at a cabin altitude of 8000 feet to a hospital located 4000 feet above sea level, the following calculations illustrate the required FiO₂ during transport and after arrival:

\[
\text{In-flight required } \text{FiO}_2 = \frac{0.50(686)}{517} = 0.66
\]

\[
\text{Destination required } \text{FiO}_2 = \frac{0.50(686)}{609} = 0.56
\]

If a patient requires substantial oxygen supplementation, it may not be possible to deliver sufficient oxygen to correct hypoxia. For example, if 75% or greater FiO₂ is required at sea level, it is not possible to deliver the same PiO₂ at a cabin altitude of 8000 feet even if the FO₂ is raised to 1.0.⁵

| Table 23.2. Barometric pressure at indicated altitude and standard temperature. |
|-----------------|-----------------|-----------------|-----------------|
| Altitude (ft)   | Barometric pressure (mm Hg) | Barometric pressure – 47 (mm Hg) | Temperature (°C) |
| 0               | 760              | 713             | 15.0            |
| 1000            | 733              | 686             | 13.0            |
| 2000            | 706              | 659             | 11.0            |
| 3000            | 681              | 634             | 9.1             |
| 4000            | 656              | 609             | 7.1             |
| 5000            | 632              | 585             | 5.1             |
| 6000            | 609              | 562             | 3.1             |
| 8000            | 564              | 517             | –0.8            |
| 9000            | 542              | 495             | –2.8            |
| 10,000          | 523              | 476             | –4.8            |
| 11,000          | 503              | 456             | –6.8            |
| 12,000          | 483              | 436             | –8.8            |
| 14,000          | 446              | 399             | –12.7           |
| 16,000          | 412              | 365             | –16.7           |
| 18,000          | 379              | 332             | –20.7           |
| 20,000          | 349              | 302             | –24.6           |
| 22,000          | 321              | 274             | –28.6           |
| 24,000          | 294              | 247             | –32.5           |
| 26,000          | 270              | 223             | –36.5           |
Pneumothorax

An unrecognized pneumothorax can have a devastating effect on respiratory system function during AE. Even a small pneumothorax on the ground may develop life-threatening tension pneumothorax because gas trapped in this closed space expands as the aircraft ascends. For this reason, special efforts should be made to diagnose a simple pneumothorax prior to flight in high-risk patients, such as trauma or mechanically ventilated patients. In general, a chest tube should be placed in all patients with a pneumothorax prior to AE, even in the absence of symptoms. Once inserted, the chest tube should never be clamped during transport but must instead be vented using a one-way (eg, Heimlich) valve, a water seal, or a continuous suction device.

Effects on Equipment

The risk of altitude-related gas expansion is also a concern for air-containing medical devices, such as a Foley catheter or endotracheal tube. On the ground, air in an endotracheal tube cuff is extremely unlikely to expand to the point of causing tracheal injury. However, during ascent the cuff can expand to a sufficient diameter to rupture the trachea and/or obstruct the endotracheal tube, especially in the event of cabin decompression. For this reason, the USAF AE system insists that all patients with endotracheal and tracheostomy tubes have the cuffs filled with sterile saline rather than air prior to take-off. If air is left in the cuff, pressures must be measured and documented frequently during AE.

Low Humidity

The fresh air supply of the aircraft, obtained from the surrounding atmosphere, becomes progressively drier as altitude increases. As a flight progresses, moist air is continuously replaced by drier air, resulting in a decreasing humidity within the aircraft. The cabin humidity may drop as low as 5% after 2 hours and as low as 1% after 4 hours of flight. This low humidity may result in symptoms of dry mouth, chapped lips, hoarseness, or sore throat among crew members and patients.

Long flights with such low humidity may complicate patients’ underlying medical conditions. Patients with respiratory problems will begin to be uncomfortable if the humidity drops much below 5% to 10%. Respiratory secretions may become thick, resulting in impaired gas exchange and thus contribute to hypoxia. Humidified oxygen should be used for patients requiring oxygen therapy. Warmed, humidified air should be supplied to tracheostomy patients, even if supplemental oxygen is not given.

Low ambient humidity increases insensible fluid losses in all patients but especially those who are flown >4 hours, have large surface-area open wounds, or require mechanical ventilation. For patients with large open wounds, insensible fluid losses can be limited by covering the wound or affected extremity with a non-permeable plastic sheet. In high-risk patients, this increased insensible fluid loss may increase the risk of hypovolemia, and thus two large-bore intravenous (IV) catheters should be placed prior to take-off. In the event of cardiovascular deterioration, fluid resuscitation needs to be increased accordingly.

Temperature Changes

As altitude increases, the temperature outside the aircraft decreases an average of 2°C (3.4°F) for every 1000 ft. These temperature changes may not be adequately ameliorated by the aircraft climate control system, potentially exposing a patient to a significant variation in temperature. In addition, during long-distance AE significant temperature variation commonly develops in different locations of the aircraft cabin.

Exposure to temperature extremes for an extended period may result in motion sickness, headache, disorientation, fatigue, discomfort, and irritability. It will also increase metabolic rates, resulting in increased oxygen consumption. For patients with borderline pulmonary reserve, significant physiological compromise can result.
Technology Required for Transportation

Medical equipment commonly used for critical care in fixed medical facilities may not function properly in an aircraft, primarily because of the changes in cabin pressure. For this reason, a number of devices have been modified and, after extensive testing, approved for AE by the Armstrong Research Site of the Air Force Research Lab. All AE aircraft must be capable of providing electrical power for medical equipment, and this is often accomplished by using an inverter. The inverter transforms aircraft power to 110V/60Hz, the wall source power almost exclusively used in US hospitals. In a dedicated ambulance aircraft, this is never an issue. However, contingency AE may be accomplished in any available aircraft. If a non-AE–dedicated aircraft is used, the aeromedical crew must make sure that the appropriate power source is available for any necessary medical equipment.

Monitoring Devices

The most commonly used devices during AE are electronic monitoring devices. These include a cardiac monitor, external blood pressure monitor, arterial line monitor, pulse oximetry, end-tidal CO₂ monitor, in-line O₂ analyzer, Wright spirometer, and cufflator (endotracheal tube cuff pressure measurement device) (Table 23.3).⁶

Pulmonary Conditions

Respiratory considerations are paramount for successful AE. The effects of altitude, while inconsequential to a healthy individual, may be devastating to the compromised patient. Therefore, a crucial AE concern is identification of patients susceptible to hypoxia so that the effects of altitude can be prevented or recognized early.

Pneumothorax

An untreated pneumothorax is a contraindication to AE (Table 23.4). A pneumothorax of any size must be treated prior to flight because expansion of intrapleural air with aircraft ascent can compress functioning lung tissue and compromise oxygenation. Tension pneumothorax can develop as continued expansion of trapped air shifts the mediastinal contents toward the opposite hemithorax. The resultant compression of the vena cava decreases venous return, resulting in decreased cardiac output and potential cardiopulmonary collapse.

Table 23.3. Medical equipment approved for use during aeromedical transport.

<table>
<thead>
<tr>
<th>Monitoring devices</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Pulse oximetry (SpO₂)</td>
<td></td>
</tr>
<tr>
<td>External blood pressure measuring device</td>
<td></td>
</tr>
<tr>
<td>Cardiac monitor</td>
<td></td>
</tr>
<tr>
<td>Arterial line monitor</td>
<td></td>
</tr>
<tr>
<td>End-tidal CO₂ monitor</td>
<td></td>
</tr>
<tr>
<td>Defibrillators</td>
<td></td>
</tr>
<tr>
<td>Paddle Model</td>
<td></td>
</tr>
<tr>
<td>“Hands-off” model</td>
<td></td>
</tr>
<tr>
<td>Ventilators</td>
<td></td>
</tr>
<tr>
<td>Adult/child</td>
<td></td>
</tr>
<tr>
<td>Infant</td>
<td></td>
</tr>
<tr>
<td>Portable laboratory instruments</td>
<td></td>
</tr>
<tr>
<td>Arterial blood gases</td>
<td></td>
</tr>
<tr>
<td>Hemoglobin and hematocrit</td>
<td></td>
</tr>
<tr>
<td>Electrolytes</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
</tr>
<tr>
<td>Suction pump and tubing</td>
<td></td>
</tr>
<tr>
<td>Resuscitation bag</td>
<td></td>
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</tbody>
</table>

Table 23.4. Contraindications to AE of medical patients.

<table>
<thead>
<tr>
<th>Absolute*</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated pneumothorax</td>
<td></td>
</tr>
<tr>
<td>Chest tube without one-way valve, water seal, or suction</td>
<td></td>
</tr>
<tr>
<td>Uncorrected severe arterial oxygen desaturation</td>
<td></td>
</tr>
<tr>
<td>Uncorrected respiratory acidosis</td>
<td></td>
</tr>
<tr>
<td>Life-threatening hypotension</td>
<td></td>
</tr>
<tr>
<td>Uncontrolled cardiac arrhythmia</td>
<td></td>
</tr>
<tr>
<td>Relative†</td>
<td></td>
</tr>
<tr>
<td>MI within one week</td>
<td></td>
</tr>
<tr>
<td>Unstable angina</td>
<td></td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td></td>
</tr>
<tr>
<td>Severe anemia (hemoglobin &lt;7 mg/dL)</td>
<td></td>
</tr>
<tr>
<td>Alcoholism without a prior 3–5 day observation period</td>
<td></td>
</tr>
</tbody>
</table>

* Contraindication to Elective, Urgent or Contingency AE.
† Contraindication only to Elective AE.
Tension pneumothoraces must be treated immediately with a needle thoracostomy in the second or third anterior rib interspace, followed by the insertion of a chest tube. The chest tube should be connected to a Heimlich valve or other one-way valve system to prevent further expansion of the pneumothorax. Lack of a one-way valve on a chest tube is another contraindication to AE.

**Acute Respiratory Failure**

Acute respiratory failure is classified as either primary or secondary. Primary respiratory failure refers to the inability of the lungs to maintain adequate gas exchange (oxygenation and carbon dioxide removal) because of a severe pulmonary condition such as pneumonia or pulmonary embolism. In contrast, secondary respiratory failure refers to inadequate pulmonary gas exchange due to extrapulmonary causes such as cardiac failure or the hypermetabolism associated with sepsis.

**Implications for AE**

The AE transportation of patients with acute respiratory failure requires meticulous planning, special equipment (ie, respirator, pulse oximeter, et.), and, in almost every case, accompaniment by a respiratory therapist or critical-care physician.

The patient’s precarious medical condition may be made worse by altitude-associated hypoxia, requiring careful adjustment of the respirator. In addition, equipment and incompatibility of supplies such as connectors are often a problem, especially at interface points where the responsibility for care of a patient is transferred from one group of clinicians to another. Patients may quickly deteriorate while clinicians try to fix these problems. For this reason, the respiratory therapist is an irreplaceable resource for troubleshooting and improvising. A well-prepared respiratory therapist will bring a supply of the most common fittings and the necessary tools to connect them.

The most difficult types of respiratory failure patients to transport by AE are those with ARDS. As the aircraft ascends, the altitude-related hypoxia will often result in decreased oxygenation for “borderline” ARDS patients. Unfortunately, increasing the inspired oxygen concentration alone may not improve oxygenation because these patients have a marked degree of pulmonary shunting. The most effective way to improve oxygenation is to re-expand collapsed alveoli, thereby increasing functional residual lung capacity (FRC). This is accomplished with a combination of positive pressure ventilation and positive end-expiratory pressure (PEEP). Recent work has demonstrated the value of PEEP in correcting altitude-associated hypoxia in an animal model of ARDS. Changes in cabin pressure make adjustment of respirator settings extremely difficult. This, plus the nature of ARDS, puts the patient at increased risk of pulmonary barotrauma during AE.

**Chronic Obstructive Pulmonary Disease**

Chronic obstructive pulmonary disease (COPD) refers to the triad of asthma, emphysema, and chronic bronchitis. Each of these diseases involves airway obstruction in some manner and predisposes a patient to complications associated with the flight environment.

Both acute and subacute aggravating factors can predispose these patients to complications both at sea level and during flight. Acute factors that can result in immediate respiratory deterioration include pneumothorax, pulmonary embolism, and lobar atelectasis. Subacute factors that can result in a slower deterioration include acute bronchitis, pneumonia, small pulmonary emboli, segmental atelectasis, minor trauma such as rib fractures or small pulmonary contusions, and metabolic factors. In addition, gastric distention secondary to decreased cabin pressure may limit diaphragmatic excursion and reduce vital capacity.

**Implications for AE**

During AE, the COPD patient should be observed for early signs and symptoms of hypoxia, including tachycardia, tachypnea, dyspnea, hypertension, confusion, restlessness, and headache. Pulse oximetry should be used
during AE to continuously monitor the oxygenation of COPD patients.

Arterial oxygen saturation is $\geq 95\%$ in normal healthy patients at sea level. Patients with COPD frequently have lower readings (90–94%) which appear to be tolerated chronically and do not require oxygen supplementation. However, any drop in a patient’s oxygen saturation requires immediate evaluation of ventilation and initiation of oxygen therapy to restore oxygenation to an acceptable value ($\geq 90\%$).

The use of high levels of supplemental oxygen therapy in patients with COPD can be relatively dangerous since increased oxygen may decrease the patient’s hypoxic drive to breathe, resulting in acute respiratory acidosis. This usually occurs in unstable patients with an acute exacerbation rather than in patients with compensated respiratory acidosis. Although a patient’s arterial PCO$_2$ may rise somewhat with judicious use of supplemental oxygen, in most cases marked respiratory acidosis is avoided. However, an unstable patient with an acute exacerbation of COPD cannot be transported without significant risk unless personnel and facilities are available for inflight endotracheal intubation and mechanical ventilation. Obviously, such patients are not candidates for elective AE.

In patients requiring mechanical ventilation, several factors need to be considered. Ventilators should be plugged into an external power source if possible to conserve battery power and sufficient battery reserve should be present to operate the ventilator for 1.5 times the expected flight duration. Expected oxygen utilization should be carefully calculated using the patient’s minute ventilation. At least 1.5 times the expected oxygen utilization should be available on board the aircraft.

As gases expand with ascent to altitude in accordance with Boyle’s law, air in an endotracheal tube cuff will expand as well, although usually not enough to cause injury to the trachea. Rapid decompression, however, could result in tracheal rupture or obstruction of the distal outlet of the endotracheal tube. Endotracheal cuff pressures may be monitored with use of a cufflator pressure monitor. Alternatively, the endotracheal tube cuff can be filled with saline, which will not expand with ascent to altitude. The expansion of gas at altitude also requires that the tidal volume of ventilators be recalibrated at altitude to avoid barotrauma. Patients should be closely monitored with cross-reference to the patient, cardiac monitor, and ventilator. In cases where the patient’s respiratory status is in unclear, an arterial blood gas may be able to provide guidance. Finally, a high index of suspicion should be maintained for development of a pneumothorax in patients who demonstrate respiratory distress or cardiopulmonary decomposition.

**Cardiovascular Conditions**

**Myocardial Infarction and Unstable Angina**

A diseased and recently injured heart has a limited ability to compensate for the additional cardiovascular stresses imposed by AE. One of the greatest threats to a diseased heart is hypoxia. Patients with ischemic heart disease demonstrate decreased oxygen saturation during AE, with a reported oxygen saturation of $<90\%$ in approximately 20% of patients. This drop in oxygen saturation increases both myocardial workload and oxygen demand and can result in clinical deterioration of patients with little cardiac reserve.

