29. AIR TRANSPORT OF THE CRITICALLY INJURED PATIENT: CONTROLLING PAIN DURING TRANSPORT AND FLIGHT

INTRODUCTION

Contemporary warfare has brought both advancements and new challenges for acute pain management in the combat setting. Although survivability has increased secondary to improvements in body armor, the necessarily exposed limbs of soldiers have become even more vulnerable to progressively more destructive explosive devices. The lethality of improvised explosive devices, explosively formed penetrators, and other weapons has clearly increased during the course of the current conflict. Rapid patient evacuation out of the battlefield, far-forward advanced surgical capabilities, and rapid air evacuation of combat wounded to critical care facilities outside of the war theater are the key factors resulting in a less than 10% died-of-wound rate. Historically, the relatively austere medical environment of the US Air Force (USAF) evacuation aircraft (Figure 29-1) made the management of acute pain in multitrauma patients particularly difficult.

Today, the ability to evacuate patients from the battlefield has evolved into the most efficient transport and medically capable system in history. At the core of this system lies the USAF aeromedical evacuation system (AES). With the inclusion of the critical care air transport team (CCATT), the AES has been described as a 6,000-mile-long intensive care unit in the sky, stretching from staging areas in the Middle East to the continental United States.

Although CCATTs focus on the critical care patient, the majority of injured soldiers require AE transport without mechanical ventilation, inotropic medications, or other measures typically associated with critical care. However, these patients often have sustained massive injury, such as multiple amputations of limbs and complicated orthopedic injuries. Although "hemodynamically stable," these patients still have acute needs for in-flight monitoring and aggressive pain management.

Figure 29-1. Interior of air evacuation aircraft.

The US military experience with evacuating casualties by air dates to World War I. Until recently, advances in pain management during evacuation have not kept pace with advances in casualty resuscitation and transport. This chapter will address the historical casualty transport capabilities of the military, advances in patient care enroute, and the addition of advanced pain management during evacuation. Specific challenges encountered in patient care while traveling for hours for thousands of miles on military aircraft will also be addressed.

HISTORICAL TRANSFORMATION OF THE AIR FORCE ENROUTE CARE PLATFORM

The World War I air evacuation efforts led to the organization of an integrated AES by the US Army Air Corps during World War II. This system included nurses with specific AE training serving on cargo aircraft returning from the theater of battle.

By the 1990s the AES included command and control functions, trained crews, mobile facilities for staging patients preflight, and extensive logistical support. The system could rapidly deploy, set up, and evacuate large numbers of stable casualties, but it lacked the intrinsic capability to manage critically ill casualties, instead relying on medical attendants, supplies, and equipment provided by the sending medical facility. The requirement to provide these resources was a particular challenge for small field hospitals with limited personnel, which cannot lose personnel without seriously degrading their capability. This problem became evident in Somalia when the surge of combat casualties on October 3–4, 1993, overwhelmed the medical response capabilities, casualties accumulated, and the most critical patients could not be immediately evacuated. Following Operation Desert Storm in 1990, calls were made for the addition of AE physicians and equipment capable of managing unstable patients in flight.

JOINT ENROUTE CARE SYSTEM

The current joint enroute care system includes contributions from each of the US military services and, in many cases, from coalition military medical services as well. Casualties are evacuated through five levels of care with increasing capability, from self care and buddy care with initial management at aid stations close to the point of injury, through advanced rehabilitative care at military and Veterans Administration medical centers in the United States.

Casualty evacuation (CASEVAC), a term used by all services, refers to the movement of unregulated casualties by nonmedical units aboard nonmedical ground vehicles, without enroute care by medical professionals. The casualty is taken from the point of injury to the most appropriate medical facility; typically level I or level II facilities. The CASEVAC mission may involve care under fire, and speed and security are more important than advanced enroute care. In the US military, CASEVAC is overwhelmingly an Army, Marine Corps, or Navy mission.

Medical evacuation (MEDEVAC) refers to a US Army capability involving designated rotary-wing aircraft and specially trained enlisted medical crewmembers. In MEDEVAC casualties are transported aboard medical helicopters under the care of combat medics with advanced flight training. Constituting a paramedic level of care, this capability can be used from the point of injury to a medical facility, or between facilities.

