

Chapter 27

MILITARY MEDICAL EVACUATION

COLIN A. B. McLAREN, QHP, MB, ChB, FC ANAES* ; LOUIS M. GUZZI, M.D.†; AND RONALD F. BELLAMY, M.D.‡

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*Formerly, Air Commodore, Consultant Adviser Anaesthetics, The Royal Air Force (ret); Central Medical Establishment, Kelvin House, Cleveland Street, London, W1P 5FB, England; Currently, Consultant Anaesthetist, 12 Broadacres, Broad Town, Wootton Bassett, Wiltshire, SN4 7RP, England

†Major, Medical Corps, U.S. Army; Chief, Combat Trauma Research, Walter Reed Army Institute of Research, Washington, D. C. 20307-5100

‡Colonel, Medical Corps, U.S. Army; Managing Editor and Officer in Charge, Textbook of Military Medicine, Borden Institute, Walter Reed Army Medical Center, Washington, D. C. 20307-5001

INTRODUCTION

Unless an army is prepared to deploy its major medical assets, including its hospitals, into the middle of a battlefield, it must be capable of carrying out that “undeniable but unavoidable evil of evacuation of the sick and wounded,”¹ in the words of Nikolai I. Pirogov, one of the founders of 19th century military surgery. Pirogov’s use of the word “evil” may seem extreme, but harmful effects can arise during evacuation, especially when it is viewed simply as transportation.

That military medical evacuation is more than transportation is clear from its official definition. According to U.S. Army Field Manual (FM) 8-10-6, *Medical Evacuation in a Theater of Operations*, military medical evacuation includes^{2(p4-1)}:

- collecting the wounded,
- performing triage,
- providing an evacuation mode or transportation,
- providing medical care en route, and
- anticipating complications and being ready to perform emergency medical interventions.

Evacuation is not an end in itself but, at a minimum, is a tool that makes possible more effective treatment. At the same time, by allowing the deployment of the most logistically demanding, immobile, and vulnerable medical assets far to the rear, evacuation simplifies the commander’s combat service support mission. Ideally, treatment is ongoing during evacuation.

Most ancient armies had medical staffs to look after their sick and wounded, but it would seem that their chief responsibility was to attend to the well-being of officers and princes.³ The problems of removing the sick and wounded from the battlefield were probably not viewed as one of the functions of the medical staff but rather as a logistical problem that needed to be solved: the dead and dying on the battlefield interfered with the fighting. Such considerations no doubt motivated the first well-documented instance of evacuation, namely, when Scipio temporarily broke off his ultimately successful attack on Hannibal in the climactic battle of the Second Punic War at Zama in 202 BC:

Implicit in the official definition of medical evacuation is the fact that the act of evacuating casualties covers a wide spectrum of contingencies that range from

- manual evacuation (by two-man carry) of the casualty to a sheltered site 100 m distant, to
- ground ambulance evacuation to a battalion aid station several kilometers distant, to
- helicopter evacuation to a mobile army surgical hospital (MASH) 30 km distant, to
- *intratheater* (ie, tactical) aeromedical evacuation by fixed-wing aircraft to a communication zone hospital 300 km distant, to
- *intertheater* (ie, strategic) aeromedical evacuation by long-range transport to a hospital in the zone of the interior 10,000 km distant.

Not surprisingly, the indications for evacuation, the medical diagnoses of the evacuees, and the differing technical characteristics of the means of evacuation interact to produce a variety of potential medical treatment problems. However, certain basic medical truths predicated on human anatomy and physiology remain constant and cannot be ignored without dire consequences for the casualty. The potential medical “evil” of evacuation, especially that which may arise from the physiological threat of aeromedical evacuation, is the primary subject of this chapter.

HISTORY

The space between the two corps which still remained on the field was by now covered with blood, corpses, and wounded men, and the physical obstacle created by the enemy’s rout presented a difficult problem to the Roman general. Everything combined to make it hard for him to advance without losing formation: the ground slippery with gore, the corpses lying in blood-drenched heaps, and the spaces between encumbered with arms that had been thrown away at random. However, Scipio first arranged for his wounded to be carried to the rear....^{4(p477)}

It is unclear when the rationale for evacuation was first looked on as medical rather than as the

logistical process of “clearing the battlefield.” Certainly by the Napoleonic era, some military surgeons recognized that early evacuation from the battlefield even before the fighting had ended was a necessary prerequisite for effective treatment. Foremost among them was Dominique-Jean Larrey, who was surgeon to Napoleon’s Imperial Guard.

Larrey’s recognition of the need to improve evacuation preceded any of Napoleon’s battles, and he presented his conclusions regarding evacuation at a conference held on 17 November 1789. This conference was convened in Paris by the National Convention of the Revolution to study Larrey’s report describing the medical treatment of French troops fighting in the battles of Limbourg and Speyer.⁵ At this time, the treatment, or lack of it, depended on the result of the battle: success meant that the casualty would receive some sort of treatment, albeit 48 hours after wounding, whereas defeat meant no care and almost certain death.

Larrey pursued his ideas despite his initial lack of success. He developed the use of horse-drawn vehicles to evacuate the sick and wounded from the battlefield via the *ambulance volante* (ie, flying ambulance), which was first used in 1797 on the battlefield of Konigstein, in the Taunus mountains of the Rhineland Palatinate. Although Larrey’s flying ambulances were available in only a tiny part of Napoleon’s army, their ability to provide rapid and humane evacuation was widely recognized. James McGrigor, Wellington’s outstanding chief medical officer in the Peninsular campaign, in attempting to justify the acquisition of similar vehicles, wrote the following classic description of evacuation gone wrong:

The suffering of the sick and wounded was very great.... They suffered so much by the transport [ie, slow, clumsy ox-carts—*RFB*], the weather, and the privation...that...many of the wounded and those ill of dysentery arrived in so bad a state as only to survive a few days....^{6(p121)}

Other modes of transportation were adopted for the evacuation of casualties during the 19th century. Florence Nightingale was instrumental in organizing hospital ships to evacuate the sick and wounded during the Crimean War. (The first reports of the use of ships for the transfer of the wounded had occurred during the Eighth Crusade, when galleys were used to move them to Damietta.³) At the same time, the rapid growth of railways as the principal mode of transportation offered an

alternative. Given the appalling state of the roads in any battle area and the congestion of vehicles traveling to the battle area (causing delays with the ambulances traveling in the opposite direction), and the ever-increasing size and complexity of the rail networks, it is not surprising that several countries investigated the possibility of using the railway systems to permit rapid evacuation of large numbers of sick and wounded in warmth, light, and relative comfort, where they could continue receiving medical and nursing care.

The first examples of medical evacuation by rail occurred in 1859, during the Italian War, when large numbers of French casualties were moved via railway. The seriously wounded were transported in baggage cars, the less seriously wounded in passenger cars.³ During the American Civil War, many attempts were made to organize a satisfactory evacuation service using railway trains. After many experiments, the Union Army developed a well-organized ambulance train service, which, as well as carrying the sick and wounded, had facilities to maintain treatment and provide catering during the journey. In some of the campaigns, the distance from the front line to the base hospitals was several hundred miles. In 1864, the Army of the Cumberland River made use of three trains per day to transfer the sick and wounded back to Louisville, Kentucky. The Confederate forces were not so lucky: only irregular service was available, with none of the amenities available to the Union forces.³

Owing to the leadership of Jonathan Letterman, the chief medical officer of the Army of the Potomac, by the end of the American Civil War military medical evacuation was seen as a systematic process to be carried out by a dedicated corps of specialists under the command and control of the medical department. Letterman’s influence was such that he was able to get the U.S. Congress to enact a law codifying the organization and function of ambulance corps and ambulance trains.⁷ Many of the subsequent developments in military medical evacuation revolved around the technical characteristics of the evacuation vehicles, but the correctness of Letterman’s doctrinal and organizational innovations is still considered beyond dispute.

By the second half of the 20th century, aircraft had become the preferred evacuation vehicle in western armies, but use and acceptance came slowly. The first aircraft did not fly until 1903; however, the future use of rapid air transport of the sick and wounded had already been conceived by imaginative minds:

- Jules Verne, in his book *Robert le Conquerant*, published in 1854, described the use of an airship to rescue injured and shipwrecked seamen.⁸
- War historians have described the use of hot-air balloons to evacuate the sick and wounded during the siege of Paris during the Franco-Prussian War (1870–1871); unfortunately, however, this romantic description cannot be supported by fact.⁹
- In the last decade of the 19th century, the Dutch Surgeon General de Mooy described and illustrated his concepts of air evacuation (Figure 27-1).

Only 7 years after the Wright brothers' first flight, two U.S. Army officers had developed an airplane for the transport of casualties but the venture did not receive War Department backing. A second attempt to obtain U.S. Army funding for the construction of an airplane to transport the severely wounded was made during a conference in Baltimore, Maryland, only to be followed by an editorial in the following day's *Baltimore Sun* (23 October 1912) that stated: "Surely the hazard of being severely wounded was sufficient without the additional hazard of transportation by airplane."¹⁰ A similar fate followed the first demonstration flight in the United Kingdom, which took place in 1913 and lasted exactly 45 seconds. The surrogate patient's shouts of fear as he slid gently across the wing toward the pusher propeller caused a rapid landing and a complete lack of interest by the army general staff who were present.¹¹

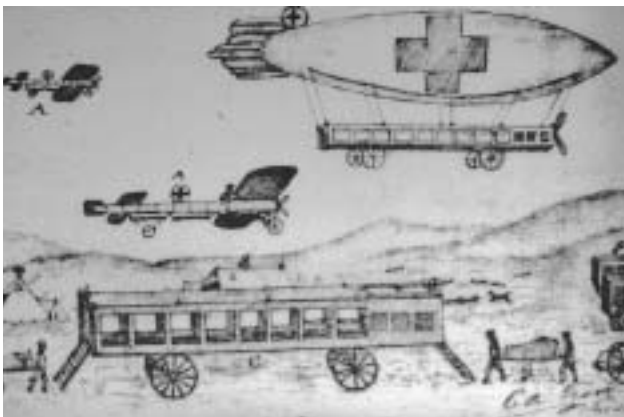


Fig. 27-1. Aeromedical evacuation as envisioned by Dutch Surgeon General de Mooy during the late 19th century. Photograph: Reprinted from Vincent A. *Le transport des blessés par avion*. *Rev Int Croix Rouge*. 1924;6:720–723.



Fig. 27-2. Rarely, aircraft were used to evacuate casualties during World War I. Reprinted with permission from Andrews DR. *Helicopter ambulances in critical care*. *J R Army Med Corps*. 1994;140:22.

Aircraft were used to evacuate casualties during World War I (Figure 27-2), but the first use of an airplane specifically modified for casualty evacuation appears to have occurred in 1920 during a British expedition to what is now Somalia.¹² The mass transportation of sick and wounded by air first occurred during the Spanish Civil War (1936) and was carried out by the newly formed German Luftwaffe. The Condor Squadrons, flying unheated and unpressurized Junkers JU 52s, transported sick and wounded back to Germany in a few hours rather than the days that would have been required for road, rail, and sea transport.¹³ The resulting improvement in the morale of the sick and wounded were exactly the same as Larrey had described 140 years earlier.¹⁴ The full development of German aeromedical evacuation occurred during the early years of World War II and especially during the Russo-German campaign, where the great distances made evacuation by air especially desirable (Figure 27-3).

During the fall of 1942, far-sighted U.S. military medical authorities, in recognition of the value of aeromedical evacuation, established three patient categories that would justify trans-Atlantic evacuation to the continental United States (CONUS): (1) emergency cases for whom essential treatment was not locally available, (2) casualties whose air evacuation the chief surgeon deemed a military necessity, and (3) casualties who required prolonged hospital and convalescent care. Nevertheless, by the end of 1943, only 116 patients had been evacuated by air from the European Theater of Operations. By the last year of the European war, from 2,000 to 4,000 casualties per month were being evacuated to CONUS by air. This number, although large, needs to



Fig. 27-3. A German aeromedical staging base in the southern portion of the eastern front during 1943. The JU 52s shown here could carry up to 12 litter casualties; their short takeoff and landing capability were impressive (the minimum runway length was about 400 m). The relatively idyllic circumstance shown here was exceptional. More representative of German aeromedical evacuation was the situation at Stalingrad during the great battle in 1942–1943, in which 25,000 German casualties were evacuated under appalling weather conditions and in the face of overwhelming Soviet military strength. Reprinted with permission from Carell P. *Der Russlandkrieg: Fotografiert von Soldaten* [in German]. Frankfurt, Germany: Verlag Ullstein GmbH; 1967: 320–321.

be put in perspective; casualties returned by air constituted only about 10% of the total number of evacuees from Europe. The great majority were sent home by ship.¹⁵

Because of its success in World War II and rapid developments in aviation technology, aeromedical evacuation from the hospital level soon came to dominate all other forms of military medical evacuation. The Secretary of Defense directed in September 1949 that all evacuation of sick and wounded, both in peace and in war, shall be accomplished by air whenever aircraft are available and proper medical treatment can be provided to the patient en route.¹⁶ The rationale for this policy, which remains in effect, is stated in Table 27-1.