There are other cardiovascular stresses imposed by AE related to the physiology of flight. These include acceleration during take-off, which can decrease cardiac output by decreasing venous return, especially if litter patients are transported with their head positioned forward. The low humidity associated with flight may cause mild dehydration, thus increasing cardiac workload. Finally, the stress of flight can result in the increased release of catecholamines and autonomically induced dysrhythmias.

**Implications for AE**

Because of the increased risk of complications immediately after a myocardial infarction (MI), elective AE is contraindicated until at least 1 week after the acute event.
A study of 196 patients who traveled on commercial aircraft after an MI found that while complications occurred in <5% of patients the majority of these occurred in patients transported <14 days following the event. Additional time for recovery before elective AE may be indicated based on factors that could predispose the patient to complications in-flight. These factors include extensive coronary disease, a difficult postinfarction course, limited cardiovascular reserve, and a substantial need for medications.

In contrast to commercial transport of patients post-myocardial infarction, AE utilizing dedicated air ambulances and experienced medical personnel may be achieved earlier. Essebag and colleagues retrospectively reviewed transport of 109 patients with serious cardiovascular disease by commercial and dedicated air ambulance flights as long as 10 hours duration. Of these patients, 51 who were transported by air ambulance had suffered myocardial infarctions, and one half of these were complicated (Killip class II, III or IV). In 16 patients transported >7 days post infarction, there were no in-flight complications. Five of 35 patients transferred 0–7 days post infarction suffered complications during AE. Four patients had chest pain and one exhibited arterial desaturation. All patients responded to conventional measures and had no sequelae. These data underscore the importance of experienced teams in successful Urgent or Contingency AE. Although data in the literature is sparse, it is clear that the closer in time to the myocardial infarction, the more likely serious events will occur. AE of patients with MI during the initial phases of their illnesses should be carried out only after careful planning and in the presence of experienced critical-care personnel.

AE of patients with unstable angina should be attempted only when absolutely necessary because of their tenuous medical condition. Castillo and Lyons reported outcome data on 59 patients with unstable angina who underwent transoceanic AE. Unfortunately, in-flight data were only available on 31 of the patients. Of these, six patients had in-flight events (three with chest pain, one each with arterial desaturation, headache and hypertension). None suffered a myocardial infarction during AE. Of the 31 patients with available in-flight data, there were no reported arrhythmias. It is not clear if this data is applicable to all cases of unstable angina considering the relatively benign outcomes in all 59 patients (five with congestive heart failure, two with eventual myocardial infarction and one death). Patient selection for AE may have been responsible for the generally favorable outcomes reported. Unfortunately there are no prospective controlled studies published in the literature regarding AE of patients with severe cardiovascular problems.

Several basic principles should be applied when AE is required for patients with severe coronary disease or recent MI. These patients should be transported by litter and receive continuous supplemental oxygen to minimize cardiac stress. Pulse oximetry should be used to make certain that the patient’s oxygen saturation remains >95%. Appropriate cardiac drugs must be available, including antiarrhythmic and vasoactive drugs, sedatives, and analgesics. IV access is important for fluid therapy and the administration of cardiac drugs. Cardiac monitoring should be used in any patient at risk of dysrhythmia. Central venous and/or arterial monitoring may be necessary in unstable patients. A cardioversion unit should be readily available. In all cases, the patient should be accompanied by critical-care specialists trained in the treatment of acute complications of coronary artery disease.

**Congestive Heart Failure**

Heart failure occurs when the pumping action of the heart is inadequate to meet the circulatory requirements of the body. Common precipitating factors include cardiac tachyarrhythmias and acute myocardial ischemia. The primary treatment of congestive heart failure includes oxygen administration and the pharmacological reduction of preload and afterload.

**Implications for AE**

The stresses of flight may significantly worsen the cardiovascular state of a patient with con-
gestive heart failure, and thus this condition is a relative contraindication to elective AE, especially in class 3 and 4 congestive heart failure. The hypoxia associated with ascent to altitude may worsen the patient’s condition by predisposing to tachyarrhythmias and acute myocardial ischemia. Hypoxia also increases right ventricular afterload by an increase in pulmonary arterial pressure. Unfortunately, even a small increase in afterload can result in cardiovascular decompensation and cardiogenic shock in those patients with significant right ventricular failure. Oxygen supplementation to prevent hypoxia and monitoring arterial saturation by pulse oximetry are indicated.

Decreases in preload may also result in cardiac decompensation in these patients. During flight, decreased cabin pressure may predispose to loss of intravascular volume into the interstitial space (ie, third spacing). Some patients might have inadequate cardiac reserve to compensate for the increased myocardial workload resulting from the compensatory increased heart rate and contractility. The resulting interstitial edema often will manifest clinically as a dry cough, while progression to alveolar edema will appear as pink, frothy sputum.

If urgent or contingency AE is required, critical-care specialists prepared to detect and treat deterioration in the patient’s condition must be available. A patient with congestive heart failure should be positioned with the head oriented toward the front of the aircraft so that the acceleration during take-off will not transiently exacerbate the congestive failure.

Pacemakers
Modern cardiac pacemakers have advanced to the point that they can emulate the heart’s natural response to the demands of exercise by increasing heart rate during periods of increased physical activity. Pacemakers accomplish this by sensing vibration and interpreting this as increased physical activity.

The vibration of flight, in particular in rotary-wing aircraft, may actuate pacemakers with activity-sensing functions and increase the pacemaker rate. This may have significant implications for patients with severe cardiovascular disease as they may be unable to tolerate a prolonged tachycardic rate. The increased rate is easily correctable by placing a magnet over the pacemaker and converting it to a non-inhibited unsynchronized paced rhythm.

Dysrhythmias
The early recognition and treatment of dysrhythmias is essential in the safe aeromedical transport of patients. Dysrhythmias should be treated the same as would be treated at ground level. When at altitude, however, special attention should be given to ensuring the patient is receiving adequate oxygenation and ventilation. Defibrillation and cardioversion can be performed during flight provided standard safety precautions are observed to ensure the safety of medical attendants, crew members, and other patients. Although defibrillation has demonstrated no adverse effect upon an aircraft’s instruments, navigation, or electrical supply, aircrew members should be notified prior to use of this intervention.

Other Medical Conditions
Anemia
Hemoglobin functions as a carrier of oxygen from the lungs to the tissues. A reduced level of hemoglobin (actual or functional) reduces the oxygen-carrying capacity and subsequently tissue oxygenation. One gram of hemoglobin will carry approximately 1.4 ml of oxygen. With an average hemoglobin concentration of 15 g of oxygen per 100 ml of blood (dl), the average male will have an O₂ concentration of approximately 21 ml/dl (ie, 1.4 × 15) at 100% oxygen saturation.

Anemia seriously reduces tolerance to a hypoxic environment. At 100% oxygen saturation, the maximum O₂ concentration for a patient with a hemoglobin reduced to 7 g/dl will be only 9.8 ml/dl. To compensate for this decreased oxygen-carrying capacity, cardiac output must increase. If a patient’s compensatory mechanisms are compromised, slight reductions in arterial oxygenation may produce hypoxic symptoms. Alternatively, increased cardiac stress in a patient with borderline
cardiac reserve may result in angina, MI, or heart failure.

**Implications for AE**

Severe anemia (<7 mg/dl) is a relative contraindication to AE. At this level, even healthy individuals are at risk. Patients should be transfused with whole blood or packed red blood cells until the hemoglobin concentration is >10 mg/dl. If transfusion is unavailable, either altitude restriction should be imposed to maintain a cabin pressure equal to sea level or sufficient supplemental oxygen should be administered to ensure maximum possible oxygen saturation.

Mild anemia (hemoglobin 10 to 15 mg/dl) is usually well tolerated by healthy individuals during AE. However, supplemental oxygen should be administered. This is especially important during pregnancy, when most patients have physiological anemia and the stresses imposed by pregnancy make them more likely to become symptomatic (see chapter 22).

Patients who have or are at risk of cardiac disease are at special risk of hypoxia-related complications with any degree of anemia. If transfusion is not practicable, pulse oxymetry and supplemental oxygen to maintain a saturation of >90% is the mainstay of treatment. Patients must be closely monitored for decompression. Symptoms that do not respond to increased oxygen may require altitude restriction or diversion to the nearest appropriate medical facility.

**Sickle Cell Disease**

Sickle cell disease is a hereditary chronic hemolytic anemia due to the presence of an abnormal hemoglobin molecule, hemoglobin S. The disease is present in individuals homozygous for the sickle cell gene (SS) or in heterozygous states when hemoglobin S is paired with other abnormal hemoglobins.

Sickle cell crisis is characterized by severe joint and abdominal pain related to sludging of crescent-like “sickle” erythrocytes, which occurs when hemoglobin S polymerizes into tube-like fibers. By far the important cause of this sickling is deoxygenation, and the critical arterial $P_O_2$ at which this occurs is <60mmHg. Fortunately, during flight in individuals without pulmonary disease this level is reached at a cabin altitude of approximately 10,000 ft, and modern aircraft are pressurized to maintain a cabin altitude of <8000 ft. However, in patients with pulmonary abnormalities, sickling can be induced at a cabin altitude as low as 4000 ft. For this reason, patients with sickle cell disease should receive supplemental oxygen during AE.

Patients who are heterozygous for the sickle cell gene (ie, sickle cell trait) do not appear to be at risk for altitude-related symptoms in which aircraft are pressurized to about 8000 ft or lower, the level of commercial aircraft pressurization. When transporting patients with sickle cell trait, however, the patients’ overall medical condition must be considered including the pulmonary, vascular, and hematologic status.

**Gastrointestinal Diseases**

The gastrointestinal (GI) tract normally contains a small amount of gas that will expand upon ascent. In healthy individuals, gas expansion is rarely problematic at cabin pressures at or below 8000 ft equivalent because of the resilience of the intestinal walls and the ability to relieve the increased pressure through belching or flatulence. On occasion, intraluminal gas expansion during flight may cause abdominal discomfort because of tight clothing or restraining devices. Also, gas expansion in the splenic flexure of the colon can cause upper-left quadrant fullness and a pressure radiating to the left side of the chest that can be confused with the pain of cardiac ischemia.

In contrast, patients with GI disorders (eg, bowel obstruction, ileus, or motility problems) may have significant difficulties during flight. Excessive gas production and the inability for gas to be normally transported through the intestines place patients at risk of significant problems related to gas expansion during flight. In addition to abdominal discomfort and pain, the patient may suffer from nausea, vomiting, shortness of breath, and, in extreme cases, vagal symptoms.
Implications for AE

All patients known to have GI disorders should have a nasogastric tube placement prior to flight. During flight, the tube should normally be attached to a low-flow suction device. If suction is not available, an open nasogastric tube may be of some use whereas a clamped tube will not.

Patients with colostomies may have an increased amount of bowel elimination during flight due to the increased peristaltic motion stimulated by intraluminal gas expansion. All such patients should have their colostomy bag replaced immediately prior to AE, and extra bags should be available. Excess flatus and gas expansion in the bag may require careful release in some cases.

Airsickness

Airsickness occurs in some people as a result of abnormal labyrinthine stimulation from unaccustomed pitching, rolling, yawing, accelerating, and decelerating forces experienced during flight. The result is a predictable sequence of symptoms that progress from lethargy, apathy, and stomach awareness to nausea, pallor, and cold eccrine perspiration, and finally to retching and vomiting and total prostration.

Motion sickness can complicate the care of patients and their attendants and on occasion incapacitate an AE crew member. Interventions should be initiated promptly following the onset of early signs and symptoms, and include the administration of oxygen, placing the patient in a supine position with restricted head motion and a cross-cabin orientation if possible, cooling of the environment, and the administration of antiemetic medications.

Neurological Disorders

The care of the nontraumatic neurological patient entails the prevention of complications associated with their underlying medical condition. In the case of paralyzed patients, special attention should be paid to ensuring insensitive areas of the body are protected from injury. Those patients on Stryker frames should be turned on a prescribed basis, usually 2 hours in the supine position and 1 hour in the prone position.

Some patients may have increased intracranial pressure as a result of trauma, cranial surgery, or infection such as bacterial meningitis. For these patients, steps should be taken to prevent factors that are known to increase intracranial pressure further, such as vomiting, hypoxia, and seizure activity.

Patients with a seizure disorder may be at increased risk during AE because hypoxia lowers the convulsive threshold. For this reason, a therapeutic level of an anticonvulsant medication should be documented prior to flight and supplemental oxygenation should be provided. The treatment of seizures during flight begins by ensuring that the patient’s oxygenation and ventilation are adequate, followed by administration of anticonvulsive medication.

General treatment of the obtunded or comatose patient includes an in-dwelling urinary catheter and IV fluid administration. These patients must be observed closely throughout flight because they are at increased risk of airway compromise and aspiration of gastric contents.

Renal Failure

Patients with acute renal failure should undergo dialysis immediately prior to all long-distance AE flights. The normal interval between dialysis treatments is usually 1 to 2 days; thus, the need for dialysis during AE will be unlikely if the flight is point to point. However, during overseas AE the aeromedical crew should be aware of when the next dialysis treatment is required so that arrangements can be made en route if required. Serum electrolytes should be routinely reassessed every 3 days for patients with acute renal failure, even if they are not yet dialysis dependent.

Alcoholism

The importance of considering the special need of the alcoholic patient is made clear by the special AE categories used to designate these patients (see chapter 7, Table 7.2). Alcoholism may be the primary reason for AE or an
undiagnosed disease process in a patient being transported for another condition. The major risk in either case is acute alcohol withdrawal, which can be fatal if unrecognized or untreated.

Alcohol withdrawal symptoms develop within 8 to 24 hours after the reduction of ethanol intake and peaks between 24 and 36 hours. These symptoms range from mild withdrawal characterized by insomnia and irritability to major withdrawal typified by autonomic hyperactivity resulting in tachycardia, fever, diaphoresis, and disorientation.

**Implications for AE**

To minimize the risk of alcohol withdrawal during AE, patients known to be alcoholic should be hospitalized for 3 to 5 days of observation prior to flight. Alcohol withdrawal symptoms that present unexpectedly in-flight require the prompt recognition and treatment of symptoms. A high index of suspicion is required in patients who are not known to be alcoholic.

Mild alcohol withdrawal symptoms may be effectively treated with supportive care alone, such as reassurance, personal attention, and general nursing care (Table 23.5). If the symptoms progress, moderate to severe withdrawal should be treated with pharmacological doses of benzodiazepines. Withdrawal symptoms unresponsive to benzodiazepines may benefit from haloperidol. If IV hydration is given with glucose-containing fluids, these patients should first receive magnesium and thiamine to prevent the precipitation of Wernicke’s encephalopathy.

### Septic Shock

The use of aircraft for the transportation of severely ill and injured patients is becoming increasingly more common. As a result, it is inevitable that a patient thought to be stable will deteriorate in flight. One diagnosis that must be considered in these patients, especially those who are immunocompromised, have experienced recent surgery, sustained significant trauma, or have in-dwelling catheters, is the development of sepsis.

