Military aeromedical evacuation, with special emphasis on craniospinal trauma

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This brief intends to educate civilian neurosurgeons on the structure and function of the US military aeromedical evacuation (AE) system, with special focus on the role of the military neurosurgeon. It highlights the thought process required to participate as a surgical provider in the AE system. It further clarifies the expanded role the AE system plays in nonbattle evacuation. (DOI: 10.3171/2010.2.FOCUS1023)

Key Words • military aeromedical evacuation • casualty • trauma • traumatic brain injury

The natural cost of war is casualties. Previously these were treated near the front lines in abbreviated fashion and in cramped conditions, due to the inherent difficulty in moving severely injured patients, especially when that transportation was rough, slow, and limited. These latter conditions no longer apply, and casualty evacuation is possible to an unprecedented degree with respect to speed and distance. This is due to more than the rapid global reach of modern airlift; the current golden age of quick and long-distance casualty evacuation owes much to clinical advancements in the quick stabilization of severe injuries.

What is Military AE?

The US military uses its AE system for flexible movement of casualties. “Casualty” is a practical term including anyone needing evacuation; it implies a mismatch between medical capability at the place of injury and the degree of injury—or illness. Battle casualties must be air-lifted out, but so too must US soldiers with other diseases and nonbattle injuries, such as a herniated disc thrown out during an impromptu football game. The US AE network routinely transports coalition forces and even enemy combatants requiring medical treatment. The AE system moves sick and injured refugees and humanitarian crisis survivors. In short, AE provides relief for more than just battle injuries and to more than just US soldiers.

Abbreviations used in this paper: AE = aeromedical evacuation; AF = Air Force; CAR = cabin altitude restriction; CASF = Contingency Aeromedical Staging Facility; CCAT = Critical Care Air Transport; ICP = intracranial pressure; ICU = intensive care unit.

The Stages of Patient Movement

Combat casualties are sent rearward in stages. Immediately following the injury, a soldier is trained to apply “self-aid,” followed by squad mates providing “buddy care.” On-scene evacuation occurs via a helicopter or ground vehicles (known as Vehicles of Opportunity) close at hand. The patient is taken to the first echelon of care, the first medical provider. This person may be a company medic, or in some cases a forward surgical team. The forward surgical team is a 4-person squad: trauma surgeon, orthopedic surgeon, anesthesiologist, and operating room technician or nurse. They carry portable operating supplies in backpacks and can perform several operations before resupply. Frequently they work in any shelter available, even under trees or in bombed-out buildings. As soon as practical, the patient is sent on to the nearest true field hospital with an airfield adjoining; this will be the first stop if a helicopter evacuation is available from the scene of injury. Field hospitals are usually within 30–90 minutes’ helicopter time from the front lines. Once at a field hospital, the patient enters the official AE system. Administrators coordinate the patient’s movement request with logistics and aircrew supervisors overseeing the entire theater’s situation. Patients can be requested for “urgent,” “priority,” or “routine” evacuation (Table 1). Meanwhile, the trauma and/or orthopedic surgeons who staff these field hospitals will assess and stabilize the patient to prepare him or her for air evacuation to the major theater hospital, which will have surgical subspecialization, including neurosurgery and a CT scanner.

Travel from a field hospital to one of the main theater hospitals (Balad base, Iraq, or Bagram base, Afghani-
Further surgical or intensive stabilization is provided at the theater hospital; if the injury can be definitively corrected, it will be. Most patients need further specialized care, recuperation, or staged procedures; they are moved to Germany (in the case of casualties generated in Central Asia or the Middle East), to the regional medical center at Landstuhl. This involves a 5- to 7-hour flight in either a C-17 or a KC-135 transport. Once there, a patient may stay weeks, days, or only hours before setting off to the continental US, which takes 7-8 hours to Maryland, for the Army and Navy hospitals in Washington, DC; or 10 hours to Texas, for the military burn and trauma center in San Antonio. Each of these military treatment facilities is connected by air routes; at each of these stops the patient is reevaluated. The goal is to take the patient as far as required, as fast as required. As with civilian patient transfers from hospital to hospital, the patient remains the responsibility of the relinquishing physician until the gaining physician takes over. Unlike normal civilian transfers, however, air evacuation is a multistep, frequent, and high-volume exodus of casualties. Coordination among the multiple players is the crucial step.

