# 23
# Medical Casualties

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The transport of critically ill patients from one location to another is inherently perilous. Although this is true even for in-hospital conveyances (eg, down the hall to accomplish a computed tomography scan), the risk is considerably greater during long-distance aeromedical evacuation (AE) because the only expertise and medical equipment available is that which was enplaned with the patient. For this reason, AE of medical casualties (especially those needing intensive care) requires extensive preplanning and careful preparation for both predictable and unanticipated problems.

Unfortunately, the ability to prepare for AE is limited by the amount of personnel, equipment, and supplies that will fit on a rotary-wing or fixed-wing aircraft. Therefore, successful transport of medical casualties depends on (1) an accurate understanding of the diseases that afflict the patient; (2) knowledge of potential or likely complications; and (3) a clear appreciation of how the AE process can aggravate disease. Simply put, you can take only what is necessary but you must ensure you have what you need!

## Definition of Terms

### Medical Evacuation vs AE

The first important distinction to be made is between medical evacuation (MEDEVAC) and AE, two clearly different processes that are often confused because they have much in common. MEDEVAC is defined as transportation of casualties from the site of injury to a medical facility or between relatively nearby medical facilities.[1] This includes both ground transportation and air transportation, most commonly by rotary-wing aircraft. In the civilian sphere, MEDEVAC is the majority of air transportation, and the most common scenario is transportation of trauma patients from the site of a motor vehicle accident to an emergency department. In the military, the MEDEVAC system is designed to transport combat and noncombat casualties to the closest field medical facility or between medical facilities within the theater.

On the other end of the spectrum, AE is defined as the long-distance (usually >300 miles) air transportation of casualties between medical facilities. In the civilian sphere, this is likely to be a shorter distance between an emergency department and an ICU to a higher level of care at another facility. It is usually performed using rotary-wing aircraft. However, it has also been clearly demonstrated that transportation of patients over distances greater than 800 miles is safe.[2] For military AE, the distance of transport is often measured in thousands of miles and fixed-wing aircraft are almost exclusively used. The similarities between AE and MEDEVAC are obvious, especially when transporting critically ill patients by air.

### Elective vs Urgent or Contingency AE

#### *Elective AE*

Elective AE is characterized by virtually unlimited time for planning prior to transportation.

In most cases, elective AE takes place well after definitive therapy, when the rigors of air travel are unlikely to result in medical decompensation. Although these patients are stable and convalescing, some may be critically ill and require high levels of in-flight medical care and support requirements. In addition, even the most stable patients may experience complications and become unstable when exposed to the sometimes-rigorous AE environment.

For the critically ill patient, the goal of elective AE is seamless critical care from the point of transfer through arrival at the accepting facility. The most significant determination of the quality of transport care is the training and expertise of the medical attendants. To this end, medical attendants should be knowledgeable in the environment of flight as well as the provision of critical care.

Elective AE of a medical casualty is most commonly performed to transport a patient to a facility capable of a higher level of care. It is also used to transport a patient from a foreign environment where the culture, language, and medical capabilities are significantly different. In every case, the decision to transfer a patient should be made with consideration of (1) the risks to the patient of *not* being transferred; (2) the risks inherent to AE; and (3) the expected benefits of the transfer. Regardless of the reason, elective AE patients should be stable with a secure airway and have demonstrated an appropriate response to therapy, including stable vital signs prior to transport.

### *Urgent and Contingency AE*

Medical casualties may sometimes have to be transported by AE after having received only enough therapy to "stabilize" their disease process (Fig 23.1). Common reasons for urgent or contingency AE include:

1. Transportation to a facility capable of a higher level of care when appropriate care is not available locally.

FIGURE 23.1. A recently stabilized patient being carried up the ramp of a C-141 Starlifter during a contingency AE exercise.

TABLE 23.1. Medical conditions that often require urgent AE to a higher level of care.

| |
|---|
| Respiratory conitions |
| ARDS |
| Acute respiratory failure requiring mechanical ventilation |
| Pulmonary embolism, with or without shock |
| Toxic gas inhalation with respiratory injury |
| Respiratory failure secondary to sepsis or cardiac causes |
| Cardiovascular conditions |
| MI |
| Unstable angina |
| Congestive heart failure |
| Recurrent ventricular tachycardia |
| Septic shock |

2. Removal from a military theater of operations.
3. Removal from a disaster area where local medical facilities are saturated.

There are a number of medical diseases and conditions that commonly require urgent AE to a higher level of care (Table 23.1). These seemingly disparate conditions are similar in that they all possess an increased risk for en route deterioration. Aggregate experience from the USAF Critical Care Air Transport (CCAT) Teams suggest that a preponderance of these risks relate to acute airway compromise. In some patients, rapid airway deterioration can require immediate recognition and definitive intervention to avoid loss of life. Continuous and comprehensive physiological monitoring is essential in these patients to recognize impending disasters and permit preemptive intervention.

A surprisingly large number of previously healthy patients develop life-threatening cardiac syndromes (eg, infarction, pump failure, or uncontrolled hypertension) in relatively austere locations, necessitating transfer to higher levels of care. Because of lack of appropriate medical facilities locally, these patients often require transfer during the most unstable phases of their diseases.[3] Complete evaluation and definitive treatment is often unfeasible prior to AE. This results in reliance on state-of-the-art monitoring throughout AE for timely detection of complications that may develop during the natural progression of the disease.

## Description of Patient Condition

Another important area to consider is the use of precise terms to describe a patient's medical condition. A patient who is described as "critically ill" by one provider may be depicted as "stable" by another. For example, a patient with primary respiratory failure on a mechanical ventilator requiring adjustment once or twice daily is critically ill, but is also stable. This is in contrast to a patient with respiratory failure secondary to evolving adult respiratory distress syndrome (ARDS), who is both critically ill and unstable. The relative risk involved in moving these two patients on ventilators is drastically different and is influenced by the patient's medical condition, the equipment available, and the experience level of the providers caring for the patient.

Safe AE is dependant on reliable communication between all involved physicians to ensure that the right personnel and equipment are available. Using the same terminology to express the difference in acuity of illness is one of the most fundamental requirements of critical-care–related casualty transport. While this is vital for critically ill patients, it is also true for medical casualties of lesser acuity.