Sepsis may present in a spectrum of signs and symptoms that may range from extremely subtle in the early phases of the disease to complete cardiovascular collapse. This later phase, sepsis with hypotension and inadequate tissue perfusion, is defined as septic shock. The constellation of signs and symptoms of sepsis include fever, chills, tachycardia, tachypnea with respiratory alkalosis, dermatologic changes, widened pulse pressures, and altered mentation. Although fever is common in sepsis, patients may present with hypothermia, especially neonates or elderly patients. With decreased perfusion of tissues in septic shock, severe metabolic acidosis is a common additional complication.

The goal of the treatment of sepsis should be the eradication of the infecting organism prior to the onset of the cascade of cellular, microvascular, and cardiovascular events that lead to septic shock. Therefore, treatment is usually initiated prior to the identification of a specific infecting organism. Empirical treatment is recommended using broad spectrum antibiotics chosen to cover the organisms most likely to be responsible for the sepsis. The patient’s history of illness of trauma is especially helpful in determining the choice of antibiotics.

Supportive therapy is essential in maintaining adequate oxygenation and hydration. Adequate ventilation with supplemental oxygen will correct hypoxia and its associated symptoms. IV fluid therapy will enhance tissue perfusion and oxygen delivery. In those cases where septic shock does not respond to fluid therapy, treatment with vasoactive pharma-
logical agents such as dopamine may result in increased cardiac output and improved tissue perfusion.

**Implications for AE**

Monitoring for signs and symptoms attributable to early sepsis is essential in patients who have conditions that are predisposed to this development and subsequent progression to septic shock. Initial evaluation of the patient’s oxygenation and tissue perfusion is a priority because the aeromedical environment may predispose a patient to hypoxia and dehydration, compounding the effects of sepsis upon the respiratory and cardiovascular systems. Early intubation and mechanical ventilation may be required in these patients. IV fluid administration is important in maintaining appropriate blood pressure and tissue perfusion. Anemia may be extremely detrimental in patients with sepsis. Although healthy individuals in the aeromedical environment may tolerate mild anemia, septic patients who are anemic are at increased risk and may require transfusion to maintain oxygenation of tissues.

Precautions required to prevent secondary infection during AE depends upon the minimum infective dose to produce illness and the mode of transmission of the disease. **Airborne precautions** are designed to reduce risk of infection transmitted by airborne particles ≤5 μm in diameter. These particles remain suspended in air indefinitely. Diseases communicated by larger (>5 μm) particles are less transmissible and require **droplet precautions**. Less stringent respiratory precautions are required since large droplets remain suspended in air for short periods of time. **Contact precautions** are used to prevent illnesses spread by direct contact with skin, contaminated surfaces and body fluids. Standard infection control procedures are sufficient for diseases spread by the contact or droplet modes and only airborne diseases require additional special techniques such as high efficiency particle filtration (HEPA) masks. The prototype of this class of agents is the smallpox virus. The viral hemorrhagic fevers have been considered to be in this class in the past, but uncertainty has developed in this position based on observations of patients with Lassa fever who have been transported by commercial and AE flights. For the purposes of AE, all patients exposed to a biologic agent should be considered infected, regardless of symptoms. Although the infectious risk to medical personnel depends on the agent involved, it may be impossible to determine the exact agent prior to AE.

**Biologic and Chemical Casualties**

Patients contaminated with chemical or biologic agents as a result of occupational exposure or terrorist event may sometimes need AE transportation. External decontamination is the first important consideration and must be performed prior to AE for all patients exposed to chemical or biologic agents. Once patients are decontaminated, the degree of further precautions needed during AE will be determined by the actual or suspected agent involved and the patient’s medical condition. To protect medical personnel and other patients, precautions should be used when transporting any patient exposed to chemical or biologic agents, as outlined in Chapter 11 and the excellent review of Withers and Christopher.

Both the incubation period prior to symptomatic disease and the time of greatest infectivity vary greatly for different biologic agents. Diseases that are transmissible during the incubation period present the greatest challenge. Because the infected individual cannot be identified on the bases of clinical findings, the chance of secondary infection of other personnel is increased and preventive measures cannot be applied selectively.

**Isolation During AE**

Patients confirmed or suspected to have a highly infectious or contagious disease can be isolated during AE using the Vickers aircraft transport isolator (VATI) (see chapter 11, Fig. 11.2) an air transport isolator. A stretcher isolator is a lightweight unit for initial patient retrieval, where the patient is then transferred to the air transport isolator in or near the aircraft. This allows for full nursing capability provided by an isolation team from the USA Medical Research Institute of Infectious Diseases to care for patients in-transit. All air passing in and out
of the unit travels through a high-efficiency particulate air filter. If the unit is accidentally punctured, negative pressure within the unit prevents potentially contaminated air from contaminating the cabin air. Gloved sleeves within the unit facilitate care of the patient. Because of its size, the use of this unit is limited to large transport aircraft such as the C-130 and C-141. For shorter distances, the CH47 Chinook helicopter may transport patients.

A few diseases are considered by the World Health Organization to be internationally quarantinable and are thus a contraindication to elective AE. Authorization by both command, if military, and diplomatic authorities must be obtained prior to AE across international borders.

In both the civilian or military spheres, the possibility exists of chemical contamination as a result of either occupational exposure or terrorist activities. Onset of symptoms is usually rapid after exposure to most chemical agents, although symptoms may be delayed for several hours after exposure to some agents.

Patients exposed to chemical agents must be thoroughly decontaminated prior to AE. Treatment may be required throughout the AE flight. Medical attendants must be familiar with appropriate therapies for various chemical agent exposures.

References

The specialty of pediatrics was one of the earliest to recognize the benefit of moving patients between medical treatment facilities. The impetus for this was to both maximize patient outcomes and conserve medical resources. By 1900, the Chicago Lying-In Hospital had developed specific equipment for transporting newborn infants. By 1950, the New York City Department of Health had set up a newborn transportation system to serve a network of hospitals, complete with specific transportation equipment and teams and a central dispatcher. During 1950 to 1952, this system moved more than 1200 patients between hospitals.1

Many areas of the United States developed regional neonatal ICUs during the 1960s and 1970s as a result of both the significant medical progress in this area and the increasing difficulty of supporting such units. This regionalization further increased the number of infants being transported.

As the size of the regions increased, the potential benefits of aeromedical evacuation (AE) compared to traditional ground transport became obvious. Early reports of this mode of transport were encouraging and included 53 infants transported by large fixed-wing military aircraft (Operation Baby Lift, 1969 to 1970) and 101 infants moved by both rotary-wing and small fixed-wing aircraft by St. Anthony’s Air Transport Service (Denver) from 1972 to 1973.2,3

The advantages of transporting neonates to regional ICUs quickly became apparent to other pediatric subspecialists. The subsequent development of regional pediatric ICUs and regional centers for trauma, dialysis, and transplantation further increased the need for interhospital transport of pediatric patients. In response, the American Academy of Pediatrics published guidelines for both air and ground transport in 1986, with subsequent revisions in 1993 and 2000.4 In addition, many pediatric subspecialty textbooks in neonatology, pediatric intensive care, and pediatric emergency medicine now contain chapters on ground and air transport of pediatric patients.5–7

This chapter will first cover pediatric transport goals and the composition, training, and equipment of pediatric transport teams. Next, the most common general pediatric conditions moved via AE and the AE implications will be described. Finally, common neonatal conditions requiring AE will be discussed.

Pediatric Transportation

Transportation Goals

The ultimate goal of pediatric AE is to rapidly bring the patient to a higher level of care. To do this successfully, three tasks must be accomplished. First, the transport team must assess the patient’s needs with the assistance of the referring medical care providers. A key determination at this point is which personnel are necessary for the transport team. The second task is to determine that the patient is stable enough to transport. This determination is a joint responsibility of the referring medical care providers and the transport team after they have arrived on-scene. The final task is to
maintain stability of the patient throughout the course of movement between medical treatment facilities, counteracting the stresses associated with AE as well as potential progression of the underlying medical problem.

Transport Team Composition

The composition of the transport team utilized for a particular mission will vary based on patient needs and the potential for complications. A transport team is most commonly composed of some combination of the following personnel: pediatric nurses with special expertise in the appropriate subspecialty (eg, neonatal intensive-care nurses or nurse practitioners), emergency medical technicians with pediatric experience, respiratory therapists with pediatric experience, pediatricians in training (ie, residents and fellows), general pediatricians, and subspecialty trained pediatricians. The exact combination depends on the diagnosis, condition, and age of the patient to be transported. Not all teams require physicians and in some locales physicians participate in only a few selected transports.

The Children’s Hospital Medical Center transport team (Cincinnati) always includes a pediatric nurse with additional skills in the patient’s disease (eg, neonatology) and a respiratory therapist with pediatric experience. Physicians participate in 22% of the neonatal transports and 38% of the pediatric transports. Recently, all ground transport teams have been augmented with emergency medical technicians for technical and logistical assistance (Shelton G. 2000. Unpublished data).

Ideally, all pediatric transport service directors should be physicians with expertise in the evaluation and treatment of pediatric disease and injury. These expert pediatricians include board-certified specialists and subspecialists in neonatology, pediatric emergency medicine, and pediatric intensive care. Although they personally participate in only a minimal portion of the patient movements, they are responsible for administrative, technical, and medical decision making as well as education of transport teams. Actual transport team members must have pediatric skills that support the anticipated needs of the patient transported.

In reality, it is sometimes difficult for regional planners to construct expert pediatric emergency teams. When expert pediatricians are unavailable, various levels of technicians, nurses, and physicians in training can be utilized to maximize the pediatric skills of the team.

Regional planners are encouraged to organize the base of their transport system at a pediatric center of excellence. This allows for the accomplishment of two important objectives. First, the primary team members located at these centers can establish and maintain their clinical skills. Second, other pediatric specialists available at these centers serve as a large pool to draw from in the event their special skills are required for a specific pediatric transport. When a team is augmented by a specialist with little background in pediatric transport, good communication between the expert and the transport team is essential to assure that patient care is not fragmented.

Team Training

All aeromedical transport team members must be trained in flight preparations, flight physiology, and safety. The specific content and currency requirements for transport team training are outlined in the Air Medical Crew National Standard Curriculum, which is based on both Federal Aviation Administration regulations and the Commission on Accreditation of Air Medical Services standards.

Transport teams may be combined neonatal/pediatric teams or separate teams for neonatal and other pediatric transports. Members of both combined and separate neonatal/pediatric transport teams require further specialized training in pediatric and/or neonatal resuscitation, stabilization of infants and children for transport, and in the frequently encountered diseases in each respective age group. Well-organized educational programs on these topics are offered by the American Heart Association, the American Academy of Pediatrics, the American College of Emergency Physicians, and the University of Virginia Medical Center. Advanced training for team members may sometimes be required, depending on team composition and required transport missions.
Continuing education for all team members is crucial to the maintenance of knowledge and skills. Those efforts should include not only operational and medical aspects of transport but also strategies for enhancing team communication skills and stress management.

Transport Team Supplies and Equipment

Supplies
Neonatal/pediatric transport supplies should be maintained separately from adult supplies. Although this will result in some duplication of supplies carried by adult transport teams, it is necessary to avoid the potential danger that can result from confusion of medicine doses and concentrations.

Equipment
Pediatric and neonatal transport equipment must be lightweight, compact, durable, and easily secured to function well in the AE environment (Table 24.1). Some basic equipment for pediatric transportation, such as cervical collars and backboards, are part of the standard emergency medical service inventory and usually do not need to be duplicated by the pediatric transport team.

Electrical equipment represents a special challenge for pediatric aeromedical transport. In addition to the previously mentioned attributes, this electrical equipment must have an extended battery capability because a long time can easily elapse between leaving the sending medical facility and enplaning. However, equally important considerations are the effects of flight on equipment performance and the effects of the equipment on the aircraft.

Performance of pediatric transport equipment should be thoroughly tested for the stresses of flight, including: altitude-related changes in pressure, temperature, and humidity; acceleration–deceleration forces; vibration; and the airframes’ electromagnetic environment. In addition to adversely affecting the performance characteristics, these stresses may significantly shorten the useful life of the equipment. Because of these environmental stresses, an effective biomedical maintenance program is critical.

In addition, the effects of pediatric transport equipment on the aircraft must be thoroughly tested to verify that the electromagnetic emissions of the equipment does not interfere with the performance of aircraft avionics, including communications and navigational devices.

Extensive safety and performance evaluation of equipment for AE has been carried out by both the USAF Medical Equipment and the USA Aeromedical Research Laboratory.9,10 Civilian testing labs and transport organizations have only recently begun to develop comprehensive testing programs for avionics and pediatric aeromedical equipment. Unfortunately, the majority of the transportation equipment that has been tested and approved for use on aircraft (eg, infusion pumps and ventilators) was designed for treatment of adult patients. In many cases, it may not be appropriate for use in pediatric patients if it lacks accuracy at the small volumes that must be delivered for pediatric and especially neonatal patients.

Incubators
The incubator is the focal point of the neonatal transport system because it provides for two of the most critical aspects of transport, thermal support and patient monitoring. It is also the largest and heaviest piece of equipment used in neonatal transport (Fig 24.1). Thus, it has a

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**Table 24.1. Neonatal transport equipment.**

<table>
<thead>
<tr>
<th>Transport Incubator or Litter</th>
<th>Monitors</th>
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<tr>
<td></td>
<td>Pulse/respiratory rate</td>
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<tr>
<td></td>
<td>Pulse oximetry</td>
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<td></td>
<td>Temperature (skin, core +/– air)</td>
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<td></td>
<td>Blood pressure (invasive, non-invasive)</td>
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<tr>
<td></td>
<td>ECG: Digital and waveform displays</td>
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<tr>
<td></td>
<td>Ventilator with humidification device</td>
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<tr>
<td></td>
<td>Oxygen blender with flow meter up to 15 LPM</td>
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<tr>
<td></td>
<td>Portable suction unit</td>
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<tr>
<td></td>
<td>Infusion pumps</td>
</tr>
<tr>
<td></td>
<td>Portable compressed gas with oxygen +/– air at 50 psi</td>
</tr>
<tr>
<td>Auxiliary equipment</td>
<td>Defibrillator-cardioverter</td>
</tr>
<tr>
<td></td>
<td>Intracranial pressure monitor</td>
</tr>
<tr>
<td></td>
<td>Point of care blood analyzer</td>
</tr>
<tr>
<td></td>
<td>Nitric oxide delivery system</td>
</tr>
</tbody>
</table>
significant impact on the final configuration and composition of the entire transport system. Prior to using an incubator for the first time in a particular aircraft, it must be verified that the incubator fits through the aircraft door and can be fixed firmly in place. In rotary-wing and smaller fixed-wing aircraft, the chief pilot must carefully review any impact on weight and balance calculations because an incubator and cart can weigh as much as 285 lb.

Ventilators

The choice of ventilator for air medical transport, although limited, is based on power source requirements, gas consumption, and the age of the patient because different ventilators are required for neonates and infants. The delivery volumes, pressures, and rates must be carefully evaluated to ensure that the ventilator meets the respiratory management philosophy of the regional neonatal care team. Critical evaluation by the respiratory care department will identify potential needs and problems. The respirator most commonly used by the USAF AE system is the Impact Uni-Vent Eagle Model 754 Positive Pressure Ventilator (Impact Instrumentation Inc, West Caldwell, NJ), which is described in chapter 19.

