Transfer and Evacuation

28

Ian Ewington

28.1 Introduction

The aim of evacuation is to get the casualty from the point of wounding to definitive care. To do this safely requires comprehensive and robust plans in place by the local healthcare provider to ensure appropriate teams are tasked with the right resources to get the patient to the right treatment location. Depending on the clinical and logistical circumstances, this may require a number of staged transfers between medical treatment facilities. Intervention maybe necessary at these intermediate facilities in order to stabilise the patient for the onward move.

In the UK, the introduction of Major Trauma Centres (MTC) and Trauma units in a network arrangement have facilitated the improved care of patients. They have also resulted in a reduced need for secondary transfer between hospitals [1]. This reduction in secondary moves is due in part to the implementation of protocols which allow the Ambulance Service to bypass local hospitals in order to get the patient to the MTC. If the patient is too unstable for a prolonged transfer, then they will go to the local Trauma Unit where they will be stabilised first.

The factors to be considered when developing a patient transfer service include: Patient population at risk; geographical area; personnel; equipment; vehicles; clinical guidelines; administration and governance. Pre-hospital care transfer teams, as well as in some areas secondary care transfer teams are now common in the UK. These are usually provided by a mix of NHS and charity funded organisations. They also utilise a mix of air and land based assets.

I. Ewington
Department of Anaesthetics and Critical Care, Royal Centre for Defence Medicine,
Queen Elizabeth Hospital Birmingham, Edgbaston, Birmingham B15 2WB, UK
e-mail: ianewington1@nhs.net

J. Breeze et al. (eds.), *Ballistic Trauma*, https://doi.org/10.1007/978-3-319-61364-2_28

28.2 The Military Experience

The military have gained a comprehensive knowledge of trauma management over a 15 year period in Iraq and Afghanistan. Part of this has been the development of safe and effective transfer teams in the pre-hospital environment as well as for secondary transfers following initial stabilisation. Some of this experience has been successfully transferred into the civilian environment. This has included clinical elements such as the introduction of pre-hospital blood products and in training by developments in medical simulation. Such experience may be particularly useful in preparation for and response to mass casualty trauma incidents such as those seen in the Paris terrorist attack (2015) and London bombings (2007).

For the most seriously injured patients in the combat environment, damage control surgery and resuscitation is usually performed prior to transfer to higher levels of care [2]. In a major civilian event, it may be that local Trauma Units or even ad hoc surgical teams on scene have to undertake this function. This would ensure the entire trauma network is utilised more effectively and patients who require further management at the MTC reach it in a more stable state. Clearly the role of each element of the trauma network will be incident related and will require direction from the command teams at the time.

In the military, casualty evacuation is typically divided into three phases: forward, tactical and strategic. Forward medical evacuation is movement of the casualty from the point of injury to a medical facility within the operational area. Tactical evacuation moves the patient from the initial medical facility to another with higher levels of care still within the operational area. Strategic evacuation moves the patient to the highest level of care outside the operational area.

The forward area involves the location of the original incident therefore evacuation may need to be carried out whilst under fire. This means that assets should be readily available and well prepared to operate under such circumstances. Initial evacuation may even be on foot if the local medical aid post is close by. If not, then depending on the distances involved, the terrain and availability of assets, evacuation may be by land or air.

The tactical area involves the wider operational area but remains under control of the local commanders. Evacuation to levels of intermediate care often involves air assets either rotary or fixed-wing. These transfers are usually under less time pressure than those from the forward area which means crews may not be held on the highest state of readiness. It may even involve re-tasking of aircraft in order to undertake the transfer.

Strategic evacuation often means transferring the patient back to their country of origin, but this is not always the case. They may be moved to another nations facility but the key is that the patient is moved to a safe location outside the operational area with the highest level of care.

Casualties are prioritised into three main categories using the ‘P’ system to classify in order to influence those responsible for arranging initial treatment and transport as well as a guide to the receiving medical facility. Exact time frames may depend somewhat on the situation but utilising clinical priorities as part of the initial medical planning should ensure appropriate resources are in place in order to provide timely treatment:

- Priority 1 (P1)—highest priority and these patients usually need resuscitation and urgent surgery or other interventions—evacuation should be undertaken as soon as possible.
- Priority 2 (P2)—may require surgery or other treatment but can be delayed for a few hours without immediate threat to life
- Priority 3 (P3)—may still require early treatment but can be delayed if necessary without anticipating clinical consequences

The choice of assets to move the patient will be guided by clinical need, availability, terrain and the combat situation. The latter two factors often mean that an air frame is the optimal choice if the transfer is over a significant distance. Mountainous terrain and lack of adequate road infrastructure in particular will also favour aeromedical evacuation.