### *Stable vs Stabilized vs Unstable Patients*

Patients who require AE can be divided into three basic groups: stable, stabilized, and unstable. Stable patients are those patients who are extremely unlikely to medically decompensate during a prolonged flight either because their medical condition is not life-threatening or because they are in the convalescent stage of their illness or injury. For the purposes of this book, these are the patients transported by elective AE and are classified as "routine" using the standard AE patient nomenclature (see chapter 7).

The second group are stabilized patients: those who have received just enough medical care to allow them to be transported by AE but are at significant risk of becoming unstable during the flight. These include patients transported by urgent AE (when a patient's serious condition cannot be adequately treated locally) and what we termed in this book contingency AE (when patients are moved for nonmedical reasons, including armed combat or natural disaster). These patients are termed “special” by standard AE patient classification because they require special equipment or expertise for AE.

The final AE group is made up of unstable patients. These patients require continued intensive care throughout AE for survival. These patients are also classified as both urgent and special and may be more common during contingency AE. In response to US military doctrinal changes, AE of both stabilized and unstable patients is becoming increasingly common. For this reason, the AE system now includes CCAT Teams made up of intensive-care providers trained to use sophisticated air-transportable intensive-care equipment (see chapter 9).

## Variables Influencing Long-Distance AE

### Stressors of Flight

Successful AE of medical casualties requires a clear understanding and insight of the stressors of flight on a patient. These stressors can be considered in three broad categories: (1) physical, (2) mechanical, and (3) environmental.

The most important *physical* stressors are the consequence of altitude-induced changes in cabin pressure on the patient and the adjunctive medical devices used en route. The physiological implications of these effects will be discussed in the respiratory and cardiovascular sections below.

*Mechanical* stressors include aircraft-specific factors, such as vibration, noise saturation, and poor lighting. Noise and vibration render auditory diagnostic assessment difficult or impossible. For this reason, medical equipment must provide ample visual cues, especially for alarms on devices such as mechanical ventilators and cardiac monitors. In a contingency situation, this problem may be compounded by a high patient-to-provider ratio (Fig 23.2). In this potentially low-light environment, visual alarms must reliably attract the caregivers' attention (eg, by blinking incessantly).

Finally, the most important *environmental* stressors include those related to extremes of temperature and low humidity. Failure to

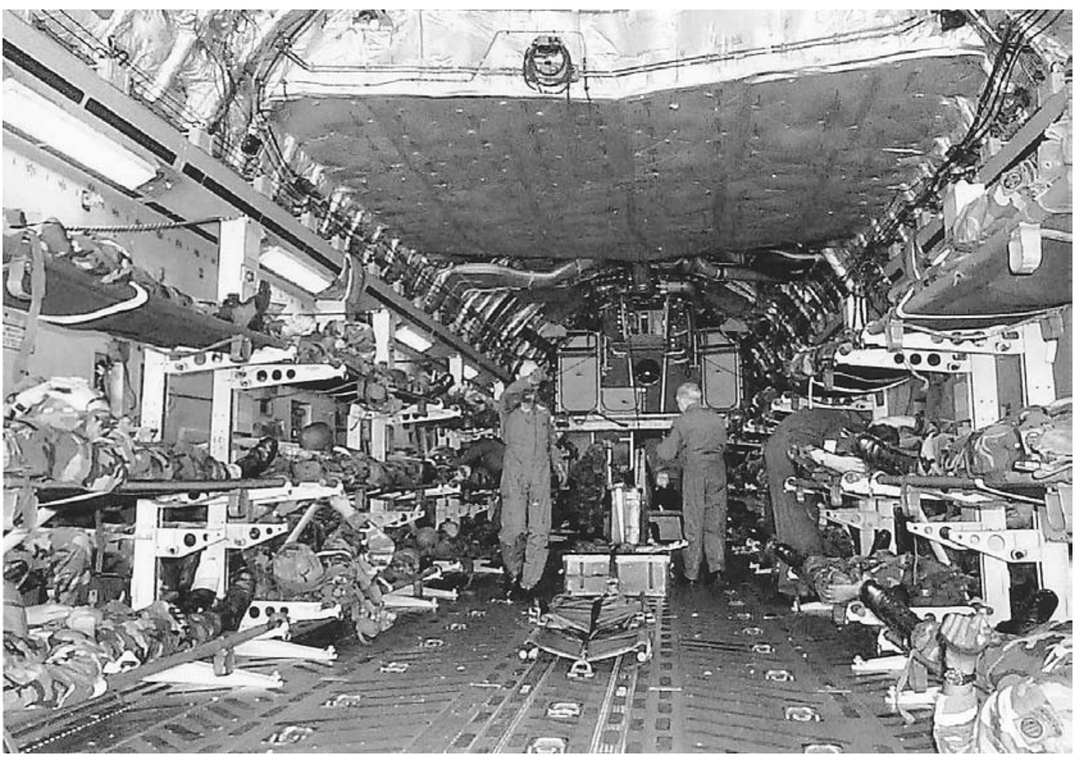

FIGURE 23.2. A C-17 Globemaster configured to transport 36 littered patients and 48 ambulatory patients using a three-tier litter system (USAF photo).

account for these variables can significantly complicate patient management.

## Decreased Pressure

At the altitude flown during routine fixed-wing AE, the cabin pressure in a pressurized aircraft is equivalent to an altitude of approximately 8000 ft. This lower pressure significantly decreases the amount and rate of oxygen that diffuses across alveolar–capillary membrane surfaces. For this reason, the flight altitude must be restricted for patients with severe lung disease and unresolvable hypoxemia at the normal cabin altitude. Even with a partial altitude restriction (ie, 3000 to 7500 ft) during fixed-wing AE, the $PaO_2$ in a majority of casualties may be compromised to <60 mm Hg.[4]

Altitude restriction for AE aircraft creates a significant cost in terms of speed and fuel efficiency; thus, it should only be used when essential. The obvious result is increased duration of the flight, related both to decreased air speed and increased refueling stops. This, in turn, increases the overall risk to the patient transport and must be carefully accounted for during the AE planning phase.