Participants and Roles

The AE system depends on four types of clinical teams to shuttle severely injured patients safely and promptly across continents (Table 2). The provider—who is often a trauma surgeon or an orthopedic surgeon until the theater hospital level of care—evaluates and sets the treatment plan for the patient. Immediate or planned stabilization follows, and the surgeon uses any intervening time to ensure that the patient is ready for transport. This entails understanding the unique stresses of flight and adapting the clinical orders to care for the patient in flight as well as on the ward or in the unit.

The flight surgeon provides guidance to coordinate the aviation and clinical situations. His contribution is to verify that the patient meets criteria for flight and that safety measures have been ordered. Each patient will have orders written by the provider and reviewed by the flight surgeon—especially with regard to the need for oxygen, pressure-related precautions, and in-flight comfort. The flight surgeon’s presence is the final step needed to clear the patient to leave the hospital and fly to the next echelon of care. All flight surgeons fly in military aircraft frequently as nonpilot aircrew. They are trained to understand physiological and pathological conditions related to altitude, speed, and military aviation environments. This skill set enables them to ensure that a stabilized patient will fly with the typical risks of altitude and flight mitigated.

Working with the flight surgeon are the nurses, technicians, and pharmacists of the Aeromedical Staging Facility (in contingency/wartime operations this is called a CASF). This team expedites the gathering of supplies and preparation of the patient to be ready and loaded onto the mission aircraft in an orderly, safe, and expeditious manner. Moving even one patient can present a nightmare in keeping together all the supplies, medications, dressings, additional equipment, records, and personal effects; the CASF team ensures continuity during transfer to and from the aircraft of all the many patients moving simultaneously at all hours of the day and night. Also, they can provide an overnight ward level of care for patients passing through on a short layover.

Once the patient gets to the aircraft, the on-board AE team takes over. These are flight nurses and flight medical technicians who will provide a ward level of care for patients in flight. They are highly trained to be self-sufficient in handling the rare emergencies and other spur-of-the-moment issues that arise. Similarly to civilian medical flight crews, they are handpicked for their seniority, experience, and clinical maturity. There is no physician present on routine AE flights. In the cases in which a patient must be transported at an ICU level of care, a special team of medical attendants will care for the patient in transit. This is the CCAT team; this team is composed of an ICU-certified physician (usually a pulmonologist, cardiologist, or emergency room physician, because the surgeons are occupied in the field hospitals), an ICU nurse, and a cardiopulmonary technician. Because CCAT teams care for ICU-level patients en route, close communication between the CCAT team attending physician, who is not a surgeon, and the relinquishing surgeon is vital. With the advent of CCAT teams, regular and safe evacuation of ICU patients has become feasible. This is the highest example of the coordination among the different clinical teams flying the evacuation missions.

### TABLE 1: Patient movement precedence

<table>
<thead>
<tr>
<th>Requested Precedence</th>
<th>Expected Time to Movement</th>
</tr>
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<tbody>
<tr>
<td>routine</td>
<td>&lt;72 hrs</td>
</tr>
<tr>
<td>priority</td>
<td>&lt;24 hrs</td>
</tr>
<tr>
<td>urgent</td>
<td>as soon as possible</td>
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</tbody>
</table>

### TABLE 2: Participants and roles*

<table>
<thead>
<tr>
<th>Team/Participant</th>
<th>Role(s)</th>
</tr>
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<tbody>
<tr>
<td>primary surgeon</td>
<td>assess, stabilize, define Tx goal, request air evacuation &amp; precedence, write orders for transfer</td>
</tr>
<tr>
<td>flight surgeon</td>
<td>review case, clear pt to fly, act as consultant for primary surgeon, coordinate CASF &amp; AE efforts</td>
</tr>
<tr>
<td>CASF</td>
<td>ensure pt prepared for flight, screen pt for security, deliver pt to/from aircraft</td>
</tr>
<tr>
<td>AE medical flight crew</td>
<td>in-flight medical care per orders (ward level)</td>
</tr>
<tr>
<td>CCAT team</td>
<td>deliver ICU pts to/from aircraft, in-flight ICU-level care</td>
</tr>
</tbody>
</table>