Rotary wing aircraft have several advantages including flexibility over landing sites and flight path. The disadvantages include potential vulnerability to attack, load restrictions and patient access issues. Fixed wing aircraft have the advantage of height and speed but their use maybe restricted by availability of adequate landing sites.

The choice of escorting medical personnel will be dictated in part by availability, the dependency of the patient and the length of the transfer. For the critically injured this transfer will often be undertaken by specialist teams. In the pre-hospital environment this may consist of a Doctor, Nurse and Paramedic. This was seen to good effect in Afghanistan with the use of the Medical Emergency Response Teams (MERT). The aim for future conflicts will be to replicate this capability with appropriate operational modifications. For transfer to higher levels of care following initial stabilisation, the UK military capability of choice is the Royal Air Force (RAF) Critical Care Air Support Team (CCAST) (Fig. 28.1). This team will be discussed later in this chapter.

28.3 Major Incidents

In the UK, evacuation of civilians following for example a domestic terror incident is likely to follow the local major incident planning protocols. These will involve the MTCs and the associated network of trauma units outlined above. A major incident in the UK is that which requires special arrangements to be implemented by one or more of the emergency services. The casualty numbers that define this will vary between areas. It is usually necessary to call in extra personnel and equipment in order for it to be dealt with effectively.

The initial scene may well be chaotic with uncertainty about further hazards until command and control is established by the emergency services. Once a triage process has commenced evacuation of the priority casualties from the scene will begin. Depending on the location this may be by a combination of air

Fig. 28.1 CCAST. Reproduced from Ryan's ballistic trauma 3rd Edition, drawn by the Artist Tony Green

ambulance and the local road ambulance service. In the case of large numbers of casualties, the MTC would be the primary receiving unit for the most severely injured with the surrounding trauma units taking the less injured. The exception to this is where damage control surgery and resuscitation is required to stabilise, in which case the local Trauma Unit may be better placed to do this depending on geographical location.

Domestic terror events whilst uncommon do not just have the potential to cause significant numbers of casualties with the resultant impact on local health care services. There is also the risk of further incidents and if there is chemical, biological or radiation elements involved, then responding emergency personnel as well as the wider public could be at risk. There may also be a danger to local infrastructure which may influence how the emergency services are able to respond. The need to react in a structured and well planned manner is vital to ensure that all such potential incidents are dealt with effectively.

For the purposes of transfer and evacuation of casualties this includes ensuring teams are prepared for such attacks with appropriate training, adequate equipment and specialised drugs. For hazardous and particularly for toxic environments, the ability to deploy expert medical response teams is essential. In the UK this includes an integrated approach between all emergency services and for the NHS in England and Wales, the use of Hazardous Area Response Teams (HART). The personnel on such teams include Paramedics who have undergone training in use of specialised personal protective equipment, working at height, and working on water. In addition, they are specifically able to deal with chemical, biological and radiation incidents whether those are deliberate or accidental.

28.4 Transfer by Land

For trauma patients in the UK, transfer by land is far more common but also not without challenges. Depending on the position of the casualties evacuating them quickly by land could be difficult. This could be due to the rural, even mountainous location of the incident but equally could be just as limited by the traffic congestion of major cities. In mass casualty events, the use of novel transfer vehicles such as coaches or trains may be necessary for even the severely injured in order to get them away from the scene if there are ongoing hazards. This is not without risk of course and needs to be carefully weighed up. In the modern military, transferring patients by land is often reserved for moves over shorter distances due to limitations of terrain, potential for ground attack and location of medical facilities. When air transfer is not feasible due to the combat situation, environment or availability of assets then if appropriate and available a dedicated medical vehicle should be used. The British military use the Battlefield Ambulance (BFA) as the primary ground transfer vehicle (usually a Land Rover Defender), one limitation of this vehicle is it is not armoured. Therefore, if the transfer is prolonged and there is a significant ongoing risk of attack an armoured vehicle will be more robust. This may be a dedicated medical vehicle or an armoured personnel carrier adapted to the role.

28.5 Transfer by Air

The primary strengths of air power are height, speed and reach. It is these same characteristics that mean an aircraft can be a very effective platform on which to transfer patients. This can be particularly relevant in the combat environment where ground transfers may be limited due to the reasons outlined above. The choice of aircraft will be determined by several factors including other taskings if there is no dedicated medical air frame. Negotiations maybe necessary in order to secure an aircraft for medical transfers but where the patient is a P1 there is usually little that would take precedence.

The military will consider whether there is a need for air transfers as part of medical planning for any operation. Where the risk of significant casualties is high then they may incorporate an air based response team such as MERT as part of the deployment. There will also be a plan for escalation to higher levels of care as part of the same medical plan. This may involve deployed or host nation medical facilities.

