In Clinical Practice

Sam D. Hutchings *Editor*

Trauma and Combat Critical Care in Clinical Practice

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Sam D. Hutchings
Editor

Trauma and Combat Critical Care in Clinical Practice

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Editor
Sam D. Hutchings
Royal Navy and King's College Hospital
London
UK

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To the men and women of the military medical services involved in the Iraq and Afghanistan conflicts. You made the unsurvivable survivable.

Foreword

Trauma and combat medicine exemplifies perfectly the juxtaposition of the destructive and creative capacities of human beings. As it seems unlikely that the former element will be tamed, creativity and commitment in trauma research and clinical practice will be needed for the foreseeable future. *Trauma and Combat Critical Care in Clinical Practice* demonstrates effectively how civilian and military trauma research cross-fertilise each other to provide evidence-based practical guidance to maximise recovery from life-threatening injury. This book distils research evidence and wisdom acquired the hard way – from caring for victims of trauma often in the most difficult circumstances, as captured by the clinical vignette in the opening chapter.

The recent military experience in Afghanistan in particular has brought unique expertise in immediate resuscitation, stabilisation and surgery of soldiers suffering profoundly destructive injuries. Once stabilised, the critical care odyssey of evacuation by air – a feat of endurance by the attending clinical staff of up to 36 h – has made it possible for these patients to receive continuing multidisciplinary care in a major trauma centre and to be reunited with their families. Improvements in survival achieved by advances in the early stages of trauma care must now be accompanied by a better understanding of the immuno-inflammatory and endocrine responses to tissue injury and a focus on improving long-term outcomes.

Intensive care medicine has an increasingly important role in this complex recovery pathway though minimisation of secondary complications such as remote organ injury, infection and sepsis, muscle loss, scarring and ectopic calcification; and enhanced regeneration of tissue, restoration of function and psychological support. The bimodal distribution of trauma – the young and the old – provides an opportunity to study how the youthful capacity for regeneration and resilience may be promoted in the elderly, with the opportunity for translation into non-trauma critical illness. Many recent advances in the care of acutely and critically ill patients have come through better organisation and implementation of existing knowledge, and here again the trauma experience is invaluable in informing all aspects of acute care practice. This book provides valuable guidance not just for trauma care but for critical care management in general.

Brigadier Professor Tim Hodgetts CBE PhD
FRCP FRCSEd FRCEM
Medical Director, Defence Medical Services
Professor Julian Bion FRCP FRCA FFICM MD
Professor of Intensive Care Medicine
University of Birmingham

About the Editor

Surgeon Commander Sam D. Hutchings is the Royal Navy's head of specialty for Intensive Care Medicine and undertakes his clinical practice at King's College Hospital, London. He is also a clinical academic with areas of research interest covering resuscitation endpoints in traumatic haemorrhage and the use of novel point of care perfusion assessment tools. He has deployed operationally to Iraq, Afghanistan and Sierra Leone.

Preface

In the early 1980s, Trunkey[1] described a pattern of trauma mortality that is still widely referred to today. His tri-modal distribution model considered that death could occur in one of three peaks. The early peak (death within minutes) is caused by catastrophic injuries with severe anatomical disruption. These injuries were, and still are, difficult or impossible to treat, although preventative measures such as car seat belts and military combat body armour have reduced the frequency. The middle peak consists of deaths occurring within the first hours following injury and mainly results from profound disruption of homeostasis and physiology. Examples include uncontrolled blood loss leading to traumatic haemorrhagic shock or failure of respiration secondary to an obstructed airway or intrinsic lung damage. A vast amount of clinical academic endeavour has been spent on reducing this second peak. Some of the multitude of examples include the adoption of standardised ATLS teaching highlighting the importance of the "Golden Hour", the development of dedicated major trauma networks, physician-delivered pre-hospital care, and changes to resuscitation paradigms that emphasise the importance of physiological damage control rather than anatomical restoration and the adoption of point of care devices to prevent catastrophic haemorrhage. Many of these advances have been driven forward at pace by the Defence Medical Services of nations involved in combat operations during the first two decades of the twenty-first century, and there is no doubt that many military casualties

[1] Trunkey DD. Trauma. Sci Am. 1983;249(2):28–35.

have recovered from injuries that would have been deemed un-survivable just a few years earlier.