The various modes of transportation that are used in military medical evacuation should not be thought of as mutually exclusive. In fact, more than one type of evacuation vehicle is commonly needed. The complexity and interrelation of evacuation assets was nowhere more obvious than in the European Theater of Operations at the end of World War II, in which evacuation was carried out every using almost every type of land, sea, and air vehicle (Figure 27-4). Although the U.S. Army's experience since World War II has emphasized evacuation by air at all echelons, the number of casualties generated in a high-intensity war and the

conditions present in such a war may allow only for ground evacuation. For example, medical planning for a war between North Atlantic Treaty Organization (NATO) and Warsaw Pact countries envisioned the extensive use of hospital trains in addition to tactical medical evacuation flights from the corps communication zone. Military anesthesia providers need to maintain a broad perspective when thinking about medical evacuation if for no other reason than to ensure that the system is resilient.

Although air transportation has become the dominant mode of evacuation, its utility is based on a frequently unrecognized assumption; namely, that a forward air base would always be available for use as an evacuation and holding center. The British experience in the Falklands War in 1982 showed that this is not always true. No forward air base was available initially, which made it impossible to fly treated casualties out of the combat zone. This would have been difficult even if an airfield had been available because the distance between the Falkland Islands and the nearest British air base, on Ascension Island, is 4,000 miles (6,400 km). The solution to the problem was to evacuate casualties by helicopter to a hospital ship, which then sailed to neutral territory (Uruguay), from where the casualties were evacuated by air.¹⁷

TABLE 27-1
ADVANTAGES OF AEROMEDICAL MEDICAL EVACUATION

Advantage	Rationale
Speed	The “Golden Hour” of resuscitation can be better utilized by rapid and safe air transport of the casualty. The value of rapid evacuation to a Level-1 trauma center has been well-demonstrated in civilian medicine.
Range	Transport of casualties over long distances in a relatively short period of time allows fewer tertiary centers to support several units.
Trafficability	Rotor-wing aircraft can pick up patients in relatively inaccessible areas and transport them quickly and safely. The minimal landing requirements provide this feature.
Flexibility	A casualty can be airlifted quickly to that medical installation where appropriate specialized care may be available, thereby bypassing unnecessary delays.
Comfort and Morale	Because of the speed and comfort of flight, the soldier knows that if injured, he can be transported to the appropriate medical treatment facility quickly and in stable condition.
Economy of Resources	Because one large hospital is able to accommodate several battle areas, fewer facilities need to be set up.

The hospital ship was obtained by converting the cruise liner *SS Uganda*, the conversion being carried out in only 4 days. The vessel, which was equipped with a helicopter landing pad, full hospital facilities, and an intensive care unit, was only 15 minutes’ flying time from the land battles. International Red Cross regulations required that once on board the hospital ship, all casualties had to be evacuated from the war zone. Their repatriation required the good offices of the Uruguayan authorities, who permitted their transfer by sea (in small survey vessels), over 1,500 km from the Falkland Islands to Montevideo, for onward air transportation to the United Kingdom. Five hundred eighty casualties were evacuated by this route.¹⁷ The experience of the *SS Uganda* constitutes one of the few recent instances in which a hospital ship has been used as a evacuation vehicle in addition to functioning as a hospital. Much more common is the use of hospital ships as deployable hospitals.

The British experience in the Falkland Islands has led to a reevaluation of the role of hospital ships in any future conflict, resulting in the U.S. Navy’s converting two supertankers into the hospital ships *Comfort* and *Mercy*, two 1,000-bed hospitals with full facilities. However, few countries can afford the luxury of maintaining permanent, fully equipped hospital ships. A less expensive system has been developed, whereby hospital facilities such as wards,

operating theaters, radiographic units, laboratories, and intensive care facilities have been modularized, based on the International Standards Organization’s (ISO’s) standard container. The number of units can be varied as required and rapidly installed in any suitable ship.

The ships must have unobstructed deck space, such as is usually found on fleet auxiliaries, tank-landing ships, or roll on–roll off merchant ferries. The great advantage of the modular system is that the vessel can carry out its ordinary task until it is required for medical duties. The benefits offered by the Rapid Deployment Hospital Ship program are low cost, a dual role for the ship, extremely rapid conversion into the war role, a controlled hospital environment, and the possibility that any of the modules can be transferred to land, if required. This excellent, low-cost facility was used when a British Naval Auxiliary vessel was converted into a 100-bed facility in a short time and sailed to the Persian Gulf during the hostilities there (1990–1991).

In describing the evolution of military medical evacuation in the 20th century, evacuation from forward hospitals to hospitals in the communication zone or CONUS has been emphasized almost exclusively. However, regardless of how successfully this link in the evacuation chain functions, it remains totally dependent on the casualty’s first having been evacuated from the battlefield. Even

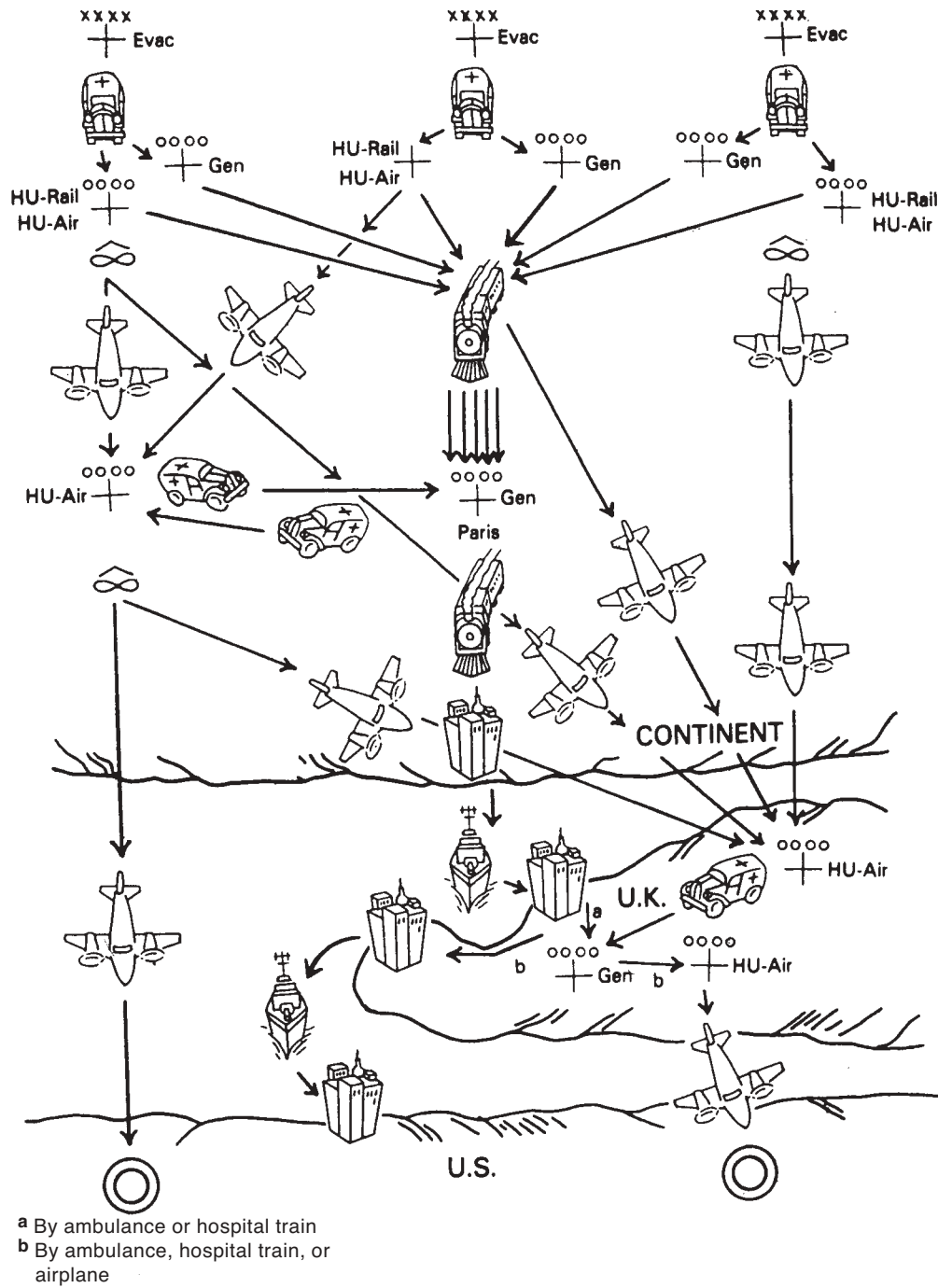


Fig. 27-4. This cartoon shows how evacuation was carried out in and from the European Theater of Operations in World War II. The built-in redundancy allowed for maintenance of the casualty flow even if the activity of one form of evacuation was impaired (eg, when aeromedical evacuation was hindered by bad weather). It is important to recognize that evacuation in and from the theater of operations depends totally on the casualty's arriving at this echelon after successful evacuation from the unit, division, and corps levels. The symbols indicate army-level, general, and evacuation hospitals. HU: holding units. Reprinted from Cosmas GA, Cowdrey AE. *Medical Service in the European Theater of Operations*. Washington DC: Center of Military History, US Army; 1992: 335.

with the field ambulances of Larrey and Letterman, the casualty would first have to be taken to a collection point from where he could be removed from the battlefield. Extracting casualties from the battlefield, frequently while under enemy fire—the most difficult, arduous, and dangerous segment of the evacuation chain—remained the province of medics, litter bearers, and nonmedical soldiers, who all depended on human muscle power to move the casualty. The advent of mechanized warfare in World War II made possible an alternative approach, namely, the use of equipment: first, armored fighting vehicles; and second, small, fixed-wing aircraft and helicopters. The latter had a revolutionary effect on evacuation because it made possible the speedy transportation of casualties directly from the scene of wounding on the battlefield to a surgical hospital.

Helicopter evacuation from the battlefield first occurred in 1944 in Burma, but first assumed prominence in the Korean War, during which approximately 17,700 casualties were evacuated from the battlefield to hospitals.¹⁸ Although more than 300,000 casualties were evacuated from Korea to Japan during the Korean War, the true value of air evacuation was in the timely pick-up and transport of the soldier from the point of wounding to the point where he was seen by a medical officer. It was widely recognized by medical authorities, both military and civilian, that timely evacuation, together with the use of whole blood and antibiotics, were the three factors responsible for the low mortality during the Korean War.

During the Vietnam War, between 850,000 and 900,000 allied military personnel and Vietnamese civilians underwent aeromedical evacuation. At least 90% of all hospitalized U.S. Army battle casu-

alties were evacuated by helicopter at one time or other during their treatment.¹⁸ There can be no doubt that the helicopter, by making unnecessary many long and difficult litter carries as well as uncomfortable trips in ground ambulances, made life much more tolerable for both casualties and medics (Figure 27-5).

Nevertheless, helicopter evacuation of casualties directly from the battlefield was not without drawbacks. For example, when compared with fixed-wing aircraft, helicopters have limited operational ranges. On an extensive battlefield such as characterized the Persian Gulf War, direct helicopter evacuation from the site of injury to the hospital level is usually impractical. In addition, darkness and weather conditions at times interfere with aeromedical evacuation. More importantly, helicopter evacuation from the battlefield can be very dangerous. It has been estimated that one third of all air ambulance pilots in the Vietnam War sustained either battle or nonbattle injuries, and medical evacuation helicopters sustained more than three times more battle damage than helicopters used in combat and combat support missions.¹⁸ Although regulations initially precluded making casualty pickups from landing zones that were subject to enemy fire, this became commonplace in both the Korean and Vietnam wars. The heroism of helicopter crews made possible the evacuation of casualties that in many instances, in retrospect, seems impossible.

Even so, helicopter evacuation from the high-intensity battlefield is probably suicidal. In fact, U.S. Army regulations do not foresee casualty extraction by helicopter occurring forward of the battalion aid station when enemy air-defense artillery capabilities are substantial; thus, the need for evacuation vehicles capable of functioning far forward



Fig. 27-5. A scene from the Somalia peacekeeping operation. A casualty is being removed from a UH-1 medical evacuation helicopter while a UH-60 hovers in the background. The latter is now the US Army's primary air ambulance, replacing the former, which has served with distinction since its introduction in 1959. The UH-60 has greater range and speed, and superior avionics compared with the UH-1 but, surprisingly, can carry no more casualties. Photograph: Public Affairs, Office of The Surgeon General, US Army.



Fig. 27-6. Evacuation during an armored battle fought in central Russia during summer, 1943. The armored unit's medical officer rode into battle in the tank shown on the left and was accompanied by an armored personnel carrier, which was used to evacuate the casualty. First aid and preparation of the casualty for evacuation took place in the open. Although the casualty was protected from small-arms fire and fragments from shells during evacuation, the small internal volume of the armored personnel carrier precluded effective ongoing care. Furthermore, the separation of the physician and the casualty during evacuation no doubt resulted in increased mortality and morbidity. Reprinted with permission from Pielkalkiewicz J. *Unternehmen Zitadelle* [in German]. Bergisch Gladbach, Germany: Gustaf Lübke Verlag GmbH; 1983.

under enemy fire.^{2(p4-12)} The precedent for the use of armored fighting vehicles for this purpose dates from early in World War II, when German armored formations used half-track vehicles for casualty evacuation (Figure 27-6). More recently, many other armies have used armored personnel carriers for

evacuating casualties under enemy fire. The Israelis have even used their main battle tank—the Merkava—for this purpose. The Merkava's engine is in the front, which leaves a space in the rear—accessed by an armored door—that can be used for carrying several casualties.