* pt = patient.
TABLE 3: Aircraft types involved in AE*

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Description</th>
<th>Phase of AE</th>
</tr>
</thead>
<tbody>
<tr>
<td>UH-1 “Huey”</td>
<td>Army helicopter, Vietnam-era</td>
<td>front lines to field hospital</td>
</tr>
<tr>
<td>UH-60 “Blackhawk”</td>
<td>Army et al. helicopter</td>
<td>front lines to field hospital</td>
</tr>
<tr>
<td>C-9 “Nightingale”</td>
<td>AF medical transport</td>
<td>front lines to field hospital</td>
</tr>
<tr>
<td>C-17 “Globemaster III”</td>
<td>AF large jet transport, bare field capability, long-distance craft</td>
<td>theater to regional hospital (Central Asia to Germany), regional hospital to CONUS (Germany to MD or TX)</td>
</tr>
<tr>
<td>KC-135 “Stratotanker”</td>
<td>AF jet air refueler/tanker, long-distance craft</td>
<td>theater to regional hospital</td>
</tr>
<tr>
<td>C-130 “Hercules”</td>
<td>AF turboprop, medium-sized, medium-distance, bare field capability, loud &amp; rough ride</td>
<td>field to theater, (rarely) theater to regional hospital</td>
</tr>
<tr>
<td>C-12</td>
<td>AF turboprop, small-sized</td>
<td>field to theater, (rarely) theater to regional hospital</td>
</tr>
<tr>
<td>C-21 Learjet</td>
<td>AF small jet</td>
<td>as needed</td>
</tr>
<tr>
<td>KC-10</td>
<td>AF large jet refueler/tanker</td>
<td>as needed</td>
</tr>
<tr>
<td>C-5 “Galaxy”</td>
<td>AF very large jet transport</td>
<td>as needed</td>
</tr>
</tbody>
</table>

* CONUS = continental US; MD = Maryland; NA = not applicable; TX = Texas.

The USAF is the main branch of the armed forces providing aircraft and manpower for AE. The Army does provide helicopters for the early stages of evacuation before arrival at a fixed facility; these are the venerable UH-1 “Huey” or the UH-60 “Blackhawk” helicopters (Table 3). In past years, AE relied primarily on the C-9 “Nightingale,” heavily modified jets with their sole use as medical transports. More recently, the military has adopted a more generalized and flexible philosophy; any aircraft that can physically accommodate litters and/or ambulatory patients can be used. In practice, however, there are several common aircraft. The C-17 transport is a large 4-engine cargo jet with a long range and the ability to land on dirt runways. It can hold several dozen patients of both litter-bound and ambulatory types. The slightly smaller C-130 is a medium-sized 4-engine propeller aircraft with less range but more flexibility in landing in less improved places. It is legendarily loud, slow, and useful for all transport missions, including AE. The third most common airplane is the KC-135, which is primarily an air-to-air refueling tanker with some cargo capacity. Other less commonly used aircraft in AE include the small C-21 Learjet, the smaller C-12 (twin-engine propeller plane), and the enormous C-5 “Galaxy,” which is nearly too big to carry people efficiently. The KC-10, another tanker with some cargo space, is occasionally used too. The clinician does not control which type of aircraft is used; it rarely matters much. There is a set list of generalized stressors of flight that must be considered, no matter the aircraft type.

Stressors of Flight and General Clinical Considerations

Flight surgeons exist because the aviation environment is notably different from that at altitude sea-level and speed zero. Flight poses unique stressors (Table 4). The first and greatest risk is hypoxia. Half the atmosphere is below 18,000 feet; above that there is simply less air, and less air means less oxygen. With increasing altitude, the partial pressure of oxygen decreases; this is the Dalton law. Even in a normally pressurized commercial aircraft cabin, the effective altitude is 8–10,000 feet. This rarely causes noticeable hypoxia in resting, healthy airline passengers, but it can adversely affect ill patients. Comorbid conditions can worsen the risk of hypoxia. The greatest danger with hypoxia is that it can affect individuals in highly unique ways, and it usually has a very subtle onset. Altitude can cause other blood gas disorders. Altitude “bends” (that is, decompression sickness) or even arterial gas embolisms are possible, although they rarely occur without inadvertent decompression of the cabin above 18,000 feet in altitude. These disorders occur because gas solubility changes with decreased pressure at altitude. These are the worst and most feared possible pressure-related side effects, and fortunately they are rare. Another barotrauma effect involves the Boyle law, which describes the volume expansion of gas with increased altitude (that is, decreased pressure). Besides flatulence and discomfort in ears and sinuses, this can cause damage to the tympanic membrane, rupture of sinuses, distension of the diaphragm, and altered thoracic hemodynamics. If there are traumatic or iatrogenic air pockets in vital structures like the eyeball or brain or chest, the normal operating altitude-related increase in volume can cause catastrophic effects. Additionally, barotrauma is a unique and easily forgotten source of pain, which may be especially dangerous in cases of head trauma with tenuous ICP control.