### *Oxygen Therapy*

All AE patients should receive the same amount of oxygen equal to that received prior to transport to minimize complications of hypoxia. This requires maintenance of the same inspired oxygen partial pressure ($PiO_2$). Even though the inspired fraction of oxygen is constant at all altitudes, the reduction of barometric pressure with ascent to altitude decreases the ambient $PiO_2$ according to the following formula:

$$PiO_2 = (PB - PH_2O)FiO_2$$

where PB is ambient barometric pressure and $PH_2O$ is the partial pressure of water vapor that is dependent on the patient's temperature. At 37°C, body temperature, $PH_2O$ is 47 mmHg. Although $PH_2O$ will vary with patient temperature, for practical purposes it can be assumed to be constant over the range of temperatures present in patients. Thus, the required $FiO_2$ to maintain $PiO_2$ constant during exposure to a lower barometric pressure can be calculated as follows:

$$\text{Required } FiO_2 = FiO_2\,(PB_1 - 47)/(PB_2 - 47)$$

where $FiO_2$ is the current $FiO_2$, $PB_1$ the current barometric pressure and $PB_2$ the barometric pressure at the new altitude (Table 23.2).

For example, if a patient is located in a city 1000 feet above sea level and is receiving an $FiO_2$ of 0.50, but will be transported at a cabin altitude of 8000 feet to a hospital located 4000 feet above sea level, the following calculations illustrate the required $FiO_2$ during transport and after arrival:

$$\text{In-flight required } FiO_2 = 0.50\frac{(686)}{(517)} = 0.66$$

$$\text{Destination required } FiO_2 = 0.50\frac{(686)}{(609)} = 0.56$$

If a patient requires substantial oxygen supplementation, it may not be possible to deliver sufficient oxygen to correct hypoxia. For example, if 75% or greater $FiO_2$ is required at sea level, it is not possible to deliver the same $PiO_2$ at a cabin altitude of 8000 feet even if the $FO_2$ is raised to 1.0.[5]

TABLE 23.2. Barometric pressure at indicated altitude and standard temperature.

| Altitude (ft) | Barometric pressure (mm Hg) | Barometric pressure − 47 (mm Hg) | Temperature (°C) |
|---|---|---|---|
| 0 | 760 | 713 | 15.0 |
| 1000 | 733 | 686 | 13.0 |
| 2000 | 706 | 659 | 11.0 |
| 3000 | 681 | 634 | 9.1 |
| 4000 | 656 | 609 | 7.1 |
| 5000 | 632 | 585 | 5.1 |
| 6000 | 609 | 562 | 3.1 |
| 8000 | 564 | 517 | −0.8 |
| 9000 | 542 | 495 | −2.8 |
| 10,000 | 523 | 476 | −4.8 |
| 11,000 | 503 | 456 | −6.8 |
| 12,000 | 483 | 436 | −8.8 |
| 14,000 | 446 | 399 | −12.7 |
| 16,000 | 412 | 365 | −16.7 |
| 18,000 | 379 | 332 | −20.7 |
| 20,000 | 349 | 302 | −24.6 |
| 22,000 | 321 | 274 | −28.6 |
| 24,000 | 294 | 247 | −32.5 |
| 26,000 | 270 | 223 | −36.5 |

### *Pneumothorax*

An unrecognized pneumothorax can have a devastating effect on respiratory system function during AE. Even a small pneumothorax on the ground may develop life-threatening tension pneumothorax because gas trapped in this closed space expands as the aircraft ascends. For this reason, special efforts should be made to diagnose a simple pneumothorax prior to flight in high-risk patients, such as trauma or mechanically ventilated patients. In general, a chest tube should be placed in all patients with a pneumothorax prior to AE, even in the absence of symptoms. Once inserted, the chest tube should never be clamped during transport but must instead be vented using a one-way (eg, Heimlich) valve, a water seal, or a continuous suction device.

### *Effects on Equipment*

The risk of altitude-related gas expansion is also a concern for air-containing medical devices, such as a Foley catheter or endotracheal tube. On the ground, air in an endotracheal tube cuff is extremely unlikely to expand to the point of causing tracheal injury. However, during ascent the cuff can expand to a sufficient diameter to rupture the trachea and/or obstruct the endotracheal tube, especially in the event of cabin decompression. For this reason, the USAF AE system insists that all patients with endotracheal and tracheostomy tubes have the cuffs filled with sterile saline rather than air prior to take-off. If air is left in the cuff, pressures must be measured and documented frequently during AE.

## Low Humidity

The fresh air supply of the aircraft, obtained from the surrounding atmosphere, becomes progressively drier as altitude increases. As a flight progresses, moist air is continuously replaced by drier air, resulting in a decreasing humidity within the aircraft. The cabin humidity may drop as low as 5% after 2 hours and as low as 1% after 4 hours of flight. This low humidity may result in symptoms of dry mouth, chapped lips, hoarseness, or sore throat among crew members and patients.

Long flights with such low humidity may complicate patients' underlying medical conditions. Patients with respiratory problems will begin to be uncomfortable if the humidity drops much below 5% to 10%. Respiratory secretions may become thick, resulting in impaired gas exchange and thus contribute to hypoxia. Humidified oxygen should be used for patients requiring oxygen therapy. Warmed, humidified air should be supplied to tracheostomy patients, even if supplemental oxygen is not given.

Low ambient humidity increases insensible fluid losses in all patients but especially those who are flown >4 hours, have large surface-area open wounds, or require mechanical ventilation. For patients with large open wounds, insensible fluid losses can be limited by covering the wound or affected extremity with a nonpermeable plastic sheet. In high-risk patients, this increased insensible fluid loss may increase the risk of hypovolemia, and thus two large-bore intravenous (IV) catheters should be placed prior to take-off. In the event of cardiovascular deterioration, fluid resuscitation needs to be increased accordingly.

## Temperature Changes

As altitude increases, the temperature outside the aircraft decreases an average of 2°C (3.4°F) for every 1000 ft. These temperature changes may not be adequately ameliorated by the aircraft climate control system, potentially exposing a patient to a significant variation in temperature. In addition, during long-distance AE significant temperature variation commonly develops in different locations of the aircraft cabin.

Exposure to temperature extremes for an extended period may result in motion sickness, headache, disorientation, fatigue, discomfort, and irritability. It will also increase metabolic rates, resulting in increased oxygen consumption. For patients with borderline pulmonary reserve, significant physiological compromise can result.