Strategic evacuation (STRATEVAC) is primarily the domain of the USAF. AES refers to the regulated movement of casualties from level II or III through level V facilities by fixed-wing USAF aircraft. Staging facilities at hubs of the AES serve as buffers, allowing casualties to be housed, fed, and prepared for flight at a location from which they can be rapidly loaded as aircraft become available. Basic medical care and wound care, as well as basic (oral and intravenous [IV] bolus) pain control, are provided at these locations. Patients waiting at the hubs typically have minor injuries preventing them from immediately returning to duty. Aboard the aircraft, an AE crew, consisting of flight nurses and AE medical technicians who have undergone specialized training, manages the patients. The care given by an AE crew is limited by the large number of patients they are tasked to manage and their level of medical training. If a patient requires more care than this basic level, the sending facility has historically been responsible for providing a medical attendant during evacuation. Today, for casualties who are critically ill or injured, the AE system provides the medical attendants in the form of the CCATT.

The AE function can be categorized as tactical evacuation (TACEVAC) within a military theater of operations or STRATEVAC between theaters of operation. The most commonly used aircraft for TACEVAC is the C-130 Hercules (Figure 29-2). This aircraft is capable of operating from unimproved airfields and in hostile locations. The C-130 flies at 318 knots at 20,000 feet, with a maximum ceiling of 23,000 feet. It has the capacity for up to 74 litter patients, but does not have onboard oxygen systems, mandating that oxygen to be carried onboard as a portable liquid oxygen system or a compressed gas. The electrical system provides 400 Hz AC power through specially configured outlets, limiting its direct utility for medical devices. Therefore AE/CCATT must rely on battery power, or power provided through an electrical converter, which limits the total amperage output for medical equipment use. Lighting and environmental control systems are minimal, requiring additional measures for patient warming and visualization of patient care. Lastly, access to patients is limited to 180°.

The C-17 Globemaster III (Figure 29-3) has the unique quality of being an excellent aircraft for both TACEVAC and STRATEVAC. It has a speed of 450 knots at an altitude of 28,000 feet, with an unrefueled range of 2,400 nautical miles and unlimited range with aerial refueling. This range makes it useful for transoceanic missions. The C-17 can also utilize small, unimproved airfields with runways as short as 3,500 feet long and 90 feet wide. The aircraft's interior is well lit, and the system of litter stanchions provides 360° access to critical patients. The C-17 contains built-in systems that provide medical oxygen at 50 psi and 60 Hz AC electric power through standard US outlets. Currently the workhorse in patient transport, the C-17 can be rapidly configured from use as a cargo aircraft to accommodate 36 litter patients.

Figure 29-2. C-130 Hercules

PIECES OF THE ENROUTE CARE PUZZLE

The USAF is solely responsible for the transport of injured US military from the theater of operation to their home station. This requires the ability to transport and provide ongoing care during long distance flights lasting from 2 to 5 days. The system relies on available USAF aircraft that are temporarily converted into AE-capable platforms as the need

Figure 29-3. C-17 Globemaster III

arises. USAF teams involved in patient transport include the aircraft crew, AE medics, and the CCATT.

Until the mid-1990s, most if not all injured patients requiring AE transport had to be relatively stable for transport. Very little care was performed in the aircraft due to limited capabilities of the medical AE teams. For example, if a patient in Germany had an uncomplicated exploratory laparotomy, he or she would have to stay at the hospital where the surgery was performed until considered stable for transport, which would have been anywhere from 3 to 5 days postoperation. If patients required any special care or pain medicine other than oral or intermittent IV bolus, a medical attendant would have to travel with them to manage their care during transport. Early AE teams typically consisted of a mix of registered nurses and medical technicians, specifically trained for air transport of the medical patient. A typical AE team included two nurses and three technicians; an expanded team consisted of three nurses and four technicians. The personnel assigned to AE varied from outpatient clinic personnel to critical care personnel, and the patient care abilities and comfort levels of AE team members ranged vastly. Anything other than basic care was limited by the makeup of the AE team. The typical AE transport had a patient load of anywhere from 1 to over 50 patients, depending on the types of patients, whether they were ambulatory or not, and the aircraft available. To support this method of AE, the holding capabilities of medical facilities in and out of theater had to be robust, which was logistically difficult to support and often not in the best interest of the patient.

During the 1980s and early 1990s, Dr Paul K Carlton Jr, a surgeon and later the USAF surgeon general, developed capability for the rapid effective stabilization and transport of significantly injured or traumatized casualties. Carlton based his method on his experience at Wiesbaden, Germany, receiving casualties from the embassy bombing in Beirut, Lebanon. In 1994 Carlton and Dr Joseph C Farmer, a medical intensivist, launched the CCATT program, consisting of teams with a critical care physician, critical care nurse, and respiratory therapist, accompanied by the supplies and equipment necessary to create a critical care environment that would move with the patient during evacuation. Team members were specifically trained to provide specialized care in the high-altitude, extreme aircraft environment, with emphasis on the "AE environment." The concept of CCATT is to manage stabilizing casualties—those who have undergone initial resuscitation but remain critically ill. A physician was included on the team to provide continuous medical decision-making, so that therapies could be titrated to the patient's condition, new therapies started if required, and patients could continue progressing toward stability without interruption or setback for transport. Having a CCATT physician available during an AE mission also allowed better medical care for the non-CCATT patients, including pain management.