But what of the third peak? Trunkey attributed these late deaths to multiple organ failure occurring days or often weeks after the initial injury. However, an examination of the demographics of trauma deaths today shows that this third peak has been substantially reduced. Of the 518 British military casualties of the war in Afghanistan who received a massive transfusion at the Role 3 hospital in Camp Bastion, over 91 % survived.[2] This occurred despite an average injury severity score of over 30. Much of this success was due to a reduction in the second (early) mortality peak but not all. Of the 441 British military personnel who died from combat related injuries in the Iraq and Afghanistan conflicts, 83 % died prior to hospital admission, reflecting the persistence of Trunkey's first peak. Of the 17 % who died after reaching hospital, 53 % died in the first 24 h, meaning that those that survived beyond 24 h had a 93 % chance of long-term survival.[3] Those 7 % who suffered late deaths can be compared with around 20 % of deaths occurring during the late peak of the original Trunkey study, many of whom were also much less severely injured.

This trend of falling late mortality is also found when examining modern civilian trauma systems. A recent randomised study[4] examining the optimal ratio of packed cells to plasma in American trauma patients who received a massive transfusion showed a lower mortality than predicted pre-study (24 % vs. 35 %) but also a low incidence of death from multiple organ failure (12.8 % of those who died and 3 % of those who were enrolled).

Certainly more effective early resuscitation strategies play a key role in reducing late deaths However, the often unrecognised success story in these improvements in trauma

[2] Data from Defence Statistics (Health): Recovery rates for UK Service Personal admitted to Camp Bastion Field Hospital. 25 September 2013.
[3] Keene DD, Penn-Barwell JG, Wood PR, et al. Died of wounds: a mortality review. J R Army Med Corps. October 2015:jramc–2015–000490.
[4] Holcomb JB, Tilley BC, Baraniuk S, et al. Transfusion of Plasma, Platelets, and Red Blood Cells in a 1:1:1 vs a 1:1:2 Ratio and Mortality in Patients With Severe Trauma. JAMA. 2015;313(5):471–12.

mortality over the past three decades is the role of intensive care medicine.

Effective intensive (or critical) care underpins initial trauma resuscitation with intensivists often adopting key roles in the pre-hospital and emergency department environment. However, it is the dramatic changes that have occurred within intensive care units that have arguably had the most impact in reducing late mortality following traumatic injury. Examples are too numerous to detail in full, but the adoption of lung protective ventilation, advanced haemodynamic monitoring, targeted fluid management and protocol based sedation are but four examples where practice is radically different to that seen in the 1980s.

Perhaps more important than individual changes in treatment is the development of systems and guidelines based on robust evidence. This approach to management has been widely embraced by the new specialty of intensive care medicine. This book has its origins in one such set of guidelines, developed by the United Kingdom Defence Medical Services to support the delivery of critical care during the 2001–2014 Afghanistan conflict and subsequently adapted to other deployed environments. Many of the authors involved in that work have contributed to this book.

Finally, but crucially, is the role of the intensive care specialist themselves. This relative new comer to the hospital scene is a key facilitator in the management of critically injured patients. Intensivists not only provide organ system support to their patients but crucially act as links between the multitude of other specialties involved in the management of severely injured patients, constantly ensuring joined up management across the multi-specialty and multi-disciplinary team.

