4 En Route Care

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Abstract

The history of aeromedical evacuation parallels that of manned flight. The first fixed wing aeromedical evacuations occurred on limited basis during the First World War with a significantly increased experience occurring during the Second World War. The Korean War introduced the role of rotary-wing transport in decreasing transport time from the forward area of battle to medical care units. Vietnam expanded on this rotary-wing evacuation experience and introduced a limited set of medical interventions for the casualty during the transport process. The experience of aeromedical evacuation in the military during Vietnam was largely responsible for the subsequent proliferation of civilian aeromedical evacuation services in the trauma system of the United States during the latter part of the twentieth century.

The last 15 years of conflict as a result of the Global War on Terrorism has provided an extended experience in the art and medical science of aeromedical evacuation. The scope of this chapter will focus on current concepts of aeromedical evacuation as it evolves into a process of en route care. The evolution from safe transport via the air to a continuous process of medical care and continuous resuscitation marks the pivotal changes that have emerged over the last decades of care in the air. The evolution of terminology from aeromedical evacuation to en route care highlights the focus on principles of care rather than mode of transportation.

This chapter will focus on the challenges of the aeromedical environment, the composition of the advanced care teams (Critical Care Air Transport Teams), and the processes of provision of care in this uniquely challenging space. The current team composition and equipment sets will be discussed along with opportunities for new technologies to positively impact on the provision of en route care.

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4.1 Introduction

The concept of transporting combat casualties by air parallels the history of military aviation. Many texts cite the aeromedical evacuation of casualties by balloon during the Franco-Prussian War

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(1870) as the first successful instance of aeromedical evacuation. More recent publications have challenged and refuted this claim [1]. The true initiation of aeromedical evacuation awaited the successful development of the fixed-wing aircraft. During the First World War, British, French, German, and American forces all utilized fixed-wing evacuation on a very limited basis. These first aeromedical evacuations provided the opportunity for medics to overcome the "tyranny of distance" facing the medic and the casualty. The introduction of flight evacuation during the First World War offered the advantage of speed and time while avoiding the arduous task of ground evacuation via carriage or rudimentary gas-powered vehicles of the era.

During the Second World War, more than a million injured combatants would be evacuated by British, American, and German aircrafts. During this period, aeromedical evacuation was largely reserved for very stable or ambulatory casualties who had been managed at established rear hospital facilities (weeks to months following wounding) and were sufficiently recovered to sustain (and survive) the relatively difficult transport process in unpressurized aircraft.

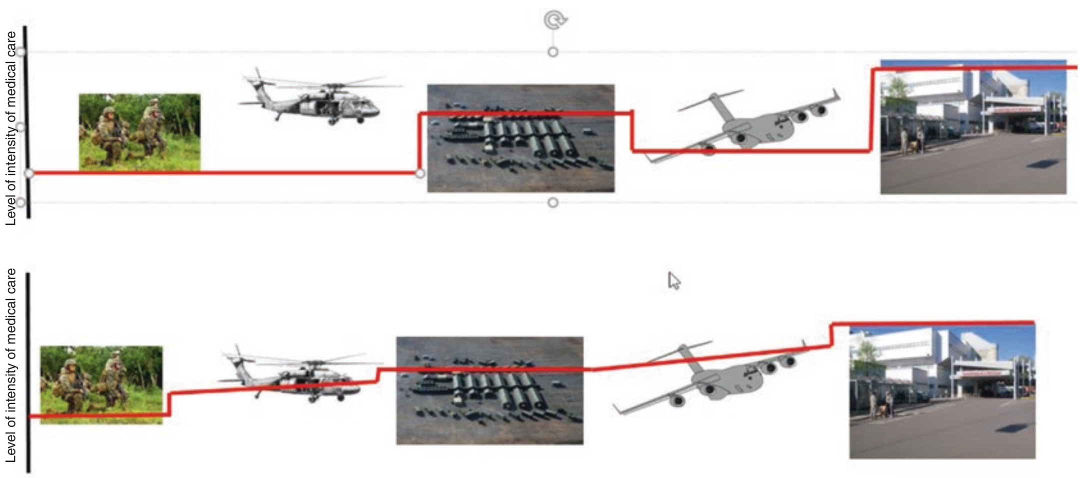
The Korean conflict was the first to demonstrate the advantages of rotary-wing evacuation and its ability to clear casualties from the forward area of battle. The introduction of helicopter evacuation during the Korean War demonstrated the extension of aeromedical care into the far-forward area of prehospital care. The venerable OH-13 Sioux helicopter was utilized to evacuate casualties over the inhospitable and mountainous terrain of Korea. Combat casualties were delivered to nearby MASH units within minutes rather than hours or days. The role of rotary-wing evacuation became even more preeminent during the United States' combat role in Vietnam. The widely visible success of the US Army's MEDEVAC units (DUSTOFF) in clearing casualties and providing rapid delivery to definitive trauma care hospitals would be widely copied by the civilian trauma system then developing in the US (1970–1980). The Vietnam Dustoff era is also recognized as the first time when rudimentary medical care (hemorrhage control and IV fluids) was delivered by medical personnel while en route from the point of wounding to the first level of surgical care (Fig. 4.1).