The timing of CCATT development allowed the US military healthcare system to adjust its doctrine in response to changing military strategy. During the Cold War, US forces prepared for large battles in predictable locations supported by established hospitals with the capacity to hold large numbers of casualties until they had completed convalescence and were returned to duty. After the Cold War ended, the US military became engaged in a large number of activities ranging from humanitarian and peacekeeping operations to combat. These operations often arose quickly, took place in unpredictable locations, and in some cases changed locations rapidly; establishing large-capacity hospitals whenever and wherever needed became impossible. Instead, the military needed to deploy small, high-capability, limited-holding-capacity facilities that could stabilize and evacuate casualties with far less logistic support. To accomplish this objective, medical personnel needed to be able to evacuate even unstable casualties safely, and CCATT offered that capability.

Enroute Pain Management. Despite advances made in the enroute care system, one aspect in need of improvement involved patients who were not critical enough for CCATT but had significant pain secondary to their injuries, which was worsened by the vibration, bouncing, and noise of the continuously moving aircraft transport environment. Due to the aircraft environment and external forces, patients frequently experienced inadequate pain control during bus transport and the aeroevacuation flight.

The aerospace environment presents numerous physiological and psychological challenges, especially with trauma patients, to medical personnel. Altitude changes, extremes of temperature, noise, vibration, lighting, power, space, and equipment restrictions are just a few of these issues. Constant vibration and the cramped conditions aboard the aircraft can make a painful injury excruciating. Appropriate padding and securing of wounded extremities help to reduce pain and protect the patient from compression injuries. Some injured military members have even gone as far as posting signs saying, "Don't bump the stump!" Attention to such simple details goes far in the management of pain in this complex environment.

Until recently, oral medication or intermittent morphine (bolus IV) were essentially the only pain management therapies available for injured soldiers during transport. Medications for pain carried on a routine AE mission included acetaminophen; ibuprofen; Tylenol 3 (McNEIL-PPC Inc, Fort Washington, Pa); Percocet (Endo Pharmaceuticals, Chadds Ford, Pa); Demerol (Sanofi-Aventis, Bridgewater, NJ); and morphine. Patients were provided written orders for either oral pain medication or IV morphine. This was the AE standard of care until mid-2002. Despite having served the military well in the past, this type of pain management fails in today's complex evacuation systems.

In a typical AE mission, patients are held in a centralized location before transport via ambulance bus (AMBUS [Figure 29-4]) to the aircraft, where they are loaded as either ambulatory or litter patients. After taxi and takeoff, a safe altitude must be reached before patient care can be given, a process lasting about 60 minutes. At the end of the mission, all personnel must remain seated during approach, landing, and taxi, which also takes about 60 minutes. Unloading patients from the aircraft onto an AMBUS and transport lasting 60 to 90 minutes to the receiving facility is the next evacuation step. At the receiving facility, unloading patients from the AMBUS into the facility for admission and room assignment adds additional time before patient care resumes. During the time of landing, taxi, loading, transport, unloading, and in-processing at the receiving facility, pain control received by the patient is minimal (Figure 29-5).

The problem of patients enduring extended time between pain medication administration was identified early in Operation Enduring Freedom and Operation Iraqi Freedom, secondary to the large numbers of patients arriving at the various receiving facilities (Landstuhl Regional Medical Center, Germany; Walter Reed Army Medical Center, Bethesda Naval Medical Center, and Malcolm Grow Medical Center, Andrews Air Force Base, in the Washington, DC, area; and Brook Army Medical Center, San Antonio, Tex) in extreme amounts of pain. An early attempt to combat this problem involved anesthesia pain teams meeting casualties as they arrived at receiving facilities. However, although the teams treated the immediate pain on arrival, the pain endured from aircraft approach to facility arrival was not treated. Anesthesia teams then began greeting the aircraft on arrival to provide pain medication (oral or IV) prior to AMBUS loading and transport. Both measures helped significantly but did not adequately address the issue of pain during transport as a whole, and the extended periods of time between dosing were not adequately resolved.