LOGISTICAL AND OPERATIONAL ASPECTS

The schematic diagram that is part of the front matter of this book shows the organization for evacuation as it existed in the U.S. Army at the time of publication. For purposes of this chapter, the system used to evacuate sick and wounded soldiers will be studied in three segments: (1) the unit (ie, the medical platoon) and the division level, (ie, the medical company or medical battalion, which usually have no surgical capabilities); (2) the corps level and the communication zone, which contain the deployable hospitals; and (3) the domestic system, which is operated by the U.S. Air Force.

Unit and Division Levels

Evacuation at the unit level can be by ground or by air. The type of vehicle used depends on the warfighting scenario. In a high-intensity war, it is likely that 90% of casualty evacuation will be by

ground, with the remaining 10% by air (—RFB, personal observation, 1994). In a low-intensity war, most evacuation can be expected to be by air. Evacuation at the unit level is regulated by the battalion surgeon or the medical company commander; at the division level, by the division medical operations center.^{2(p4-2)}

Ground Evacuation

As previously indicated, aerial transport may not be feasible because of enemy action. Furthermore, bad weather, darkness, and distance may preclude aeromedical evacuation. Ground ambulances may be used at these times. These ambulances, which are *organic* (ie, intrinsic; included in the Table of Organization and Equipment) to the U.S. Army Medical Department units that are responsible for transporting the sick and wounded,

have the basic supplies and are staffed with ambulance personnel qualified in basic emergency medical care and treatment procedures. An ambulance crew consists of a driver and an additional soldier, both of whom are medical aidmen. Current ground ambulances include the following vehicles^{2(pp10-1-10-16)}:

- M1010 truck ambulance, 1¼ ton 4 x 4. This truck is designed to transport the sick and wounded and is the standard field ambulance of medical units at the division and higher-level units where suitable roads exist. The patient compartment is separated from the remainder of the vehicle and has a heater and a surgical light. The capacity is 4 litter patients, or 8 to 10 ambulatory patients, or a combination of litter and ambulatory patients (eg, 2 litter and 5 ambulatory patients).
- High-mobility, multipurpose, wheeled vehicle (HMMWV, M996 and M997) truck ambulance, 4 x 4, armored tactical vehicles. The HMMWV is designed to be used cross-country and over all types of terrain. Depending on the configuration, the vehicle can carry 2 to 4 litter patients, or 6 to 8 ambulatory casualties, or a mixture of litter and ambulatory casualties. These vehicles can be modified for operation in a nuclear, biological, or chemical warfare environment.
- M113 carrier, personnel, full-tracked, armored. The M113 can carry up to 10 ambulatory or 4 litter patients.

The M792 (Gamma Goat), M170, and M718 evacuation vehicles are being phased out of the U.S. Army's inventory. Any military vehicle may be adapted for carrying patients as the situation allows, but safety and stability during transport are important priorities that need to be satisfied by any putative ambulance.

Air Evacuation

An assigned mission of the U.S. Army is to provide air transportation for the sick and wounded within the combat zone. The major objective of air transportation is the expedient delivery of the casualty to the care level necessary for survival. The flexibility and rapid deployment of air services make this an optimal method of delivery. Air transport involves the use of either fixed- or rotor-wing aircraft.

Organization of U.S. Army Air Evacuation

A soldier injured in a forward area may initially receive first aid from an aidman. Then the soldier may be transported by ground to the battalion aid station, where the injury is reassessed; if evacuation is necessary, it is the U.S. Army's responsibility to provide appropriate ground or air evacuation. The latter is usually provided by the medical air ambulance company. The medical company's air ambulance is normally assigned to the corps medical brigade and is attached to the medical evacuation battalion for command and control.^{2(p3-7)}

The capabilities of the medical air ambulance company include

- aeromedical evacuation of critically wounded or other patients;
- extrication and then air evacuation of personnel from crashed aircraft;
- emergency aid at air-crash sites, in-flight medical treatment, and surveillance of patients en route to treatment facilities;
- expeditious delivery of medical personnel and material to meet emergency treatment requirements within a combat zone; and
- in-flight emergency medical care.

The core of the air ambulance company is its air ambulance platoon. Military physicians need to be aware of the composition and skill level of this platoon. Each consists of a platoon leader, two section leaders, nine evacuation pilots, one platoon sergeant, six air ambulance aidmen, six crew chiefs, and one voice-radio operator. Each platoon is authorized six UH-60A helicopters. Each helicopter has an assigned crew consisting of a crew chief, two pilots, and an air ambulance aidman. All are proficient in emergency medical treatment. Although each air ambulance has a capacity for six litter patients or nine ambulatory patients (the UH-1), or four litter and seven ambulatory patients (the UH-60A), the combat load for each is three litter and four ambulatory patients.^{2(p10-27)}

The situation may occur when nonmedical aircraft such as the U.S. Army's CH-47 Chinook will be used for evacuation at the division level. This helicopter can carry up to 24 litter patients.

Only approved and tested equipment may be taken aboard aircraft, and each type of aircraft has its own list of approved equipment. Medical personnel should consult with the crew chief or senior medic of the particular aeromedical evacuation

ambulance to ascertain what equipment is presently available and approved.

Air Ambulance Operations

Air ambulances are used as far forward as possible and as the numbers of combat casualties allow. Ambulances should be used only if the landing zone is both free of hostile fire and secure. If it is not, the pilot must be notified. The base of operations must be located and operated so that it can respond as quickly as possible when there are casualties on the battlefield. In the absence of clear guidelines as to the casualty's destination, the pilot is the final authority.

All medical officers of deployable units should know how to arrange aeromedical evacuation. FM 8-10-6 should be consulted for a detailed description of the official procedure; a brief overview follows. Requests for air ambulance evacuation must contain concise, accurate, and reliable information so that appropriate equipment can be provided and flights planned. The commander of the air ambulance team supporting the division decides whether to accept the mission, based on meteorological conditions or the availability of aircraft. All U.S. Army aeromedical evacuation requests should provide information in the sequence provided in FM 8-10-6 (Exhibit 27-1).

Assignment of Medical Evacuation Priority

FM 8-10-6 specifies the following categories of precedence and the criteria used for their assignment:

Priority I—URGENT is assigned to emergency cases that should be evacuated as soon as possible and within a maximum of 2 hours to save life, limb, or eyesight; to prevent complications of serious illness; or to avoid permanent disability.

Priority IA—URGENT-SURG is assigned to patients who must receive surgical intervention far forward to save life and stabilize for further evacuation.

Priority II—PRIORITY is assigned to sick and wounded personnel requiring prompt medical care. This precedence is used when (a) the individual should be evacuated within 4 hours or his medical condition could deteriorate to such a degree that he will become an URGENT precedence, or (b) requirements for special treatment are not available locally, or (c) will suffer unnecessary pain or disability.

Priority III—ROUTINE is assigned to sick and wounded personnel requiring evacuation but whose condition is not expected to deteriorate signifi-

EXHIBIT 27-1

SEQUENCE OF INFORMATION REQUIRED IN U.S. ARMY AERO- MEDICAL EVACUATION REQUESTS

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- LINE 1: Location of pick-up site
 LINE 2: Radio frequency, call sign and suffix
 LINE 3: Number of patients by precedence, as described in FM 8-10-6 (p7-1)
 LINE 4: Special equipment required (eg, ventilator)
 LINE 5: Number of patients and type of injury
 LINE 6: Security of pick-up site
 LINE 7: Method of marking pick-up site
 LINE 8: Patient nationality and status
 LINE 9: Nuclear, biological, and chemical contamination
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Adapted from Department of the Army. Field Manual 8-10-6. *Medical Evacuation in a Theater of Operations*. Washington DC: Headquarters, DA; 31 October 1991: pp 7-3–7-5.

cantly. The sick and wounded in this category should be evacuated within 24 hours.

Priority IV—CONVENIENCE is assigned to patients for whom aeromedical evacuation is a matter of medical convenience rather than necessity.^{2(p7-1)}

Civilian Approaches to the Assignment of Evacuation Priority

The assignment of evacuation priorities according to FM 8-10-6 is, by its very nature, subjective. In an effort to bring objectivity to the determination of the need for helicopter evacuation to a trauma center, civilian emergency medical systems have adopted the use of triage scoring systems. The civilian approach needs to be understood by military anesthesiologists because a modification may be applicable to military medical evacuation:

- The Trauma Score (Exhibit 27-2) is a composite that includes measures of the status of the cardiovascular, respiratory, and central nervous systems. (It incorporates the

EXHIBIT 27-2

TRAUMA SCORE USED IN CIVILIAN EVACUATION

Trauma Score Component	Value	Points	Score
A. Respiratory Rate			
Number of respirations in 15 s, multiplied by 4	10–24	4	A. _____
	25–35	3	
	> 35	2	
	< 10	1	
	0	0	
B. Respiratory Effort			
Normal	Normal	1	B. _____
Shallow—markedly decreased chest movement or air exchange	Shallow	0	
Retractive—use of accessory muscles or intercostal retraction	Retractive	0	
C. Systolic Blood Pressure			
Systolic cuff pressure, either arm, auscultate or palpate	> 90	4	C. _____
	70–90	3	
	50–69	2	
	< 50	1	
No carotid pulse	0	0	
D. Capillary Refill			
Normal—forehead, lip mucosa, or nail-bed color refills in 2 s	Normal	2	D. _____
Delayed—more than 2 s of capillary refill	Delayed	1	
None—no capillary refill	None	0	
Total Glasgow Coma Scale Points			
E. Glasgow Coma Scale (GCS)	Value	Score	
1. Eye Opening			
Spontaneous	4	5	E. _____
To voice	3	4	
To pain	2	3	
None	1	2	
2. Verbal Response			
Oriented	5		
Confused	4		
Inappropriate words	3		
Incomprehensible words	2		
None	1		
3. Motor Response			
Obeys commands	6		
Purposeful movement (pain)	5		
Withdraw (pain)	4		
Flexion (pain)	3		
Extension (pain)	2		
None	1		
Total GCS points (1 + 2 + 3)	_____	Trauma Score _____ (Total points A + B + C + D + E)	

Reprinted with permission from Champion HR, Sacco WJ, Carnazzo AJ, et al. Trauma score. *Crit Care Med.* 1981;9:672.

Glasgow coma scale as its central nervous system component.) The best feature of the Trauma Score is that it measures the physiological state at the scene of the injury. Patients who require prompt diagnosis and definitive care at a Level 1 trauma center are those with a score of 12 or less.¹⁹

- The CRAMS scale was developed by S. P. Gormican in 1982 and modified by T. P. Clemmer in 1985 (Exhibit 27-3).²⁰ It is a simple and easy scale to remember, with the letters of the acronym representing circulation, respiration, abdomen, motor, and speech.

EXHIBIT 27-3

MODIFIED CRAMS SCALE USED IN CIVILIAN MEDICAL EVACUATION

Circulation

- 2: Normal capillary refill and blood pressure > 100 mm Hg systolic
- 1: Delayed capillary refill or blood pressure 85–99 mm Hg systolic
- 0: No capillary refill or blood pressure < 85 mm Hg systolic

Respiration

- 2: Normal
- 1: Abnormal (labored, shallow, or rate > 35)
- 0: Absent

Abdomen

- 2: Abdomen and thorax not tender
- 1: Abdomen and thorax tender
- 0: Abdomen rigid, thorax flail, or deep penetrating injury to either chest or abdomen

Motor

- 2: Normal (obeys commands)
- 1: Responds only to pain, no posturing
- 0: Postures or no response

Speech

- 2: Normal (oriented)
- 1: Confused or inappropriate
- 0: Unintelligible or no sounds

— Total CRAMS Score

Reprinted with permission from Clemmer TP, Orme JF Jr, Thomas F, et al. Prospective evaluation of the CRAMS scale for triaging major trauma. *J Trauma*. 1985;25:189.

Recommended equipment for civilian helicopter evacuation is shown in Exhibit 27-4. A simplified triage flow sheet (Figure 27-7) and a recommendation for helicopter transport at all times (Exhibit 27-5)²¹ are also included to allow some familiarity with civilian decision making. Additional recommendations have been set forth for the transport of the critically ill patient and have been reviewed and approved by The Association of Air Medical Service.²²

Corps and Communications Zones: Zone of the Interior

Much of the medical evacuation that occurs at the corps level and above will involve the U.S. Air Force. However, the corps level medical evacuation battalion has as one of its missions the task of evacuating casualties from the division to the corps level, and does this by using the army’s ground or air assets.