As alluded to earlier many recent advances in trauma critical care have been driven by recent military conflict. This book aims to provide an overview of trauma critical care, but it has a distinct military feel and focus. Almost all the chapter authors are military clinicians, from Britain and Australia, who have served in the recent Iraq and Afghanistan conflicts. Despite this, all of the chapters have relevance to the practice of trauma critical care in any environment. The first chapter of this book describes a patient journey, for a British military casualty of a hypothetical future conflict, from injury to tertiary care. Many of the early themes from this chapter are subsequently developed later in this book. Although the early chapters set the scene by describing the initial stages of the trauma patient pathway, the bulk of this book focuses on decisions faced by the intensivist once the patient has arrived within the intensive care unit. The whole book is laid out in a question-and-answer format and aims to provide useful guidance to some of the common questions that intensivists caring for trauma patients are faced with every day. Wherever possible, the evidence base behind the suggested answers is discussed, and where uncertainty exists over best practice, this is acknowledged and discussed.

It is my hope that the experience gained in recent conflicts, and reflected in this book, can continue to provide benefit for both civilian and military trauma patients in the years and decades ahead and that they may go some way to further flattening Trunkey's third peak.

Finally the views and opinions expressed in this book represent the personal experience of the authors and editor and should not be taken to represent the official view of the UK Ministry of Defence.

London 2016 Sam D. Hutchings

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Contributors

Editor

Surgeon Commander Sam D. Hutchings, MRCS, FRCA, FFICM, DICM, DipIMC, Royal Navy Department of Military Anaesthesia and Critical Care, Royal Centre for Defence Medicine, Kings College Hospital, London, UK

Contributors

Jonathan Crighton, MBBS, FRCR Derriford Hospital, Plymouth, Devon, UK

Major William R.O. Davies, MBChB, MRCP, FRCA, FFICM Intensive Care, Royal Sussex County Hospital, Brighton, UK

Surgeon Commander Catherine M. Doran, BA, MB BCh, BAO, MD, FRCS, Royal Navy General Surgery, Royal Centre for Defence Medicine, Queen Elizabeth Hospital, Birmingham, UK

Squadron Leader George Evetts, MBBS, BSc, MRCP, FRCA, RAF Imperial School of Anaesthesia, London, UK

Wing Commander Ian Ewington, MBChB, MML, MRCP, FRCA, FFICM, RAF Royal Centre for Defence Medicine, Queen Elizabeth Hospital Birmingham, Birmingham, UK

C. Andrew Eynon, MBBS, MD, FRCP, FRCEM, FFICM Wessex Neurological Centre, University Hospital Southampton NHS Foundation Trust, Southampton, UK

Karen Friend, BSc, PgDip Department of Critical Care, King's College Hospital NHS Trust, London, UK

Surgeon Commander David A.T. Gay, MBBS, FRCR, PGCE, Royal Navy Derriford Hospital, Plymouth, Devon, UK

Commander Anthony D. Holley, MBBCh, DipDHM, FACEM, FCICM Department of Intensive Care Medicine, Royal Brisbane and Women's Hospital, Brisbane, Australia

Emrys Kirkman, OBE, PhD Defence Science and Technology Laboratory, Porton Down, Salisbury, UK

Lieutenant Colonel Stephen Lewis, Royal Army Medical Corps Department of Critical Care, King's College Hospital, London, UK

Surgeon Commander Simon J. Mercer, FRCA, Royal Navy Department of Anaesthesia, Aintree University Hospital, Liverpool, UK

Mark Midwinter, CBE BMedSci, MB BS, Dip App Stats, MD, FRCS Wide Bay Hospital and Health Services, Queensland Health, Brisbane, Australia

Major David N. Naumann, MA, MB, BChir, DMCC, MRCS, Royal Army Medical Corps NIHR Surgical Reconstruction and Microbiology Research Centre, Queen Elizabeth Hospital, Birmingham, UK

Academic Department of Military Surgery and Trauma, Royal Centre for Defence Medicine, Queen Elizabeth Hospital, Birmingham, UK

Surgeon Commander Kate Prior, FRCA, Royal Navy Department of Anaesthesia, King's College Hospital, London, UK

Colonel Michael C. Reade, MBBS, MPH, DPhil, FANZCA, FCICM Joint Health Command, Australian Defence Force, Canberra, ACT, Australia