Extracorporeal Membrane Oxygenation

Extracorporeal membrane oxygenation (ECMO; also known as extracorporeal life support) is the use of a modified heart–lung machine for days or weeks to support life and permit treatment and recovery during severe cardiac or pulmonary failure in neonates, children, and adults.11 Neonatal ECMO is indicated in acute severe reversible respiratory failure when the risk of dying from the primary disease despite optimal conventional treatment is high (>50%). The most common neonatal indications include meconium aspiration syndrome, congenital diaphragmatic hernia, persistent pulmonary hypertension, respiratory distress/hyaline membrane disease, and neonatal pneumonia/sepsis. The current overall survival rate for neonatal respiratory failure is 80%.

ECMO machines are now routinely being flown in both rotary-wing and fixed-wing aircraft (Figs 24.2 and 24.3). Because of the size and weight of these units, the USAF primarily uses its larger aircraft (eg, C-9, C-17) to move...
infants on the ECMO. Because of the complexity of the equipment and treatment, specialized “ECMO teams” are required for all such transports.

Transportation Risks

Transportation of neonatal and pediatric patients, either by ground or air, represents a real risk for many reasons. In one study, interfacility transport of premature neonates was associated with a slightly increased risk of advanced intraventricular hemorrhage. In all cases, the risks of transport must be weighed against the patient’s need for advanced care and the ability of the referring medical facility to provide this care. Simultaneously, the added risk of air transport must be measured in light of the availability, duration, and utility of ground transport.

Psychological

When patients are moved between medical treatment facilities, families are usually separated, even if one or more family member accompanies the patient as a nonmedical attendant. Separation of a child from loved ones or parents from their normal support network may adversely affect the psychological health of both the child and family.

The Harsh Aeromedical Environment

The simple act of patient movement can put the patient at increased risk of displacing airways or intravascular lines. Movement, plus the vibration associated with flight, can further loosen dressings and disrupt healing wounds. The noise in most AE environments exceeds the recommended levels for children and completely precludes the use of auscultation by medical personnel. The variation in lighting often diminishes visual assessment skills as well.

Thermal Stress

One of the most important aspects of neonatal AE is the maintenance of an optimal thermal environment. Cold or heat stress significantly

Figure 24.2. USAF doctors and AE crew members monitor a baby being supported with an ECMO machine aboard a C-9A Nightingale (USAF photo by Captain John Sheets).
increases both the caloric and oxygen needs of an already compromised infant. Unlike the adult, the neonate is severely limited in his or her capabilities to compensate. Heat loss can occur through evaporation, radiation, convection, or conduction. Both radiation and evaporation are responsible for significant heat loss because of the neonate’s large body surface area. Evaporative heat loss that results from the administration of dry medical gases contributes to the thermal imbalance.

The exposure to thermal stress is not well tolerated by pediatric patients even when specific measures (eg, incubators) are used to counteract this stress. Although the purpose of an incubator is to maintain a stable environment in terms of temperature and humidity, each time the incubator is opened this advantage is lost until the system re-equilibrates.

Continuous temperature monitoring of the neonate and of his or her environment is crucial. Monitoring the infant’s axillary temperature alone does not assure that the thermal environment is appropriate. A table of age and weight should be used to determine the proper neutral thermal air temperature, which is in the range of 32 to 36°C.

Effects of Altitude

In contrast to rotary-wing aircraft, which fly at relatively low altitudes, pressurized fixed-wing aircraft usually fly with a cabin altitude equivalent to approximately 8000 ft. The more fragile physiology of an ill infant or child is especially sensitive to the three-fold problems associated with altitude, which include gas expansion, decreased oxygen concentration, and decreased air humidity. The effects of these problems are discussed in depth in Chapter 9.

Isolation from Comprehensive Medical Care

The time the patient spends between medical treatment facilities during long-distance AE can range from a few hours to 10 or more hours. The time is determined not only by flying time but also the two ground transport legs from the referring hospital to the aircraft and from the aircraft to the special-care unit/hospital. Weather and mechanical difficulties with the aircraft or ground transport vehicle may increase the time further.

This time away from comprehensive medical care presents multiple problems. Probably the
most significant problem occurs when the patient’s condition worsens. Adjustments in care are severely limited because of limited supplies and equipment and the lack of both diagnostic imaging and all but the most rudimentary laboratory tests.

Another significant problem related to isolation is equipment failure. Most AE equipment is powered by batteries or self-contained pressurized gas. Prolonged transportation times, especially if unexpected, may exceed the reserve of the equipment power source. Even on relatively short flights, equipment failure can adversely affect patient status because repairing or replacing equipment en route may not be feasible.

**Conditions Requiring Transport for Tertiary Care**

The scope and nature of pediatric transport is wide ranging. However, some of the most common problems encountered can be ascertained by examining the types of patients who required emergency transport to a large, tertiary-care pediatric medical center. From July 1, 1999, through June 30, 2000, almost 800 children were transported to the Children’s Hospital Medical Center at the University of Cincinnati, including 462 neonatal and 334 pediatric transports. A series of 100 consecutive patients from this group is presented in Table 24.2.

### Table 24.2. Conditions requiring transport to the Children’s Hospital Medical Center in 100 consecutive patients.

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonatal</td>
<td></td>
</tr>
<tr>
<td>Respiratory insufficiency</td>
<td>21</td>
</tr>
<tr>
<td>GI problems</td>
<td>16</td>
</tr>
<tr>
<td>Cardiac anomalies</td>
<td>8</td>
</tr>
<tr>
<td>Infection</td>
<td>6</td>
</tr>
<tr>
<td>Pediatric</td>
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<tr>
<td>Respiratory conditions</td>
<td>12</td>
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<td>Trauma</td>
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<td>Serious infections</td>
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<td>Neurological conditions</td>
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<tr>
<td>Cardiac disease</td>
<td>5</td>
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<td>GI conditions</td>
<td>4</td>
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<tr>
<td>Diabetes</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
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</tbody>
</table>

For neonatal transportation, by far the most common indication was respiratory insufficiency, related primarily to respiratory distress of the newborn and meconium aspiration syndrome. Gastrointestinal (GI) conditions (eg, esophageal atresia) were the second most common, followed by congenital cardiac anomalies and infections, such as sepsis.

Conditions requiring pediatric transport were more varied. The most common were respiratory conditions, such as severe asthma and croup. The next most common conditions were various types of traumas most commonly related to motor vehicle accidents, serious infections such as meningitis and pneumonia, and neurological conditions most commonly with seizure activity.

### Specific Pediatric Conditions

#### Asthma

Asthma (ie, reactive airway disease) affects more than 4.8 million children under the age of 18, and of these more than 150,000 are hospitalized each year. Including adults with this condition, there are more than 5000 deaths from asthma annually. From these statistics the implications for the AE system are obvious.

#### Implications for AE

Children with severe asthma are at risk during AE for acute exacerbations, probably because of the dry cabin air and the other stresses related to flight. An acute asthma attack is characterized clinically by increased wheezing, respiratory rate, and inspiratory–expiratory ratio and the increased use of accessory muscles. Pulse oximetry will reveal decreased oxygen saturation, which can be <70% on room air in severe cases. Spirometry, when available, will reveal a peak expiratory flow rate of 35% to 75% of predicted values.

#### Treatment of Acute Asthma

The initial approach to an acute exacerbation of asthma in children is administration of the beta-2 agonist terbutaline. This can be given either by nebulization (0.5 mL of a 1-mg/mL...
respiratory solution in 2mL of 0.9% saline) or by one puff of a 0.5-mg/dose terbutaline turbohaler.

If symptoms do not resolve, the patient should receive either prednisolone tablets 2mg/kg (maximum dose, 60mg) or a single dose of budesonide turbohaler 1600µg (four puffs of budesonide, 400µg/puff). For those who responded well, steroids should be continued while en route in the AE system, with either prednisolone tablets four times daily (2mg/kg per day) or budesonide turbohaler 200µg. Long-term therapy will be determined by the receiving physician, but may include a maintenance course of corticosteroids for several weeks.

Acute Epiglottitis and Upper-Airway Obstruction

Acute epiglottitis is a potentially fatal cause of airway obstruction in both young children and adults. In recent years, there has been a marked decline in the number of pediatric cases, most likely due to the introduction of efficacious vaccines against H. influenzae type b.

Clinical Presentation

The most common symptoms for children are difficulty breathing, stridor, fever, and sore throat. In contrast, the most common symptoms in adults are sore throat, difficulty swallowing, and difficulty breathing.17

Implications for AE

Children with acute epiglottitis but without respiratory difficulty, stridor, or drooling and who have only mild swelling upon laryngoscopy can often be managed without an artificial airway. The parents should be encouraged to keep the child calm during flight. Sedation that may weaken muscle tone or depress respiratory effort should be avoided. Preparations for in-flight establishment of an emergency airway (emergency intubation or cricothyroidotomy) are mandatory. In “borderline” situations with regard to intubation of patients to be transported, “semielective” intubation prior to transport may be preferred to emergent intubation during transport, where neither radiographs nor auscultation can be used to confirm tube placement. In addition, anesthesia support during transport is in general not available and vibration and vehicle movement complicate the mechanics of any procedure attempted.

An artificial airway will be required in almost 70% of children and more than 20% of adults with acute epiglottitis.17 Those who present with severe respiratory distress or actual airway obstruction will require oropharyngeal intubation or surgical intervention (eg, cricothyrotomy) as part of the initial treatment. A partially open airway can be converted to complete airway obstruction with injudicious maneuvers (eg, foreign bodies, stable epiglottitis).

An artificial airway should be established prior to AE for any patient who has significant interference of airway function, most commonly manifested by respiratory discomfort present even in the upright position, stridor, or drooling. Patients at high risk of airway obstruction are those whose symptoms are of short duration (<24 hours) or rapidly progressing, those with significant enlargement of the epiglottis, and children under 5 years of age. These factors may be suggestive of an influenza infection.

If a patient meeting this criteria does not have an artificial airway established prior to AE, they must be closely observed during flight and monitored by pulse oximetry. Administration of humidified oxygen (2L/minute by nasal prongs) is advisable. If acute respiratory obstruction occurs during flight, facemask ventilation might be attempted prior to intubation. However, a two-handed facemask seal must be made and high enough oxygen flow and pressures used to overcome the resistance of the severely narrowed airway. Adequate ventilation should be determined by adequate chest wall movement and O2 saturation of >90% by pulse oximetry. Placement of an endotracheal tube is often extremely difficult. If intubation is not possible and equipment for surgical cricothyrotomy is not available, a needle cricothyroidotomy may be lifesaving.

Seizure Disorders

A generalized tonic–clonic (grand mal) seizure during flight is a disturbing and potentially
serious occurrence. Any seizure that lasts >10 minutes becomes a life-threatening emergency and should be treated aggressively. Status epilepticus refers to an epileptic seizure lasting >30 minutes or when there is not full recovery of consciousness between seizures.

Seizure etiologies include febrile convulsions (a cause rarely found in adults), acute central nervous system (CNS) injury (eg, trauma, infection, mass/vascular lesion, metabolic disorder, or anticonvulant withdrawal/noncompliance), chronic CNS injury (eg, previous trauma, stroke, infection, encephalopathy), and intoxicant induced (eg, cocaine, tricyclic antidepressants). Many seizures are idiopathic.

**Treatment of Seizures**

In the convulsing patient, initial supportive, therapeutic, and diagnostic measures need to be conducted simultaneously. The goal of anticonvulsant treatment is the rapid termination of clinical and electrical seizure activity by the prompt administration of appropriate drugs in adequate doses. Attention must be given to the possibility of complicating apnea, hypoventilation, and other metabolic abnormalities.

**Assure Adequate Oxygenation**

Hypoxemia can be both the cause and consequence of a seizure. In severe episodes, hypoxemia can lead to bradycardia and hypotension. Initial treatment is airway maintenance by proper positioning of the head and neck and suctioning of the mouth and oropharynx. An oral airway should be inserted if this can be done without trauma to the mouth and teeth. Oxygen should be administered by nasal cannula or ventilation with a bag–valve–mask apparatus. In prolonged seizures, endotracheal intubation should be considered. However, administering an anticonvulant is a top priority because managing the airway and assisting respiration are much easier after the convulsion has stopped.

**Maintain Normal Blood Pressure**

Hypotension can exacerbate any already existing malfunction of cerebral physiology and function. Hypotension can result from three major physiological derangement; diminished cardiac output, poor vascular tone, or low blood volume. In combination or individually, these derangements result in poor delivery of nutrients and oxygen to end-organ systems and the poor removal of the waste products of metabolism. If allowed to persist, a downward cycle of hypoglycemia, hypoxia, acidosis, and hypercarbia can cause serious morbidity or mortality. Systolic blood pressure should be maintained at normal levels. If there is no evidence of shock, intravenous (IV) isotonic fluids should be given at minimal flow rates (2 to 3 ml/kg per hour).

**Maintain Normal Glucose**

Hypoglycemia is a rare cause of prolonged seizures in children. However, all patients should have prompt measurement of blood glucose. If hypoglycemia (blood glucose <40 mg/dL) is documented or if it is impossible to obtain the measurement, IV glucose (5 mL/kg) should be administered as 10% glucose.

**Administer Antiseizure Medications**

The efficacy of diazepam for the treatment of status epilepticus is well recognized, with termination of episodes in 80% of cases. Diazepam, administered either intravenously (0.2 mg/kg) or rectally (0.2 to 0.5 mg/kg), can significantly shorten the duration of status epilepticus and reduce the likelihood of recurrent seizures. Although IV diazepam may be more readily available, the possibility of respiratory depression must be considered and adequate support for breathing must be assured.

If available, rectal diazepam should be used instead because respiratory depression from rectal diazepam is rare among children. This is probably related to the slower rise in serum diazepam concentrations compared with that achieved after IV administration. The clinical effect from rectal diazepam occurs in approximately 5 minutes and peak serum concentrations are achieved 6 to 10 minutes after administration. Even with rectal diazepam, patients with serious comorbidity, those on regular anticonvulsants, or those with chronic CNS abnormalities are at increased risk of respiratory depression and thus should be
treated with a lower rectal dose of diazepam (0.25 mg/kg).

**Diabetes Mellitus**

Diabetes mellitus is one of the most common chronic diseases diagnosed among pediatric populations. The two most significant problems associated with diabetes are hypoglycemia and diabetic ketoacidosis, both of which are potentially severe problems during AE.

**Hypoglycemia**

All possible measures should be taken to avert severe hypoglycemia in diabetic children. These may include regular monitoring of blood glucose, decreasing insulin dosages, altering insulin regimens for patients with prior severe hypoglycemia, or administering slowly released carbohydrate (eg, uncooked cornstarch). Mild to moderate hypoglycemia (blood glucose $<100$ mg/dL) is treated with oral glucose-containing solutions followed by complex carbohydrate. Self-treatment is usually in the form of 4 oz of juice or soft drink followed by a cookie or candy. Blood glucose testing should be repeated within 30 minutes to ensure resolution of hypoglycemia.

Severe hypoglycemia cannot be identified by a fixed blood glucose value but rather by noticing a hypoglycemic child who requires assistance with treatment or who loses consciousness. When the child is unable to take oral glucose-containing solutions, treatment consists of IV glucose (2 cc/kg of a 10% glucose solution bolus followed by IV maintenance with 10% glucose solution) or glucagon (see below). Both of these solutions should be available when moving insulin-dependent diabetics in the AE system.