The model of aeromedical evacuation (AE) developed since Korea through the First Gulf War comprised a dichotomous, two-step process. The first step consisted of forward (tactical) evacuation of casualties from the point of wounding and was

Fig. 4.1 The OH-13 "MASH" helicopter (authors picture)

accomplished via rotary-wing transport to an established surgical unit. The primary focus of this phase was the provision of rapid transport out of a hostile/combat environment. The opportunity to provide medical care during these transports was not a primary objective, and care en route was rudimentary at best. Once at a more established facility (mobile or theater surgical facility), the casualty would recover until sufficiently stable to tolerate the second phase of the process. This second phase (strategic aeromedical evacuation) consisted of transport of the casualty over much greater distances using fixed-wing aircraft.

The scope of this chapter will be to examine the continued evolution of the AE process during the last 15 years including the Global War on Terror and Operation Iraqi Freedom and Operation Enduring Freedom. This evolution has changed the scope of AE from a process which hoped to deliver casualties from the forward area of battle safely and without further harm to today's system which emphasizes the provision of sophisticated en route critical care ensuring rapid transport while providing for, and improving upon, the medical conditions of the patient. The ideal system state sought is a continuum of care which begins at the forward area and continues to provide movement capability in a timely and integrated process to deliver the casualty to progressively more sophisticated and capable facilities across the echelons of care. The challenge to be met is to ensure that the provision of medical care to the injured soldier remains continuous, capable, and as sophisticated/intense as the ground-based combat medical treatment facilities.



4.2 Development of Critical Care Air Transport Teams

Review of medical care delivery during the First Gulf War (1991) resulted in critical introspection of the capabilities (or lack thereof) of the military health service and its ability to provide medical support for combat operations. Medical doctrine was realigned to emphasize mobility and proximity of surgical support to an increasingly agile and mobile fighting force. Small, mobile surgical teams moved forward to provide surgical stabilization capability in far-forward and austere settings. The proximity and capabilities of these robust surgical support teams (US Army FST, US Navy FRSS, US Air Force MFST) proved themselves capable of salvaging critically injured soldiers with practices such as whole blood transfusion, permissive hypotension, and damage control surgery. The demonstrated lifesaving capabilities of these far-forward teams created a new class of patient, namely, the patient who had been surgically stabilized but was far from medically stable. This new class of patients were those who would have previously died at the point of injury (KIA) or succumbed while en route or at a far-forward battalion aid station. Supporting these critically ill, surgically stabilized patients necessitated either moving ICU resources and capabilities to every far-flung resuscitation team (not logistically or practically possible) or formulating a process capable of moving critically ill patients through time and space in a combat theater of operation. En route care and the US Air Force's Critical Care Air Transport Teams were that answer to this dilemma.

The need for realignment of the abilities of aeromedical evacuation into a more sophisticated and continuous process of en route care was further emphasized during the peacekeeping mission in Mogadishu ("Black Hawk Down"—October 1993). The patient care requirements for a requested long-range aeromedical evacuation of a critically injured soldier from the US Army medical facility in Mogadishu exceeded the capabilities of the assigned Air Force AE crew team. This capability shortfall was recognized on the tarmac of the airfield in Mogadishu and required the surgeon from the Army facility to accompany the patient during the evacuation to Germany. Shortly after this mission departed Mogadishu, the 75th Ranger Regiment became engaged in a firefight that resulted in 18 deaths and 73 wounded while one of the three surgeons assigned to the Army's Mogadishu FST team was en route to Germany. The review of this action drove two key elements of the foundation of modern en route care. The first was to ensure that medical capability of the en route care team could provide critical care support to a stabilized but not necessarily stable patient. The second requirement was that the en route care team had to be self-sustaining with respect to personnel and equipment in order not to strip critical elements of manpower or equipment from the far-forward surgical resuscitation teams.

The US Air Force set about the process of formulating a solution that would address the needs of the dynamically changing AE requirements. The US Air Force is doctrinally responsible for the strategic movement of wounded combatants of all branches. The Critical Care Air Transport (CCAT) Team would be developed as a solution to the perceived capability gaps developed by the changing nature of conflict in the twenty-first century. In past conflicts, AE movement was a process of providing transport with concomitant basic medical support for casualties. The new paradigm challenge facing the CCAT process was to prepare, and assume responsibility for, the provision of uninterrupted intensive care for critically ill soldiers from the furthest forward and austere location to the rearward area(s). The challenge was to ensure that the medical intensity of care never degraded or suffered because of the transport process or environment. It was no longer acceptable to simply ensure the safe transport of the casualty to the next point of care. The challenge was to match the intensity and capability of the far-forward resuscitation surgical teams and continue the process of stabilization and intensive medical care while simultaneously moving the patient across a distance small or great. ICU care was no longer the sole domain of ground-based theater facilities. Now CCAT teams were charged with ensuring the uninterrupted provision of critical care and patient optimization throughout the continuum from point of wounding to return to the Continental United States (CONUS).

The original concept and first CCAT teams were developed in the early 1990s at Wilford Hall Medical Center, San Antonio Texas. The original intent of the teams was to provide effective and capable means of transporting care-eligible active duty, dependent, and retirees from outside civilian ICUs throughout the United States back to Wilford Hall Medical Center. The opportunity to evolve these teams as a key element of the concomitant reengineering of combat medical care capability was recognized by Lt Gen PK Carlton Jr., (USAF/SG retired). Over the next decade, the CCAT process would grow from concept to accepted doctrine under the vigilant leadership of Lt Gen Carlton along with a handful of young AF Medical Service officers.