Table 23.3. Medical equipment approved for use during aeromedical transport.

| | |
|---|---|
| Monitoring devices | |
| | Pulse oximetry ($SpO_2$) |
| | External blood pressure measuring device |
| | Cardiac monitor |
| | Arterial line monitor |
| | End-tidal $CO_2$ monitor |
| Defibrillators | |
| | Paddle Model |
| | "Hands-off" model |
| Ventilators | |
| | Adult/child |
| | Infant |
| Portable laboratory instruments | |
| | Arterial blood gases |
| | Hemoglobin and hematocrit |
| | Electrolytes |
| Miscellaneous | |
| | Suction pump and tubing |
| | Resuscitation bag |

# Technology Required for Transportation

Medical equipment commonly used for critical care in fixed medical facilities may not function properly in an aircraft, primarily because of the changes in cabin pressure. For this reason, a number of devices have been modified and, after extensive testing, approved for AE by the Armstrong Research Site of the Air Force Research Lab. All AE aircraft must be capable of providing electrical power for medical equipment, and this is often accomplished by using an inverter. The inverter transforms aircraft power to 110 V/60 Hz, the wall source power almost exclusively used in US hospitals. In a dedicated ambulance aircraft, this is never an issue. However, contingency AE may be accomplished in any available aircraft. If a non-AE–dedicated aircraft is used, the aeromedical crew must make sure that the appropriate power source is available for any necessary medical equipment.

## Monitoring Devices

The most commonly used devices during AE are electronic monitoring devices. These include a cardiac monitor, external blood pressure monitor, arterial line monitor, pulse oximetry, end-tidal $CO_2$ monitor, in-line $O_2$ analyzer, Wright spirometer, and cuffolator (endotracheal tube cuff pressure measurement device) (Table 23.3).[6]

# Pulmonary Conditions

Respiratory considerations are paramount for successful AE. The effects of altitude, while inconsequential to a healthy individual, may be devastating to the compromised patient. Therefore, a crucial AE concern is identification of patients susceptible to hypoxia so that the effects of altitude can be prevented or recognized early.

## Pneumothorax

An untreated pneumothorax is a contraindication to AE (Table 23.4). A pneumothorax of any size must be treated prior to flight because expansion of intrapleural air with aircraft ascent can compress functioning lung tissue and compromise oxygenation. Tension pneumothorax can develop as continued expansion of trapped air shifts the mediastinal contents toward the opposite hemithorax. The resultant compression of the vena cava decreases venous return, resulting in decreased cardiac output and potential cardiopulmonary collapse.

Table 23.4. Contraindications to AE of medical patients.

| | |
|---|---|
| Absolute* | |
| | Untreated pneumothorax |
| | Chest tube without one-way valve, water seal, or suction |
| | Uncorrected severe arterial oxygen desaturation |
| | Uncorrected respiratory acidosis |
| | Life-threatening hypotension |
| | Uncontrolled cardiac arrythmia |
| Relative† | |
| | MI within one week |
| | Unstable angina |
| | Congestive heart failure |
| | Severe anemia (hemoglobin $<7$ mg/dL) |
| | Alcoholism without a prior 3–5 day observation period |

* Contraindication to Elective, Urgent or Contingency AE.
† Contraindication only to Elective AE.

Tension pneumothoraces must be treated immediately with a needle thoracostomy in the second or third anterior rib interspace, followed by the insertion of a chest tube. The chest tube should be connected to a Heimlich valve or other one-way valve system to prevent further expansion of the pneumothorax. Lack of a one-way valve on a chest tube is another contraindication to AE.

## Acute Respiratory Failure

Acute respiratory failure is classified as either primary or secondary. Primary respiratory failure refers to the inability of the lungs to maintain adequate gas exchange (oxygenation and carbon dioxide removal) because of a severe pulmonary condition such as pneumonia or pulmonary embolism. In contrast, secondary respiratory failure refers to inadequate pulmonary gas exchange due to extrapulmonary causes such as cardiac failure or the hypermetabolism associated with sepsis.

### *Implications for AE*

The AE transportation of patients with acute respiratory failure requires meticulous planning, special equipment (ie, respirator, pulse oximeter, et.), and, in almost every case, accompaniment by a respiratory therapist or critical-care physician.

The patient's precarious medical condition may be made worse by altitude-associated hypoxia, requiring careful adjustment of the respirator. In addition, equipment and incompatibility of supplies such as connectors are often a problem, especially at interface points where the responsibility for care of a patient is transferred from one group of clinicians to another. Patients may quickly deteriorate while clinicians try to fix these problems. For this reason, the respiratory therapist is an irreplaceable resource for troubleshooting and improvising. A well-prepared respiratory therapist will bring a supply of the most common fittings and the necessary tools to connect them.

The most difficult types of respiratory failure patients to transport by AE are those with ARDS. As the aircraft ascends, the altitude-related hypoxia will often result in decreased oxygenation for "borderline" ARDS patients. Unfortunately, increasing the inspired oxygen concentration alone may not improve oxygenation because these patients have a marked degree of pulmonary shunting. The most effective way to improve oxygenation is to re-expand collapsed alveoli, thereby increasing functional residual lung capacity (FRC). This is accomplished with a combination of positive pressure ventilation and positive end-expiratory pressure (PEEP). Recent work has demonstrated the value of PEEP in correcting altitude-associated hypoxia in an animal model of ARDS.[7] Changes in cabin pressure make adjustment of respirator settings extremely difficult. This, plus the nature of ARDS, puts the patient at increased risk of pulmonary barotrauma during AE.

## Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease (COPD) refers to the triad of asthma, emphysema, and chronic bronchitis. Each of these diseases involves airway obstruction in some manner and predisposes a patient to complications associated with the flight environment.

Both acute and subacute aggravating factors can predispose these patients to complications both at sea level and during flight.[8] Acute factors that can result in immediate respiratory deterioration include pneumothorax, pulmonary embolism, and lobar atelectasis. Subacute factors that can result in a slower deterioration include acute bronchitis, pneumonia, small pulmonary emboli, segmental atelectasis, minor trauma such as rib fractures or small pulmonary contusions, and metabolic factors. In addition, gastric distention secondary to decreased cabin pressure may limit diaphragmatic excursion and reduce vital capacity.