Evacuation from the division is regulated by the division Medical Operations Center and the medical group Medical Regulations Officer.^{2(p4-2)} Evacuation from the corps level to the communication zone and higher is the mission of the Military Airlift Command of the U.S. Air Force. Medical regulating at this level proceeds from the patient administrator of a given hospital to the medical group and medical brigade Medical Regulating Office to the theater-level Joint Medical Regulating Office. Medical regulating for evacuation from the communications zone to the zone of the interior is carried out by the Armed Services Medical Regulating Office.

It is important that military anesthesiologists recognize that when the casualty initially enters the U.S. Air Force’s medical evacuation system, he will be at a Mobile Aeromedical Staging Facility (MASF). The function of this unit is to collect casualties, not to provide treatment. Physicians are not assigned to a MASF and casualties should not be sent there unless they are in stable condition. Furthermore, the MASF does not have a holding capability; patients are not to remain there longer than 6 hours.^{2(p6-9)}

Tactical Evacuation System

The tactical evacuation system provides for the airlift of patients within the corps level and from the corps level to the communication zone. Most of these casualties will have had initial surgery and should be in stable condition. U.S. Air Force guidance indicates that mission duration will not exceed

EXHIBIT 27-4

RECOMMENDED CIVILIAN HELICOPTER CHECK LIST

In Side Wall Blue Pouches:

- 1 pair wrist restraints
- 1 roll 2-in. cloth tape
- 2 oral airways (small, medium)
- 1 30-mL syringe
- 1 10-mL syringe
- 2 pairs eyeglasses
- Masks and gloves

In Front Wall Pockets:

- 2 survival kits
- 2 life vests
- Doppler flow probe and acoustic coupler
- 2 lithium-powered batteries
- Obesity blood-pressure cuff
- Large adult blood-pressure cuff
- Passenger guide

On Side Wall:

- Suction cannister with suction tubing and yankeur
- 2 oxygen regulators
- Personal mask resuscitation bag, with mask

In Clam Shell:

- 2 head rolls
- Cervical collars (small, medium, large)
- 1 spider strap
- Pediatric immobilizer with pump

In Airway Seat:

- Large survival kit
- 1 life vest

In Side Seat Drawer:

- 4 D-cell batteries
- 2 reflective vests
- 1 syringe pump
- 1 syringe pump charger
- 2 spare stretcher brackets
- 1 flashlight
- 1 L normal saline
- 500 mL Tridil*
- Charcoal and ipecac syrup†
- Foam ear plugs
- Charger for PROPAC‡ monitor and pulse oximeter

Between Bench and Side Seat:

- Military antishock trousers bag

In Side Rear Pouch:

- 1 trauma dressing
- 1 sterile drape
- 2 reflective vests
- 1 camp light

Under Bench Seat:

- Linen
- Pneumatic shock garments, adult and pediatric, with pump
- Clipboard with flight charts

Under Side Seat:

- Elastic bracket for lithium-powered battery

On Wall Next to Side Seat:

- Backup stretcher
- KED extraction splint§
- Scoop stretcher
- Blue interhospital patient-attendant bag
- Red scene bag

Behind Side Seat:

- 3 oxygen tanks

With Stretcher:

- Oxygen tank and regulator
- PROPAQ monitor with cables and cuff

Also Aboard Helicopter:

- 1 spare headset
- 2 fire extinguishers
- Portable, free-standing suction unit¶
- Suction kits and 1 yankeur
- Charger for lithium-powered battery

*Nitroglycerin in 1,2,3-propanetriol trinitrate, manufactured by Du Pont Multi-Source Products, Garden City, NY

†Syrup of Ipecac, manufactured by Roxane Laboratories, Inc, Columbus, Oh

‡Manufactured by Protocol Systems, Inc, Beaverton, Ore

§Kendrick Extraction Device, manufactured by Medix Choice, Santee, Calif

¶Portable: Continuous and Programmable Intermittent Suction System, Model 326/326M, manufactured by Impact Instrumentation, Inc, West Caldwell, NJ

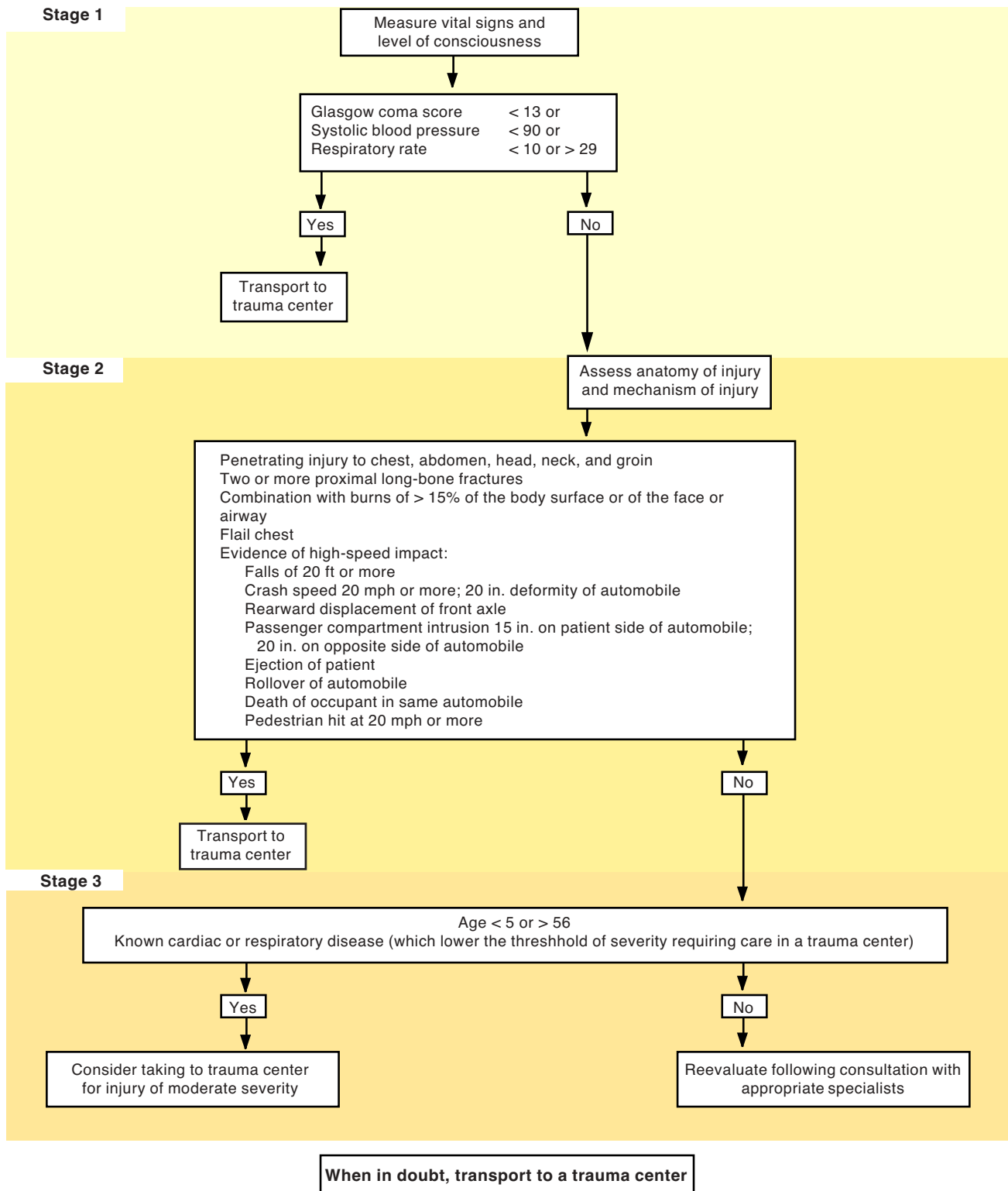


Fig. 27-7. Civilian triage decision scheme. In stage 1, if easily determined clinical indices such as the Glasgow coma score, systolic blood pressure, and respiratory rate are abnormal, the patient should be flown directly to a trauma center. Stage 2 is implemented in patients in whom these indices are not grossly abnormal. The anatomical location of the injury and its mechanism are used as discriminators. In stage 3, extremes of age and the known presence of cardiopulmonary disease are used as further triage discriminators. Adapted with permission from Champion HR. Helicopter triage. *Emerg Care Q.* 1986;2:13-21.

EXHIBIT 27-5

SIMPLIFIED CIVILIAN EVACUATION POLICY

A helicopter should be used for patient transport under any of the following conditions:

- Urban and suburban environments
- Transport time to the trauma center > 15 min by ambulance
- Ambulance transport impeded by access to or egress from the accident scene
- Presence of multiple casualties
- Rural environment
- Time to local hospital via ambulance > time to trauma center via helicopter
- Wilderness rescue

Reprinted with permission from Champion HR. Helicopter triage. *Emerg Care Quart.* 1986;2:20.

4 hours. The most commonly used aircraft is the C-130 Hercules (Figure 27-8).^{2(p10-45)} The C-130 is a long-range, high-wing, four turboprop-engine aircraft. The fuselage is divided into the cargo compartment and the flight deck. It can be fully pressurized, heated, and air conditioned. The C-130 can maintain a sea-level cabin pressure at an altitude up to 19,000 ft and an 8,000-ft cabin pressure at



Fig. 27-8. A C-130 Hercules taking off somewhere in the Kuwaiti Theater of Operations during the Persian Gulf War. The original design of the C-130 dates from 1951. The rugged construction of these aircraft allows them to use unprepared runways, as are found forward on the battlefield. Photograph: Defense Audio-Visual Agency, Still Media Depository, Washington, DC.

an altitude of 35,000 ft. It can land and take off on runways as short as 600 m, a capability that allows for rapid transportation of personnel and equipment to and from the battlefield. The C-130 can readily be configured for aeromedical evacuation by using seat and litter provisions stowed in the cargo compartment, but military anesthesia providers should not expect to find extensive resources available for treatment. Depending on inherent equipment and the model of the aircraft, it can hold a maximum of 74 litter patients, 92 ambulatory patients, or various combinations (Figure 27-9).

Strategic Evacuation System

The mission of the strategic evacuation system is to provide controlled evacuation of stable patients to medical treatment facilities that are located outside the theater of operations—frequently in CONUS. U.S. Air Force guidance on mission duration



Fig. 27-9. This photograph, taken during an exercise in 1980, shows the extremely tight space available for individual casualties. The space and the sparse medical equipment provided markedly limit the provision of in-flight medical care. Photograph: Defense Audio-Visual Agency, Still Media Depository, Washington, DC.



Fig. 27-10. The C-141 Starlifter (a) and its loading ramp (b). This aircraft was the mainstay of the US Air Force's strategic aeromedical evacuation system during both the Vietnam and the Persian Gulf wars. Photographs: Courtesy of Lieutenant Colonel Charles Beading, MD, Medical Corps, US Air Force, Flight Surgeon, Uniformed Services University of the Health Sciences, Bethesda, Md.

is 7 to 14 hours. The aircraft currently used is the C-141 Starlifter (Figure 27-10).^{2(p10-46)} The C-141 is a long-range, high-speed, high-altitude aircraft designed for the airlift of combat support equipment, troops, or aeromedical evacuation patients. It is powered by four jet engines, cruises at 550 mph at

an altitude of 30,000 ft, and has a range of 5,250 miles. When used for aeromedical airlift, a self-contained comfort pallet can be placed in the forward section of the cargo compartment. Conditions aboard a typical strategic aeromedical evacuation flight during the Persian Gulf War era are shown in Figure



Fig. 27-11. In-flight conditions for casualties aboard a C-141 during a strategic aeromedical evacuation. Access to patients and the availability of medical equipment are superior to that on the C-130. Photograph: Courtesy of Lieutenant Colonel Charles Beading, MD, Medical Corps, US Air Force, Flight Surgeon, Uniformed Services University of the Health Sciences, Bethesda, Md.



Fig. 27-12. The C-9 Nightingale (a), a modified version of the commercial DC-9 and the only US Air Force aircraft especially designed for aeromedical evacuation. (b) The loading ramp. Photographs: Courtesy of Lieutenant Colonel Charles Beading, MD, Medical Corps, US Air Force, Flight Surgeon, Uniformed Services University of the Health Sciences, Bethesda, Md.

27-11. Maximum capacity of the aircraft is 103 litters or 147 ambulatory patients, or various combinations of litter and ambulatory patients. The conditions are much better than in the C-130. Patients are not overcrowded, hot meals are provided, and the cabin temperature is better controlled than in tactical aircraft. Oxygen and electrical outlets permit the use of complex medical equipment en route. However, dehydration may occur because the flights are long and the ambient humidity is low (5%–30%). There has been recurrent interest in configuring and outfitting a small number of C-141s as flying intensive care wards.

Domestic Aeromedical Evacuation System

The U.S. Air Force's daily system of flights within CONUS has flight crews and aircraft dedicated to aeromedical evacuation of military casualties. The aircraft currently used is the C-9 Nightingale, which is a modified version of the commercial DC-9.^{2(p10-45)} The T-tailed aircraft is powered by twin, aft-mounted jet engines and cruises at 500 mph. Its range exceeds 2,300 miles. The C-9 is the only U.S. Air Force aircraft specifically designed for aeromedical evacuation. An integral folding ramp enables efficient enplaning and deplaning of litter patients (Figure 27-12). The C-9 can hold a maximum of 40 litter patients, 40 ambulatory patients, or a variety of combinations of litter and ambulatory patients (Figure 27-13). The environment on board is comparable to first-class accommodations on a commercial airline. Most specialized equipment available on a hospital ward can be provided on a C-9, including isolation and humidity control.