By November 9, 2001, the CCAT team was a recognized component of the larger AE movement process yet largely an untested concept. Combat operations following 9/11 would be the first large-scale test of the CCAT team(s) and their concept of operations. The initial years of combat casualty care (2001–2004) provided challenges to meet the extremely fluid, dispersed, and varied context of combat medical operations. Medical facilities in the combat zone were varied in size and shape as well as frequently relocating to remain relevant and near the soldiers they were supporting. Initially deployed CCAT teams were positioned at major air hubs such as Landstuhl Regional Medical Center or Al Udeid Air Base (Qatar). CCAT teams would fly "downrange" into theater onboard strategic cargo aircraft and assume responsibility for the stabilization and subsequent return transfer of patients from the forward-deployed facilities. New operational paradigms were developed as combat operations and casualties expanded and as theater medical facilities matured. CCAT teams were forward embedded at the location of major medical facilities in the theater of operations (Balad Air Base Iraq and Bagram Air Base Afghanistan) and subsequently other facilities such as the Navy's hospital in Kandahar Afghanistan. By 2005 a significant number of CCAT teams were deployed to these various facilities within the theater of operations. The forward positioning of CCAT teams provided the advantage of additional critical care personnel at the theater medical facilities as well as a knowledge base of how to prepare and position a critically ill patient in anticipation of a long-range CCAT.

The challenge for the CCAT teams was to ensure and sustain the intensity of medical care (that was being delivered in the forward facilities) throughout the transport process. In some cases, this meant the provision of critical care for a shorter (1–2 h) period during an intra-theater transport onboard a C-130 Hercules cargo plane. In most cases, it meant preparing for, and sustaining care throughout, strategic intercontinental flights from theater (Iraq or Afghanistan) to Landstuhl Regional Medical Center in Germany. The mission profile was flown onboard various cargo aircrafts such as the C-141 (now retired from inventory), the C-130, the C-17, or the KC-135 tanker. The missions were usually accomplished at night, and the duration of each mission often extended into the range of 8–12 h. Over the course of combat operations, the time window to CCAT movement would be increasingly shortened as trauma medical care and capabilities became increasingly practiced. By 2006 it was common for a wounded casualty to undergo one to two surgical stabilization procedures in theater and subsequently be transported to Germany within a 30–36 h period. A ten year review of CCATT team activity during OIF/OEF revealed that ninety three percent of all seriously wounded casualties arrived at the Role IV military treatment center in Landstuhl Germany within 72 hours. This is an even more remarkable statistic when one considers that this chain of care usually included one to three surgical procedures in theater (at Role II and Role III facilities) prior to a ten to twelve hour strategic, Critical Care evacuation flight to Germany. [2]

4.3 The CCAT Team

4.3.1 CCAT Team Composition

The current composition of a CCAT team includes a physician, a nurse, and a respiratory therapist. This three-person team may be tasked with caring for up to six critically ill patients including three critically ill patients requiring mechanical ventilation. Although members of the team come from a varied background, emphasis is placed on a collective understanding of all individual roles. This includes mastery of all equipment and a baseline fund of knowledge to ensure redundancy within the group. Each member of the team must have the ability and training to function independently if the physician is not immediately available or if immediate lifesaving interventions are required. This is due to operational realities that the team may have to split for periods of the transport when moving multiple patients. A well-constructed team includes a mix of skill, strong team dynamics, and a high level of situational awareness.

4.3.1.1 Physician

The physician functions as team leader and accepts responsibility for each patient being transported. The CCAT physician role requires critical care capability and is drawn from the specialties of emergency medicine, anesthesia, pulmonary critical care, cardiology, and general surgeons. Regardless of background training, clinical currency in the care of critically ill patients remains essential to provide the degree of support necessary to establish stabilization prior to transport and to perform critical interventions while en route (see training requirements below). In addition to the baseline medical knowledge required, the physician must also maintain operational and situational awareness to anticipate and reduce the occurrence of clinical incidents.

4.3.1.2 Critical Care Nurse

The CCAT nurse fills a vital role in the transport of the critically ill patients and is essential to the team. Most CCAT nurses have experience caring for critically ill patients on a daily basis in some form of ICU setting. This role has also been filled by advanced care nurse practitioners and certified registered nurse anesthetists. The RN must be current in advanced cardiac life support (ACLS); have worked in critical care or special care unit, emergency department, or postanesthesia care unit within 2 years of selection; and have a minimum of 1 year experience. Trauma Nursing Core Course (TNCC) is highly encouraged, but not required.

4.3.1.3 Cardiopulmonary/Respiratory Therapist

The CCAT respiratory therapist (RT) fills the final essential role on the team. This member must have 1 year of critical care experience, receive annual training in an intensive care unit, and must have worked with ventilated patients within the past year to be eligible for participation. The CCAT RT is held to the standard of being an expert with the transport ventilator, understanding all aspects of its functions and operations. In addition to the other roles, the respiratory therapist functions as the "medical mechanic" for the team. This role includes a thorough understanding of all the equipment in the allowance standard to be able to troubleshoot malfunctions smoothly during transport.