The nature of rotary wing aircraft means that their value lies in the forward area. Whilst generally slower (100–150 mph) they have much more flexibility and manoeuvrability around landing sites compared to fixed wing. The crew need to be prepared to respond quickly and this is the benefit of having a dedicated medical air frame. If not, then the aircraft will need to be adapted quickly to undertake the medical role for each mission. In the forward environment there may be the requirement to put force protection personnel on the aircraft to protect it, the crew and the patient. They cannot be pressurised and therefore are altitude limited, usually 10,000–14,000 ft compared to over 30,000 ft for fixed wing. This may also put the aircraft at risk if there is a ground threat of surface to air missiles. Limitations in the medical role include the number of patients that can be transferred at the same time and the stability of the platform.

In the civilian environment rotary wing aircraft are used extensively in the air ambulance role. They offer the ability to transfer patients rapidly over longer distances to the regional trauma centres. In the larger urban areas such as London, the benefit comes from being able to bypass congestion on the roads. London Air Ambulance carries a doctor trained in pre-hospital care as well as dedicated paramedics. They began carrying blood in 2012 and since then many air ambulances in the UK have also introduced this as well as lyophilised plasma and tranexamic acid [3].

In the case of urban mass casualty incidents, the air ambulance would be of limited use in moving patients due to capacity. However, the London Air Ambulance was used to good effect in the 7/7 bombings, as it was employed to move medical personnel forward in order to improve initial triage and treatment. This was thought to have helped reduce the critical mortality at one receiving hospital to 15% [4].

Fixed wing aircraft are especially useful for covering long distances at speed but they are limited by the need for some form of stable runway. Some military aircraft such as the Lockheed C130 Hercules can land on small areas of unprepared ground but even they need the area to be free of obstructions and relatively flat. Fixed wing aircraft such as the Boeing C17 Globemaster III, allow strategic moves over intercontinental distances and provide a relatively stable environment in which to provide treatment to multiple critically ill patients if required. The utility of these aircraft is such that during military operations in Iraq and Afghanistan, the RAF CCAST were often able to transfer patients back to the Role 4 hospital in Birmingham within 24 h of injury.

28.6 Critical Care Transfers

When the patient is critically injured they will require specialist clinical care during the transfer, which depending on the context may be over many hours. In the forward combat environment, the critically injured casualty is likely to need resuscitation and stabilisation. This is usually started by team medics and combat medical technicians who will subsequently hand over to pre-hospital care teams such as MERT, for the transfer back to a medical treatment facility (MTF). When a doctor deploys with the MERT it is designated MERT((E)nhanced). Both Anaesthetists and Emergency Medicine Physicians have fulfilled this role in the past.

During the transfer various medical interventions such as endotracheal intubation or thoracostomy may be delivered. In effect it is possible to commence damage control resuscitation prior to arrival at the MTF, including the administration of blood products. It is therefore essential that the team are confident in providing this care in the austere military aviation environment. This has been achieved in the past by enhanced pre-deployment training, standard operating procedures and the MERT course [5].

Critically injured patents transferred by air who have undergone initial stabilisation at an MTF but require onward movement to a higher level of care are also escorted by specialist teams. These are formed from within the Critical Care cadre of medical and nursing staff. In the UK military sphere, these are drawn from the Royal Air Force and formed into Critical Care Air Support Teams (CCASTs). Such transfers may be in the tactical environment, moving patients within the theatre of operations for clinical reasons such as neurosurgical intervention. Strategic transfers were undertaken to move the patient outside the theatre of operations and for the UK this usually meant transfer back to the Role 4 facility in Birmingham. This transfer could take between 10 and 14 h depending on air frame and route.

These teams have a core structure of:

- Two intensive care trained nurses called a Flight Nursing Officer (FNO) or a Flight Nurse (FN) one of whom is also the Team Leader.
- A flight Medic who assists with patient interventions, transfer of the patient, and administrative duties.
- A medical devices technician who maintains the equipment and also provides assistance with transfer of the patient.
- A Consultant Anaesthetist.

This core team of five personnel has the capability to transfer one critically ill patient. The missions can be long and complex and therefore one of the Nurses undertakes the team leader role. This allows the Consultant and other Nurse to concentrate on clinical care whilst the team leader manages the mission. This will include liaison with aircrew, ground crew and the MTF.

The team may be augmented with a third nurse (FNO or FN) which increases the capability if there are more patients. The team will also often have a FNO, FN, Medic and/or an anaesthetist under training as it is essential for personnel to gain experience of the CCAST environment before being tasked to undertake unsupervised missions. This team, in addition to their core training for their specialty, also undergo specific training relevant to their mission, whether that be the specific clinical challenges of transferring a patient long distances at altitude (with the consequent effects on the patient's physiology) or the practical considerations of travel on military aircraft (evacuation, safe use of aircraft systems, safe loading of patients and equipment and Dangerous Air Cargo regulations).