### *Implications for AE*

During AE, the COPD patient should be observed for early signs and symptoms of hypoxia, including tachycardia, tachypnea, dyspnea, hypertension, confusion, restlessness, and headache. Pulse oximetry should be used during AE to continuously monitor the oxygenation of COPD patients.

Arterial oxygen saturation is ≥95% in normal healthy patients at sea level. Patients with COPD frequently have lower readings (90–94%) which appear to be tolerated chronically and do not require oxygen supplementation. However, any drop in a patient's oxygen saturation requires immediate evaluation of ventilation and initiation of oxygen therapy to restore oxygenation to an acceptable value (≥90%).

The use of high levels of supplemental oxygen therapy in patients with COPD can be relatively dangerous since increased oxygen may decrease the patient's hypoxic drive to breathe, resulting in acute respiratory acidosis. This usually occurs in unstable patients with an acute exacerbation rather than in patients with compensated respiratory acidosis. Although a patient's arterial $PCO_2$ may rise somewhat with judicious use of supplemental oxygen, in most cases marked respiratory acidosis is avoided. However, an unstable patient with an acute exacerbation of COPD cannot be transported without significant risk unless personnel and facilities are available for inflight endotracheal intubation and mechanical ventilation. Obviously, such patients are not candidates for elective AE.

In patients requiring mechanical ventilation, several factors need to be considered. Ventilators should be plugged into an external power source if possible to conserve battery power and sufficient battery reserve should be present to operate the ventilator for 1.5 times the expected flight duration. Expected oxygen utilization should be carefully calculated using the patient's minute ventilation. At least 1.5 times the expected oxygen utilization should be available on board the aircraft.

As gases expand with ascent to altitude in accordance with Boyle's law, air in an endotracheal tube cuff will expand as well, although usually not enough to cause injury to the trachea. Rapid decompression, however, could result in tracheal rupture or obstruction of the distal outlet of the endotracheal tube. Endotracheal cuff pressures may be monitored with use of a cuffolator pressure monitor. Alternatively, the endotracheal tube cuff can be filled with saline, which will not expand with ascent to altitude. The expansion of gas at altitude also requires that the tidal volume of ventilators be recalibrated at altitude to avoid barotrauma. Patients should be closely monitored with cross-reference to the patient, cardiac monitor, and ventilator. In cases where the patient's respiratory status is in unclear, an arterial blood gas may be able to provide guidance. Finally, a high index of suspicion should be maintained for development of a pneumothorax in patients who demonstrate respiratory distress or cardiopulmonary decomposition.

# Cardiovascular Conditions

## Myocardial Infarction and Unstable Angina

A diseased and recently injured heart has a limited ability to compensate for the additional cardiovascular stresses imposed by AE. One of the greatest threats to a diseased heart is hypoxia. Patients with ischemic heart disease demonstrate decreased oxygen saturation during AE, with a reported oxygen saturation of <90% in approximately 20% of patients.[9] This drop in oxygen saturation increases both myocardial workload and oxygen demand and can result in clinical deterioration of patients with little cardiac reserve.

There are other cardiovascular stresses imposed by AE related to the physiology of flight. These include acceleration during take-off, which can decrease cardiac output by decreasing venous return, especially if litter patients are transported with their head positioned forward. The low humidity associated with flight may cause mild dehydration, thus increasing cardiac workload. Finally, the stress of flight can result in the increased release of catecholamines and autonomically induced dysrhythmias.[10]

### *Implications for AE*

Because of the increased risk of complications immediately after a myocardial infarction (MI), elective AE is contraindicated until at least 1 week after the acute event.

A study of 196 patients who traveled on commercial aircraft after an MI found that while complications occurred in <5% of patients the majority of these occurred in patients transported <14 days following the event.[11] Additional time for recovery before elective AE may be indicated based on factors that could predispose the patient to complications in-flight. These factors include extensive coronary disease, a difficult postinfarction course, limited cardiovascular reserve, and a substantial need for medications.

In contrast to commercial transport of patients post-myocardial infarction, AE utilizing dedicated air ambulances and experienced medical personnel may be achieved earlier. Essebag and colleagues[12] retrospectively reviewed transport of 109 patients with serious cardiovascular disease by commercial and dedicated air ambulance flights as long as 10 hours duration. Of these patients, 51 who were transported by air ambulance had suffered myocardial infarctions, and one half of these were complicated (Killip class II, III or IV). In 16 patients transported >7 days post infarction, there were no in-flight complications. Five of 35 patients transferred 0–7 days post infarction suffered complications during AE. Four patients had chest pain and one exhibited arterial desaturation. All patients responded to conventional measures and had no sequelae. These data underscore the importance of experienced teams in successful Urgent or Contingency AE. Although data in the literature is sparse, it is clear that the closer in time to the myocardial infarction, the more likely serious events will occur. AE of patients with MI during the initial phases of their illnesses should be carried out only after careful planning and in the presence of experienced critical-care personnel.

AE of patients with unstable angina should be attempted only when absolutely necessary because of their tenuous medical condition. Castillo and Lyons[13] reported outcome data on 59 patients with unstable angina who underwent transoceanic AE. Unfortunately, in-flight data were only available on 31 of the patients. Of these, six patients had in-flight events (three with chest pain, one each with arterial desaturation, headache and hypertension). None suffered a myocardial infarction during AE. Of the 31 patients with available in-flight data, there were no reported arrhythmias. It is not clear if this data is applicable to all cases of unstable angina considering the relatively benign outcomes in all 59 patients (five with congestive heart failure, two with eventual myocardial infarction and one death). Patient selection for AE may have been responsible for the generally favorable outcomes reported. Unfortunately there are no prospective controlled studies published in the literature regarding AE of patients with severe cardiovascular problems.