CCAT Training Requirements

CCAT training begins with the assumption: that the provider entering the training pipeline is clinically current and competent in the environment and delivery of critical care. The goal of the course is not to develop the existing critical care skill set of the individual but rather to teach the provider how to adapt the clinical skills that they already possess into the context of the en route care environment. The familiarization process begins with recognition that the en route environment is an austere environment where additional capabilities and resources are limited. The en route environment imposes limits upon many normally utilized clinical capabilities, and the impact of these limitations must be recognized, understood, and compensated for by the provider to ensure seamless care for the casualty (see environmental considerations below).

Members who have deployed as CCAT medics utilize the term "situational awareness" to describe the unique challenges posed by the provision of critical care in a remote and often austere environment that traverses many different platforms of care. The term situational awareness originates in the aviation community and refers to the ability of a pilot to maintain a comprehensive appreciation of where the aircraft is with respect to space, time, and energy. The term situational awareness in a medical sense implies the ability of the clinician to constantly assess the patient and their current status regardless of the environmental or situational distractors. A primary focus of the CCAT curricula is to teach the provider to recognize that traditional medical cues and signs utilized in daily bedside care (the tone of an oximeter, auscultation of breath or heart sounds, sufficient light to observe the patient, etc.) are compromised in the environment of care that occurs in the dark, with loud ambient noise and multiple situational distractors. Emphasis is placed on the provider maintaining patient "situational awareness" despite the challenges of a combat environment in the back of an aircraft executing a combat takeoff in a turbulent airspace.

One focus of the CCAT curricula is to develop an ingrained familiarity with the allowance standard (soft goods and medications) as well as patient movement items (equipment). Emphasis is placed upon patient preparation and the ability to anticipate and intervene in physiologic events that may occur because of the patient's preexisting condition or secondary to the rigors of the en route movement. The initial course is standardized across team members and regardless of background medical training. This helps to ensure that CCAT team members can move between teams as operational circumstances dictate. While maintaining the integrity of any single CCATT team is desirable, replacing a member of the team at any time when needed (illness, emergency) assures operational flexibility.

The initial stage of CCAT training consists of the selection process of team members from the various clinical specialties. Members selected are commissioned officers and enlisted personnel from Active Duty (AD), Air National Guard (ANG), or Air Force Reserve Command (AFRC) components of the US Air Force. All members must demonstrate regular participation in the care of critically ill patients. Once chosen, the member must successfully complete two separate courses before being qualified to fly operational CCAT missions.

The *CCAT Initial Course* is a 10-day curricula designed to introduce and prepare providers performing CCAT duties to meet the wartime and peacetime missions of caring for critically ill and injured patients in the aeromedical evacuation environment. The course takes place at the US Air Force School of Aerospace Medicine (USAFSAM) located at Wright-Patterson Air Force Base in Ohio. The focus of the initial course is to acquire an understanding of the aeromedical evacuation environment, as well as gain familiarization with aeromedical evacuation aircraft and the CCAT equipment set. The course also provides and extensive introduction to altitude physiology. Along with a detailed review of the CCAT mission, equipment, and organization, members receive hands-on training in altitude physiology including flights in a hypobaric chamber. Members also receive an introduction to the Joint Trauma System Clinical Practice Guidelines (CPGs) and receive training on how to adapt their baseline clinical skills to both the deployed and en route environment.

The second course is the CCAT Advanced Course which is held at the University of Cincinnati Medical Center in Cincinnati Ohio. The University of Cincinnati Medical Center is home to USAF Cincinnati CSTARS (Center for Sustainment of Trauma and Readiness Skills) and is one of five designated civilian strategic military collaborating hospitals that serve as military trauma training facilities within the United States. The advanced course builds on the concepts introduced at the CCAT Initial Course and further emphasizes core critical care principles routinely encountered in the deployed environment. Didactic portions of the course focus on delivering care in the deployed environment and understanding the treatment goals within the context of the CPGs. Effort is devoted to training to lessons learned from current real-world missions. Students and instructors join in on the weekly video teleconference call from the theater to maintain situational awareness of current operational challenges.

To ensure timely and relevant mission scenarios, the instructor cadre stationed at the University program routinely deploy into theater as part of a continuous deployment model. The CCAT Advanced Course is unique among military courses in terms of its flexibility and ability to rapidly adjust course content to real-world operations. As a clinically focused course, cadre have the discretion to adjust course material to ensure it is reflective of current operations with the aim of optimally preparing students for the deployed environment they are about to enter.

The hallmark of the CCAT Advanced Course is the employment of high-fidelity simulation to immerse teams in training in real-world patient care scenarios. High-fidelity mannequins reside in a training center designed to replicate the cabin of a C-130—complete with low light and aircraft noise. The simulator center and scenarios are intended to provide a realistic and life-like training environment where the provider team must effectively manage challenging clinical scenarios. Over the two-week period of the advanced course, CCAT student teams will spend over 10 h in simulated flights and medical scenarios that emphasize not

Fig. 4.2 CCAT students and their instructor discuss a patient scenario while in flight onboard a C-130

only medical management but also team building and crew resource management. During the second week, students and their instructors will participate in a full-day scenario that includes transportation of simulated patients by ambulance bus to a nearby airport. Once at the airport, the teams continue to monitor and prepare their patients for fixed-wing evacuation. A C-130 from the Kentucky Air Guard meets the teams at the airport and enplanes the teams and their instructors for a flight modeling a realistic mission profile (3 h) (Fig. 4.2).