The Glucagon Emergency Kit (Eli Lilly and Co, Indianapolis, Ind) contains a vial of powdered glucagon (1 mg) together with a syringe prefilled with 1 mL of diluting solution. After reconstitution, children $<20$ kg are given 0.5 cc by subcutaneous (SC), intramuscular (IM), or IV injection. Larger children and adults are given 1 cc. The time of onset of action varies from 1 to 10 minutes and the duration of effect ranges from 9 to 32 minutes, depending on the dose and route of administration. Some authorities advise using 0.5 cc to start, then giving the other 0.5 cc about 20 minutes later if needed.

**Diabetic Ketoacidosis**

Diabetic ketoacidosis (DKA) is the most common cause of hospitalization of children with diabetes and has a fatality rate of 1% to 2%. DKA is preceded by hyperglycemia secondary to insulin deficiency. The resulting decrease in glucose uptake induces hyperketonemia. Both the hyperglycemia and hyperketonemia cause an osmotic diuresis that manifests clinically as dehydration and increased thirst. The dehydration is often worsened by hyperventilation and vomiting that can be either a part of the primary precipitating illness or resulting from the ketosis. Eventually, the hyperosmolality associated with untreated DKA can progress to coma and even death as a result of intracerebral crises.

Diabetic children should be evaluated for ketonuria if they have either persistent hyperglycemia (blood glucose $>240$ mg/dL) or a serious intercurrent illness. The primary goals of treatment are to restore perfusion to reverse the progressive acidosis and stop ketogenesis by normalizing blood glucose concentration with insulin therapy.

For fluid therapy with DKA, it is safe to assume dehydration of approximately 10% for children (100 mL/kg) and 15% for infants (150 mL/kg). Based on this, initial fluid therapy (0.9% NaCl) should be given as 5 to 10 mL/kg over the first hour or less to restore peripheral perfusion. If peripheral perfusion or blood pressure is not restored with the initial 10-cc/kg bolus, further bolus doses should be given until this result is achieved. Maintenance fluid (0.45% NaCl) can be calculated using a standard formula (eg, 1000 mL for the first 10 kg + 500 mL for the next 10 kg + 20 mL/kg for over 20 kg) and administered over the subsequent 22 to 23 hours. Bicarbonate is rarely indicated.

Insulin therapy can be started simultaneously with initial fluid expansion or can be held until the fluid expansion is completed for a more realistic starting glucose level. Ideally, insulin is administered at 0.1 U/kg per hour by continuous-infusion pump. If a pump is unavailable,
an alternative is to administer insulin 0.1 U/kg IV push and 0.1 U/kg IM with subsequent doses of 0.1 U/kg IM or SC hourly.

During initial fluid expansion, elevated blood glucose levels can be expected to drop 10 to 15 mmol/L, even without insulin infusion. Following this, insulin doses should be titrated to result in a drop of blood glucose levels of 3 to 8 mmol/L per hour but not >12 mmol/L per hour. If the blood glucose level falls to 15 mmol/L or >12 mmol/L per hour, 5% to 10% dextrose should be added to the IV fluids. If the blood glucose level falls below 8 mmol/L with 10% dextrose solution running, the insulin dose should be reduced to 0.05 U/kg per hour. The insulin dose should not be reduced below 0.05 U/kg per hour because a continuous supply of insulin is needed to prevent ketosis and permit continued anabolism.

Patient monitoring in a hospital setting is extensive and includes monitoring of electrolytes and indicators of kidney function, together with assessing hydration status. Given the limitations of AE, monitoring during flight should be recorded at 30-minute intervals and include vital signs, Glasgow Coma Scale score (see chapter 14), blood glucose, and urine ketones. In addition, fluid intake and output and insulin administration should be carefully recorded.

Other Pediatric Conditions with AE Implications

Otitis Media and Ear Block

The failure to equilibrate tympanic cavity and atmospheric pressures, usually during descent of an aircraft, can result in aerotitis media (ie, "aviation otitis"). This acute and potentially chronic inflammation of the middle ear is the result of Eustachian tube obstruction and is especially prone to occur in the presence of an upper respiratory tract infection or otitis media. Preschool-aged children appear to be in particular susceptible to ear pain during both ascent and descent phases of air travel.

Certainly, avoiding air travel with acute upper respiratory tract infection or otitis media is ideal. However, air travel may sometimes be required, and these conditions are so common that flying with an undiagnosed otitis media may be unavoidable. Common strategies to prevent or alleviate this condition include chewing, yawning, and swallowing during ascent and especially during descent. Some physicians advocate the administration of oral or nasal decongestants and/or antihistamines prior to take-off because this approach has been found to be effective in adults. For children, administration of oral pseudoephedrine hydrochloride (1 mg/kg, using a 6-mg/mL syrup) 30 to 60 minutes prior to departure may have some benefit in decreasing the incidence of aerotitis media.

Sickle Cell Disease

Sickle cell disease is an inherited blood disorder that affects about 90,000 Americans, mostly African-Americans. It leaves patients vulnerable to repeated crises that can cause severe pain, multisystem organ damage, and early death. Although the life expectancy of patients with the most severe form of the disease is into the mid-40s, many patients become symptomatic as children and almost 15% die before the age of 20.

Sickle cell disease includes several disease states with a varying percentage of sickle cell hemoglobin (HbS), ranging from sickle cell trait (25% to 45% HbS) to sickle cell anemia (100% HbS). Intermediate conditions (in order of increasing severity) include sickle cell hemoglobin C (SC) disease, sickle cell β + thalassaemia, and sickle cell β0 thalassaemia. Intravascular sickling is induced by hypoxia, but the degree of sickling depends on the combination of the concentration of HbS and the degree and duration of hypoxia.

Sickle Cell Pain Crises

Sickle cell pain crises are acute painful episodes that typically last for 5 to 7 days but may last for only minutes or persist for weeks. These crises are usually triggered by a physiological stress, such as acute infection, dehydration, extremely hot or cold temperatures, or hypoxia. The result is deoxygenated HbS, which forms rod-like polymers that change the normally
round and pliable red blood cells into stiff, sickle-shaped cells. These deformed cells cause vaso-occlusion, which results in a cycle of localized tissue hypoxia leading to further sickling and additional vaso-occlusion. The end result may be tissue infarction and necrosis.

The pain of a sickle cell crisis can be localized or diffuse, constant or intermittent. About half of all patients will also have fever, swelling in the joints of the hands or feet, long-bone pain, tachypnea, hypertension, nausea, and vomiting. In the severest forms, organ infarction will manifest. Spleen infarction, usually resulting in severe abdominal pain, has been reported in patients with previously asymptomatic sickle cell trait during unpressurized flight.27 Rib and/or lung infarction results in an acute chest syndrome consisting of chest pain, dyspnea, fever, and leukocytosis. Other severe manifestations include stroke, pulmonary fat embolism, and seizures.26

Implications for AE

Many of the stresses associated with AE (eg, dehydration, extremely hot or cold temperatures, and hypoxia) are known to be triggers for sickle cell crises. For this reason, special efforts should be made to maintain a comfortable cabin temperature with the liberal use of blankets when needed. In addition, all patients with sickle cell disease should be well hydrated, either by frequent drinking or IV fluids. The need for oxygen during flight remains controversial. Hypoxia associated with increased altitude is known to increase the incidence of sickle cell crises.27 Nevertheless, sickle cell crises during air travel in pressurized aircraft are extremely uncommon.28 In general, patients with sickle cell disease can fly on commercial airline flights without supplemental oxygen. However, if a patient is being transported by AE because of a complication associated with their sickle cell disease (ie, pain crisis, stroke, etc), it seems prudent to give supplemental oxygen during flight because of the certain health risks associated with crises.

Treatment of Sickle Cell Pain Crises

If a patient is transported during a sickle cell pain crisis or a crisis occurs in-flight, the treatment is primarily supportive. The patient should be placed on supplemental oxygen to minimize altitude-related hypoxemia. IV hydration with a balanced salt solution will help reverse any degree of dehydration, especially in patients experiencing vomiting or known to have kidney impairment.

Pain control is an important aspect of early treatment. Severe pain should be treated with nonsteroidal anti-inflammatory drugs and IV morphine or hydromorphone. Meperidine can be used short term but should not be continued for long periods of time because its metabolite normeperidine can cause seizures. Pain medications should be titrated aggressively to ensure pain relief.

The patient must be monitored carefully for signs of oversedation, and naloxone should be readily available in the event of respiratory depression. Other common narcotic side effects include constipation, urinary retention, pruritus, nausea, and vomiting. Diphenhydramine can be given for itching and prochlorperazine or other antiemetics may be required to reduce nausea.

Once the acute crisis subsides, oral narcotics (eg, acetaminophen with codeine or hydrocodone) may be used. It is usually a matter of days until patients are switched to nonnarcotic oral analgesics.

Lowering the percentage of HbS in the patient to the 30% to <50% range can prevent further sickling but will not necessarily eliminate symptoms related to sickling that has already occurred. When pain related to sickle cell crisis is prolonged despite the use of the supportive measures mentioned above, transfusions are commonly given. If patients with sickle cell disease and frequent sickle cell crises must be transported, transfusion of packed red blood cells prior to AE is a reasonable precaution.

Neonatal Transport

The transition from fetus to neonate involves a miraculous combination of physiological processes. One of the most challenging is establishing independence from the respiratory, circulatory, and homeostatic functions performed...
by the placenta. As a result, many perturbations can occur in the transition to extrauterine life.

The following section will discuss the timing and special preparations necessary for successful neonatal AE. This will be followed with a discussion of the more common neonatal problems that require transportation and their implications for AE.

Timing for AE
Neonatal transportation is usually carried out on an emergency basis (ie, urgent AE) or performed after the first 12 hours of life (ie, elective AE). The key factor to consider when deciding between urgent and elective AE is the ability of the neonate to effectively breath independently. A delay for up to 12 hours for logistic consideration is safe if the neonate is stable and breathing without difficulty with the administration of 21% to 40% oxygen therapy, as documented by physical examination, radiographic imaging, monitors, and blood studies. In these cases, the timing of transport is based on a thorough analysis of the capabilities of the institution and support staff as determined by the patient’s referring physician.

Another consideration is the gestational age and weight of the neonate at the time of delivery. In addition to neonates with severe respiratory distress syndrome (or other related conditions), extremely low-birthweight infants (<28 weeks’ gestation, <1000 g) should be transported as soon as preflight respiratory and circulatory assessments indicate the neonate is relatively stable. The parents must consent to transfer with a clear understanding of the risks of transport and their child’s prognosis.

Very low-birthweight infants (28 to 31 weeks’ gestation, 1000 to 1500 g) often have a milder forms of respiratory distress syndrome and the associated complications of prematurity, especially if they have received antenatal steroids. They may safely wait for transport for 12 hours or more depending on their degree of illness.

Low-birthweight infants (32 to 36 weeks’ gestation, 1500 to 2500 g) usually have a milder pattern of disease and will on occasion need transport to a higher level of care for prematurity and related conditions. A need for transport is based on the attending physicians’ analysis of the availability of local institution and staff resources to care for this patient.

Preparation for AE
Careful preparation is necessary prior to neonatal AE to minimize the risk of this often hazardous undertaking. A checklist of this somewhat complex process is included below (Table 24.3).

Table 24.3. Premature neonate AE checklist.

<table>
<thead>
<tr>
<th>Baseline vital signs</th>
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<tbody>
<tr>
<td>Vascular access</td>
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<tr>
<td>Umbilical artery and vein</td>
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<tr>
<td>Peripheral veins</td>
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<tr>
<td>Adhesive reinforcement</td>
</tr>
<tr>
<td>Skin protection</td>
</tr>
<tr>
<td>Thermal management</td>
</tr>
<tr>
<td>Incubator prewarmed</td>
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<tr>
<td>Ambient air</td>
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<tr>
<td>Plastic wrap</td>
</tr>
<tr>
<td>Chemical blanket</td>
</tr>
<tr>
<td>Incubator cover</td>
</tr>
<tr>
<td>Preflight imaging</td>
</tr>
<tr>
<td>ET tube placement confirmed</td>
</tr>
<tr>
<td>Central line placement confirmed</td>
</tr>
<tr>
<td>Chest X-ray interpreted</td>
</tr>
<tr>
<td>Chest tube care</td>
</tr>
<tr>
<td>Heimlich valve</td>
</tr>
<tr>
<td>Suction available</td>
</tr>
<tr>
<td>Preflight laboratory</td>
</tr>
<tr>
<td>Arterial blood gas</td>
</tr>
<tr>
<td>Complete blood count</td>
</tr>
<tr>
<td>Anemia therapy when indicated</td>
</tr>
<tr>
<td>Antibiotic therapy when indicated</td>
</tr>
<tr>
<td>Blood glucose normal, dextrose infusion started</td>
</tr>
<tr>
<td>Full monitoring applied with gel electrocardiogram leads</td>
</tr>
<tr>
<td>Orogastric tube</td>
</tr>
<tr>
<td>Sedation adequate</td>
</tr>
<tr>
<td>Urethral catheter considered</td>
</tr>
<tr>
<td>Patient securing straps applied</td>
</tr>
<tr>
<td>Check lines, cables, hoses, and tubing for security and connections</td>
</tr>
<tr>
<td>Hearing protection</td>
</tr>
<tr>
<td>Parental considerations</td>
</tr>
<tr>
<td>Time given for bonding</td>
</tr>
<tr>
<td>Consent signed for transport and procedures</td>
</tr>
<tr>
<td>Crew alert</td>
</tr>
<tr>
<td>Prewarmed cabin</td>
</tr>
<tr>
<td>Altitude limitations</td>
</tr>
<tr>
<td>Nonmedical attendant</td>
</tr>
<tr>
<td>Bring copies of all images and infant’s chart</td>
</tr>
</tbody>
</table>
Data Collection Prior to AE

The collection of pediatric data is similar to adult data with a few exceptions. For neonatal transport, the mother’s history of pregnancy, labor, and delivery becomes important. The neonates’ weight, Apgar scores, and gestational age are additional items. The use of a standardized data collection form for pediatric and neonatology patients is recommended.

Vascular Access

Vascular access with an umbilical venous catheter and umbilical arterial catheter is desirable. An additional peripheral venous catheter will create more therapeutic flexibility and can be used to monitor blood pressure, draw blood samples, and administer fluids and medications. Because heat, vibration, and acceleration–deceleration forces of flight often dislodge adhesives, crews must be ready to reinforce or replace the adhesive on all tubes and lines if they appear unstable.

Thermal Management

Closely controlled thermal management will minimize the potentially severe problems associated with hypothermia. The ambient air should be kept 24°C or greater in both the ground ambulances and aircraft. The incubator temperature should be set at 36°C. A chemical warming blanket and thermal cover to the incubator may help maintain temperature in transport, especially in large aircraft cabins, such as the C-141. Plastic wrap blankets will minimize evaporative heat loss.

Pulmonary Function

Neonates that have minimal respiratory distress syndrome may not require ventilator support. Apnea (central or obstructive) in these infants is a key physical finding. In addition, it may be difficult to intubate a small infant during flight. If there is any doubt as to their respiratory reserve, the neonate should be intubated and placed on a ventilator prior to transport with the plan to wean from ventilator support at the receiving institution.