Additional stressors of flight include temperature shifts, vibration, noise, decreased humidity, and g-forces. Despite rudimentary environmental controls, the cabin pressurization system causes refrigeration of the air. A typical military transport is either too cold or too hot: frequently it is both on the same flight, and there are frequent oscillations between the two. Unlike helicopter transfers, fixed-wing aircraft cannot taxi as close to the medical center, so more in-transit exposure to the elements (hot and cold) occurs. Airplanes that are propeller driven, like the C-130, tend to have high vibration loads. Any patient situated near the bulkheads (walls) or ramp will be subjected to total body vibration. With vibration comes gen-
eralized muscle stimulation and increased metabolism. Sound also can be highly uncomfortable, detract from rest, and increase stress. Vibration, noise, and dry air make the cabin tiresome at best. Routine air exchange is integral to maintaining pressurization and breathability, but it does cause a loss of moisture. A 2-hour flight will drop the cabin humidity to 5%; a 4-hour flight can see the humidity at or below 1%. This can cause breathing problems and can exacerbate clearing ears and sinuses of pressure. It can also worsen dehydration. The movement of body fluids touches on another stress of flight: g-forces. Most transports, even in combat zone landings and takeoffs, do not sustain high g-forces (>2–3 times gravity’s force). Most of the impetus is in the fore-aft direction, and is usually worse with takeoff than landing. However, this is a stress that easily slips the mind of a provider on the ground writing orders for a patient soon to be spending hundreds of miles and hundreds of minutes in the air.

*HOB = head of bed; IV = intravenous; temp = temperature.*

**TABLE 4: Stressors of flight and their management***

<table>
<thead>
<tr>
<th>Stressor</th>
<th>Management/Prevention</th>
</tr>
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<tbody>
<tr>
<td>hypoxia</td>
<td>supplemental oxygen, CAR, assign additional medical attendant</td>
</tr>
<tr>
<td>barotrauma (to ears, sinuses, abdomen, chest, pneumocranium)</td>
<td>rare w/o cabin decompression above 18,000 ft</td>
</tr>
<tr>
<td>decompression sickness, arterial gas embolism</td>
<td>provide blankets, assess pt &amp; temp regularly</td>
</tr>
<tr>
<td>temp shifts</td>
<td>position pt away from bulkheads, verify that litter is buffered</td>
</tr>
<tr>
<td>vibration</td>
<td>earplugs</td>
</tr>
<tr>
<td>noise</td>
<td>fluids (oral/IV); assess eyes, breathing, &amp; hydration</td>
</tr>
<tr>
<td>decreased humidity</td>
<td>positioning: feet forward, HOB 30°, notify aircrew via flight surgeon</td>
</tr>
<tr>
<td>g-forces</td>
<td>antiemetic provided as needed</td>
</tr>
<tr>
<td>air sickness</td>
<td>sedate if necessary, regularly assess for comfort, keep pt oriented, ambulate/</td>
</tr>
<tr>
<td>cumulative fatigue, pain</td>
<td>range-of-motion exercises</td>
</tr>
</tbody>
</table>