Several basic principles should be applied when AE is required for patients with severe coronary disease or recent MI. These patients should be transported by litter and receive continuous supplemental oxygen to minimize cardiac stress. Pulse oximetry should be used to make certain that the patient's oxygen saturation remains >95%. Appropriate cardiac drugs must be available, including antiarrhythmic and vasoactive drugs, sedatives, and analgesics. IV access is important for fluid therapy and the administration of cardiac drugs. Cardiac monitoring should be used in any patient at risk of dysrhythmia. Central venous and/or arterial monitoring may be necessary in unstable patients. A cardioversion unit should be readily available. In all cases, the patient should be accompanied by critical-care specialists trained in the treatment of acute complications of coronary artery disease.

## Congestive Heart Failure

Heart failure occurs when the pumping action of the heart is inadequate to meet the circulatory requirements of the body. Common precipitating factors include cardiac tachyarrhythmias and acute myocardial ischemia. The primary treatment of congestive heart failure includes oxygen administration and the pharmacological reduction of preload and afterload.

### *Implications for AE*

The stresses of flight may significantly worsen the cardiovascular state of a patient with congestive heart failure, and thus this condition is a relative contraindication to elective AE, especially in class 3 and 4 congestive heart failure. The hypoxia associated with ascent to altitude may worsen the patient's condition by predisposing to tachyarrhythmias and acute myocardial ischemia. Hypoxia also increases right ventricular afterload by an increase in pulmonary arterial pressure. Unfortunately, even a small increase in afterload can result in cardiovascular decompensation and cardiogenic shock in those patients with significant right ventricular failure. Oxygen supplementation to prevent hypoxia and monitoring arterial saturation by pulse oximetry are indicated.

Decreases in preload may also result in cardiac decompensation in these patients. During flight, decreased cabin pressure may predispose to loss of intravascular volume into the interstitial space (ie, third spacing). Some patients might have inadequate cardiac reserve to compensate for the increased myocardial workload resulting from the compensatory increased heart rate and contractility. The resulting interstitial edema often will manifest clinically as a dry cough, while progression to alveolar edema will appear as pink, frothy sputum.

If urgent or contingency AE is required, critical-care specialists prepared to detect and treat deterioration in the patient's condition must be available. A patient with congestive heart failure should be positioned with the head oriented toward the front of the aircraft so that the acceleration during take-off will not transiently exacerbate the congestive failure.

#### *Pacemakers*

Modern cardiac pacemakers have advanced to the point that they can emulate the heart's natural response to the demands of exercise by increasing heart rate during periods of increased physical activity. Pacemakers accomplish this by sensing vibration and interpreting this as increased physical activity.

The vibration of flight, in particular in rotary-wing aircraft, may actuate pacemakers with activity-sensing functions and increase the pacemaker rate.[14] This may have significant implications for patients with severe cardiovascular disease as they may be unable to tolerate a prolonged tachycardic rate. The increased rate is easily correctable by placing a magnet over the pacemaker and converting it to a non-inhibited unsynchronized paced rythm.

### Dysrhythmias

The early recognition and treatment of dysrhythmias is essential in the safe aeromedical transport of patients. Dysrhythmias should be treated the same as would be treated at ground level. When at altitude, however, special attention should be given to ensuring the patient is receiving adequate oxygenation and ventilation. Defibrillation and cardioversion can be performed during flight provided standard safety precautions are observed to ensure the safety of medical attendants, crew members, and other patients. Although defibrillation has demonstrated no adverse effect upon an aircraft's instruments, navigation, or electrical supply, aircrew members should be notified prior to use of this intervention.

## Other Medical Conditions

### Anemia

Hemoglobin functions as a carrier of oxygen from the lungs to the tissues. A reduced level of hemoglobin (actual or functional) reduces the oxygen-carrying capacity and subsequently tissue oxygenation. One gram of hemoglobin will carry approximately 1.4 ml of oxygen. With an average hemoglobin concentration of 15 g of oxygen per 100 ml of blood (dl), the average male will have an $O_2$ concentration of approximately 21 ml/dl (ie, $1.4 \times 15$) at 100% oxygen saturation.

Anemia seriously reduces tolerance to a hypoxic environment. At 100% oxygen saturation, the maximum $O_2$ concentration for a patient with a hemoglobin reduced to 7 g/dl will be only 9.8 ml/dl. To compensate for this decreased oxygen-carrying capacity, cardiac output must increase. If a patient's compensatory mechanisms are compromised, slight reductions in arterial oxygenation may produce hypoxic symptoms. Alternatively, increased cardiac stress in a patient with borderline cardiac reserve may result in angina, MI, or heart failure.

### *Implications for AE*

Severe anemia (<7 mg/dl) is a relative contraindication to AE. At this level, even healthy individuals are at risk. Patients should be transfused with whole blood or packed red blood cells until the hemoglobin concentration is >10 mg/dl. If transfusion is unavailable, either altitude restriction should be imposed to maintain a cabin pressure equal to sea level or sufficient supplemental oxygen should be administered to ensure maximum possible oxygen saturation.

Mild anemia (hemoglobin 10 to 15 mg/dl) is usually well tolerated by healthy individuals during AE. However, supplemental oxygen should be administered. This is especially important during pregnancy, when most patients have physiological anemia and the stresses imposed by pregnancy make them more likely to become symptomatic (see chapter 22).

Patients who have or are at risk of cardiac disease are at special risk of hypoxia-related complications with any degree of anemia. If transfusion is not practicable, pulse oxymetry and supplemental oxygen to maintain a saturation of >90% is the mainstay of treatment. Patients must be closely monitored for decompensation. Symptoms that do not respond to increased oxygen may require altitude restriction or diversion to the nearest appropriate medical facility.

## Sickle Cell Disease

Sickle cell disease is a hereditary chronic hemolytic anemia due to the presence of an abnormal hemoglobin molecule, hemoglobin S. The disease is present in individuals homozygous for the sickle cell gene (SS) or in heterozygous states when hemoglobin S is paired with other abnormal hemoglobins.

Sickle cell crisis is characterized by severe joint and abdominal pain related to sludging of crescent-like "sickle cell" erythrocytes, which occurs when hemoglobin S polymerizes into tube-like fibers. By far the important cause of this sickling is deoxygenation, and the critical arterial $PO_2$ at which this occurs is <60 mmHg. Fortunately, during flight in individuals without pulmonary disease this level is reached at a cabin altitude of approximately 10,000 ft, and modern aircraft are pressured to maintain a cabin altitude of <8000 ft. However, in patients with pulmonary abnormalities, sickling can be induced at a cabin altitude as low as 4000 ft. For this reason, patients with sickle cell disease should receive supplemental oxygen during AE.