In most cases, respiratory function should be stable prior to AE. In the rare situation where stability cannot be achieved, it must be clear that the benefits of advanced diagnostics and therapeutics at the receiving hospital outweigh the risks of continued resuscitation during flight. If intratracheal surfactant has been given, the neonate should be observed carefully for the first 2 hours for signs of improving lung function (eg, improved chest expansion, improved oxygen saturation) and consideration given to decreasing ventilator pressures prior to AE. Narcotic and sedative therapy (eg, morphine and midazolam) should be used at doses low enough to avoid respiratory suppression in an effort to promote comfort, control pain, and minimize swings in blood pressure.

If ventilator dependent, an altitude restriction should be required to maintain a cabin altitude <2000 ft or the altitude of the referring or accepting facility if higher. The neonate should be stabilized on the ventilator that is going to be used for transport as far ahead of transport as possible. The ventilator should be connected to hospital medical gases so that the ventilator tank gas can be preserved for transport. An artificial nose should be placed in-line to maximize airway humidification and help prevent thick secretions. The endotracheal (ET) tube should be suctioned with saline immediately before flight, and during a long flight repeat suction will be required. Even a minor pneumothorax should be treated with a chest tube connected to a Heimlich valve prior to AE because trapped pleural air expands at altitude.

A set of arterial blood gases and serum chemistries should be reevaluated as close to the time of transport as feasible, both to help make ventilator adjustments and guide fluid therapy. Ideally, arterial blood gases on the current ventilator settings should reveal pH 7.25, PaCO₂ 40 to 50 mm Hg, and PaO₂ 60 to 90 mm Hg (exception: pulmonary hypertension; see below). The base deficit should be 5 or better.

Psychosocial Considerations

Every effort should be made to establish a warm and cordial professional relationship with the referring staff and family. The parents,
especially the mother, will have bonded to the fetus and will often be anxious about the health challenges to their child. Every effort should be made to safely bring the mother to the baby prior to transport. Ideally, one or both parents should be transported as nonmedical attendants and the family unit transported back to the referring hospital as soon as the need for special care has been eliminated.

Final Preparation for AE

Immediately prior to AE, several details must be accomplished. Upon examining the neonate for the last time in the referring facility, a transport flow sheet should be started. Full electronic monitoring should be instituted (temperature, blood pressure, heart rate, respiratory rate, and oxygen saturation) using gel leads to maintain skin integrity. An orogastric (OG) tube should be placed and secured to minimize the effect of swallowed intestinal air on diaphragmatic movement. The OG tube should remain open to allow for gas expansion at altitude. A chest X-ray should confirm all of the following: an OG tube tip in the stomach, ET tube placement in middle third of the trachea, 8 to 9 rib lung inflation, absence of air-leak syndromes, a normal cardiac silhouette, and appropriate locations of umbilical central lines.

Earplugs or muffs should be placed on the neonate (and any nonmedical and medical attendants) to protect hearing. To limit motion during transport, the neonate must be secured adequately with straps with the ET tube clearly visible.

Specific Conditions

Prematurity

Extreme prematurity (less than 28 weeks) and the associated extremely low birthweight (<1000 g) creates one of the greatest challenges found in AE, as these neonates often have multiple conditions that make their care extremely complex (Table 24.4). The skills and knowledge required for neonatal AE overlap those of other pediatric patients described earlier. Less extreme degrees of prematurity usually have fewer and less severe forms of these related conditions.

<table>
<thead>
<tr>
<th>Table 24.4. Conditions and complications commonly encountered in extremely premature and extremely low-birthweight neonates.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuse vascular access</td>
</tr>
<tr>
<td>Hypothermia</td>
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<tr>
<td>Respiratory distress syndrome</td>
</tr>
<tr>
<td>Air leak syndrome</td>
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<tr>
<td>Apnea</td>
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<tr>
<td>Intraventricular hemorrhage</td>
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<tr>
<td>Hypoxia</td>
</tr>
<tr>
<td>Hypercarbia</td>
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<tr>
<td>Respiratory and metabolic acidosis</td>
</tr>
<tr>
<td>Patent DA</td>
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<tr>
<td>Shock (distributive or cardiogenic)</td>
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<tr>
<td>Disseminated intravascular coagulation</td>
</tr>
<tr>
<td>Bacterial or viral infection</td>
</tr>
<tr>
<td>Hypoglycemia</td>
</tr>
<tr>
<td>Hyponatremia</td>
</tr>
<tr>
<td>Hypocalcemia</td>
</tr>
<tr>
<td>Hyperkalemia</td>
</tr>
<tr>
<td>Immature renal and gastrointestinal function</td>
</tr>
<tr>
<td>Limited skin integrity</td>
</tr>
<tr>
<td>Absence of parental bonding</td>
</tr>
</tbody>
</table>

One problem unique to the premature infant is extremely fragile skin. Above all, the skin must be handled gently. To minimize denuded skin and the associated infectious risks, clear occlusive dressings should be used on the skin before applying adhesive tape or temperature probe covers.

IV Fluid Management

Maintenance fluids (80 to 100 mL/kg per day) are usually given in the form of D_5W for infants weighting <1000 g and D_10W for those weighing >1000 g. The adequacy of fluid replacement can be judged by following the heart rate (target range 120 to 160 bpm), mean blood pressure (target range 25 to 35 cm H_2O), and urine output (target range >1 mL/kg per hour). When necessary, infusion rates can be carefully increased or pressor therapy begun (eg, dopamine drip at 4 to 15 mU/kg per minute or dobutamine drip at 5 to 15 mU/kg per minute). A urethral catheter is rarely necessary because posttransport diaper weights are sufficient to measure urine output.

Metabolic acidosis is common in premature infants. Judicious use of normal saline venous boluses (10 mL/kg, repeated up to two to three times) may correct mild acidosis or flush acid
out of the tissues in severe acidic states. A 5% plasmanate or albumin bolus can be substituted in the presence of hypoalbuminemia. If the pH is below 7.20, sodium bicarbonate can be carefully given by slow IV bolus (4.2%, 2 to 4mL/kg).

Intraventricular hemorrhage may be caused by large fluctuations in arterial blood pressure. For this reason, flushing fluid through the umbilical arterial catheter at more than 1mL/minute must be avoided. Therapeutic interventions (eg, line placement and tracheal suctioning) may initiate or exacerbate intraventricular hemorrhage by temporarily increasing blood pressure, and thus preprocedure sedations should be considered.

Disseminated Intravascular Coagulation

Disseminated intravascular coagulation (DIC) is suggested in a premature neonate by a platelet count <150,000/mm³, a decreasing trend in platelet count, or persistent bleeding from any skin laceration or venous puncture site. If the diagnosis of DIC is made, the neonate should be treated with fresh frozen plasma or platelet transfusion prior to transport, especially with an accelerated drop or an absolute platelet count <50,000/mm³.

Infection

Bacterial infection is a common cause of prematurity. Ampicillin and gentamicin treatment is often begun after blood cultures are taken. Cerebrospinal fluid culture is considered when the patient is physiologically stable. Acyclovir treatment for herpes simplex virus can be started based on history or suspicious physical exam.

Hypoglycemia

Hypoglycemia is one of the most common metabolic problems in premature infants. When low blood glucose levels are prolonged or recurrent, they may result in acute systemic effects and neurological sequelae. For this reason, the management of low blood glucose in the first postnatal days takes on some importance. At birth, the sudden discontinuation of the nutrient and other supplies from the mother requires the neonate to mobilize glucose and fatty acids from glycogen and triglyceride depots to meet the energy demands. Unfortunately, infants born prematurely or following intrauterine stress (eg, malnutrition, maternal diabetes, endogenous fetal hyperinsulinism) may be unable to mount an appropriate and adequate counterregulatory metabolic and endocrine response and thus develop abnormally low plasma glucose concentrations for a prolonged period.

Clinical manifestations of hypoglycemia include tremor, sweating, lethargy, floppiness, coma, and seizures. In some cases, hypoglycemia is asymptomatic. However, it remains uncertain as to whether asymptomatic hypoglycemia actually causes brain damage. Routine measurements of blood glucose concentration should be continued during AE for any infant known to be at risk for hypoglycemia. Glucose monitoring can be initiated as soon as possible after birth, within 2 to 3 hours after birth and before feeding, or at any time there are abnormal signs. If the plasma glucose concentration remains <36mg/dL (2.0mmol/L) or if abnormal clinical signs develop, IV glucose infusion is administered to raise the plasma glucose levels to >45mg/dL (2.5mmol/L).

Respiratory Distress

Increased work breathing and elevated oxygen requirements often result from two conditions: prematurity and meconium aspiration syndrome. Premature infants have a relative surfactant deficiency that often results in diffuse atelectasis and respiratory insufficiency termed respiratory distress syndrome. The frequency and severity of this disorder has been decreased by the use of prenatal steroids and postnatal installation of surfactant. However, the delivery and resuscitation of ever smaller premature infants makes respiratory distress syndrome the most common reason for admission to the neonatal ICU. Similar symptoms of respiratory distress can occur as a result of congenital sepsis, pneumonia, or pulmonary hemorrhage.
Aspiration of meconium prior to and at the time of birth, termed meconium aspiration syndrome, continues to be a common event in both full-term and postterm infants despite the widespread application of aggressive suctioning of the upper airway at the time of delivery. This syndrome is associated with focal areas of atelectasis, air trapping, and persistent pulmonary hypertension of the newborn with right to left shunting through the foramen ovale or ductus arteriosus (DA).

**Implications for AE**

Neonates with respiratory compromise are especially susceptible to the effects of altitude related hypoxia. In all cases, an altitude restriction is required to maximum cabin altitudes <2000 ft. Prior to transport, a ventilator-dependent infant should be assessed for anemia and transfused if necessary with packed red blood cells to maintain the hematocrit above 35%.

A pulse oximeter to measure oxygen saturation and/or a portable laboratory device to measure blood gases should be used to assure that the patient is well oxygenated and adequately ventilated. Endotracheal tube suction should be done on a scheduled basis during transport to clear increased tracheal secretions associated with meconium aspiration syndrome. It is especially important to maximize humidity in the airway through the use of an artificial nose on the endotracheal tube.

The transport team must be prepared to identify and manage in-flight hypoxemia or pneumothorax. If a pneumothorax is suspected, it should be treated with needle decompression and chest tube placement (betadine, 23-gauge butterfly needle, 3-way stopcock, 20-mL syringe, sterile gloves, scalpel, hemostat, and a chest tube).

**Diaphragmatic Hernia**

This congenital defect occurs in 1 of 2200 live births. A diaphragmatic hernia allows abdominal organs to enter the thorax, thus severely affecting lung growth and development. The key physical exam findings include a scaphoid abdomen, severe respiratory distress, shift of the heart sounds to the right, and diminished or absent breath sounds on the left. Bowel sounds may be heard on the left. The result is often a lethal combination of pulmonary hypoplasia and persistent pulmonary hypertension.

If positive pressure ventilation is required, the infant should be intubated as soon as possible because mask ventilation results in air entering the stomach and intestines, further compressing already compromised lungs, especially without a gastric tube. These infants are at high risk of developing pneumothoraces following resuscitative efforts.

**Implications for AE**

An altitude restriction is required to maximum cabin altitudes <2000 ft. It is essential that the gastrointestinal tract remains decompressed and any pneumothorax is treated prior to AE. The impact of altitude-related expansion of gas in the thorax and intestine can be lessened by maintenance of patency and suction of the chest and/or gastric tubes connected to Heimlich valves. Frequent (every 15 minutes) intermittent suction should be used to remove gastric air.

These patients often require ventilator therapy for the pulmonary hypoplasia and pulmonary hypertension. Surfactant therapy may help inflate the stiff hypoplastic lungs, although one half the usual dose per kilogram should be considered because of the diminished lung volume of hypoplastic lungs. Treatment for pulmonary hypertension is discussed below.

Urgent AE is required for these patients when they present with severe respiratory distress in the newborn period. Advanced pediatric surgical skills, inhaled nitric oxide therapy, and ECMO are often required to treat diaphragmatic hernia. Fortunately, many neonates afflicted with diaphragmatic hernia are being identified by antenatal ultrasound. In such cases, the maternal–fetal unit is often transported to a tertiary-care center for delivery.

**Intestinal Obstruction**

Intestinal obstruction can present soon after birth. Some obstructions can lead to severe
morbidity and death while others can be stabilized and transported electively. Proximal intestinal obstructions often present antenatally with polyhydramnios. In such cases, the mother will often be transferred antenatally to a tertiary-care facility to allow advanced care of her newborn immediately following birth.

Intestinal obstruction from a volvulus or congenital obstruction may present in the neonatal period with bilious vomiting. An X-ray of the abdomen may reveal a double-bubble sign, which suggests duodenal obstruction from an atresia or annular pancreas. Intestinal obstruction that presents after birth may result in marked abdominal distension, which will in turn elevate the diaphragm and compromise respiratory function.

Volvulus of the intestines can result in complete occlusion of the superior mesenteric artery. Because occlusion of this vessel can result in the necrosis of all bowel from the distal duodenum to transverse colon, volvulus can lead to a severe form of short-bowel syndrome with disastrous consequences. If volvulus is diagnosed, emergency laparotomy is indicated.

Implications for AE
In the presence of suspected malrotation and/or signs of volvulus with ischemic bowel, urgent AE is indicated because advanced diagnostic studies are mandatory. Operative repair and/or postoperative care will then be utilized as required. In the presence of respiratory compromise, gastric decompression and elective intubation prior to AE should be considered. If there is a distal obstruction without signs of bowel ischemia or respiratory compromise, the infant can be placed on maintenance IV fluids, OG decompression achieved, and transport accomplished electively.

Omphalocele and Gastroschisis
Omphalocele and gastroschisis can be life-threatening if not recognized, stabilized, and treated promptly. Associated defects, including chromosomal disorders and heart disease, occur more commonly with omphalocele. This abdominal wall defect results in exposure of the GI tract to the exterior of the patient. Significant heat and fluid can be lost from the exposed gut by evaporation. Infection can be prevented with the use of sterile surgical-grade gauze, sterile bowel bags, and broad-spectrum antibiotic administration.

The circulation to the intestine should be assessed in a sterile manner. The intestine should be pink with good capillary refill when blanched. Twisting of the superior mesenteric artery or cicatrix of the surrounding abdominal skin may compromise the circulation to the intestine. A compromised intestine may appear dark purple because of venous congestion. If the tight skin opening is causing ischemia, the local surgeon or transport team, in consultation with a pediatric surgeon, may need to widen the opening before transport.

Implications for AE
These infants require urgent AE, and the stabilization and treatment during transport is similar for both conditions. Altitude effects upon gas volumes may compromise circulation to trapped segments. Prior to AE, an OG tube should be placed and open air with intermittent suction utilized to minimize the accumulation of intraluminal air.

These patients require strict attention to both temperature control and cardiovascular support. They should be transported in an incubator that is kept at 36°C. The vehicle cabin should be kept as close as possible to 24°C (80°F).

An umbilical vessel catheter and one or two peripheral IV lines should be established for transport. IV maintenance fluids should be given at 150 mL/kg per day and the infant monitored for skin perfusion and metabolic acido-isis. If capillary refill is longer than 2 seconds, or if arterial blood gases indicate metabolic acidosis, 10-mL/kg boluses of crystalloid solutions should be given and the maintenance fluids increased.