Although the domestic system is in operation daily, it is during emergencies, when military casualties of accidents and disasters require evacuation to specialized hospitals within CONUS, that its function is most clearly illustrated, as in the following incident.

The air force's domestic aeromedical evacuation system was activated in March 1994 after two army training planes (a four-engine turboprop C-130 Hercules transport plane and a single-engine F-16D) crashed and burned while attempting to land at Pope Air Force Base, North Carolina. Twenty-three paratroopers died and 83 others sustained burns or other injuries in the accident. The severely burned survivors were aeromedically evacuated to the burn center at Brooke Army Medical Center, Fort Sam Houston, San Antonio, Texas.²³

While the injured were being triaged and treated at Womack Army Medical Center, Fort Bragg, North Carolina; [civilian hospitals in Fayetteville and Chapel Hill]; and Portsmouth [Virginia] Naval Hospital; the Aeromedical Evacuation Coordination Center (57th Aeromedical Evacuation Squadron) at Scott Air Force Base (AFB), Illinois...was dispatching two C-9As and medical crew members to Fayetteville.

In the meantime, the Air Education and Training Command (Randolph AFB, San Antonio [Texas]) provided a twin-jet T-43 A...to fly a burn team from Brooke Army Medical Center to Pope AFB.

.....

[T]he first C9-A departed Pope AFB the following morning for Kelly AFB, San Antonio, with 11 patients on litters, nine of whom were on ventilators. All had second- and third-degree burns covering from 30% to 80% of their bodies.... The second C-9A made the flight about 5 hours later with nine



a



b

Fig. 27-13. (a, b, and c) Patient conditions aboard the C-9 Nightingale. Photographs: Courtesy of Lieutenant Colonel Charles Beading, MD, Medical Corps, US Air Force, Flight Surgeon, Uniformed Services University of the Health Sciences, Bethesda, Md.



c

EXHIBIT 27-6

U.S. AIR FORCE CLASSIFICATION OF PATIENTS SCHEDULED FOR AEROMEDICAL EVACUATION

Class 1. Neuropsychiatric Patients

- 1A. Severe psychiatric litter patients requiring the use of restraining apparatus, sedation, and close supervision at all times.
- 1B. Psychiatric litter patients of intermediate severity requiring tranquilizing medication or sedation, not normally requiring the use of restraining apparatus, but who react badly to air travel or who may commit acts likely to endanger themselves, others, and/or the safety of the aircraft. Restraining apparatus should be available for use.
- 1C. Psychiatric walking patients of moderate severity who are cooperative and who have proved reliable under observation.

Class 2. Litter Patients (Other Than Psychiatric)

- 2A. Immobile litter patients unable to move about of their own volition under any circumstances.
- 2B. Mobile litter patients able to move about of their own volition in an emergency.

Class 3. Walking Patients (Other than Psychiatric)

- 3A. Nonpsychiatric and nonsubstance abuse patients who require medical treatment, assistance, or observation en route.
- 3B. Recovered patients who are returning to their units and require no medical attention en route.
- 3C. Ambulatory drug or alcohol substance-abuse patients.

Class 4. Infant Category

- 4A. Infants under 3 years of age, occupying a seat or in a bassinet or car seat secured in an ambulatory seat.
- 4B. Recovered infants under 3 years of age, occupying a seat or in a bassinet or car seat secured in an ambulatory seat.
- 4C. Infants in an incubator.
- 4D. Infants younger than 3 years of age on a litter.
- 4E. Outpatients under 3 years of age on a litter for comfort.

Class 5. Outpatient Category

- 5A. Ambulatory outpatients, non psychiatric and non substance abuse, who are traveling for an outpatient visit and do not require a litter or medical assistance in flight.
- 5B. Ambulatory drug- or substance-abuse outpatients going for treatment.
- 5C. Psychiatric outpatients going for treatment.
- 5D. Outpatients on a litter for comfort or safety.
- 5E. Returning outpatients on a litter for comfort or safety.
- 5F. Other returning outpatients.

Class 6. Attendant Category.

- 6A. Medical attendants, either physician, nurse, or technician, who are assigned to give specialized medical treatment or nursing care to a particular patient.
- 6B. Nonmedical attendants, either relatives or friends, who may assist with the patient's care and who may also require support.

Sources: (1) Department of the Army. Field Manual 8-10-6. *Medical Evacuation in a Theater of Operations*. Washington DC: Headquarters, DA; 31 October 1991: p F-1. (2) Department of the Air Force. *Physicians' Roles and Responsibilities in Aeromedical Evacuation*. Washington, DC: Secretary of the USAF; 1995: in press. Air Force Joint Manual 41-306.

patients on litters, five of whom were on ventilators. Two patients already had undergone leg amputations.

[T]he flights were cleared to fly directly to San Antonio and thus were able to do so in less than 2 hours.^{23(p1225)}

Military anesthesiologists need to be aware that to overcome shortfalls of strategic evacuation capability during a major war, the air force, in conjunction with a number of airlines and the U.S. Department of Transportation, has expanded the existing Civilian Reserve Air Force program to provide aircraft dedicated to aeromedical evacuation. The primary aircraft to be provided to support aeromedical airlift is the B-767. Once activated, each B-767 would be reconfigured from its civilian passen-

ger configuration to an aeromedical configuration in about 18 hours.

Because casualties who enter the U.S. Air Force medical evacuation system during wartime should be medically stable, the prioritizing of precedence for picking up and moving casualties is more commonly applicable to emergency situations such as peacetime disasters²⁴:

- URGENT: pick up immediately
- PRIORITY: pick up within 24 hours
- ROUTINE: pick up within 72 hours

The air force places considerable importance on the classification of patients to be evacuated (Exhibit 27-6).^{2(pF-1)} The great majority of combat casualties will be placed into Classes 2A and 2B.

MEDICAL IMPLICATIONS OF BIOPHYSICAL EFFECTS OF AEROMEDICAL EVACUATION

Many potential problems are associated with aeromedical evacuation, but most of the unique threats are specific to long-range flight at high altitude and are a consequence of human adaptations to life at sea level. The modern jet must fly at the highest possible levels (9,000–12,000 m) for reasons of speed, fuel economy, and comfort. At 12,000 m the barometric pressure is only 140 mm Hg. At this level, the partial pressure of oxygen is approximately 30 mm Hg, which cannot sustain human life. Jet aircraft can operate at such altitudes only because the pressurized cabin was developed, which

maintains ambient cabin altitude at a barometric pressure equivalent to that found between 1,500 and 2,600 m. Despite all the problems of living in a strange environment, “aeromedical transport of patients presents no problems so long as one remembers that man is adapted for life at sea level.”^{25(p237)}

Barometric Pressure

Barometric pressure falls as a function of height above the surface of Earth (Figure 27-14). This fact explains not only the etiology of hypoxia at altitude

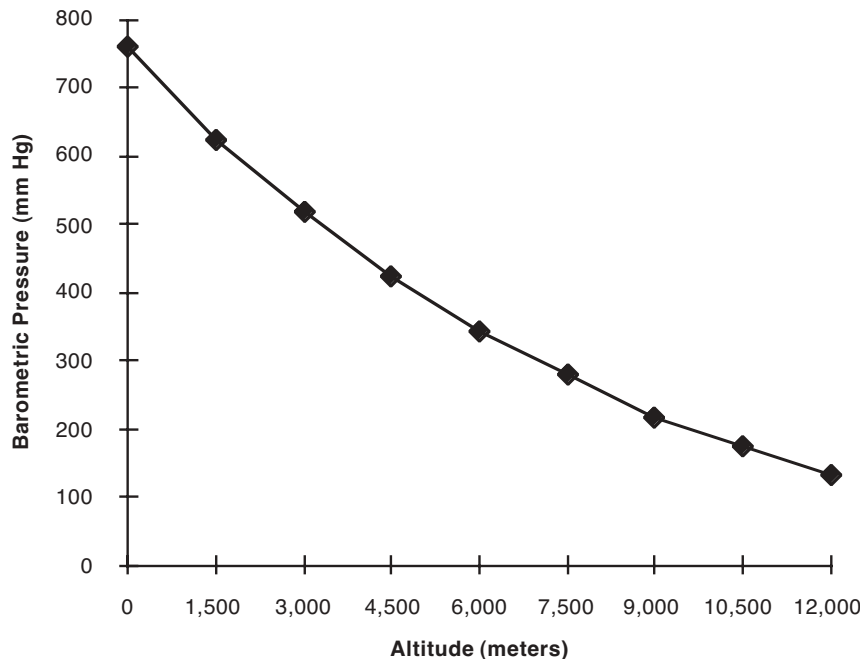


Fig. 27-14. Barometric pressure as a function of altitude.

but also why gas trapped within body cavities, as well as gas used to fill medical devices, can constitute a significant hazard to casualties undergoing aeromedical evacuation. The effect of falling barometric pressure is understandable in terms of the gas laws of Boyle and Dalton. Boyle's law states that at a constant temperature, the volume of a gas is inversely proportional to the pressure to which it is subjected. As altitude increases in an unpressurized aircraft and as barometric pressure decreases, gas in a closed or semiclosed space expands. All common drug vials, albumin infusions, and medical containers act like closed spaces when taken to altitude.

Patients with pneumothorax, bowel obstruction, and other conditions in which gas is trapped in a closed space are at risk. The most serious problem occurs in casualties who have an untreated pneumothorax. In properly treated casualties, a chest tube attached to a one-way valve will have been inserted and left in place until the air leak has sealed. However, if undetected prior to evacuation, the volume of trapped gas will increase as the ambient pressure falls, producing a degree of cardiorespiratory embarrassment that may require urgent decompression. Therefore, in cases of suspected pneumothorax, it is essential to obtain a chest radiograph prior to evacuation. It is much easier for the physician and safer for the patient to delay the evacuation, or, if evacuation must take place, to insert the chest tube, before departure. The alternative is being presented with the need to perform an arduous and dangerous act during the flight.

Expansion of gas in the intestinal tract can also give rise to problems. Although only small volumes are involved, there is a theoretical risk that the expansion of the gas could produce damage to anastomotic suture lines following intestinal surgery or dehiscence of the abdominal incision. One of the earlier tenets of air evacuation was to defer moving recently operated patients for at least 14 days although, based on Israeli experience with aeromedical evacuation starting with the Yom Kippur War and continuing through the Lebanon War of 1982, recent abdominal surgery is no longer considered a contraindication if the gastrointestinal tract is kept decompressed with a nasogastric tube.²⁶

In a group of patients with paralytic ileus who were treated with hyperbaric oxygen, studies have shown that high concentrations of oxygen can reduce abdominal distension. It is possible to move casualties who have had recent operations if the patients receive 100% oxygen (via mask or endotracheal tube) during the flight.²⁷

Of paramount importance is the status of the endotracheal tube or tracheostomy cuff balloon, which will expand at increasing altitude. This expansion can preclude patient ventilation and cause pressure necrosis of the tracheal wall. Although the volume of air used to inflate the cuff of an endotracheal tube used for ventilatory support is small, the changes in volume can produce complications even when using the modern, low-pressure, high-volume cuffed endotracheal tube. It is essential that the cuff be inflated with either saline or water to overcome this further complication of a change in ambient pressure.

During long-range medical evacuation, many casualties will be receiving intravenous fluids, the daily requirements of which have been carefully calculated. The fall in ambient pressure in the aircraft cabin can cause an appreciable acceleration of the rate of infusion because the volume of air in the intravenous infusion set will increase with increasing altitude. A drip chamber with a total volume of 9 mL that contains 2 mL of fluid at sea level will be completely empty at 2,000 m. It is therefore essential to monitor the drip rate, if infusion pumps are not in use. Care must be taken to ensure that adequate replacement fluid volumes are available (it is very difficult to obtain extra supplies while flying at 10,000 m). A final precaution to be observed is that all infusion fluid should be carried in flexible plastic containers, *not* in glass bottles, which could explode during the flight.

The problems associated with expansion of gas in closed spaces is found in air-pressure splints including pneumatic antishock garments (PASGs) and even certain types of stretchers. As ambient pressure decreases, the transmural pressure across the wall of the PASG will increase, causing it to inflate and thereby compress the casualty's incarcerated extremities and lower trunk. This effect is especially noticeable above 1,000 m. If the trousers are inflated while in flight, the opposite effect occurs during descent of the aircraft: the PASG becomes flaccid and therefore less effective than expected. Careful attention must be paid to changes in altitude to avoid mishaps en route. Experiments in a decompression chamber confirmed the theoretical consideration that there will be considerable increase in the volume of air in the splint as ambient pressure falls: measurements indicate a change in volume of almost 50% for every 1,000 ft, or about 16% per 100 m in altitude ($-CABMcL$, personal observation). In other words, the contained volume doubles for every 610 m increase in altitude. This finding is of importance in helicopter transfers, where air splints are used frequently.

