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Mobile Critical Care (Michael C. Reade)

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Rapid evacuation of critically ill patients is central to modern military medicine. Here, evidence underpinning various aspects of 'mobile critical care' in Afghanistan is discussed, highlighting several lessons for civilian systems.

Introduction

The essence of military combat casualty care is rapid evacuation from the combat zone to progressively safer and better resourced areas, facilitating consolidation of advanced technological healthcare into small numbers of secure hospitals. Rapid transit distinguishes military trauma care from that delivered by civilian hospitals in war zones, which generally must treat patients in one location until they recover or die. Military trauma systems have always focused on rapid evacuation. Many aspects of the structure (if not function) of the modern NATO (U.S.-led) Joint Trauma System in Afghanistan would look familiar to a medical officer of the First World War (see Table 1). The differences would be speed of transit, the ability to bypass steps if a patient requires a surgical specialty (most commonly neurosurgery) only available at a larger hospital, and the complexity of en route medical care. The ability to provide this 'mobile critical care' has facilitated a revolution in modern combat healthcare. Robust epidemiological analysis of the Joint Trauma System in Afghanistan has facilitated rapid system- and practitionerlevel improvements, and holds lessons for all trauma systems, both military and civilian.

Speed of Transit

Many people know of the dramatic reduction in time from battlefield to initial wound surgery facilitated by the helicopter, first used in substantial numbers during the Korean War. Less appreciated is the dramatic fall in time from initial wound surgery to the most sophisticated multidisciplinary care outside the combat zone that has occurred since 2001 (see Table 2). In the Vietnam War, the average time a wounded casualty took to return to the United States was 45 days (Carlton, Jr. and Jenkins 2008), as no transport capability existed that could provide even the rudimentary critical care organ supports available at the time. In contrast, modern Critical Care Aeromedical Transport Teams (CCATTs) (also known as Military Critcare AME Teams (MCATs) in Australia and Critical Care Air Support Teams (CCASTs) in the UK) are able to transport patients on every form of organ support, including extracorporeal membrane oxygenation (Neff et al. 2013), which allows patients to arrive in a Role 4 hospital (currently located in Germany for US and Australian casualties, and in Birmingham for UK patients) within as little as 36 hours or less after wounding. This has dramatically changed the configuration of hospitals in the area of operations. For example, the ratio of ICU to ward beds in a typical NATO Role 3 hospital in Afghanistan in 2013 is 1:2.5, in comparison to 1:16 at the 1st Australian Field Hospital in Vietnam. Modern combat hospitals can only continue to function with effective 'mobile critical care'.

Figure 1.Royal Air Force Medical Emergency Response Team aboard a CH-47 Chinook.

Complexity of En Route Care

a. From point of wounding ("Forward AME")

Understanding the optimal cost-benefit relationship in aeromedical evacuation (AME) assets is still evolving, driven largely by excellent data capture and epidemiological analysis in the current conflict. Two landmark studies demonstrated mortality benefit associated with more sophisticated care at the point of wounding. The first took advantage of the 'natural experiment' when a rotation of U.S. National Guard paramedics (who were flight paramedics in civilian life) replaced active-duty army medics (fulltime military personnel with comparatively basic medical training) as clinicians on MEDEVAC helicopters retrieving patients from the point of wounding.(Mabry et al. 2012) Mortality at 48 hours fell from 15% to 8% without any other obvious explanation. A related international study compared hospital or 30-day mortality associated with retrieval by the British Medical Emergency Response Team (MERT), comprising a critical care physician, emergency nurse, and two paramedics transported in the relatively roomy CH-47 Chinook, with that of U.S. Army 'Dustoff' medics (with relatively basic training and scope of practice), transported in a comparatively small UH-60 Blackhawk, and U.S. Air Force Parachute Rescue PEDRO paramedics (trained to a more advanced level than army medics, and transported in a dedicated HH-60 Pavehawk). For the most minor and most severe wounds transport method had no effect, but for patients with an Injury Severity Score (ISS) of 16 – 50, mortality associated with the MERT (12.2%) was significantly (p=0.035) less than the composite mortality with the other two teams (18.2%) (Morrison et al. 2013). Possible confounding limits the certainty of this conclusion: for example, MERT patients were more likely to be from NATO countries, and were more commonly wounded by blast, neither of which is captured by ISS. The MERT frequently performed procedures in transit: for example in patients with ISS 16-50: chest decompression 24.9%, advanced airway intervention 40.5%, and prehospital blood transfusion 32.2%. Unfortunately, no comparative U.S. data was collected. MERT patients had a shorter time between hospital admission and operating theatre arrival, suggesting many emergency department- level interventions had already been performed, or that clinical planning and handover by a physician in flight led to expedited transit to surgery. A later study using the same database found that mortality of more severely wounded patients (ISS 20-29) associated with the MERT was significantly lower than that of those associated with the well-trained PEDRO medics (4.8% vs. 16.2%) (Apodaca et al. 2013), suggesting the size of the team and airframe influenced outcome.