The Burns, Trauma and Critical Care Research Centre, University of Queensland and Royal Brisbane and Women's Hospital, Brisbane, QLD, Australia

Surgeon Commander Paul S.C. Rees, MD, FRCP, DipIMC, Royal Navy School of Medicine, University of Saint Andrews and Ninewells Hospital Dundee, Dundee, UK

Squadron Leader Edward Spurrier, BM MD (Res) MRCS FRCS (Tr&Orth) Defence Medical Services, Birmingham, UK

Surgeon Captain Sarah A. Stapley, MB ChB FRCS FRCS (Tr&Orth) DM Trauma and Orthopaedics, Portsmouth NHS Trust, Royal Centre for Defence Medicine (Research and Academia), Birmingham, UK

Stephanie R. Strachan, MBBS, MMedEd, MRCP, FRCA, DICM Department of Critical Care, King's College Hospital NHS Trust, London, UK

Chapter 1
Treating the Critically Injured Military Patient

Sam D. Hutchings

Abstract Injuries sustained during armed conflict are often of a magnitude not seen in civilian practice, frequently occurring as a result of high velocity projectiles and explosives. The environment in which military healthcare providers operate is often remote and austere and treatments must be adapted accordingly. This chapter describes, using a fictional account of one possible future scenario, the pathway from wounding to strategic evacuation for an injured UK serviceman. It also outlines the critical care facilities provided by the UK Defence Medical Services on deployed operations.

Keywords Armed conflict • Major trauma • Military healthcare • Pre-hospital care • Critical care

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S.D. Hutchings, MRCS, FRCA, FFICM, DICM, DipIMC
Department of Critical Care, Kings College Hospital,
Denmark Hill, London SE5 9RS, UK
e-mail: sam.hutchings@kcl.ac.uk

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The following is a work of fiction based on one hypothetical future combat medical scenario. The medical capabilities described are either in current use, or proposed for use by the UK Defence Medical Services. Some of the treatments described are currently undergoing evaluation, and are not yet supported by robust evidence. They may, or may not, prove to be of use in severely injured patients in the future.

160400Z JUN 20[1]: Somewhere on a Distant Ocean

From the bridge of HMS *Queen Elizabeth* the officer of the watch could see the shapes of the other ships in the joint allied taskforce illuminated by the first rays of the sun as it inched over the horizon. Centred on the new British aircraft carrier the task force consisted of the French amphibious assault ship *Mistral* and her Royal Navy equivalent HMS *Albion*; these two vessels were currently close in to the coast, in preparation for the amphibious assault, planned to coincide with the first light of day. The remainder of the central core of the task force comprised two large replenishment ships and the Primary Casualty Receiving Ship, RFA *Argus*, herself a veteran of three previous conflicts and now in her 35th year of service. Further out, two Royal Navy Type 45 destroyers, along with a US Navy *Aegis* equipped cruiser provided air cover for the group. The young lieutenant looked at his watch; as the hand passed 0400, a flight of F35 fighters swept overhead. Over the distant horizon the first wave of landing craft were approaching the hostile enemy coast.

[1] This nomenclature is termed a date time group and is used by NATO and other military organisations. The time here is 0400 on 16 June 2020 and is given as Zulu (Z) time, which is GMT.

160500Z JUN 20: *Sabre* Beach

The young Royal Marine commando didn't even see the flash of the rocket propelled grenade as it launched from a concealed firing position in the treeline that fringed the beach. The warhead exploded less than half a metre away, kicking up a cloud of shrapnel that peppered the marine. The blast wind physically picked him up and threw him several feet in the air. Although the damage from most of the RPG fragments were absorbed by his Osprey body armour, one penetrated his upper thigh lacerating the femoral vein and puncturing the femoral artery. In addition, the physical force of the explosion and the impact of his landing fractured his left humerus, now bent at an unnatural angle. Still under hostile fire from the tree line his colleagues were prevented from reaching him to provide immediate assistance. However, his section commander was able to report the incident and a 'nine liner' casualty report[2] was sent to the task force.