The vacuum stretcher consists of a mattress containing a vast number of polystyrene beads. In its softened state, it is molded around the casualty, giving support and a degree of comfort. As the air is extracted from the mattress, the beads expand so that the mattress makes a total-body splint. However, as the ambient pressure falls, support decreases, requiring the further evacuation of air to maintain the support. During the descent, the support pressure increases and it is essential to maintain close control of the mattress's rigidity.

Oxygenation

While changes in air pressure are critical, given their potential for causing complications, of even greater importance is the need to deliver an adequate amount of oxygen not only to the patient but to the flight crew as well. The degree of hypoxia depends on the partial pressure of oxygen (P_{O_2}) in the atmosphere. The P_{O_2} decreases in direct proportion to the decrease in pressure because the concentration of atmospheric oxygen remains about 21%. Therefore, at sea level, with barometric pressure approximately 760 mm Hg, the P_{O_2} in dry air is 169 mm Hg (21% of 760 mm Hg). At 3,000 m, where the barometric pressure is about 500 mm Hg, the partial pressure is 105 mm Hg (21% of 500 mm Hg). At the summit of Mount Everest (8,848 m or 29,028 ft, which is slightly below the normal cruising altitude of modern jet transports), the measured barometric pressure is 253 mm Hg and the estimated P_{O_2} is 53 mm Hg. Owing to the presence of water vapor in the lung and depending on the respiratory rate, the partial pressure of alveolar oxygen (P_{AO_2}) will be lower to a variable extent. The measured P_{AO_2} on the summit of Mount Everest is 35 mm Hg, from which an arterial P_{O_2} (P_{aO_2}) of only 28 mm Hg can be calculated.²⁸

A simple consideration of the effect of barometric pressure on P_{O_2} explains why signs of hypoxia become increasingly obvious in even healthy persons as they fly higher than 3,000 m without supplemental oxygen. As P_{O_2} falls, the amount of oxygen transported by hemoglobin also falls, but the reduction is not a linear function of P_{aO_2} because the shape of the oxyhemoglobin dissociation curve is sigmoidal (see Figure 25-2 in Chapter 25, Acute Respiratory Failure and Ventilatory Management). At sea level, the P_{aO_2} is 100 mm Hg, which results in an arterial oxygen saturation of 95%. As a person goes to higher altitude, the P_{O_2} in the surrounding air decreases, resulting in a decrease in the amount of transported oxygen. The P_{O_2} in blood in the

lungs and arteries decreases to the point that at 3,000 m, the P_{aO_2} is about 60 mm Hg and the hemoglobin in the arteries is only about 87% saturated (Figure 27-15). Because of the sigmoid shape of the oxyhemoglobin dissociation curve, a further increase in altitude results in a precipitous fall in oxygen saturation, such that at an altitude corresponding to the summit of Mount Everest, the estimated arterial oxygen saturation is only about 50%—substantially below the normal oxygen saturation of venous blood at sea level.

The importance of understanding the physics and physiology of hypoxia and oxygen delivery stems from the fact that battlefield casualties may have impaired pulmonary compliance, hypovolemia, anemia secondary to acute blood loss, acidosis, and also be hypothermic—factors that impair oxygen pickup in the lungs and oxygen delivery at the cellular level. Studies carried out early in the Vietnam War heightened concern about arterial desaturation occurring during high-altitude aeromedical evacuation. It was not unusual to find casualties being prepared for aeromedical evacuation with an arterial P_{O_2} of 50 mm Hg or less, breathing room air with a P_{O_2} of 150 mm Hg. Because the P_{O_2} is about 118 mm Hg in the cabin of a C-141 pressurized to about 2,400 m, a real potential existed for fatally low arterial oxygen saturations to develop.²⁹

Accordingly, supplemental oxygen is needed by many casualties during aeromedical evacuation. The amount necessary to maintain a P_{aO_2} at 100 mm Hg is shown in the upper curve in Figure 27-15. In some cases, the fraction of inspired oxygen (F_{iO_2}) needed is so high that elective intubation with positive pressure ventilation may be necessary to prevent significant desaturation at altitudes higher than 2,000 m.³⁰ However, because of the logistical and manpower constraints associated with the aeromedical evacuation of casualties who need mechanical ventilation, such casualties should be evacuated only in very unusual circumstances.

Almost all the oxygen transported by blood is carried by the hemoglobin in red blood cells; at sea level, only 0.2 mL of oxygen per 100 mL of blood is being carried in direct solution in the plasma. Therefore, the casualty's hemoglobin concentration and blood volume become important determinants of oxygen transport. Severely anemic or hypovolemic casualties are at risk during aeromedical evacuation even if their arterial oxygen saturation exceeds 90%. Hemoglobin levels should be measured prior to transfer in casualties who had sustained acute blood loss; the lowest acceptable level is approximately

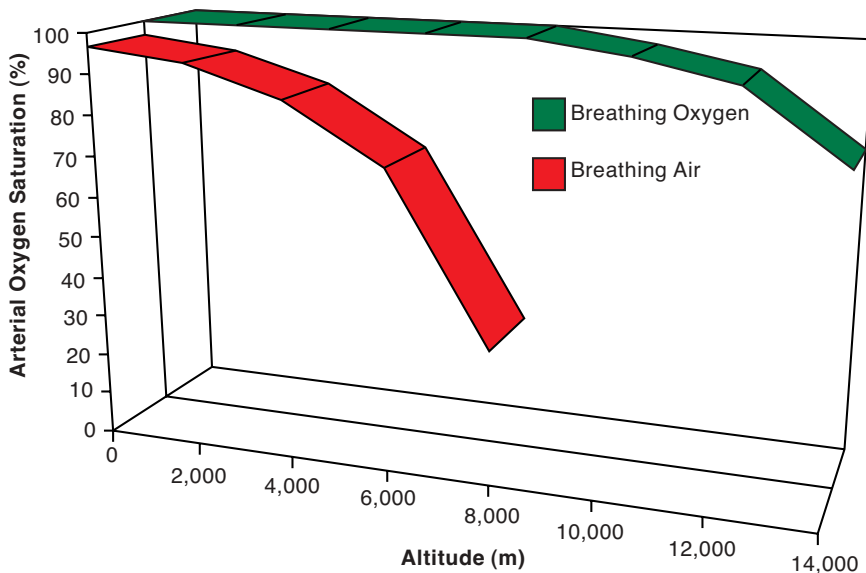


Fig. 27-15. Maintenance of arterial PO_2 with supplemental oxygen.

7.5 g of hemoglobin per deciliter of blood. A level of 10 g/dL will have already set into motion the several physiological compensatory mechanisms and so the casualty will be able to tolerate air transport.³¹

Blood volume cannot be so easily checked but is an equally important determinant of oxygen transport. A study carried out on casualties waiting to be evacuated from Vietnam found that 13 of 43 were hypovolemic, and an additional 8 were hypervolemic. Hematocrit values were not useful indicators of volume status, although anemic casualties were usually hypovolemic. Hypovolemia was especially common in casualties who were evacuated within 2 to 3 days of being wounded.²⁹

Gravitational and Accelerative Forces

While not commonly thought of as causing patient problems, the effects of gravitational forces (g) can be quite detrimental during aeromedical evacuation. An individual sitting in a seat has a force equal to his weight, which is pressing against the seat. The intensity of this force, equal to the pull of gravity at the surface of Earth, is said to be 1g. The factors influencing gravitational forces are weight and its distribution; gravitational pull; and acceleration, which is caused by the movement of the vehicle. The most important effect of acceleration is on the circulatory system because blood, being mobile, can be translocated from one part of the body to another. Other tissues can also be displaced and distorted by accelerative forces, but they usually remain functional.

Both positive and negative gravitational forces affect casualties on medical evacuation flights. At accelerations greater than 4g, the systemic arterial pressure at the level of the heart falls to approximately 40 mm Hg. Therefore, a decrease in cardiac output may occur, which is secondary to venous pooling of blood in the lower extremities. Because of this complication, patients with compromised cardiac function should be positioned with the head toward the rear of the aircraft.³²

The contrary process is also possible, because negative gravitational forces can cause a tremendous increase in arterial pressure that, when transmitted to the head, can cause blood pressure to rise as high as 400 mm Hg. This extreme pressure increase may cause a paradoxical effect via the baroreceptor reflex, with slowing and even stopping of the heart. The cerebrospinal fluid in the cranial vault may act as a buffer to the expansion of the intravascular blood volume. However, some small vessels on the surface may rupture and subarachnoid hemorrhages have developed in animals exposed to negative gravitational forces. For these reasons, a casualty with a head injury or increased intracranial pressure should be positioned with his head toward the front of the aircraft.³³

Thermal Stress

Battlefield casualties may have been exposed to the elements for extended periods. Extremes of heat and cold can both cause medical problems. The vascular system's compensatory vasoconstriction and vasodilation associated with thermal regu-

lation may cause significant fluid shifts and thereby make more difficult the assessment of the adequacy of volume restoration. The volume-depleted hypothermic patient, whose hemodynamics may be fairly normal while the vascular bed is contracted, becomes hypotensive as the vascular bed dilates in response to warmth.

The temperature at Earth's surface is approximately 20°C; the temperature at 10,000 ft is 0°C. While most rotor-wing flights are at a lower altitude than 10,000 ft, the thermal losses to radiation, evaporation, conduction, and convection may be significant and underestimated. Attempts to provide at least a physiologically normal temperature will decrease oxygen consumption and improve the medical officer's ability to assess the patient.

Noise and Vibration

Rotor-wing aircraft and ground ambulances create a significant amount of noise and vibration that are difficult to moderate. These factors may affect electrocardiographic monitoring, noninvasive blood pressure monitoring, pulse oximetry, and the auscultatory efforts of the monitoring team. Because of these limitations, the medical officer must be able to perform some form of adaptive monitoring procedure. These include palpating and assessing radial, brachial, and femoral pulses, and correlating them to mean arterial pressure; observing respiratory excursion and patterns of breathing for any acute changes in status; and intervening appropriately. The simplicity and reliability of mechanical monitors will commonly be lost during transport. The noise levels, especially in tracked vehicles and at aircraft takeoff and landing, are a potent source of stress. Taking clinical measurements on unconscious patients may cause sharp rises in pulse, blood pressure, and respiration rate if protective earplugs are not used. The noise levels, especially when associated with vibrational frequencies above 10 Hz, are more detrimental to patient care than are the physiological effects of the vibration.

The speed of transit can also affect the low-frequency vibrations to which casualties can be subjected. In a study of four different types of ground ambulances, marked increases in two low-frequency areas (at 4–8 Hz and 16–28 Hz) occurred when the ambulances traveled between 30 and 45 mph. The tests were repeated in ambulances fitted with a "floating" stretcher. The results confirmed that the vibrations can be damped down in the specific frequency areas, but the cost of fitting this type of stretcher would be prohibitive.³²

Fatigue and Sleep Lag

The evacuation of patients over many thousands of miles, through several time zones and different ambient temperatures, gives rise to general fatigue, due largely to disturbances of the circadian rhythms (ie, jet lag).³⁴ In addition, even in a fit person, the long flight at reduced barometric pressure, with the resulting lowered oxygen tensions, gives rise to serious fatigue problems. The level of degradation of performance is difficult to quantify, but experimental work in a decompression chamber showed a marked reduction in the appreciation and performance of tests when initially attempted, although once learned, there were no problems with retention of the newly acquired skills.³⁵ A general level of fatigue is demonstrated by patients during long-distance transfer flights, especially when overnight stops are necessary. The marked improvement as a result of direct flights was first noted in the German sick and wounded who were being evacuated during the Spanish Civil War: even though the aircraft were unpressurized and unheated, nonstop flights were considered better for the patients.²⁵

Workers in New Zealand have a possible treatment for jet lag. The pineal gland (ie, the "third" eye) secretes melatonin, which is considered to be one of the principal factors in setting the biological clock. Preliminary findings indicate that when research subjects take formulations of melatonin, compared with a placebo, the effects of jet lag are markedly reduced.³⁶

MEDICAL DETERMINANTS OF SAFE EVACUATION

Specific medical factors, such as abdominal and eye injuries, may increase the risk of medical evacuation. Clearly, other factors (eg, enemy action and mechanical problems associated with the design and operation of the aircraft) may adversely affect the evacuee, but they will not be discussed here.

In-Flight Medical Problems of Long-Range Aeromedical Evacuation

Only limited historical data have been gathered on the medical aspects of aeromedical evacuation. The most useful data are from the Vietnam War;

although long-range casualty evacuation occurred during both Operation Just Cause in Panama (1989) and the Persian Gulf War (1990–1991), the number of American casualties was too small to draw meaningful conclusions, although much interesting anecdotal information was collected.