The CCAT Advanced Course is categorized by USAFSAM as a validation course. The teams are evaluated in their ability to provide safe and efficient care during these high-fidelity simulated clinical scenarios. Providers who are unable to demonstrate the ability to effectively deliver care in the austere en route environment do not validate the course and are not eligible for deployment as a CCAT provider. The student is given recommendations on opportunities to further develop their skill set and offered the opportunity to participate in a future advanced course. Recurrent training is required to remain qualified for CCAT deployment, and each member is required to attend and validate the CCAT Advanced Course every 36 months.

4.4 CCAT Environmental Considerations

The environmental milieu of combat casualty aeromedical evacuation presents challenges to matching the intensity and precision of critical care in a more fixed facility. As previously asserted, the challenge of the CCAT mission is to ensure that the intensity and quality of critical care delivery remains sustained despite the movement of the patient through space and time onboard an aeromedical evacuation platform. The unique environmental stressors of the en route movement include hypobaria, temperature, noise, vibration, decreased humidity, acceleration forces, and fatigue. Each of these elements may have a significant impact on the mission as well as patient physiology and is described below.

4.4.1 Hypobaria and Hypoxia

One of the most prominent environmental factors influencing aeromedical evacuation remains changes in barometric pressure with increases in altitude and the resultant effect on oxygen delivery and gas expansion. The gas laws most applicable to changes in altitude include Boyle's Law, Henry's Law, and Dalton's Law.

4.4.1.1 Boyle's Law: P1/P2 = V2/V1

This equation relates how a volume of air within a closed space expands with decreases in atmospheric pressure. As an aircraft (or person) ascends in altitude, the experienced surrounding pressure decreases in an exponential fashion. At 18,000 feet, a volume of gas will be approximately doubled the volume as that at sea level. Trapped gasses can affect medical crew, patients, and equipment. The most common sites of trapped gas in healthy individuals are the sinuses, the middle ear, the gastrointestinal tract, and occasionally the teeth. Additional consideration is required for aeromedical evacuation of patients that are critically ill. Patients must be screened for evidence of a pneumothorax which may impact a physiologic response secondary to the expansion of gas at altitude. Air in the GI tract may be more problematic if the patient has an ileus or has had a recent abdominal surgery. Gastric decompression may be required for patients on mechanical ventilation or with evidence of intestinal ileus. Patients with a traumatic brain injury or an ocular injury must be screened for trapped air, as small increases in volume in these fixed compartments can have devastating effects. Gas expansion at altitude also affects medical equipment. For example, ventilators must have altitude compensation to provide accurate tidal volumes and maintain adequate minute ventilation. Additional equipments which require consideration include endotracheal tubes, Foley catheters, and IV solution bags.

4.4.1.2 Henry's Law: P1/P2 = A1/A2

This principle describes how gas dissolved in a solution varies with changes in pressure. For example, the amount of nitrogen dissolved in tissue will decrease and return to a gaseous form with decreases in atmospheric pressure. This most frequently manifests as altitude-induced decompression sickness. Symptoms can vary from mild joint pain and headaches to acute respiratory failure or neurologic dysfunction.

4.4.1.3 Dalton's Law: P = P1 + P2 + P3

This law relates that the total pressure of a gas is equal to the partial pressure of each gas within a mixture. This law explains how decreased atmospheric pressures at altitude contribute to a decrease in the availability of oxygen. For example, oxygen represents 21% of gas at sea level with an atmospheric pressure of 760 mmHg which makes the partial pressure of oxygen 159.6 mmHg. At 10,000 feet, the atmospheric pressure drops to 523 mmHg while the percentage of oxygen remains at 21%, and therefore the partial pressure of oxygen decreases proportionally to 109.8 mmHg. As the partial pressure of oxygen is reduced, diffusion across the alveolar-pulmonary capillary membrane is also reduced and contributes to hypoxia.

Cabin pressurization mitigates the effects of these gas laws to some extent. Most aircrafts pressurize the cabin by drawing in air from the outside, compressing it, and then delivering the compressed air to the cabin. The desired pressure is maintained in the cabin by controlling the flow of compressed air out of the cabin and into the environment. The pressure achieved represents a pressure equivalent to a certain altitude and thus is referred to as the cabin altitude pressure. Cabin altitude pressures fluctuate during the flight but averages range from 6000 to 8000 feet for most of the flight. The ability to further reduce the cabin altitude pressure exists; however, the aircraft must fly at lower altitudes with increased travel times and marked increases in fuel consumption.

The impact of hypobaria on human physiology is reasonably well qualified for certain organ systems such as the gastrointestinal tract, the inner ear, and alveolar oxygen exchange to name a few. Over the course of the last decade, the military has begun to focus medical and basic scientific research to discern if there are potential additional effects of hypobaria on the injured casualty. One of the most notable of these efforts has been studies examining the potential impact of aeromedical flight on the patient with traumatic brain injury. To date the conclusion of these efforts remains unclear but is sure to be a continued area of interest for the CCAT and aeromedical community [3].