The casualty pain issues on AE flights prompted

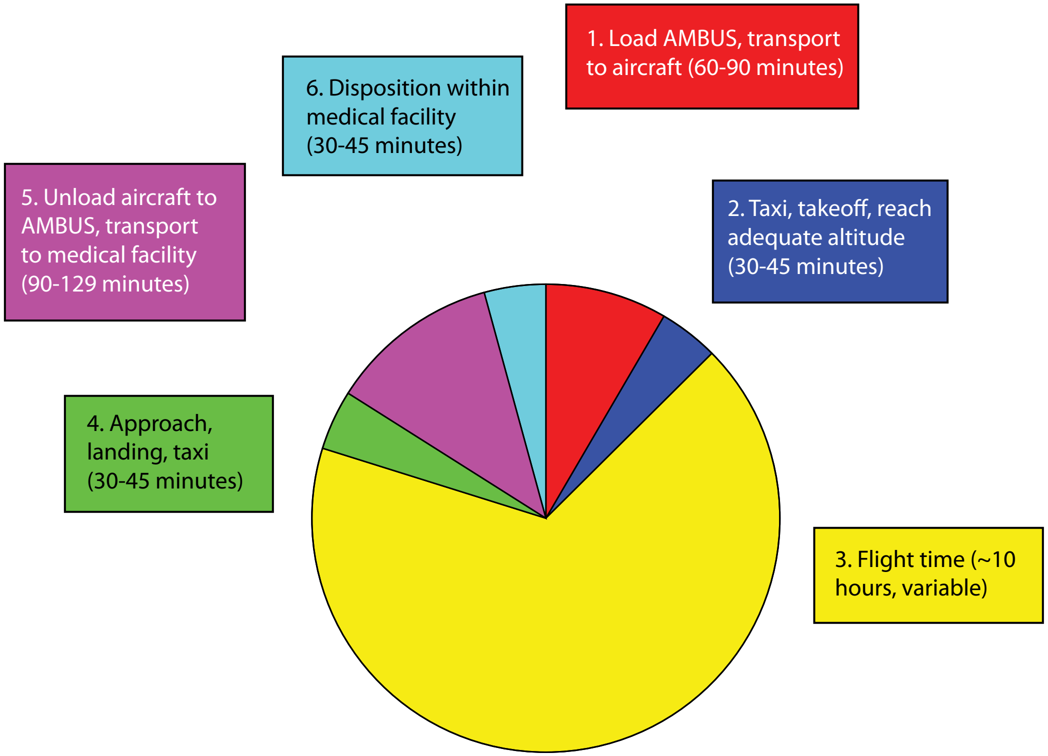

Figure 29-5. Proportionate stages of transport during air evacuation

Figure 29-4. Loading patient into AMBUS.

the triservice (Army, Navy, and USAF) anesthesia community to band together to identify and provide solutions to this problem of pain during transport. The result was the formation of the first triservice military organization specifically concentrating on management of pain in combat casualties—the Military Advanced Regional Anesthesia and Analgesia (MARAA) committee—organized in early 2002 to develop, recommend, and implement advanced pain initiatives to be placed in the AE environment.

Military Advanced Regional Anesthesia and Analgesia Initiatives. The first therapy advocated by MARAA was the continuous peripheral nerve block (CPNB), which had already proved successful for pain control but was not allowed in the AES due to lack of a medical attendant to monitor the infusion. MARAA developed a training platform for CPNBs during AE and obtained airworthiness testing and approval for the Stryker PainPump (Stryker; Kalamazoo, Mich) for the infusions. The addition of CPNBs into the AES in 2003 significantly improved the pain management of many evacuating casualties. CPNB on military aircraft has enjoyed an excellent safety record in wounded soldiers since it was first introduced on October 7, 2003. To date over 1,500 injured airmen, soldiers, sailors, and marines have benefited from this technique. However, CPNBs are appropriate only for a patient population with isolated extremity injuries, and MARAA continued developing further pain management techniques for the AES. Although none of the techniques would be considered new in a US medical facility, the application of these proven pain technologies in AE has greatly enhanced pain management in this difficult medical environment.

The second initiative was the institution of patient-controlled analgesia (PCA) for transport in 2004. PCA is common in civilian hospitals, where it is well monitored by trained nursing staff on a routine basis, whereas clinical capabilities in AE teams are unpredictable. MARAA realized that the pump selected for this mission had to be small, user-friendly, safe, and pass airworthy certification for acceptance onto military aircraft. In addition, the pump had to be relatively inexpensive and require no medical maintenance. MARAA members found the ambIT PCA pump (Sorenson Medical Inc, West Jordan, Utah) to be the best interim choice for rapid implementation of this technology.