The Vietnam War

The low frequency of death observed during aeromedical evacuation (< 1 per 20,000 casualties evacuated) during the Vietnam War does not necessarily mean that nonlethal medical problems were similarly infrequent. In lieu of data from a more recent war, the U.S. Air Force medical evacuation experience in the early years of the Vietnam War, in which casualties were evacuated through an aeromedical staging facility in the Philippine Islands prior to being evacuated to Japan, is of interest. Of some 20,000 casualties already in the evacuation chain, many (68 of 128 in one check) were found to have developed signs and symptoms indicative of the possible development of potentially serious complications. Complications were especially common in three categories of casualties^{29(p276)}:

1. Vascular injuries. Of 347 casualties who had vascular reconstruction, 187 were found during aeromedical evacuation to have developed signs and symptoms suggestive of a complication (ie, a cool, pulseless extremity; excessive pain in the limb; excessive drainage; fever). No fewer than 57 of the 187 (approximately 30%) required an extremity amputation.
2. Chest injuries. Of 629 casualties who had chest trauma, 137 were found to have a pneumothorax or a hemothorax. One third of this group, 46 casualties, presented with respiratory distress, and 16 of 17 in whom arterial blood-gas measurements were made had a PaO₂ less than 80 mm Hg while breathing room air. It seems likely that these casualties had pathologically low arterial oxygen saturation during evacuation. Thirty-one casualties of the group of 137 had a nonfunctioning chest tube in place. Heimlich valves had been used in some patients and in several this was defective, allowing air to remain in the pleural space.
3. Abdominal injuries. Of 626 casualties with abdominal trauma, 117 had signs and symptoms during the evacuation that indicated

the need for reoperation. Among the more common indications were dehiscence, evidence of peritonitis, intestinal obstruction, stress ulcer hemorrhage, hemorrhage from an abdominal wound, and wound sepsis.

It should be understood that (a) these complications were apparent after 6-hour evacuation flights, (b) many of the complications had probably existed prior to evacuation but had not been diagnosed, and (c) these casualties probably were evacuated prematurely. The Vietnam aeromedical evacuation experience strongly suggests that the medical problems that do develop are much more likely to be associated with the original injury than with abnormal environment in the evacuation.

Operation Just Cause and the Persian Gulf War

The distinguishing military medical characteristics of Operation Just Cause in Panama was the paucity of third-echelon medical assets deployed with the combat units. Although a surgical team was present to perform emergency lifesaving surgery on the critically wounded, initial surgery was performed on most casualties in military hospitals in San Antonio, Texas. After receiving first aid at the unit level and MASF, these casualties, together with those who had already been operated on, were evacuated in C-141s, which soon became aerial emergency and intensive care wards. Not surprisingly, "In-flight care for these fresh combat casualties was a challenge for the usual crew of two flight nurses and three aeromedical evacuation technicians."^{37(p943)}

In contrast to Operation Just Cause, the Persian Gulf War was characterized by a long buildup period during which extensive third-echelon medical assets were deployed. Even so, the anticipated casualty rates were so high that the need to evacuate fresh, unstable casualties was thought to be highly likely. As a result of the Panama experience and breaking with the tradition existing since World War II, medical commanders decided to assign physicians to at least some tactical and strategic air evacuation flights so as to optimize the success of lifesaving, in-flight, medical interventions.³⁷ Fortunately, actual U.S. and Allied casualties were only a tiny fraction of those anticipated, and the need for lifesaving interventions was correspondingly small.

The experiences in both of these wars suggest that injury-related complications, rather than the adverse physiological conditions of the evacuation environment, will be the major source of problems.

Furthermore, it seems likely that the proportion of evacuated casualties who develop injury-related complications during evacuation will be inversely related to the interval between wounding and evacuation (ie, the more quickly the casualty is evacuated after wounding, the more likely it is that a complication will develop). Therefore, both during mass casualty situations and when the theater evacuation policy is very short (eg, during a short but intense conflict), military anesthesia providers should be especially alert to the possibility of in-flight medical problems.

Civilian Experience

A relevant civilian experience also supports the view that medical problems during evacuation are more likely to be due to the original injury than due to evacuation per se. After resuscitative surgery (usually a laparotomy) was carried out in a rural hospital, patients were transferred to a regional trauma center within 48 hours of injury. No deaths occurred during evacuation, but 8 of the 19 patients studied developed tachycardia or became hypotensive; 7 of the 8 unstable patients subsequently died. Transport time averaged 2.4 hours. All but 3 of the patients had blunt trauma as the mechanism of their injuries. A physician and a nurse accompanied all patients, all received intravenous fluids, and all but 2 were mechanically ventilated.³⁸

Patient Conditions Leading to Medical Instability

The major constraints placed on battlefield evacuation from and to the first and second echelons of care arise not so much from the conditions of the casualties but from enemy action and the availability of the means of evacuation. Evacuation from higher echelons may, however, be constrained by the aeromedical evacuation policy of the U.S. Air Force, which is based on the realization that some patients' medical conditions predispose to in-flight complications. The air force does not recognize any absolute contraindication to aeromedical evacuation, but a variety of conditions either constitute relative contraindications to evacuation or require that arrangements be made for specialized treatment if evacuation is to proceed.^{2(pE-3),31}

When they enter the U.S. Air Force medical evacuation system, casualties should be stable enough to tolerate a 1- to 24-hour trip with a high probability that complications will not occur. The necessary degree of stabilization depends on the operational situation: tactical missions are typically shorter than

strategic missions. Therefore, less-stable patients might tolerate tactical evacuation, but strategic evacuation might be highly detrimental.

Abdominal Injuries

Patients with abdominal injuries should be carefully evaluated by a general surgeon prior to flight. Use of nasogastric or rectal tubes or both should be considered to avoid both the distention frequently encountered with a nonfunctioning bowel and the gas-volume changes associated with varying barometric pressure. Extra colostomy bags should accompany the patient. Drainage is more profuse at altitude because of gas expansion. It is essential that military surgeons close all abdominal incisions with retention sutures to minimize in-flight dehiscence due to expansion of intraabdominal gas.

Cardiovascular Disease

Patients with severe cardiovascular disease usually have reduced tolerance to hypoxia, but they generally do well during flight if provided supplemental oxygen. With appropriate preparation monitoring, patients with recent myocardial infarctions can usually be moved by airlift. Unstable patients requiring in-flight cardiac monitoring will be moved with a medical attendant, and the referring medical treatment facility must provide an air force-approved monitor. Patients who have had a myocardial infarction should not be evacuated for at least 10 days, and should have been free of pain for 5 days. If monitored, such patients must be accompanied by a physician.

Thoracic Injuries

Chest tubes should be left in place in casualties with thoracic injuries. However, each chest tube will require a Heimlich valve and an underwater chest drainage system approved for air evacuation use. Ideally, patients with recently removed chest tubes should not be airlifted until the following conditions are met:

- at least 24 hours have elapsed since the chest tube was removed;
- normal expiratory and lordotic chest radiographs have been taken at least 24 hours after removal of the chest tube (just prior to airlift, if possible), with an interpretation in the patient's medical record; and

- an occlusive dressing has been placed at the site where the chest tube was removed.

Eye Injuries

Penetrating eye wounds or surgery or both can sometimes introduce air into the globe of the eye, making it susceptible to the effects of oxygen deficiency and, especially, decreased barometric pressure. Presence of gas in the posterior chamber comes as close to constituting an absolute contraindication to high-altitude aeromedical evacuation as there is likely to be. A delay in evacuation, or an altitude restriction, is recommended for such patients.

Hematological Considerations

Ideally, patients should have a preflight hemoglobin concentration of 10 g/dL or a hematocrit of 0.30. Severely traumatized patients may have readings below those levels, and supplemental oxygen may be required. Hemoglobin concentration can be as low as 8.5 g/dL if the patient's condition is chronic, stable, and not due to bleeding.

Infectious Disease

Patients in the infectious stage of a serious communicable disease need to be segregated from the other evacuees.

Maxillofacial Injuries

Due to the increased potential for nausea and vomiting, patients with wired, immobilized upper and lower jaws must have a quick-release mechanism applied or have easy access to wire cutters in their possession. Premedication with an antiemetic should be considered.

Neurological Injuries

The decreased PO_2 at altitude can cause increased intracranial pressure in casualties with head injuries. Low-flow oxygen and an altitude restriction should be considered for flight. Noise, vibration, and thermal stresses can precipitate seizures, and adequate antiseizure medication levels should be established before flight. Valsalva's maneuver should be avoided by patients at risk from increased intracranial pressure. Therefore, administering a preflight decongestant and inserting a polyethyl-

ene tube into the patient's middle ears should be considered, especially if the patient is comatose. Patients who have had a craniotomy should not be evacuated for at least 48 hours after surgery, and should be awake and alert. The subtle changes in neurological status that are usually discovered during routine neurological checks are very difficult to detect during flight; patients requiring close observation are poor candidates for aeromedical evacuation. Stable, comatose patients can be transported. Decreased humidity at altitude dictates that patients with a loss of corneal blink reflex be provided with bilateral eye patches and eye ointment or liquid tears. Intraventricular monitoring cannot be accomplished during flight.

Orthopedic Injuries

Ideally, casts on recent fractures should be at least 48 hours old. All casts should be bivalved unless that would jeopardize the stability of the fracture. Free-swinging weights for traction are unacceptable for flight. Cervical traction is available via a Collins traction device; however, a medical officer must be present when the device is applied. Patients using crutches should travel by litter because of the safety factors involved in moving about on unstable aircraft. Crutches should accompany the patient and be stowed aboard the aircraft.

Thermal Injuries

In general, casualties with thermal injuries should not be evacuated during the period of fluid sequestration (ie, the first 48 h). Thermal injuries should be covered with occlusive dressings. Escharotomies are required for full-thickness circumferential burns. Extra burn dressings for in-flight reinforcement should be provided. Limited infusion pumps and poor in-flight refrigeration capabilities preclude the use of total parenteral nutrition. Infusions of 10% dextrose in water with necessary electrolytes should be ordered as a short-term substitute. Phosphorous injuries should be covered with saline-soaked dressings. Large vesicles and bullae should be protected during the evacuation with large, bulky dressings.

Vascular Injuries

Vascular repairs should be clearly recorded on Patient Evacuation Form DD 602 or 1380. Casts that are less than 48 hours old should be bivalved and windowed over the injured area in case excessive swelling occurs during flight.

Psychiatric Illness

Severely ill psychiatric patients (Classification 1A) require a litter, leather wrist and ankle restraints, and sedation. Patients whose psychiatric illnesses are of intermediate severity (Classification 1B) require a litter and sedation, and restraints must be available. All psychiatric patients on litters must be searched, and all sharp objects such as razor blades and pocket knives must be removed as part of the antihijacking procedure. A secondary search must be accomplished just before enplaning.

Drug and Alcohol Abuse

Soldiers who are being treated for drug and alcohol abuse should undergo 3 to 5 days of detoxification before they are airlifted. An aeromedical evacuation mission is not equipped to deal with acute withdrawal symptoms.

Preparation for Evacuation

Initial Assessment

The Advanced Trauma Life Support (ATLS) course of the American College of Surgeons is taught to military physicians as part of the Combat Casualty Care Course.³⁹ Prior to evacuation, the initial assessment of the casualty's condition is based on the ATLS ABCs (*airway, breathing, and circulation*) and the extent and location of injury, especially when the time available for battlefield medical implementation of ATLS is short and injuries may have been missed.

The "Golden Hour" concept, which arises from the civilian trauma experience, suggests that if a trauma patient with a survivable injury who is in clinical shock does not receive the definitive care necessary to reverse the process within the first hour after entering the shock state, the long-term survivability drops below 10%. This is independent of the quality of care after that 60-minute period.³⁰ In the context of combat casualty care, providing care within the Golden Hour is important, because about 90% of the total combat mortality occurs within the first hour after wounding (see Chapter 1, *Combat Trauma Overview*, for a more complete discussion). In Vietnam, transport took 35 minutes after the patient was loaded.⁴⁰ The Germans⁴¹ and Swiss⁴² can transport at least 90% of their population in 15 minutes or less, but of course conditions for civilian aeromedical evacuation in these countries are more favorable than they were in Vietnam:

there is no need to pick up casualties from a dense jungle or from a landing zone exposed to enemy small-arms fire.

The chaos of the battlefield or aid station may preclude an organized approach to each casualty. However, the rules of assessment, resuscitation, and stabilization must be followed in an orderly manner. This provides as safe a mechanism as possible for the transport of the trauma patient.

Supplies and Equipment Required From the Originating Medical Treatment Facility

The MASF does not have any equipment that can be given in replacement: all equipment and supplies that each casualty will need during the entire evacuation process must be supplied by the originating medical treatment facility (MTF) and accompany the casualty to the aeromedical staging facility. U.S. Army anesthesiologists should be aware of the following U.S. Air Force requirements for supplies and equipment³¹:

- Patient medications. Patients transported intratheater should be given a 3-day supply of medications and supplies; intertheater patients should be given a 5-day supply.
- Intravenous fluids. The referring MTF should provide a 3-day supply of intravenous fluids and infusion equipment, including all necessary supplies for antibiotic administration, if required.
- Special medical equipment. Special equipment includes cardiac monitors, ventilators, Stryker frames, continuous-suction units, pulse oximeters, oxygen analyzers, and restraints.