**Neurosurgical Patient Care in AE**

In recent wars, the pattern of injury has changed away from the torso—relatively—and increasingly to the extremities and head. Although spinal injuries are still frequent, head trauma from improvised explosive devices (IEDs) and rifle fire is nearly ubiquitous. Due to the varying types of casualties evacuated, neurosurgeons may indeed encounter diseases and nonbattle injuries requiring evacuation too. In light of the generalized stressors of flight mentioned earlier, the neurosurgeon must consider additional facts. Hypoxia in a patient with existing traumatic brain injury should be actively avoided as well as warned against; a single episode can be catastrophic. Pneumocranium should be expected with skull or facial fractures. Similarly, barotrauma in sedated or unconscious patients may result from their inability to release the pressure via swallowing or a forced Valsalva technique. Also, the normal aviation stopgap techniques for dealing with ear block or sinus pain are a forced Valsalva maneuver to clear ears or sinuses, or as a last resort a Politzer bag, which forcibly injects air to reverse the eustachian seal. Both the Valsalva technique and Politzer bag can dangerously increase ICP and/or fracture craniofacial bones.

The safest alternative is to prevent barotrauma with CAR.2 The physician can order the cabin altitude to be at or below a certain level to prevent pressure-related trauma to vital structures. Even flying over the mountains out of Afghanistan, CARs can be used. With a cabin altitude of 2000 feet, a C-17 can still climb up to nearly 24,000 feet before the pressure gradient across the plane’s bulkhead is too steep. Below this, the cabin altitude can be set to even lower levels. Most cases of CAR are to 4–8000 feet, which permits transports to fly as high as they need to. For another example, vibration in a neurosurgical patient can cause motion sickness; emesis will elevate ICP. Antiemetics consequently must be prepared for use whenever ICP is a concern. Patients with hypothalamic involvement may be at greater risk to temperature swings. Dehydration can damage exposed mucus membranes and the cornea in patients without intact blinking.

For patients with problems controlling ICP, a ventriculostomy may be safely used on board. The AE team will close the stopcock for patient movement, for takeoff, and for landing. They are trained to ensure that it is not closed longer than 15 minutes; they also have training and written guidance in troubleshooting basic ventriculostomy failures. For evacuation of ICP cases such as severe head injury, the patient is loaded in the reverse of the normal feet-forward position.2 The takeoff g-forces will draw down pressure intracranially with the patient in the feet-aft position. Even AE crews are qualified to use mannitol, drain fluid from a ventriculostomy, perform hyperventilation in the patient, and follow arterial blood gas levels with portable on-board diagnostic equipment. Head of bed elevation, via a litter-backboard, and “head midline” are routine orders for severe head injury/ICP cases. All these capabilities are included in basic AE crew training.1

Further care is available via the ICU staff of the CCAT team. Under their expertise, hypertonic saline is available, mainly 3% but occasionally 23%, for either drip or bolus at the instruction of the relinquishing surgeon and depending on the familiarity of the en-route ICU physician. On the other hand, few AE teams will have...
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encountered spinal or deep brain stimulators. If a patient with one of these devices is being transported, the neurosurgeon must make clear to the CASF and AE teams that routine antihijacking screening must not include handheld devices or detectors, which may interfere with the implant(s). In cases of spine instability, patients can be transferred on vacuum boards, in Halo braces, or on hard backboards. These patients are prepared with special instructions for hand loading, and the litter is locked into place on the cabin floor to ensure maximal rigidity during flight. In-flight deteriorations are rare with spine cases; we know this because any complication of flight is tracked and investigated by the safety branch of the Global Patient Movement Requirements Center at Scott AF Base, near St. Louis. Once all preparations are done, and the patient has flown off, the neurosurgeon can be comforted that in the event of a sudden change in status or other crisis, radio communication can connect the medical crew members with a specialist. In this case, the aircraft’s pilot plans to immediately lower cabin altitude (the term for cabin pressure and the altitude to which that pressure corresponds; the pilot will also lower the aircraft altitude if practical), and will consider diverting to an airfield with neurosurgical and radiographic capabilities. The key to anticipating modifications required by head, spine, and peripheral nerve cases during transit is to remember the stresses inherent in flight.

Conclusions

Routine AE takes sick and injured people and places them in transit in an inhospitable environment. For neurosurgical patients aboard an AE flight, this involves spending hours minimally mobile in a locked metal room that is loud and shaking, too cold and too hot and too dry, with constant exposure to less oxygen and more gas in the body cavities than is normal or comfortable. That so many do so well bears witness to the flexibility and preparedness of neurosurgeons and their associated AE colleagues.

Disclosure

The author reports no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

References


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