4.4.2 Temperature and Humidity

Ambient temperature decreases by approximately 2 °C with each 1000 ft. increase in altitude. Because of this relationship, the temperature in the aircraft can vary widely between the ground and at altitude. Further, depending on the airframe, there may be a significant difference in the cabin temperature from the front (fore) of the aircraft to the back (aft). This can be particularly problematic for critically ill patients with depressed thermoregulatory function. Additionally, critical pieces of equipment (such as blood analysis equipment) often function at an optimal temperature. Extremes of temperature impose an additional environmental stressor that may lead to degradation of human as well as equipment performance or even equipment failure. CCAT teams must monitor temperature closely and protect both the patient and equipment as needed.

As altitude increases, the level of moisture (humidity) in the air decreases significantly. As described above, air for pressurization of the interior of the aircraft is drawn from the surrounding air space. As the aircraft ascends, the humidity of the entrained air for pressurization falls and creates a very low humidity cabin environment. Patients and providers may experience an increase in insensible fluid losses, and dehydration is exacerbated. Consideration should be given to utilization of humidified air for patients who require supplemental oxygen.

4.4.3 Noise, Light, and Vibration

Noise represents a substantial barrier to care of the critically ill patient. Current CCAT platforms are primarily cargo or refueling platforms, and these aircraft do not typically have engine or cabin noise abatement. The engine noise within the cabin of these aircraft often exceeds 80 dB. Hearing protection (earplugs or headsets) are mandatory for all crew members and patients. This level of ambient noise degrades communications both within the team and potentially between the patient and providers. Routine tasks such as auscultation of the lungs for breath sounds become impossible. Team members are taught that frequent visualization of the patient and a reliance on visual alarms are essential since auditory alarms will not be heard or recognized in most cases.

An equally important consideration are the lighting conditions encountered in many missions. During combat support operations, most CCAT movements will occur at night to minimize the potential targeting of the teams or patients. Limited light sources such as red or green head lamps may be used to support visualization of key components or the patient. Takeoff and landings in theater are invariably conducted under light discipline conditions which require a darkened (or dark) environment. The CCAT provider must once again recognize the limitations imposed by these environmental and operational constraints and how they may impact on recognition of standard events routinely noted in a normal ICU environment.

Vibration represents yet another unavoidable environmental condition that may impede patient care during aeromedical evacuation. Vibration may range from barely perceptible (transmitted engine vibration) to life-threatening (evasive maneuvering, turbulence, downdrafts, etc.). The presence of vibration in the cabin applies yet another additive stressor for both the providers and the patient. Vibration can have deleterious effects on the performance of some equipment such as noninvasive blood pressure cuffs and some monitors. Additionally, care must be taken to ensure all equipment is properly secured to avoid damage and potential safety hazards which occur as unsecured medical equipment is transformed into projectiles in the setting of severe maneuvering or turbulence.

4.4.4 Acceleration and Deceleration Forces

Gravitational forces acting on the aircraft during takeoff and landing have implications on critically ill patients that may be negligible for healthy individuals. Transiently, these forces lead to pooling of blood and can influence central hemodynamics. Fluctuations in intracranial pressure have been demonstrated during both takeoff and landing and must be recognized and managed in patients with severe TBI. Attention to these concerns can guide patient positioning and location on the aircraft (Fig. 4.3).

4.5 CCAT Equipment

The safe aeromedical evacuation of critically ill patients requires modern biological monitoring equipment which has been rigorously tested. Prior to being certified as "safe to fly," all CCAT equipment undergoes a rigorous set of testing to ensure that they meet the military standards established for the aeromedical environment. Testing of equipment includes altitude testing (10,000 feet), rapid decompressions, extremes of temperature, as well as exposure to humidity changes and vibration. In addition to the stressors of flight, equipment must be able to function safely in conjunction with radiofrequency transmitting equipment and must not produce electromagnetic interference which can hinder communication and navigation systems. Also, most airframes operate on 110 V of alternating current at 400 Hz in contrast to commercial power which provides 110 V at 60 Hz. Equipment must therefore have long battery life for transport or be capable of converting to the aircraft power source at 400 Hz. Providers must be educated on the power requirements of every device and monitor battery status and reserve during flight.

4.5.1 The Allowance Standard

The equipment utilized by CCAT teams is referred to as the allowance standard.