As a rule, dressings will be reinforced but not changed during flight due to the relatively unclean in-flight environment. Serious complications such as bleeding, increased pain, or swelling may require wound inspection. Routine dressings will be provided by the air evacuation crew; however, unique dressings or dressings for patients with excessively draining wounds should be provided by the originating MTF.

Physician's Orders

Although the recommendation has been made that flight surgeons augment the basic air evacuation crew on selected tactical and strategic evacuation missions,³⁷ the absence of physicians on most U.S. Air Force aeromedical evacuation missions

emphasizes the absolute criticality that clear and concise orders, covering the entire patient transfer, be written on the Patient Evacuation Tag, DD Form 602. The referring physician is legally responsible for all medical care until the patient reaches the destination facility.

Stretchers and Securing the Casualty in the Aircraft

The first principle of aeromedical evacuation is that the casualty must be securely fastened to the evacuation platform. If a casualty has an extremity fracture, the fracture must be immobilized for both safe and humane transportation. This is especially necessary when bumpy ground evacuation is expected.

At this time, there are at least 30 different types of stretchers available for use by NATO forces, constructed from various materials, but still based on the Swiss designs of 1912 and 1922. This multiplicity of stretchers can lead to problems in locating the stretcher in the different types of transport. With the wealth of new materials available at the end of the 20th century, it seems remarkable that a suitable stretcher has not been developed that is compatible with the road, rail, sea, and air requirements. In a mass casualty situation, the loading of stretcher patients is important: more seriously ill casualties must be positioned to ensure all-around access for the medical and nursing team. Also, adequate facilities must be available at the departure airhead to enable rapid loading of the casualties. It is also necessary to have the ground facilities to maintain full medical care for at least 24 hours, should there be a delay in the evacuating flights.

The differing aircraft likely to be used have loading doors at varying heights above ground. Some, like the C-130 Hercules and the C-141 Starlifter, can of course be loaded directly, but when commercial jets such as the VC-10, Lockheed 1001, and Boeing 737, 747, and 767 are used in medical evacuation, special loading ramps are necessary.

In all forms of transportation, but especially by air, it is essential to ensure that the patients are securely strapped to their stretchers. These, in turn, are located on the fixed stretcher supports to minimize the acceleration and deceleration forces that are generated during ground transportation and takeoff and landing of fixed-wing aircraft.

Stretchers are traditionally placed longitudinally, with the casualty traveling head first, whatever form of transport is being employed. Many have suggested that the ideal siting of stretchers would

be transverse: across the aircraft cabin. This siting would lessen the fore-and-aft movements of body fluids during the acceleration and deceleration phases of travel.

Stryker frames are generally indicated for paraplegia, quadriplegia, cervical fractures, severe burns, and those patients requiring total assistance. Patients with cervical injuries and wearing halo traction may be transported on a regular litter or, if stabilized, they may be transported as ambulatory patients. All components of the Stryker frame must be sent with the casualty from the originating MTF to allow continuity of patient care and turning of patients throughout transfer. Stretcher frames and the stretcher harness must be stressed to at least 6g to give a wide margin of safety should it be necessary to abandon the takeoff in a fixed-wing aircraft.

Catheters

Intravenous Infusions. The military anesthesiologist must be extremely attentive to the establishment, securing, and maintenance of intravenous lines. These lines are important for the continued resuscitation of the casualty as well as for the administration of needed pain medication and other drugs. The establishment of large, easily accessible, secure lines should be uppermost in the anesthesiologist's mind, as these lines may provide the only means of drug delivery.

Patients who require intravenous fluids on the ground will also require them during the flight, owing to the excessively dry cabin environment. Catheter function should be assessed prior to transport to ensure that the catheter is securely in place. Patients requiring antibiotics without fluid replacements should be switched to a heparin lock with heparin flushes provided. A 3-day supply of intravenous fluid should accompany each patient who requires intravenous fluids.

Urinary Catheters. Indwelling urinary catheters and drainage bags in use before transport should be left in place during evacuation, or inserted before the flight if urinary retention is a problem. The internal balloon should be filled with sterile, normal saline or water instead of air to avoid gas expansion during the flight.

Nasogastric Tubes. Nasogastric tube insertion is recommended for patients with abdominal wounds, abscesses or obstructions, paraplegia or quadriplegia, or the potential for paralytic ileus. Limited suction capabilities are available aboard the aircraft; however, the distal end of the tube may be left to drain by gravity into a glove or bag.

Respiratory Support

The utmost concern in the mind of every anesthesiologist is the adequacy of the patient's airway and therefore of the patient's ventilation. The need to establish a definitive airway rapidly is foremost in ATLS instruction. Several aspects of the maintenance of a patent airway during aeromedical evacuation deserve special mention.

Airway Management. Endotracheal tubes should be used if the patient requires assisted ventilation and should be inserted before aeromedical evacuation begins. Balloon cuffs should be filled with normal saline instead of air, as gas expansion at altitude may cause tracheal damage.

Airway Stability. Several questions must be answered while the casualty is being prepared for evacuation. Is the patient breathing spontaneously? Will the patient's airway need attention? What is the potential that the patient's airway will be compromised? The significance of the airway in air ambulance transport revolves around the ability to control ventilation and the need for personnel (nurses, medics, respiratory technicians) and equipment to aid that ventilation. Coexisting injuries may compromise the airway, such as cervical instability and severe facial trauma including LeFort fractures. The military anesthesiologist must remember that airway problems are especially common in casualties with burn injuries.

Tracheostomies. Tracheotomy tubes should be changed before flight and an extra tube should be sent with the patient.

Ventilators. Ventilator-dependent patients will be accompanied by a respiratory therapist or other appropriate medical attendant from the referring MTF. The apneic patient requires full ventilatory support from a respirator that will provide automatic control. There are many such machines available, but in the context of military aeromedical evacuation, it is likely that compactness and durability will be preferred to sophistication (ie, a multitude of dials and controls, such as those seen in intensive care units). A further constraint is the mode of operation. All but the simplest ventilators require a compressor to provide the gas that drives the ventilator. Transportation ventilators must be lightweight, rugged, durable, and simple to operate. Manual ventilation may be all that is available on a helicopter flight.

Humidifiers. Because the ambient cabin humidity during long-distance aeromedical evacuation is usually between 5% and 20%, marked insensible water loss and drying of the respiratory tract should

be expected. This consideration applies to all patients but especially to those in whom the normal humidifying function of the nose is prevented, such as casualties with a tracheostomy or an endotracheal tube. It will therefore be necessary to provide adequate humidification to avoid the problems of ventilating with dry gases.

There are many humidifiers, as there are ventilators, but the simplest, and therefore the most appropriate, device is the small condenser humidifier, which can be plugged into the ventilating circuit. A lightweight item, it works by passing the fresh gases through the condenser foil on which the water vapor in the expired air condenses. The water is then available to humidify the inspired oxygen. A bonus, of course, is the degree of heat conservation achieved during the respiratory cycle. The efficiency of the "Swedish nose" (the Humid-Vent Heat-Moisture Exchanger, manufactured by Gibeck Respiration Co., Uplands, Väsby, Sweden) is such that a relative humidity of approximately 50% can be maintained during the transfer.⁴³

Oxygen. There are many simple devices available to deliver oxygen, ranging from nasal cannulae and the simple mask, which deliver variable concentrations and flows of oxygen, to fixed-dilution Venturi masks, which are capable of delivering 24% to 50% oxygen. It is difficult to tap into the main aircraft oxygen supplies, so the source of oxygen for patients must be cylinders; however, when required in large numbers, oxygen cylinders produce a severe weight penalty. A further problem is the availability of adequate numbers of the appropriate cylinder sizes. It is therefore necessary to consider alternative sources of oxygen for in-flight use.

Liquid oxygen, despite being considered in some quarters to be dangerous cargo on aircraft, offers an excellent alternative means, as can be seen from the volumes of gaseous oxygen available from one 30-L flask of liquid oxygen: one such flask is equivalent to 18 large cylinders of compressed gas, with the obvious weight savings. The problem of fitting a heat exchanger to avoid freezing of the delivery outlet can be overcome without much difficulty. The pressure-swing absorber system (ie, the oxygen concentrator) must also be considered as a source of additional oxygen. The concentrator works by forcing dried ambient air, at a low pressure, through fractionating columns of zeolite crystals. As air passes through the zeolite, all other constituents of air are removed except oxygen and argon. At the delivery end of the unit, a mixture of up to 95% oxygen and 5% argon is obtained, at a rate of 4 L/min. Of course, this is not the standard required for

medical oxygen, but is a perfectly satisfactory oxygen supply. There have been no reports of the effects of ventilating with a mixture of oxygen and argon. The oxygen concentrator requires a power source to drive the compressor and produce a continuous supply of oxygen, but little maintenance. If the flow through the columns is increased, a higher volume of oxygen is produced, but the percentage of oxygen falls in direct relation to the increased flow through the columns.

Fracture Stabilization

The problems that increasing and decreasing gravitational forces exert on fractures during aircraft acceleration and deceleration have already been discussed. It is during the transport of patients with severe fractures that the problems assume great importance.

Most patients transported by air or ground ambulance will be immobilized on stretchers or gurneys. The ability to maintain in-line traction for cervical injuries as well as continued support for long-bone fractures is essential. The goal is to prevent the conversion of stable injuries to unstable injuries. It is necessary in all cases of spinal fracture, especially the cervical spine, with or without paralysis, to ensure that the degree of traction on the spine is maintained accurately. Although modern jets will be flying above the weather, there is still the problem of clear-air turbulence. When this happens, the gravitational forces exerted as the aircraft is bounced about can increase 4- to 5-fold, so that a traction weight of 10 lb will immediately increase to 40 or 50 lb, with the obvious deleterious effects on the patient, even though such forces occur for extremely short periods of time.

The Stryker frame or its derivatives used for transferring patients with spinal fractures did not address the problems of (a) rapid increases in forces exerted and (b) difficulty in moving the frame and patient.⁴⁴ The Povey turning frame addresses many of the problems experienced with the Stryker frame.⁴⁵ It weighs only 70 lb and can easily be moved. The traction weights are maintained horizontally, eliminating the high vertical-acceleration forces. The weights can also be maintained during any necessary nursing procedure. The Povey frame takes up much less space on the aircraft, and the amount of whip during turbulent conditions is much reduced.

The whole frame can be turned through 360° while head and neck traction are maintained. This

is important for the nursing care of patients with fracture and paralysis. In the quadriplegic patient, it is essential to maintain full nursing care to the skin, which, deprived of sensory input, can rapidly become broken and develop serious infection at the damaged area.

Historically, motion sickness does not appear to have been a significant problem in transporting physiologically stable casualties. In all cases of spinal injury it is essential to ensure that a nasogastric tube is passed prior to takeoff, as one of the immediate and fatal complications of such injuries is acute dilation of the stomach, leading to massive emesis. The presence of the tube will permit continuous aspiration of the stomach, thus avoiding the complication.

Casualty Assessment and Monitoring

Ideally, the same monitoring equipment found in an intensive care unit in a fourth-echelon hospital (or a Level-1 trauma hospital) would be available throughout the evacuation chain. Obviously, however, logistical realities constrain equipment availability. Inspection of the patient is probably still the best monitor available. As with the ventilators, it is necessary that all items used must be rugged, lightweight, and compatible with the aircraft type. The power supplies in aircraft vary so, as the degree of sophistication of the electronic monitors used increases, it is necessary to know the type of airplane to be used.

All monitoring equipment generates a degree of electromagnetic interference, which can interfere with navigational or communication equipment of the aircraft. It is therefore necessary for all monitors to be tested for such interference. Standards have been formulated, but at this time very few of the items tested have received a seal of approval on first testing.⁴⁶

It would seem logical to employ battery-operated monitoring equipment in an attempt to avoid electromagnetic induction. There are, however, problems with the type of battery available during air transport. The sight of an acid-filled battery being carried aboard—even the nonspill type—will raise concerns about safety. The duration of battery life is also an important consideration as the battery chargers available for use give rise to an induction field, which precludes their use in flight. Several monitoring packages are now being produced that will, it is hoped, satisfy the safety requirements.

SUMMARY

The requirement to evacuate the sick and wounded is of much greater importance in military medicine than it is in civilian medical practice. This fact is a consequence of one of the distinguishing characteristics of military medicine: the provision of care by echelons. The nature of evacuation and the conditions under which it is carried out differ according to the echelons. At one extreme is the army's evacuation from the battlefield of gravely wounded, unstable combat casualties by ground ambulance or rotor-wing aircraft. At the other extreme is the air force's intertheater (strategic) evacuation of stable combat casualties by long-range jet transport. The medical complications of evacuation arise primarily from the basic injury,

but aspects of the somewhat unphysiological environment of high-altitude, long-range aeromedical evacuation may contribute to morbidity and even mortality. Foremost among these are (a) decreased barometric pressure, which can cause expansion of abnormal collections of gas trapped within the body; and (b) decreased PO₂, which may give rise to arterial desaturation and defective oxygen transport. It is imperative that military anesthesiologists understand how to order and to carry out evacuation from the battlefield and from the levels of care in which they ordinarily practice. Recognizing the capabilities and limitations of the evacuation assets serving each level of care is especially important.

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