Patients who are heterozygous for the sickle cell gene (ie, sickle cell trait) do not appear to be at risk for altitude-related symptoms in which aircraft are pressurized to about 8000 ft or lower, the level of commercial aircraft pressurization.[15] When transporting patients with sickle cell trait, however, the patients' overall medical condition must be considered including the pulmonary, vascular, and hematologic status.

## Gastrointestinal Diseases

The gastrointestinal (GI) tract normally contains a small amount of gas that will expand upon ascent. In healthy individuals, gas expansion is rarely problematic at cabin pressures at or below 8000 ft equivalent because of the resilience of the intestinal walls and the ability to relieve the increased pressure through belching or flatulence. On occasion, intraluminal gas expansion during flight may cause abdominal discomfort because of tight clothing or restraining devices. Also, gas expansion in the splenic flexure of the colon can cause upper-left quadrant fullness and a pressure radiating to the left side of the chest that can be confused with the pain of cardiac ischemia.

In contrast, patients with GI disorders (eg, bowel obstruction, ileus, or motility problems) may have significant difficulties during flight. Excessive gas production and the inability for gas to be normally transported through the intestines place patients at risk of significant problems related to gas expansion during flight. In addition to abdominal discomfort and pain, the patient may suffer from nausea, vomiting, shortness of breath, and, in extreme cases, vagal symptoms.

### *Implications for AE*

All patients known to have GI disorders should have a nasogastric tube placement prior to flight. During flight, the tube should normally be attached to a low-flow suction device. If suction is not available, an open nasogastric tube may be of some use whereas a clamped tube will not.

Patients with colostomies may have an increased amount of bowel elimination during flight due to the increased peristaltic motion stimulated by intraluminal gas expansion. All such patients should have their colostomy bag replaced immediately prior to AE, and extra bags should be available. Excess flatus and gas expansion in the bag may require careful release in some cases.

### *Airsickness*

Airsickness occurs in some people as a result of abnormal labyrinthine stimulation from unaccustomed pitching, rolling, yawing, accelerating, and decelerating forces experienced during flight. The result is a predictable sequence of symptoms that progress from lethargy, apathy, and stomach awareness to nausea, pallor, and cold eccrine perspiration, and finally to retching and vomiting and total prostration.

Motion sickness can complicate the care of patients and their attendants and on occasion incapacitate an AE crew member. Interventions should be initiated promptly following the onset of early signs and symptoms, and include the administration of oxygen, placing the patient in a supine position with restricted head motion and a cross-cabin orientation if possible, cooling of the environment, and the administration of antiemetic medications.

## Neurological Disorders

The care of the nontraumatic neurological patient entails the prevention of complications associated with their underlying medical condition. In the case of paralyzed patients, special attention should be paid to ensuring insensitive areas of the body are protected from injury. Those patients on Stryker frames should be turned on a prescribed basis, usually 2 hours in the supine position and 1 hour in the prone position.

Some patients may have increased intracranial pressure as a result of trauma, cranial surgery, or infection such as bacterial meningitis. For these patients, steps should be taken to prevent factors that are known to increase intracranial pressure further, such as vomiting, hypoxia, and seizure activity.

Patients with a seizure disorder may be at increased risk during AE because hypoxia lowers the convulsive threshold. For this reason, a therapeutic level of an anticonvulsant medication should be documented prior to flight and supplemental oxygenation should be provided. The treatment of seizures during flight begins by ensuring that the patient's oxygenation and ventilation are adequate, followed by administration of anticonvulsive medication.

General treatment of the obtunded or comatose patient includes an in-dwelling urinary catheter and IV fluid administration. These patients must be observed closely throughout flight because they are at increased risk of airway compromise and aspiration of gastric contents.[16]

## Renal Failure

Patients with acute renal failure should undergo dialysis immediately prior to all long-distance AE flights. The normal interval between dialysis treatments is usually 1 to 2 days; thus, the need for dialysis during AE will be unlikely if the flight is point to point. However, during overseas AE the aeromedical crew should be aware of when the next dialysis treatment is required so that arrangements can be made en route if required. Serum electrolytes should be routinely reassessed every 3 days for patients with acute renal failure, even if they are not yet dialysis dependent.

## Alcoholism

The importance of considering the special need of the alcoholic patient is made clear by the special AE categories used to designate these patients (see chapter 7, Table 7.2). Alcoholism may be the primary reason for AE or an undiagnosed disease process in a patient being transported for another condition. The major risk in either case is acute alcohol withdrawal, which can be fatal if unrecognized or untreated.

Alcohol withdrawal symptoms develop within 8 to 24 hours after the reduction of ethanol intake and peaks between 24 and 36 hours. These symptoms range from mild withdrawal characterized by insomnia and irritability to major withdrawal typified by autonomic hyperactivity resulting in tachycardia, fever, diaphoresis, and disorientation.

### *Implications for AE*

To minimize the risk of alcohol withdrawal during AE, patients known to be alcoholic should be hospitalized for 3 to 5 days of observation prior to flight. Alcohol withdrawal symptoms that present unexpectedly in-flight require the prompt recognition and treatment of symptoms. A high index of suspicion is required in patients who are not known to be alcoholic.

Mild alcohol withdrawal symptoms may be effectively treated with supportive care alone, such as reassurance, personal attention, and general nursing care (Table 23.5). If the symptoms progress, moderate to severe withdrawal should be treated with pharmacological doses of benzodiazepines. Withdrawal symptoms unresponsive to benzodiazipines may benefit from haloperidol. If IV hydration is given with glucose-containing fluids, these patients should first receive magnesium and thiamine to prevent the precipitation of Wernike's encephalopathy.