The third initiative by MARAA was epidural analgesia for AE patient care in late 2004. Implementation of epidural analgesia enroute also required a user-friendly, fail-safe pump with simple instructions for monitoring and care. Today the pump utilized for all three pain management techniques is the ambIT infusion pump. Labels are provided in the packaging to identify the type of infusion, as well as instructions for troubleshooting and reprogramming the infusions if required. Specific rules, training, and safeguards are in place for infusion while enroute (available to the public at www.arapmi.org and to military account holders at https://kx.afms.mil//Anesthesiology). All pain techniques are followed and managed by the various military anesthesia departments while enroute. Pain care information on individual casualties is updated and tracked via the Regional Anesthesia Tracking System (RATS), a secure Web-based tool available at all medical facilities along the AE chain. Providers of regional anesthesia and other pain care technologies input and update the database online so subsequent providers will have accurate information to make patient care decisions. RATS has been used for nearly 1,000 patients. Efforts are underway to transition the RATS system into the Theater Medical Data Store system, which is being developed as the electronic military medical record of the future.

Enroute Patient Packaging. AE mission variables include flight durations that range from 1 to more than 18 hours, significant physiologic flux demanding provider treatment flexibility, and a constantly changing mission pace that necessitates rapid assessment and prioritization of care in a medically austere environment. This practice is very different from the static hospital ward experience in the United States. Experience has shown that the independent, hands-on practitioner mind-set and skill sets of anesthesiologists and emergency physicians adapt well to the care of patients in the CCATT environment, specifically for ongoing resuscitation, required procedure, and pain management. The patient care approach these physicians bring into the development and maintenance of the CCATT program has also been a major benefit.

To package a patient for multihour transport, attention must be paid to multiple issues including prevention of pressure sores, prevention of further injury, spinal immobilization, prevention of injury from attached equipment, stabilizing extremity fractures, prevention of "blocked" extremity injury, external fixator padding and stabilization, and prevention of dislodgment of catheters or kinking of tubing, in addition to pain management. These duties are usually associated with nursing but are the responsibility of the caregiver team in the air transport arena. Patients typically require increases in pain medication during air transport because of the aircraft's constant motion, compared to the stable hospital environment. An easy technique to evaluate the effectiveness of the pain control (PCA, epidural, CPNB) is to shake the patient's hospital bed to see if it causes increased pain; if so, pain dosing during AE may need to be increased 10% to 20%.

Airworthy Certification. Medical equipment on military aircraft must meet stringent criteria of airworthiness and interoperability. The major testing hurdles before approval for in-flight use include interface with the aircraft oxygen and electrical systems; assessment of how the device functions across the cabin altitude range of a typical mission (sea level to 8,000 feet) and with rapid decompression to flying altitude; whether the device produces electromagnetic emissions that interfere with aircraft systems; whether electromagnetic emissions from the aircraft interfere with device function; and effect of vibration on the device. Another important consideration is how the equipment interfaces with that used by military ground facilities prior to AE transport. The goal is to eliminate the necessity of changing out patient-applied support devices such as intravenous drip sets, pressure transducers, disposable oximeter probes, monitoring equipment, and pain infusion pumps. Device swap-outs slow down urgent care, waste supplies, and introduce opportunity for error. Patient-applied support devices are designed to be left with the transported patient until no longer needed and then returned to the system. A robust logistics system tracks the devices while in use, and then ensures their return into the enroute care system.

CONCLUSION

Arguably the most significant advances in AE pain management in decades have been the expansion of regional anesthesia strategies, both neuraxial and peripheral, in the military air transport arena. Patients are now routinely transported with epidural catheters, CPNB catheters, and PCA pumps. Indeed, the synergism of systemic opioid via PCA, combined with the targeted (but nonrespiratory depressant) effects of CPNB therapy, seems to offer the most powerful degree of pain relief available to multitrauma patients.

The evolution in AE pain management represents a revolutionary change in thinking about battlefield management of pain. Aggressive treatment of pain is now part of every wounded soldier's care plan. Certification of an airworthy portable infusion pump paved the way for implementation of PCA, epidural, and CPNB regional anesthesia during AE on military aircraft.

Ensuring that all acute pain management options are exercised as early as possible in the AE chain is critical. Building on the lessons of combat trauma, both military and civilian anesthesiologists can increase use of new pain management techniques for the acutely injured. The experience in pain management during combat AE has brought innovative and effective pain management solutions into common military use. MARAA continues to aggressively monitor and recommend further additions to the toolbox of pain therapies available for treating wounded service members.