160505Z JUN 20: 820 Naval Air Squadron Merlin, *Piranha 1*

The Maritime in Transit Care (MiTC) team, strapped into their seats in the back of the aircraft, consisted of a Royal Navy consultant in pre-hospital medicine, an emergency nurse and a medical assistant. They were equipped with a range of resuscitation equipment and monitoring devices, enough blood products to facilitate the first phase of resuscitation and a novel device for stopping blood loss from the lower body that was about to be tested for the first time on the battlefield. Within minutes of receiving the 9 liner they lifted from the flight deck of RFA *Argus* and sped towards the distant shoreline.

[2] A '9 liner' report includes information such as location, number of casualties, and their priority for evacuation.

160510Z JUN 20: *Sabre* Beach

A series of section attacks had driven back the enemy, who had been pouring suppressing fire onto the beachhead. With the area secured a commando trained Royal Naval Medical Assistant raced forward towards the injured marine. Performing an abbreviated primary survey, he focused his initial actions on controlling the potentially catastrophic haemorrhage flowing from the wound in the Marine's groin. The injury was too proximal for the application of a tourniquet so he quickly packed the wound with a haemostatic dressing. After ensuring that the casualty's airway was patent and his respiratory rate acceptable, he moved on to assess his circulation. A significant amount of blood had already been lost and the casualty's pulse was weak and rapid, his extremities cool. In the distance the sound of the Merlin's rotors could be heard over the crash of the waves.

160520Z JUN 20: *Sabre* Beach

With the Merlin still "burning and turning"[3] the pre-hospital team ran down the stern ramp. The team had many years of experience in the pre hospital arena, some of it gained during previous conflicts and kept up to date working within civilian pre hospital care systems. They quickly ascertained that the young marine had lost a significant proportion of his circulating blood volume. Wasting no time, they moved him to the back of the aircraft, which then lifted and turned back over the ocean.

[3] A phrase indicating that the aircraft had landed but not shut down it's rotors or engines in anticipation of the requirement for a quick departure.

160525Z JUN 20: 820 Naval Air Squadron Merlin, *Piranha 1*

In the back of the aircraft the team worked on the casualty. After securing intraosseus access into the undamaged contralateral humerus, the team rapidly infused two units of blood and two units of plasma. However, the ongoing blood loss had caused his brain perfusion pressure to fall and he was becoming increasingly agitated. The team moved on to induce anaesthesia using the intraosseous route for drug delivery, before undertaking endotracheal intubation and ventilation. The critical decision now was whether there was enough time to get the casualty to the nearest medical treatment facility on RFA *Argus* before the blood loss led to hypovolaemic cardiac arrest.

With the casualty's blood pressure now barely recordable the team made the decision to institute Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) treatment.

After accessing the casualty's femoral artery on the contralateral side to the injury, the pre hospital consultant inserted the balloon occlusion catheter over a wire. An ultrasound transducer on the tip of the catheter attached to a small portable monitor allowed the catheter to be precisely placed in the distal aorta, avoiding occlusion of the renal arteries. The balloon was then inflated under ultrasound guidance until flow was just occluded. With blood loss controlled, the team continued aggressive volume resuscitation using the remaining blood products in their shock pack[4] as the aircraft touched down on *Argus*'*s* flight deck.

[4] A pack of blood products, usually containing four units of O negative packed red cells and 4 units of plasma.