Table 23.5. Patient care plan: Alcohol withdrawal syndrome

1. Administer medications as appropriate
   Sedatives to counteract the depressant withdrawal syndrome
   Thiamine to prevent Wernicke's encephalopathy
   Vitamin replacement for malnourishment
   Antacids to reduce potential gastritis symptoms
2. Monitor vital signs
3. Follow patient safety protocols because major brain functions may be impaired
4. Keep environmental stimuli at a low level as excessive stimulation leads to hallucinations and agitation
5. Provide adequate hydration and caloric intake
6. Observe for signs of increasing tremors or confusion indicating impending delirium tremens

## Septic Shock

The use of aircraft for the transportation of severely ill and injured patients is becoming increasingly more common. As a result, it is inevitable that a patient thought to be stable will deteriorate in flight. One diagnosis that must be considered in these patients, especially those who are immunocompromised, have experienced recent surgery, sustained significant trauma, or have in-dwelling catheters, is the development of sepsis.

Sepsis may present in a spectrum of signs and symptoms that may range from extremely subtle in the early phases of the disease to complete cardiovascular collapse. This later phase, sepsis with hypotension and inadequate tissue perfusion, is defined as septic shock. The constellation of signs and symptoms of sepsis include fever, chills, tachycardia, tachypnea with respiratory alkalosis, dermatologic changes, widened pulse pressures, and altered mentation. Although fever is common in sepsis, patients may present with hypothermia, especially neonates or elderly patients. With decreased perfusion of tissues in septic shock, severe metabolic acidosis is a common additional complication.

The goal of the treatment of sepsis should be the eradication of the infecting organism prior to the onset of the cascade of cellular, microvascular, and cardiovascular events that lead to septic shock. Therefore, treatment is usually initiated prior to the identification of a specific infecting organism. Empirical treatment is recommended using broad spectrum antibiotics chosen to cover the organisms most likely to be responsible for the sepsis. The patient's history of illness of trauma is especially helpful in determining the choice of antibiotics.

Supportive therapy is essential in maintaining adequate oxygenation and hydration. Adequate ventilation with supplemental oxygen will correct hypoxia and its associated symptoms. IV fluid therapy will enhance tissue perfusion and oxygen delivery. In those cases where septic shock does not respond to fluid therapy, treatment with vasoactive pharmacological agents such as dopamine may result in increased cardiac output and improved tissue perfusion.

### Implications for AE

Monitoring for signs and symptoms attributable to early sepsis is essential in patients who have conditions that are predisposed to this development and subsequent progression to septic shock. Initial evaluation of the patient's oxygenation and tissue perfusion is a priority because the aeromedical environment may predispose a patient to hypoxia and dehydration, compounding the effects of sepsis upon the respiratory and cardiovascular systems. Early intubation and mechanical ventilation may be required in these patients. IV fluid administration is important in maintaining appropriate blood pressure and tissue perfusion. Anemia may be extremely detrimental in patients with sepsis. Although healthy individuals in the aeromedical environment may tolerate mild anemia, septic patients who are anemic are at increased risk and may require transfusion to maintain oxygenation of tissues.

Precautions required to prevent secondary infection during AE depends upon the minimum infective dose to produce illness and the mode of transmission of the disease. *Airborne precautions* are designed to reduce risk of infection transmitted by airborne particles $\leq 5\,\mu m$ in diameter. These particles remain suspended in air indefinitely. Diseases communicated by larger ($>5\,\mu m$) particles are less transmissible and require *droplet precautions*. Less stringent respiratory precautions are required since large droplets remain suspended in air for short periods of time. *Contact precautions* are used to prevent illnesses spread by direct contact with skin, contaminated surfaces and body fluids. Standard infection control procedures are sufficient for diseases spread by the contact or droplet modes and only airborne diseases require additional special techniques such as high efficiency particle filtration (HEPA) masks.[17] The prototype of this class of agents is the smallpox virus. The viral hemorrhagic fevers have been considered to be in this class in the past, but uncertainty has developed in this position based on observations of patients with Lassa fever who have been transported by commercial and AE flights.[17] For the purposes of AE, all patients exposed to a biologic agent should be considered infected, regardless of symptoms. Although the infectious risk to medical personnel depends on the agent involved, it may be impossible to determine the exact agent prior to AE.

## Biologic and Chemical Casualties

Patients contaminated with chemical or biologic agents as a result of occupational exposure or terrorist event may sometimes need AE transportation. External decontamination is the first important consideration and must be performed prior to AE for all patients exposed to chemical or biologic agents. Once patients are decontaminated, the degree of further precautions needed during AE will be determined by the actual or suspected agent involved and the patient's medical condition. To protect medical personnel and other patients, precautions should be used when transporting any patient exposed to chemical or biologic agents, as outlined in Chapter 11 and the excellent review of Withers and Christopher.[17]

Both the incubation period prior to symptomatic disease and the time of greatest infectivity vary greatly for different biologic agents. Diseases that are transmissible during the incubation period present the greatest challenge. Because the infected individual cannot be identified on the bases of clinical findings, the chance of secondary infection of other personnel is increased and preventive measures cannot be applied selectively.

### Isolation During AE

Patients confirmed or suspected to have a highly infectious or contagious disease can be isolated during AE using the Vickers aircraft transport isolator (VATI) (see chapter 11, Fig. 11.2) an air transport isolator. A stretcher isolator is a lightweight unit for initial patient retrieval, where the patient is then transferred to the air transport isolator in or near the aircraft. This allows for full nursing capability provided by an isolation team from the USA Medical Research Institute of Infectious Diseases to care for patients in-transit. All air passing in and out of the unit travels through a high-efficiency particulate air filter. If the unit is accidentally punctured, negative pressure within the unit prevents potentially contaminated air from contaminating the cabin air. Gloved sleeves within the unit facilitate care of the patient. Because of its size, the use of this unit is limited to large transport aircraft such as the C-130 and C-141. For shorter distances, the CH47 Chinook helicopter may transport patients.

A few diseases are considered by the World Health Organization to be internationally quarantinable and are thus a contraindication to elective AE. Authorization by both command, if military, and diplomatic authorities must be obtained prior to AE across international borders.

In both the civilian or military spheres, the possibility exists of chemical contamination as a result of either occupational exposure or terrorist activities. Onset of symptoms is usually rapid after exposure to most chemical agents, although symptoms may be delayed for several hours after exposure to some agents.

Patients exposed to chemical agents must be thoroughly decontaminated prior to AE. Treatment may be required throughout the AE flight. Medical attendants must be familiar with appropriate therapies for various chemical agent exposures.

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