WWI health care facility	WWI staff	WWI function	Differences in the modern Joint Trauma System
Battlefield first aid	Stretcher bearers with rudimentary medical training	Tamponade of haemorrhage, removal from the battlefield	Every combatant has training and equipment to deal with the commonest causes of preventable death, primarily haemorrhage, airway obstruction, and tension pneumothorax.
Role 1. Battalion Aid Station (US) or Regimental Aid Post (UK & Commonwealth)	A non-specialist doctor with the assistance of medics and stretcher bearers	Collect casualties for casualty assessment, confirm haemorrhage tamponade, provide non-trauma primary care and occupational medicine	Moderate- to severe- trauma patients usually bypass Role 1 facilities unless they are in close proximity to the casualty (e.g. in a Forward Operating Base)
Role 2. Field Ambulance	Surgeons and supporting medical officers, medics and transport personnel to move patients to Role 3 hospitals after stabilisation	First level at which surgery could be performed, limited to life-preserving operations.	Remains the first facility at which limited surgery is possible. May or may not have inpatient holding capability, relies heavily on rapid patient evacuation and requires a logistic support. Imaging limited to plain radiology and ultrasound. Staffed by a general +/- orthopaedic surgeon and an anaesthetist. "Role 2 Enhanced" facilities have emerged in the last 10 years, which add an ICU capable of mechanical ventilation, larger blood & medication stores, +/- CT scanning. Usually staffed by a general surgeon, orthopaedic surgeon, anaesthetist & intensivist, specialist nurses, and sometimes by an emergency physician.
Role 3. Field Hospital. The largest healthcare facility deployed in the Area of Operations.	Surgeons, physicians, nurses, paramedical personnel	More complex surgery possible, in order to stabilise a patient for prolonged evacuation by land or sea. Substantial ward holding capacity.	The first hospital with a mixture of surgical specialties (including neurosurgery, cardiothoracic surgery, maxillofacial surgery, ophthalmology) complementing general and orthopaedic surgeons. CT scanning +/- MRI scanning. Larger ICU capable of all critical care interventions with the usual exception of renal replacement therapy and extracorporeal membrane oxygenation. Much smaller ward holding capacity.
Role 4. General Hospital	Similar staff to a large civilian hospital. Placed a 'safe' distance from the conflict; for expeditionary forces, in the country of origin.	The full range of surgical and medical acute care.	No different.
Role 5. Repatriation / convalescent hospital	Similar staff to a civilian rehabilitation hospital	The full range of surgical and medical sub-acute and chronic care.	No different.

Table 1. Levels of Combat Casualty Healthcare Facility, World War I – Present

	Time to first surgical care	Time spent in Area of Operations	Case Fatality Rate
World War I	12-18 hours	1-2 months	22%
World War II	6-12 hours	1-2 months	19.1%
Korean War	2-4 hours	---	25%
Vietnam War	45 minutes	45 days	15.8%
Iraq/Afghanistan Wars	1-2 hours	2-3 days	9.4%

Table 2. Speed of Transit through the Evacuation Continuum

b. Between role 2 – 3 – 4 hospitals ('Tactical AME' within the operational theatre; 'Strategic AME' outside the operational theatre) The military is not unique in being able to provide critical care organ support in large fixed-wing aircraft, but the experience of >16,000 interhospital patient transports over the last 13 years (Blackbourne et al. 2012) using highly configurable platforms such as the C-17 Globemaster has placed modern air forces at the leading edge of this practice. Nations have slightly different approaches to this task (see Table 3), but there is no evidence that these produce different results. These teams can provide all aspects of 'conventional' critical care, and can be supplemented to facilitate extracorporeal support.(Neff et al. 2013)

The variability of capabilities in en route care, the tactical vulnerability of evacuation platforms, the varying eligibility of patients for different levels of care and the different services available at Role 2 and 3 hospitals all necessitate a sophisticated system that can appropriately allocate assets to tasks. In Afghanistan in 2013 this is the role of regionalised Patient Evacuation Coordination Cells (PECCs) staffed by clinicians (usually critical care-trained nurses with advice from physicians as required) and aviation officers in much the same way as in advanced civilian aeromedical retrieval systems. While anecdotally the performance of the PECCs is excellent, curiously this is one aspect of the deployed medical system that has not been the subject of a published performance evaluation.

Figure 2. Evacuation of civilian critical care patients from Cairns Base Hospital, Australia in a RAAF C-17 Globemaster, in anticipation of Cyclone Yasi. 2011.

Evacuation Platforms

While developing effective systems and competent personnel is the main challenge in establishing a mobile critical care service, availability of appropriate evacuation platforms remains important. Some of the advantage associated with the British MERT may be simply the greater amount of space available in a CH- 47 Chinook (see Figure 1) compared to a UH- 60 Blackhawk. Strategic AME is considerably easier (and perhaps even safer) in a C17 Globemaster (see Figure 2) than in the slower, noisier and more cramped C130 Hercules. Table 3 outlines characteristics of common military aircraft. There is debate in most militaries over whether aircraft evacuating from the point of wounding should be dedicated to the AME role, but modern air forces have mostly abandoned dedicated strategic fixed wing aircraft in favour of multi-role platforms fitted as required with critical care equipment, such as the RAAF Deployable Aeromedical Retrieval and Transport System (DARTS) package. Civilian critical care AME generally involves fewer patients, transported either in small aircraft or in a reconfigured space on a commercial airliner. The time and expense of configuring civilian airliners has meant that almost all large-scale critical care air evacuations have been performed using military aircraft.