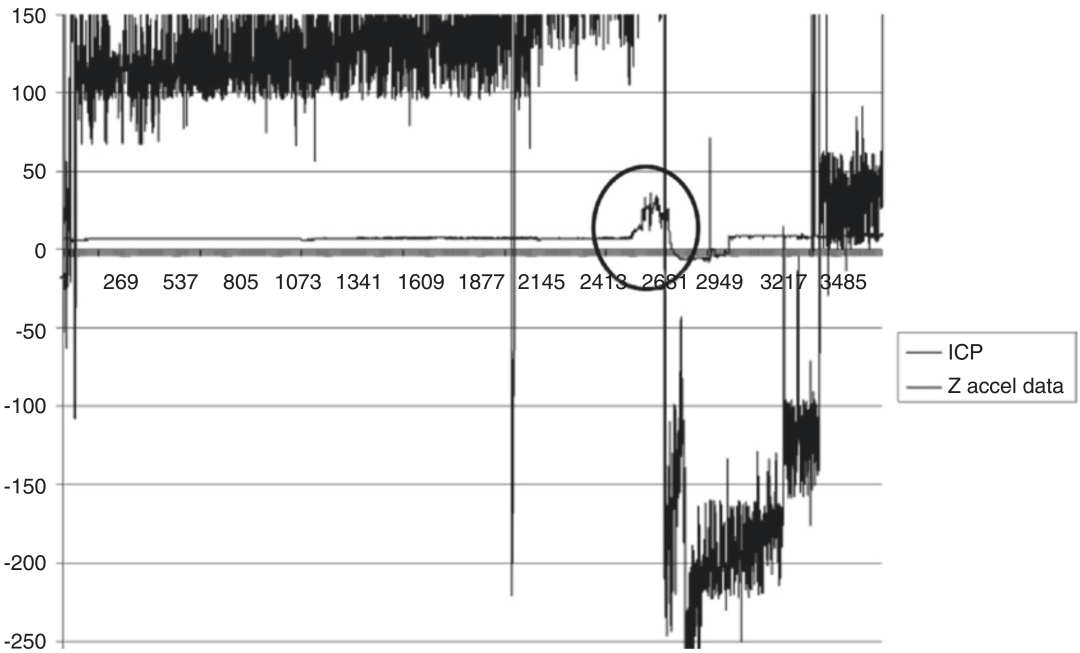


Fig. 4.3 G force (thick line) and ICP (thin line) encountered by traumatic brain injury patient during combat takeoff. The circle highlights a relative increase in intracranial pressure during takeoff

Standardization of equipment and bag sets is critical for CCAT teams to train and deploy effectively. It allows for bag sets to be exchanged between teams or between mission while maintaining confidence in knowing what the team has available and where it is located.

This allowance standard has been modified over time and is currently being deployed in its third version. The approximate weight is 650 lbs. The goal of the allowance standard is to have the capability to care for up to three high-acuity ventilated patients or six lower-acuity stabilized patients for up to 72 h. This includes several commonly used medications, supplies for common procedures (central lines, chest tubes), personal protective equipment, and communication equipment.

4.5.1.1 Patient Movement Items (PMI)

The patient movement items are stored in the gear bag. There are three identical gear bags that contain all the necessary equipment for the transport of a single ventilated patient. While a detailed description of the inventory in each bag is beyond the scope of this chapter, the main pieces of equipment located in the gear bag are described below.

4.6 Propaq MD

The Zoll Propaq MD combines the Propaq monitor with the Zoll defibrillator and noninvasive pacing technologies. This includes temperature, noninvasive blood pressure monitoring, heart rate, oxygen saturation, and ECG tracing. There are three ports for invasive monitors such as arterial pressure, central venous pressure, and intracranial pressure.

The operating time on battery power is 6 h and the battery requires 4 h to charge to full capacity.

4.7 Impact 731 Ventilator

The Impact 731 ventilator by Zoll is the current ventilator utilized for most patient transports. It weighs 9.7 lbs and is capable of multiple modes of ventilation including AC modes (volume control or pressure control), SIMV, and pressure support. It is reported to have a 10 h battery run-time and recharges in 2 h. The 731 ventilator has been utilized in the development of a novel autonomous control of inspired oxygen study that has been funded by the DoD [4]. The FDA has recently (2016) approved an investigative new device exemption study to further evaluate the potential of closed loop control of this device in a deployed setting.

4.7.1 IVAC MedSystem III

The infusion device currently employed in the allowance standard is the IVAC MedSystem III. It has the capacity for three independent infusion channels. It operates for 6 h on battery power with all three channels running.

4.7.2 Zoll Model 326: Suction Device

The multifunction aspirator can be used for oropharyngeal and tracheal suctioning as well as provide necessary suction for chest tubes and temporary abdominal closures.

4.8 CCAT Mission Profile

In an effort to understand the primary mission profile of CCAT teams in patient movement during recent conflicts in Iraq (OIF) and Afghanistan (OEF), we must first describe how patients transitioned through five defined "roles" of care at the military treatment facility (MTF). They are listed as:

- Role I—Self-aid and buddy care
- Role II—Battalion aid station or forward surgical team
- Role III—Combat support hospital
- Role IV—Established MTF outside of the theater of operations
- Role V—Military treatment facility in the United States

As described, CCAT teams were designed to care for the "stabilized" (but not necessarily stable) patient. Patients were "stabilized" at the Role II and Role III facilities as defined by four specific criteria. First, the casualty must have a stable or definitively established airway. The term "stabilized" also assumes that all fractures have been immobilized, active hemorrhage controlled, and resuscitation initiated. CCAT teams were deployed to the Role III hospitals within the theater of operations so that they could be quickly activated if patients required movement through the aeromedical evacuation system. With the robust trauma system present in OEF/OIF, CCAT teams could utilize the resources of the Role III hospital before prolonged inter-theater transport to include obtaining further medications from the pharmacy as well as blood products to further increase the capabilities of the base allowance standard. Standard missions of CCAT teams included (Figs. 4.4 and 4.5):

- Intra-theater Role II to Role III missions, primarily on C-130s by teams based at the deployed Role III
- Inter-theater Role III to Role IV missions, primarily on C-17s by teams either based at the deployed Role III or teams located at the Role IV
- Inter-theater Role IV to Role V missions, primarily on C-17s by teams based at the Role IV hospital