160600Z JUN 20: Emergency Department, Primary Casualty Receiving Facility, RFA *Argus*

The casualty was transferred into the Emergency Department (ED) after rapidly travelling down four decks in a huge purpose built lift that penetrated the cavernous hull of the ship. The purpose built facility was full of medical staff but the atmosphere remained calm and quiet. The pre-hospital consultant delivered a brief AT – MIST handover[5] to the trauma team. At the head end of the patient one anaesthetic specialist connected the patient to a ventilator whilst another inserted a large sheath into the subclavian vein. This 'trauma line' was connected to a rapid infusion device through which further boluses of blood and plasma were delivered, at a rate of up to 1000 ml/min. Concurrently a radiology consultant performed a rapid focussed ultrasound scan to exclude intra-abdominal haemorrhage and a digital chest X Ray was obtained at the outset of the primary survey. As the primary survey progressed the trauma team leader, a consultant in Emergency Medicine, had a critical decision to make; should the casualty go straight to the operating theatre or would advanced imaging enable further definition of the injuries sustained? In conjunction with the surgical specialists he decided that, although blood loss was currently controlled, the casualty required immediate surgery in order to obtain proximal vascular control, release the REBOA balloon and restore distal perfusion as soon as possible. Further imaging would be performed at the conclusion of this damage control surgery.

[5] A didactic handover format comprising information on patient **A**ge, **T**ime and **M**echanism of injury, **I**njuries, vital **S**igns and **T**reatments administered.

160615Z JUN 20: Operating Theatre, PCRF

The operating theatre in the PCRF is directly adjacent to the ED and the casualty was swiftly transferred onto the operating table. Three surgical teams were prepared to receive the patient, including specialists in general, orthopaedic and plastic surgery. A team of specialist theatre nurses prepared the patient and exposed the operative field. When the team was ready and a brief summary of priorities given by the lead surgeon and lead anaesthetist, the surgery commenced with the general surgeon obtaining proximal vascular control, after which the aortic balloon was deflated. The surgeons commenced the repair of the lacerated femoral vessels, inserting a jump graft to bypass the areas of injury and restore perfusion. Whilst this was underway the anaesthetic team undertook further volume resuscitation. Blood products including packed red blood cells, plasma, platelets and cryoprecipitate were provided from the on-board blood bank, and were tailored to meet the individual requirements of the patient's coagulopathy, guided by near patient thromboelastometry. The main objective of surgery was to obtain surgical haemorrhage control, and to restore perfusion to the lower extremities as quickly as possible, in order to minimise the subsequent ischaemia re-perfusion injury. Definitive surgical repair would be performed at a later time. The complex fracture of the humerus was expeditiously treated by the orthopaedic surgeon by the application of an external fixator.

160730Z JUN 20: CT Scanner, PCRF

After the operation concluded, the patient was moved to the CT scanner, located on the other side of the ED. His whole body was imaged to exclude other injuries, such as occult spinal fracture, and to confirm the integrity of the surgical repair. The radiology consultant reported the images in real time alongside the other members of the multi-specialty trauma team. The scan showed that flow through the arterial jump graft was adequately perfusing the lower limb and that in addition to the already noted injuries the casualty had sustained some rib fractures and associated areas of lung contusion. However, brain imaging and spinal reconstructions were reassuringly normal and there were no significant pelvic or abdominal visceral injuries.

160745Z JUN 20: Intensive Care Unit, PCRF

Less than 3 hours after he was first injured, the casualty arrived in the PCRF intensive care unit. The anaesthetist handed over to the intensive care consultant who continued the resuscitation, using focused transthoracic echocardiography to optimise the patient's volume status and thromboelastography to target on-going haemostatic resuscitation. The goal now was to ensure that tissue perfusion was normalised as quickly as possible and to aid in this a point of care videomicroscope was employed to assess flow through the sublingual microcirculation.

181500Z JUN 20: Royal Air Force C17 Transport Aircraft

The patient went on to develop a marked systemic inflammatory response and vasoplegia following reperfusion, and this necessitated ongoing organ support on the ICU. Given the operational situation, there was a delay of several days until the patient could be evacuated to a land based airhead and repatriated to the UK. He was transferred from *Argus* and met at the airhead by a dedicated Royal Air Force Critical Care Air Support Team (CCAST). This specialist team of intensivists and critical care nurses were able to provide ongoing organ support during the transfer within a C17 aircraft. Four days after injury the patient arrived at a large tertiary hospital within the United Kingdom. After further definitive surgery he was weaned from ventilatory and cardiovascular support and made a full recovery from his injuries.