Clinical Considerations in Aeromedical Evacuation

Many textbooks (such as Hurd et al. (2003)) discuss the clinical considerations in aeromedical evacuation of the critically ill, and this is not the place to reproduce their content. It is sufficient to note that the problems of lower atmospheric pressure at altitude (even in pres- surised cabins if they are not kept at sea level, as is commonly the case), lack of space, noise, vibration, temperature, vulnerability (for example to a delirious patient) and the lack of consumables all require detailed planning by clinicians familiar with this environment. Clinical 'pearls of wisdom' include the particular value of invasive arterial pressure monitoring in small aircraft in which vibration interferes with oscillometric devices, the utility of Heimlich (or similar) valves rather than waterseal chest drains, the use of endotracheal cuff manometers to prevent tracheal mucosal damage, and running infusions in syringe drivers rather than in bags hanging over volumetric pumps. A major obstacle in aeromedical critical care is the time many authorities seem to require to clear modern medical devices for use in flight, which commonly leaves the patient dependent on equipment that has long since been superseded in regular practice.

	Range, Cruising speed	Patient capacity	Medical Crew	Medical interventions that can be performed
Tactical evacuation from point of wounding and between hospitals in the Combat Zone				
CH-47F Chinook (as operated by the Royal Air Force MERT)	400nm, 120 knots	Up to 24 litters, up to 8 requiring critical care, but most often 1-2 in the MERT role from point of wounding.	1 physician, 1 nurse, 2 paramedics	All prehospital interventions likely to be required, incl. blood transfusion, rapid sequence intubation, video laryngoscopy
UH-60 Blackhawk (as operated by the Australian Army and USA rmy DUSTOFF)	348nm, 150 knots	Up to 6 litters, or typically one requiring critical care	2 emergency medical technicians	Basic interventions incl. needle thoracostomy, supraglottic airway devices & IV therapy, but not rapid sequence intubation or blood transfusion
HH-60 Pavehawk (as operated by the USA ir Force PEDRO)	373nm, 159 knots	Up to 6 litters, or typically one requiring critical care	2 paramedics	All prehospital interventions likely to be required, incl. blood transfusion, rapid sequence intubation, video laryngoscopy
Strategic evacuation from hospitals in the Combat Zone to those in secure countries				
C-130J-30 Hercules (operated by the USAF, RAF and RAAF, amongst others)	2835 nm, 348 knots	Up to 97 litter patients in stacked racks (but up to 58 if carrying staff and equipment), or up to 5 (but usually only 3) in RAAF critical care configuration	USAF CCATT has 1 physician, 1 CCRN and one respiratory therapist, in addition to general duties AME nurses, for up to 6 critically ill patients. RAAF MCLT has 1 physician and 1 nurse in addition to a general duties AME team for every critically ill patient.	All critical care interventions, but usually not extracorporeal therapy
C-17A Globemaster (operated by the USAF, RAF and RAAF, amongst others)	2420 nm, 450 knots	Up to 36 litter patients, or up to 5 (but usually only 4) in RAAF critical care configuration		All critical care interventions. In USAF practice, when augmented with suitable personnel and equipment, this has included renal replacement therapy, extracorporeal CO_2 removal and extracorporeal membrane oxygenation.

Table 3. Examples and Characteristics of Common Military Aeromedical Transport Platforms in Common Use

Future Technology for Mobile Critical Care

Future mobile critical care should be made considerably safer and easier through the application of technologies that currently exist. If patient monitoring can be wirelessly streamed to a device the clinician either carries (or wears, as a head-mounted display (Liu et al. 2009)) in the airframe, the same information could be transmitted to a senior physician at the destination hospital – perhaps with a view of the patient from a helmet-mounted camera.

Relatively inexperienced transporting clinicians are often capable of lifesaving interventions such as intubation, but are reluctant to make the decision to do so; prompting by telemedicine is a promising means of overcoming this (Skorning et al. 2012).

Conclusion

The capacity to perform 'mobile critical care' has transformed the modern combat healthcare system, and equally has changed the standard of care afforded to many remote civilian populations and those affected by natural disasters. Clinical practice only improves with constant experience, and systems only improve when the feedback loop to those writing policy is short. Having demonstrated these facts admirably in the last 13 years of conflict, many experienced military clinicians will soon return to civilian practice. This affords an opportunity to transfer and also to build upon knowledge. With the anticipated reduction in military clinical activity, strategic alliances with civilian critical care transport services also offer a system-level opportunity to improve on the lessons learnt in conflict. U.S. military responsibility for civilian prehospital transport in southwest Texas is an excellent example of such a partnership (Bailey et al. 2013), as is the regular work of UK military personnel with the civilian London Helicopter Emergency Medical Service. Investments in improving care prior to arrival in large hospitals and in more rapid transport are the greatest opportunities to reduce preventable mortality from trauma and other critical illnesses.

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