To prevent torsion of the bowel blood supply, the infant should be placed on one side and the bowel supported with a donut-shaped roll of blankets or towels. Using warm, sterile saline maintains good moisture to the sterile surgical gauze covering the mass. Intestinal perfusion should be repeatedly reassessed and the findings documented with each set of vital signs.
Cyanotic Congenital Heart Disease

Cyanotic congenital heart disease (CHD) represents a group of conditions characterized by an alteration in blood flow such that well-oxygenated systemic circulation is contaminated with deoxygenated blood. This commonly occurs in one of three ways:

1. Obstruction of blood flow to the pulmonary circulation (eg, Fallot’s tetralogy and pulmonary or tricuspid atresia). In these conditions, oxygen saturation of the blood in both the systemic and pulmonary circulations is identical.

2. Return of the deoxygenated systemic blood back to the systemic circulation without going through the lungs, resulting in severe oxygen desaturation (ie, transposition of the great vessels). Although this condition allows some increase in oxygen saturation of the blood going out to the body, this type of CHD presents with the most severe cyanosis.

3. Inability of pulmonary venous blood return to the left atrium due to anomalous return of all pulmonary veins to a systemic venous structure such as the superior vena cava (ie, total anomalous pulmonary venous return). As is the case in 1, the oxygen saturation of blood in both the systemic and pulmonary circulations will be identical.

Cyanotic CHD should be suspected whenever a neonate remains cyanotic in the absence of respiratory distress. A neonate with a PaO₂ <200mm Hg while receiving 100% inspired oxygen most likely has cyanotic CHD.

Acute nonsurgical therapy for most forms of cyanotic CHD is dependent upon maintenance of patency of the DA and control of pulmonary blood flow. Prostaglandin E1 (PGE1) is used to maintain ductal patency. Side effects of prostaglandin therapy include apnea, hypoventilation, and hyperthermia.

Proper ventilation technique to control the partial pressure of oxygen and carbon dioxide and ensure optimal acid–base balance is critical. Management of the patient during transport should be discussed in advance with the cardiologist or cardiovascular team to determine the best care plan for each specific cardiac defect. Commonly, prostaglandin therapy and SpO₂ values in the 80s are adequate.

Implications for AE

Neonates with suspected cyanotic CHD should be transported by urgent AE. These patients require an altitude restriction to maximum cabin altitudes <2000ft or the altitude of the referring or accepting facility if higher. Oxygenation that has been maximized at sea level will often deteriorate at altitude. In-flight determination of arterial blood gases with portable laboratory equipment is useful for ensuring adequate acid–base balance in the presence of lower oxygenation. Close observation for apnea is warranted for any infant receiving PGE1. If there is any concern of this, the transport team will often intubate the patient prior to transport.

Hypoplastic Left Heart Syndrome

Hypoplastic left heart syndrome (HLHS) is the most common cause of death from CHD during the first month of life and accounts for 9% of all newborn congenital heart defects. It accounts for more than one third of pediatric cardiology cases transported by some critical-care transport teams.

HLHS is characterized by underdevelopment of the left side of the heart in conjunction with mitral and aortic valve stenosis and narrowing of the ascending aorta. For HLHS to be compatible with life, both a right to left shunt and a left to right shunt must be present. These are usually in the form of ventricular or atrial septal defects, persistently patent foramen ovale, and DA.

Although newborns with HLHS often appear normal at birth, they usually display vague and nonspecific signs and symptoms, including increased respiratory effort and cyanosis when crying. If the foramen ovale or atrial septal defects restrict the delivery of oxygenated blood to the right atrium, the infant will appear cyanotic at birth.

The abrupt closing of the DA is a medical emergency for neonates who depend on it for blood flow to either the body (right to left shunting) or the lungs (left to right shunting).
When the DA closes, cessation of blood flow to the body results in cyanosis, hypoxemia, and profound shock. Congestive heart failure and metabolic acidosis occurs rapidly, with ensuing multiple-organ failure. This condition can be reversed only by quickly reopening the DA.

Management centers on careful control of blood oxygen (PaO₂), carbon dioxide (PaCO₂), and pH. Ideally, the oxygen saturation should remain 60% to 80% and the blood slightly acidic (pH 7.34 to 7.40). HLHS neonates should remain on room air because increased oxygen dilates the pulmonary bed, thus increasing blood flow to the lungs and decreasing blood flow to the body.

These infants should not be hyperventilated because accumulation of CO₂ and acidosis constrict pulmonary blood vessels, thus increasing blood flow to the body. Alternatively, high ventilator rates and large tidal volumes lower PaCO₂, resulting in alkalosis, dilated pulmonary beds, and increased blood flow to the lungs. An ideal PaCO₂ range is 40 to 50 mm Hg, titrated to maintain adequate systemic perfusion.

Infants with HLHS are routinely treated with PGE1 (0.02 to 0.05 μg/kg per minute by IV infusion) to keep the DA patent, reduce pulmonary blood flow, and enhance systemic blood flow and coronary perfusion. PGE1 is titrated to the lowest effective dose to minimize side effects, including apnea, jitteriness, hypoglycemia, hyperthermia, and cutaneous vasodilatation.

**Implications for AE**

Although these neonates do better with relatively low O₂ saturations, an altitude restriction of <2000 ft (or the altitude of the referring or accepting facility, if higher) will greatly simplify the in-flight management of HLHS. Otherwise, the most important aspects of air transport are the standard general principals of neonatal care, including maintenance of normothermia and prevention of hypoglycemia. The neonate should have IV access before transport and an OG or NG tube for stomach decompression. Elective intubation before AE should be considered if the infant appears to be at risk for airway compromise or for apnea related to PGE1 infusion. Neuromuscular blockade with sedation helps minimize the oxygen consump-

**Conclusion**

Effective and safe AE of pediatric and neonatal patients depends on early recognition of serious conditions and stabilization by the referring facility and transport team before and during transport. The referring physician and flight crew should be knowledgeable about the risks of aeromedical transport specific to the patient’s condition and able to anticipate potential transport challenges.

**References**


Military operations generate a significant number of psychiatric casualties, most commonly in the form of combat stress, adjustment disorders, and on occasion more severe psychiatric casualties. While most psychiatric patients can be treated at the locations where their disease begins, some will require aeromedical evacuation (AE) out of the theater of military operations. Military medicine and the associated AE system thus have a significant amount of experience with psychiatric patients. Although the military approach is, by necessity, different than the civilian approach, much that has been learned is applicable to both situations.

By tradition, military members suffering from combat stress have been treated as close “to the front” and unit of assignment as possible. As many as 95% of these patients can be returned to duty after appropriate treatment with basic combat stress control principles, including rest, reassurance, command involvement, and stabilizing medications. Only those few patients with more severe symptoms, such as strong suicidal ideations, mania, or psychosis, absolutely require immediate AE out of the theater.

In modern military operations, the trend has been away from the traditional “treat and return to duty” approach toward an “evacuate and replace” approach for two reasons. Perhaps the most important reason is the fast pace of most modern deployments, where few fixed medical facilities are available and retention of a symptomatic psychiatric patient in-theater represents too much of a liability. A second reason is that many duty stations and ships do not have the medical personnel or facilities to evaluate and treat problematic service members locally. However, with psychiatric patients the doctrine is to treat in-place if at all possible.

The branches of the US military vary in the mental health resources that they station overseas or deploy in the field. The USA places mental health personnel far forward in a Division Mental Health or Combat Stress Control unit. The USN and USAF have fewer assets on-ship or in the field so most symptomatic sailors, marines, and airmen will require AE for appropriate evaluation.

From a military perspective, one of the most important concepts covered in this chapter will be criteria for determining who can be best treated locally and who should be evacuated out of the theater. More universally applicable topics covered include classification and preparation of the psychiatric patient for AE, the use of attendants, medications, and restraints during the flight, and special considerations for AE of children and adolescents.

The Decision to Evacuate

Most patients presenting to a military mental health clinic will suffer from loneliness, inability to fit into their unit, worry about family matters or marital infidelity, or legal charges. Adjustment disorders or occupational problems may manifest as suicide threats or attempts. Finally, some military members are referred for a psychiatric clearance prior to disciplinary action or administrative separation.
How these complaints are handled depends on the situation (Fig 25.1). During a large-scale war, members with mild psychiatric symptoms and complaints are rarely evacuated as this could lead to an epidemic. Similarly, when service members are stationed abroad in a tedious deployment situation great caution must be used before deciding to evacuate a soldier. Many soldiers on remote assignments have to be reminded that, “If the military evacuated everybody who was worried about their family, there would be no one left here.” While this approach may seem callous from a civilian perspective, it has been found to be both effective and necessary in light of the unique circumstances and responsibilities associated with military service.

The principles of combat psychiatry are well described. Treatment of mild psychiatric symptoms, including combat stress, may be summed up in the mnemonic PIES: Proximity, Immediacy, Expectancy, and Simplicity. The patient should be treated in close proximity to the unit. The treatment should be immediate. They should expect to quickly return to duty. Finally, the treatment for most service members should be simple, consisting primarily of counseling, rest, and reassurance, ie, “three hot meals and a cot.” A “B” and “C” can be added to transform the mnemonic to BICEPS for Brevity (the treatment should be brief) and Centrality (the treatment principles should be centralized).

If a patient still needs evacuation after initial treatment according to the above principles, the patient will usually be transported by ground vehicle to the next treatment echelon that has a mental health facility, a small hospital, or a Combat Stress Control restoration unit. The distance they are evacuated is purposely limited both so that they will be able to be returned to duty in an expeditious manner and so that they retain contact with fellow soldiers and their warfighting chain of command. Their

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**Figure 25.1.** Flow chart for treatment and evacuation of psychiatric patients in the military.
continued status as a military member and a member of the unit increases their chance for rapid recovery.

Indications for AE of Military Members

Medical Indications

Not all psychiatric patients can be treated locally and therefore will be in need of AE. The most common medical indication for urgent AE of a psychiatric patient would be the sequela of a serious suicide attempt. Other patients may require AE for purely psychiatric symptoms, including persistent severe depression (especially with suicidal ideation), mania, or overt psychosis. Even patients with less severe psychiatric symptoms may have to be evacuated if their unit has no mental health resources, as often happens aboard a ship or at a small base. An attendant should accompany certain psychiatric patients, and most will require sedation, as described below.

Military Administrative Indications

Military members with psychiatric conditions may be separated from the military for either medical or administrative indications. When the member has a major psychiatric illness, they will usually be transported to a military medical center for thorough evaluation and determination of disposition. If they are stationed overseas, or a long distance from such a facility, AE is usually the transportation of choice.

Administrative separations are used for military members determined to have personality disorders rather than a major mental illness. The mechanisms used for this type of separation from the military are different depending on the branch of service. When members are administratively separated from the USA or USAF, the unit of assignment must complete the necessary paperwork. If the member is stationed overseas, it is usually better for them to separate from the military directly from the unit and then return to the United States on a commercial airline. This is in contrast to the USN, where members stationed on a ship are transported by AE to a US military medical facility for administrative separations because ships have no procedures to administratively separate sailors.

Psychiatric Medications

Medications Prior To and During AE

Psychiatric patients with significant symptoms should be treated medically for a long enough period that their symptoms are controlled prior to AE. This is especially true for patients who are actively psychotic, manic, or seriously suicidal because it is potentially dangerous to put these patients on a long flight. Most psychiatric symptoms, such as agitation, psychosis, and mania, will be adequately controlled after 3 to 5 days of treatment. Depressive symptoms may last much longer but are less of a management problem aboard an aircraft.

Once a patient’s symptoms have decreased enough to make AE safe, they should receive a 7-day supply of medications for the flight, plus extra medications for agitation of sedation in case they are needed. The following is a discussion of some of the most commonly used psychiatric medications used prior to and during AE (Table 25.1).

Agitation

In general, the type of medicine the patient requires will depend on the diagnosis. However, a complete diagnostic work-up may not be possible prior to flight. All severely agitated patients will need to be sedated prior to AE regardless of their diagnoses. The most common medications used for sedation are the benzodiazepines because of their speed of onset and relative lack of side effects. More specific antipsychotic, antimanic, and antidepressant medications are used after the patient has been more completely evaluated.

The most commonly used benzodiazepines are diazepam (Valium), lorazepam (Ativan), and clonazepam (Klonopin). Standard doses and time of administration vary depending on the agent used (Table 25.1). However, doses significantly higher than standard may be required to calm an agitated patient prior to flight. One should begin with the standard dose and repeat in 1 hour if necessary. Benzodiazepines
may be then repeated every 4 to 6 hours, if necessary, but the patient needs to be closely monitored.

**Manic and Psychotic Patients**

Manic and psychotic patients should be stabilized for 3 to 5 days on antipsychotic agents before the flight if at all possible. Some calming effect of these agents is usually evident within 1 or 2 hours, but the antipsychotic properties do not begin to take effect for 24 to 76 hours. It should be kept in mind that most antipsychotic agents work synergistically with the benzodiazepines.

One of the most commonly used antipsychotic agents is still haloperidol (Haldol). Because this drug is associated with a high incidence of extrapyramidal symptoms (EPSs) and dystonias, all patients on haloperidol should simultaneously be given an anticholinergic agent such as benztropine (Cogentin) or diphenhydramine (Benadryl). Some of the newer antipsychotic agents (eg, olanzapine or risperidone) have a significantly decreased risk of dystonias. However, these patients should still be provided with an anticholinergic agent to use, if needed, during an AE flight. The antipsychotic chlorpromazine (Thorazine) should be avoided because of the high incidence of anticholinergic symptoms.

Of the anticholinergic agents, benztropine is more commonly used because it is less sedating than diphenhydramine. The side effects of both, especially at high doses, include dry mouth, constipation, inability to regulate heat, and confusion. All these medications may be given by the oral (PO), intramuscular (IM), or intravenous (IV) route.