The Challenges of Treating Critically Injured Patients During Military Operations and the Contribution of Critical Care Services

Patients like the Royal Marine in our fictional example who sustain injuries during conflict present with a constellation of injury patterns unlike anything commonly encountered in civilian medical practice. The use of explosives and high velocity ballistic rounds often produce catastrophic injury patterns that can be rapidly fatal without appropriate management. Furthermore patients often sustain these injuries in parts of world without any modern medical, let alone specialist critical care, facilities. The point of injury may be exposed to hostile enemy fire and be many miles away from the nearest allied medical treatment facility. Although the initial treatment for these patients will usually be provided by specialists in Emergency Medicine, Surgery and Anaesthesia, without the intensive monitoring and on going resuscitation provided by a deployed critical care unit, these patients are at risk of early mortality and significant morbidity. Critical care specialists and services will play an increasingly vital role as patients move onwards following initial resuscitation and surgery.

Figure 1.1 shows the "Pathway to Recovery" for a serviceman or woman injured during military operations. As outlined in the fictional account above, each step is a vital link in the pathway from injury to eventual recovery and the absence of any of these components may lead to increased mortality or morbidity. Critical care support comes relatively late in the pathway but is often necessary for a far longer period than the other components. There are a variety of environments where deployed critical care services can be delivered.

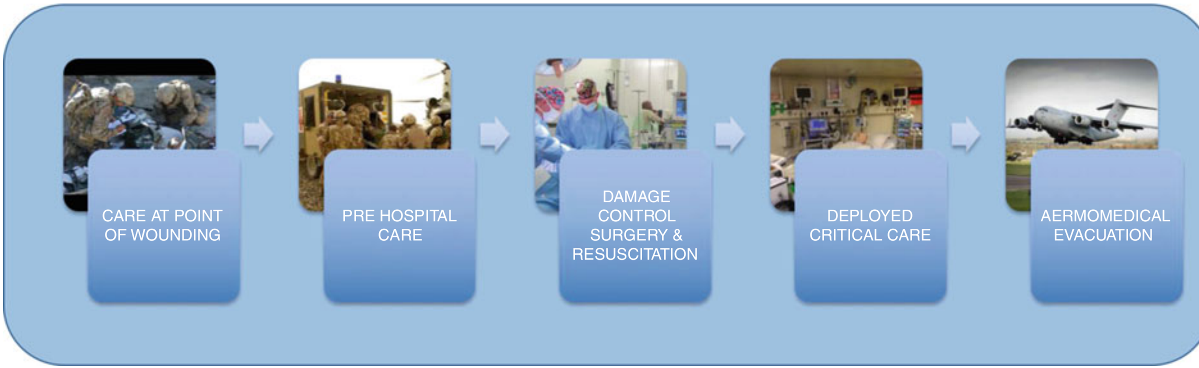

FIGURE 1.1 Pathway to recovery for critically injured UK service personnel. Each link in the chain performs a vital function but patients will often spend the majority of their time prior to strategic evacuation within deployed critical care facilities

What Types of Critical Care Services Are Provided Within Deployed Medical Treatment Facilities?

There are a variety of medical treatment facilities that can be deployed to support military operations. Those that have provision to support critically ill patients are detailed here. As discussed in the Preface, this book has a particular UK focus, but similar structures are systems are used by other NATO and allied nations.