4.9 Tactical Critical Care Evacuation Team

With the success of safe patient movement by CCAT teams during OEF and OIF, efforts were made to utilize the skills of critical care providers in a further forward environment of patient movement. The concept of joint en route care was designed by the Army and Air Force to have a greater ability to provide critical care to the patient in this far-forward environment. The Air Force developed the Tactical Critical Care Evacuation Team (TCCET) in response to this

Fig. 4.4 Onloading of CCAT patient to C-17 Globemaster during night operations

Fig. 4.5 CCAT patient in patient care stanchion prior to takeoff

Fig. 4.6 Typical configuration in rotary-wing cabin for TCCET transport (authors picture)

need. The TCCET consist of an ER or critical care physician, a certified registered nurse anesthetists (CRNA), and an ER or critical care nurse. The allowance standard is reduced to three bags, and the aircraft used are usually rotary-wing airframes or C-130s. The focus of their mission is to treat immediately life-threatening conditions, control compressible hemorrhage, and initiate the resuscitation during transportation at or very near the point of injury. These teams increased critical care capability in the POI to Role II and Role II to Role III phases of patient movement (Fig. 4.6).

4.10 Future Considerations

The CCATT community faces two major challenges when considering future operational environments. The first is supporting small, remote surgical/medical teams outside of a robust trauma system when no combat support hospital exists to prepare the patient for long-distance evacuation. The joint trauma system present during OEF/OIF and the relatively large medical footprint in those theaters of operation allowed for practice patterns to develop within CCAT that may not be possible in future operations. The advanced capabilities and holding capacity of Role III hospitals in Iraq and Afghanistan permitted for greater discretion in determining if a patient was ideally stabilized for inter-theater transport. The expected attention to pre-mission stabilization and optimization of the patient physiology for en route care that the Role III hospitals provided may not be present in future conflicts. Due to limits in capability (i.e., dialysis, neurosurgical capability, etc.) or resources (size of holding capacity), CCAT teams must prepare for managing less "stabilized" patients as the medical footprint decreases in size and more austere surgical teams are positioned throughout the globe. While CCAT teams have certainly moved less stabilized patients from Role II to Role III facilities, these have typically been short-duration intra-theater missions. As more austere surgical teams without a supporting Role III facility become the norm, these less stabilized patients will occur more frequently and require longer mission times to a higher level of medical capability. This environment will further test the resuscitative capabilities of CCAT teams.

An emerging consideration is for CCAT teams to be prepared to respond to situations where there is no medical capability at the destination site. CCAT teams are doctrinally beginning to prepare for the potential of caring for critically wounded casualties that have had limited pre-transport surgical stabilization. The potential for prolonged evacuation distances with limited on-ground surgical capability has led to the development of en route surgical teams which are embedded with, or blended into, an extended CCAT mission team. As this surgical capability continues to evolve, the support of critical care to the en route surgical team by CCAT is critical to ensuring ICU-level capability.

The transition from the height of operations during OEF/OIF to decreased medical ground resources is already taking place and the CCATT community is actively adapting to this new state. Ultrasound has recently been added to the diagnostic tools available to CCAT teams to help enhance the ability to care for the less stabilized patient. The CCAT Advanced Course continuously adjusts clinical tabletop discussions to real-world mission-based clinical scenarios, thus giving students exposure to the "new-normal" mission. These prolonged Role II transports have also been added to high-fidelity simulation scenarios. The CCAT allowance standard is also regularly reviewed and updated, ensuring the bag-set meets the needs of deployed teams as the CCAT mission continues to evolve.

Conclusion

Throughout the first 10 years of conflict from September 11, 2001 through 2010, 2899 patients were transported by CCAT teams as part of Operation Iraqi Freedom and Operation Enduring Freedom. This experience was recently reviewed and demonstrated the following:

One of the most noteworthy findings of this inquiry is that 93% of all CCAT patients (representing the most grievously injured combat casualties of this conflict) arrived at LRMC within 72 hours of wounding. Equally remarkable is the finding that 98.5% of all critically wounded soldiers were at LRMC by the 96-hour mark. The documented success and attendant minimal mortality of movement of CCAT patients within hours of surgery represent a paradigm shift for trauma surgeons and trauma surgery doctrine. The overall 30-day mortality for all patients transported by CCATs is 2.1%, and the transport mortality en route is well less than 1% despite the transport of significantly injured combat casualties (mean ISS, 23.7). This historically low mortality rate is a tribute to and reflection of the dedication of the entire chain of survival established by the military and its medical corps. The chain of survival begins with the medic providing care under fire and continues until the casualty is returned to home station, family, and community.

This low mortality rate speaks to the success of the AE "system" that enters a patient into the movement system, determines when a patient is safe to fly, and links an available aircraft/mission to an AE crew and CCAT team. This system involves multiple checks involving the current medical providers, local and theater flight surgeons, receiving providers, and transporting teams all aimed at ensuring patient safety. As successful as this aeromedical evacuation system has been, new expectations and standards now exist. Through constant evolution in training and equipment, the CCAT community remains ready to meet the challenge of moving our most critically injured warriors anywhere in the world, anytime.

Disclaimer We are pleased to participate in the publication of this important work by contributing this chapter regarding Enroute Care. The authors have been asked to contribute similar contributions to many other publications over the past twelve months. In preparation for this chapter the authors began from their text of a similar contribution to Eastridge et al (citation). This chapter has been edited in its entirety, and, as appropriate, updated.

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