**Bipolar Mood Disorders**

Patients with bipolar (ie, manic–depressive) mood disorders are most commonly treated with lithium, carbamazepine (Tegretol), or valproic acid (Depakote), although the latter two have not been approved for this purpose by the FDA. These medications will normally have to

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**Table 25.1. Common psychiatric medications, doses, and side effects.**

<table>
<thead>
<tr>
<th>Medications</th>
<th>Typical dose (mg)</th>
<th>Route</th>
<th>Interval</th>
<th>Side effect</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sedation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diazepam</td>
<td>5–10</td>
<td>PO</td>
<td>Every 4–12 h</td>
<td>Sedation, respiratory depression (rare)</td>
</tr>
<tr>
<td>Lorazepam</td>
<td>1–2</td>
<td>PO, IM, IV</td>
<td>Every 1–4 h</td>
<td>As above</td>
</tr>
<tr>
<td>Clonazepam</td>
<td>0.5–1</td>
<td>PO</td>
<td>Every 8–12 h</td>
<td>As above</td>
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<tr>
<td><strong>Antipsychotic</strong></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Haloperidol</td>
<td>5</td>
<td>PO, IM, IV</td>
<td>Every 4–6 h as needed</td>
<td>Extrapyramidal symptoms, akathisia, dystonias</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Olanzapine</td>
<td>5–20</td>
<td>PO</td>
<td>At bedtime</td>
<td>Sedation, extrapyramidal symptoms (mild)</td>
</tr>
<tr>
<td>Risperidone</td>
<td>2–6</td>
<td>PO</td>
<td>At bedtime</td>
<td>Extrapyramidal symptoms</td>
</tr>
<tr>
<td><strong>Anticholinergic</strong></td>
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<td></td>
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</tr>
<tr>
<td>Benztropine</td>
<td>1–2</td>
<td>PO, IM, IV</td>
<td>1–4 h as needed</td>
<td>Dry mouth, constipation</td>
</tr>
<tr>
<td>Diphenhydramine</td>
<td>25–50</td>
<td>PO, IM, IV</td>
<td>1–4 h as needed</td>
<td>As above</td>
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<tr>
<td><strong>Mood stabilizer</strong></td>
<td></td>
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<tr>
<td>Lithium</td>
<td>300–600</td>
<td>PO</td>
<td>2–3/d</td>
<td>Polyuria, polydipsia, toxic at high doses</td>
</tr>
<tr>
<td>Valproic acid</td>
<td>500–750</td>
<td>PO</td>
<td>2/d</td>
<td>Sedation</td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>200–400</td>
<td>PO</td>
<td>2/d</td>
<td>Ataxia, decreased white blood cell count</td>
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<tr>
<td><strong>Antidepressant</strong></td>
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<td></td>
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<tr>
<td>Fluoxetine</td>
<td>20–40</td>
<td>PO</td>
<td>Once daily</td>
<td>Sedation, nausea</td>
</tr>
<tr>
<td>Sertaline</td>
<td>50–200</td>
<td>PO</td>
<td>Once daily</td>
<td>As above</td>
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<tr>
<td>Paroxetine</td>
<td>20–40</td>
<td>PO</td>
<td>At bedtime</td>
<td>As above</td>
</tr>
<tr>
<td>Bupropion and bupropion SR</td>
<td>100–300</td>
<td>PO</td>
<td>2–3/d</td>
<td>Sedation, dry mouth, constipation</td>
</tr>
<tr>
<td>Nortriptyline</td>
<td>75–150</td>
<td>PO</td>
<td>At bedtime</td>
<td>As above</td>
</tr>
<tr>
<td>Amitriptyline</td>
<td>75–300</td>
<td>PO</td>
<td>At bedtime</td>
<td>As above</td>
</tr>
<tr>
<td>Doxepin</td>
<td>100–300</td>
<td>PO</td>
<td>At bedtime</td>
<td>As above</td>
</tr>
</tbody>
</table>

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be administered for 3 to 7 days before they will achieve a therapeutic effect. Because of their potential toxicity, all three must be monitored by following blood levels. Lithium has an especially narrow therapeutic window, with a therapeutic range between 0.6 and 1.2 mmol/L and toxicity >1.5 mmol/L. If a patient has been started on any of these drugs immediately prior to AE, they should be used only in the lowest effective dose because blood levels will be difficult or impossible to obtain while in transit.

**Depression**

The most commonly prescribed antidepressant medications are the selective serotonic reuptake inhibitors (SSRIs), both because of their relative effectiveness and because of the minimal risk of side effects. SSRIs in common use include sertraline (Zoloft), paroxetine (Paxil), and fluoxetine (Prozac). Bupropion (Wellbutrin or Zyban) is also extensively used. The major drawback of all antidepressants is the 1- to 2-week delay between the start of administration and onset of therapeutic effects. Tricyclic agents are an older class of antidepressants less commonly prescribed because of anticholinergic side effects and the danger of overdose. They include nortriptyline (Pamelor), amitriptyline (Elavil), and doxepin (Sinequan).

**Acute Management of the Violent or Agitated Patient**

On occasion, an apparently stable psychiatric or nonpsychiatric patient may become acutely agitated and possibly violent during AE. These patients can be a risk to the crew, other patients on-board, and the patients themselves. Several medications, both oral and parenteral, are useful to treat these patients acutely even if they are on other psychotropic medications (Table 25.2). The ideal psychotropic for use in such a situation should have a quick calming effect with minimal risk of oversedation. An oversedated patient can have potentially life-threatening respiratory depression or depression of the normal gag reflexes. The most commonly used drugs for acute patient sedation include haloperidol (Haldol), diphenhydramine (Benadryl), and lorazepam (Ativan). These drugs have been chosen because they are often readily available and have a relatively fast onset of action and relatively broad safety margin. The combination of haloperidol, diphenhydramine, and lorazepam may also be mixed in the same syringe.

If the patient agrees, these medications should be given by mouth. If they are uncooperative, they may need to be restrained and the medications given by shot. It is not wise to attempt to restrain an agitated person without sufficient help—at least five people need to form the restraint team, one for each limb and one for the head. Indications for IM medications include severe disruption and danger to self, others, or property (see Table 25.2).

**Preparation for AE**

The first step in the AE of a psychiatric patient is communication and coordination between the referring physician and the accepting physician in a hospital facility. The referring physician should prepare a detailed AE summary, which includes the history of present illness and reason for continued psychiatric treatment. Often, the patient’s mental status when they present to the receiving facility is vastly different from when they initially sought treatment. In many cases, this is related to the therapeutic effects of any psychotrophic drugs they may be taking.

Military members and their dependents may be treated at any military medical facility. However, medical and personnel records are usually best managed by the same branch of the military in which the patient serves. Patients returning from overseas should bring with them any important personnel documents and belongings, as it is unlikely that they will return to their unit. Active-duty members should bring their uniforms as well because most military

**Table 25.2. Medical management of the violent or agitated patient.**

<table>
<thead>
<tr>
<th>Medication</th>
<th>Dose</th>
<th>Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haloperidol</td>
<td>5mg</td>
<td>Oral, IM, IV</td>
</tr>
<tr>
<td>Diphenhydramine</td>
<td>50mg</td>
<td>As above</td>
</tr>
<tr>
<td>Lorazepam</td>
<td>2mg</td>
<td>As above</td>
</tr>
</tbody>
</table>

All three may be repeated in 30min if the patient is not yet sedated.
hospitals require that psychiatric patients wear them.

Both active-duty personnel and dependents should be encouraged to sign a voluntary admission form for the destination medical facility before the AE flight. This will avoid the less than ideal situation in which a patient is transported great distances by AE only to immediately sign out against medical advice. If a dependent declines to sign a voluntary admission form, it may be best to delay AE. If an active-duty member disagrees with the plan for AE and voluntary admission, an involuntary admission can be ordered. This will require a command memorandum that details the need for continued psychiatric evaluation and/or treatment. The guidelines for command-directed mental health evaluations are covered in Mental Health Evaluations of Members of the Armed Forces (DODD 6490.1) and Requirements for Mental Health Evaluations of Members of the Armed Forces (DODI 6490.4).6,7

AE Classification and Attendants for Psychiatric Patients

Psychiatric patients entering the AE system are by tradition classified into three categories based on their special needs and potential to cause problems en route (Table 25.3). Patients with severe psychiatric conditions (1A) are transported by litter in restraints and require an attendant. If changes in their condition warrant, their restraints can be cautiously loosened or removed during flight, but they must remain under close observation with restraints immediately available8,9 (see also the section below on restraints).

The most common category of psychiatric patients transported by AE are of intermediate severity (1B). These patients need some supervision but do not need to be flown in restraints. They can fly in a seated position if they desire but must have both a litter and restraints available. An attendant will accompany them in almost all cases, but the ultimate decision as to the need for an attendant is left to the judgment of the referring physician and flight surgeon clearing the patient for AE. All potentially dangerous objects, including sharp items and lighters, will be removed from psychiatric patients classified as 1A and 1B according to USAF regulations.9

Attendants are an essential part of the AE care for 1A and 1B psychiatric patients, especially if they are dangerous to themselves or others (ie, suicidal, threatening, manic, or psychotic). If possible, the attendant should be of the same sex as the patient to allow close monitoring of bathing and sleeping habits. This is especially critical if they have a history of sexual assault. If an adult family member is available, and their relationship with the patient is healthy, they can accommodate the patient (either active-duty or dependent) as a nonmedical attendant. However, this does not

<table>
<thead>
<tr>
<th>Aeromedical classification</th>
<th>Description</th>
<th>Mode of transport</th>
<th>Sedating medication</th>
<th>Restraint</th>
<th>Attendant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>Severe; dangerous</td>
<td>Litter</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>1B</td>
<td>Intermediate; severity: Potentially dangerous, but not at present disturbed</td>
<td>Litter (may fly seated)</td>
<td>Recommended</td>
<td>Must be available</td>
<td>Optional</td>
</tr>
<tr>
<td>1C</td>
<td>Moderately severe: Cooperative and reliable under observation</td>
<td>Ambulatory</td>
<td>Recommended</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>3C</td>
<td>Patient with drug or alcohol abuse going for treatment</td>
<td>Ambulatory</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>5B</td>
<td>Patient with drug or alcohol abuse going for treatment</td>
<td>Ambulatory</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>5C</td>
<td>Outpatient psychiatric patient going for treatment</td>
<td>Ambulatory</td>
<td>Optional</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
negate the need for a medical attendant for all 1A and most 1B patients.

A potential problem for the attendant occurs when the entire AE process takes several days and involves long stopovers, as is common when patients are transported from overseas back to the United States. To avoid an excessive workload on the attendant, the referring physician or clearing flight surgeon should write orders that direct the patient to be admitted to a local psychiatric hospital when a stopover is expected to last for more than 24 hours.

The potential risks associated with moving 1A and 1B patients by AE should not be underestimated, even in the presence of an attendant. While few patients become disruptive on an aircraft, an uncontrolled psychiatric patient during flight could have a disastrous effect. If the referring physician is uncertain about how stable the patient will remain during AE, it is best to keep the patient at the referring facility until he or she is no longer a threat. Patients should be sent in restraints only when absolutely necessary.

Stable psychiatric patients with moderately severe conditions (1C) are allowed to fly in uniform with no attendant. However, the aero medical crew must be prepared to deal with any patient who becomes disruptive during flight, including medical and surgical patients. In addition, no psychiatric patient (1A, 1B, or 1C) is allowed to sit by an exit door or an oxygen shut-off value.

Recently, three other categories of psychiatric patients have been added to the classification system. Ambulatory patients going for drug, alcohol, or substance abuse treatment are classified as 3C if they are in-patients and 5B if they are outpatients. USAF regulation requires that these patients must have undergone three to five days of detoxification prior to the flight. Other psychiatric outpatients going for treatment or evaluation are in classified as 5C. However, sending a psychiatric patient as an outpatient requires careful coordination with the receiving facility. Arrangements must be made prior to departure regarding where the patient will stay and how the temporary room and board will be funded. Patients in all three of these classifications (3C, 5B, or 5C) are treated the same as 1C patients during the flight except that they may sit by an exit door or oxygen shut-off value.

## Restraints

Only those patients who are a danger to themselves or others and cannot be controlled medically are transported in restraints (Fig 25.2). The restraints most commonly used for AE are still the traditional four-point leather restraints. They include two leather wrist cuffs and two larger ankle cuffs secured to the bed or litter by belts. There is also an optional waist belt. Because these restraints must be locked, the crew should verify prior to flight that they have the correct key to unlock the restraints in the event of an emergency. Hospitals accredited by Joint Commision on Accreditation of Health Care Organizations (JCAHO) are now required to use Velcro nonlocking cuffs. These do not require a key and are more comfortable for the patient.

The written orders for the use of restraints during AE must be detailed, specific, and written by the referring physician prior to flight. The orders must specify the justification for placement, the date and time restraint will be used, the type of restraint, and the positions on the extremities. The orders should also outline other less restrictive means to control the patient, such as medication and family involvement. By regulation, the use of restraints must be time limited and cannot exceed 24 hours. Within those 24 hours, the restraints cannot be used for more than 4 hours for adults, 2 hours for adolescents and children over age 9, or 1 hour for children under age 9. In practice, restraints are rarely used in young children for transoceanic flights.

Restraint orders can authorize a flight nurse to continue restraints for an additional 24 hours at his or her discretion. However, even if no restraint orders have been given, the commanding officer of the aeromedical crew may initiate the use of leather restraints in an emergency. If the commander is a flight nurse, as in most cases, a physician must be contacted for verbal authorization within 1 hour.

The use of restraints have certain risks to the patient. Most will be medicated. Some sedation
Figure 25.2. Four-point restraints (A) are required only for patients who are a danger to themselves or others. Velcro nonlocking cuffs (B) do not require a key and are more comfortable for patients.
(eg, a benzodiazapine) is recommended to minimize the associated discomfort and humilia-
tion. In any case, the patient will need to be carefully monitored by a dedicated attendant
for signs of oversedation, resulting in hypo-
ventilation or aspiration, or for evidence of circulatory problems related to the restraints
themselves. Hydration and elimination needs
must also be met. This intensive monitoring
should be documented on a flow sheet at 15-
minute intervals.

Children and Adolescents

Young children and adolescents are less com-
monly transported by AE for psychiatric indi-
cations than are adults. If AE is required, a
family member should accompany children
when possible. Fortunately, young children are
less likely to become disruptive during flight.
For this reason, consideration should be given
to moving children on faster and more com-
fortable commercial airlines rather than on mil-
itary AE aircraft.

Adolescents have a greater risk of becoming
disruptive during AE or running away (termed “elopement”). If elopement is at all likely, the
military AE system may be preferable to com-
mercial airlines. Essentially the same medic-
tation and restraint protocols as for adults can be
utilized if required. Informed consent should be
obtained from the parents prior to the flight.

Conclusion

The psychiatric patient presents many unique
problems for AE. When possible, the patient
should be treated medically for 3 to 7 days
so psychotic or manic symptoms can be ade-
quately controlled before flight. If urgent AE
of the acutely disturbed psychiatric patient is
required, appropriate amounts of medication
are needed for safe transportation. If traditional
antipsychotic medications are administered,
coadministration of an anticholinergic agent is
recommended. In all cases, adequate medica-
tion for sedation should be available for use
during the flight. An attendant should accom-
pany patients who are seriously depressed or
suicidal or have persistent manic or psychotic
symptoms. Restraints should be used only when
absolutely necessary and be closely monitored
when used.

References

1. US Department of the Army. Combat Stress
Control in a Theater of Operations. Washington,
8-51.
2. Jones FD, Sparacino LR, Wilcox VL, Rothberg
JM, Stokes JW. War psychiatry. In: Zajtchuk R,
Bellamy RF, eds. Textbook of Military Medicine.
Washington, DC: US Department of the Army,
Office of the Surgeon General, and Borden
Institute; 1995:1–33.
3. Artiss KL. Human behavior under stress: From
combat to social psychiatry. Milit Med 1963;
4. US Department of the Army. Standards of
Medical Fitness. Washington, DC: US Govern-
Washington, DC: US Government Printing
Office; 1996. AR 635-200.
6. Department of Defense. Requirements of Mental
Health Evaluations of Members of the Armed
Forces. Washington, DC: US Government Print-
7. Department of Defense. Requirements of Mental
Health Evaluations of Members of the Armed
Forces. Washington, DC: US Government Print-
8. Department of the Air Force. Aeromedical Evac-
uation Worldwide Aeromedical Evacuation.
Washington, DC: US Government Printing
Office; 1975. AFR 164-5.
9. Department of the Air Force. Aeromedical Evac-
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