Forward Medical Treatment Facility (Ashore or Afloat)

Smaller facilities will often be used to support more mobile operations or where there is a very long chain of evacuation back to a larger facility. They can be land based, often deliverable entirely from the air at short notice, or maritime. In the latter case a small critical care facility can be placed on a variety of existing warships or auxiliary vessels. These facilities have the capacity to hold ventilated patients for a limited time (usually up to 48 hours) prior to evacuation to a higher scale deployed medical treatment facility or the home base. However, they lack many of the services available at larger facilities. In addition to lack of imaging (which may include mobile x-ray and ultrasound rather than CT), and reduced pathology services (limited blood tests and transfusion services without platelets or cryoprecipitate), the equipment is often more basic. In the lighter scale facilities, the intensive care ventilator is no more than a simple transport ventilator. The intensive care beds are light-weight frames with issues for pressure area care. Monitoring is, however, similar, and the majority of drugs required for critical care are available, albeit in smaller quantities. An example of the critical care area within such a facility is shown in Fig. 1.2.

FIGURE 1.2 The critical care area within the Commando Forward Surgical Group (CFSG) forward medical treatment facility. Designed to support the UK Royal Marines close to the forward edge of the battle space it is staffed by surgeons, anaesthetists and intensive care nurse specialists (Photograph courtesy of Surgeon Commander Barrie Decker Royal Navy)

Vanguard Field Hospital

Newly deployed land based field hospitals will usually be designed to stay in one location, further removed from the area of battle. They will typically utilise tented accommodation and the physical infrastructure may be relatively austere. There will be less physical space than in a mature hard standing facility and this may impact on some of the interventions that can be delivered. The working environment may be harsher and supply of essentials such as lighting, temperature control and medical gases will be harder to guarantee. The impact of the environment can be more pronounced and this may produce effects on staff and service delivery. Despite this the range of clinical and support services available are not dissimilar to those in a more mature deployed treatment

Figure 1.3 A bed space within the intensive care unit of a land based field hospital, taken during an exercise (Photograph courtesy of Lieutenant Colonel Stephen Lewis RAMC)

facility. There will be a laboratory service capable of supplying blood products and supporting a massive transfusion protocol. Near patient testing in the form of ROTEM and iStat will also be available. CT scanning facilities will be available in more established facilities but not necessarily during the initial, insertion phase. An example of the critical care area in such a facility is shown in Fig. 1.3

The Mature Deployed Medical Treatment Facility

This type of unit would be very familiar to a civilian intensivist. It is usually contained within a hard standing facility and is well lit and temperature controlled. Bed spaces are large and equipped with modern electronic beds. There are usually adequate supplies of high pressure oxygen, although this will be delivered by cylinders rather than pipelines from a remote source. Electricity generation is reliable and capable of delivering an uninterrupted supply under most circumstances. There are dedicated areas for administration and staff downtime. Resupply is not normally a problem with an air bridge delivering timely resupply of consumables and equipment. Strategic aeromedical evacuation is usually conducted from a co-located airhead, reducing the requirement for a secondary transfer. Examples of this type of facility, operated by the UK DMS, include the latter build critical care areas within the Role 3 Hospital at the Contingency Operating Base, Basra, Iraq (maximum 4 beds) and the Role 3 Hospital at Camp Bastion, Afghanistan (maximum 16 beds). Figure 1.4 shows an example of such a facility.

FIGURE 1.4 A bed space within the intensive care unit at the Role 3 Hospital, Camp Bastion, Afghanistan

Primary Casualty Receiving Facility (PCRF)

The PCRF is housed within RFA Argus, shown in Fig. 1.5.

Within this ship is a modular hospital, which contains a ten bed critical care facility, shown in Fig. 1.6. The critical care facility is one part of a complex that includes a four resuscitation bay emergency department, a CT scanner and a two table operating theatre as well as dedicated support from laboratory services.

FIGURE 1.5 RFA Argus, a 28,000 tonne multi role vessel of the Royal Fleet Auxiliary. Her primary role is to deploy and operate the Primary Casualty Receiving Facility. She is a veteran of the Falklands Conflict (as the MV Contender Bezant), the Gulf conflicts of 1991 and 2003 and most recently the operation to provide assistance to Sierra Leone during the 2014/15 Ebola crisis

FIGURE 1.6 One half of the PCRF intensive care unit, showing half of the ten bed spaces. A bed space with a simulated patient from a recent exercise is also shown