Following the beach terrorist attack in Tunisia in 2015, the RAF CCAST were deployed on a Boeing C17 Globemaster in order to repatriate the critically injured to the UK. They were able to do this quickly due to the flexibility and responsiveness of the capability. The short 'notice to move' time and the ability to work on a variety of air platforms contributes to this as well as the thorough training the teams undertake.

The employment of such military teams as part of a wider civilian response can be a sensible use of resources when appropriate. In the case of this particular incident, this not only allowed the evacuation of patients back into the UK healthcare system to be nearer their families but also relieved pressure on the local medical facilities in Tunisia.

28.6.1 Equipment

Equipment for use during critical care transfers should be robust, durable and lightweight. The requirement to transfer a military casualty from the point of injury increases the demands on the equipment. This includes the potential need to operate in extremes of temperature as well as withstanding ingress of dust and water. It must also be able to function consistently in a range of ambient temperatures, humidity and pressure.

Once disconnected from mains electricity it is essential to ensure the equipment can continue to function on battery power. It may be possible to access power on the aircraft but this has the potential to interact with the avionics. Therefore, it must be either cleared for use in advance or the aircrew are made aware and a risk assessment made. The RAF CCAST run all equipment on batteries independent of the aircraft. In addition to the reduced risk to the aircraft systems, this provides flexibility should it be necessary to change air frames or there are delays in the transfer. Medical equipment has the potential to create electromagnetic interference (EMI) as well as being susceptible to it. EMI may also originate from the aircraft systems. Electromagnetic compatibility is an issue that needs to be considered as it has implications for both aircraft and patient safety. This phenomenon is not limited to just the equipment itself; power cables can also radiate emissions and act as aerials [6]. All equipment must go through a period of airworthiness testing to ensure that any interference is identified and steps taken to remove this (for example, with shielding).

28.6.2 Monitoring

There are well recognised minimum standards for monitoring that should be applied during any transfer of critical care patients whether that is within the hospital environment or between facilities [7]:

- Continuous cardiac rhythm (ECG) monitoring
- Non-invasive blood pressure
- Oxygen saturation (SaO2)
- End tidal carbon dioxide (in ventilated patients)
- Temperature

In the aeromedical transfer environment there are additional challenges in accurately monitoring the patient that require specific consideration as well as extra vigilance from trained personnel. Aircraft noise and vibration mean that clinical assessment of the patient by techniques such as auscultation and percussion can be impossible. The use of audible alarms can also be limited for the same reason therefore it is usually more effective to use medical equipment with clear visible alarms (e.g. amber and red flashing warning lights). ECG, non-invasive blood pressure and pulse oximetry are prone to artifact from functioning in the aviation environment. This can lead to inappropriate activation of alarms and increase ‘alarm fatigue’ for personnel [8].

Given the duration of transfers for strategic aeromedical evacuation as outlined earlier, there is the requirement for additional monitoring. Invasive blood pressure monitoring using a transduced indwelling arterial cannula is strongly advised; it negates some of the difficulties encountered by artifact on non-invasive monitoring and allows for arterial blood gas analysis. Notwithstanding EtCO2 monitoring and pulse oximetry, blood gas analysis remains the gold standard [6]. It also has the added benefit of providing supplementary clinical data such as basic biochemistry. Hand held analysers are available on the market and should be seen as essential on transfers more than a few hours long.

Central venous cannulation is required for administration of inotropes and can be transduced to provide clinical data in the form of central venous pressure. If not already provided from blood gas analysis, blood glucose analysis is simple to carry out using either a visual colour coded strip, or more accurately with a small, hand-held digital analyser.

Intracranial pressure (ICP) can be measured when an extra-ventricular drain is in place by connection to an appropriate transducer and thus displayed as part of invasive pressure monitoring. It is also feasible to measure ICP by an intra-parenchymal micro-sensor although this requires the use of a dedicated air worthy monitor.

Ideally, monitors should be able to measure and display ECG, pulse oximetry, non-invasive blood pressure, up to three invasive pressures, capnography, and temperature [7]. The monitor currently used by RAF CCAST is the corpuls [3] (GS Elektromedizinische Geräte G. Stemple, Kaufering, Germany) which has an integrated defibrillator and pacer. It can be split into three components (screen, patient box and defibrillator) which communicate with each other via wireless technology (Fig. 28.2). This provides greater flexibility and allows for easier monitoring during transfer, particularly when moving the stretcher.

Fig. 28.2 Corpuls [3] monitor, patient box and defibrillator/pacer. Combined together with the associated cables and consumables in side pouches (*left*). Broken down into the three component parts (*right*)

28.6.3 Batteries

RAF CCAST advocates and operates self-sufficiency in terms of electrical power. This self-sufficiency, along with the requirement that equipment be lightweight, means that the type of batteries utilised is significant; the battery will largely determine the size and weight of any device, and its duration of function. When calculating the electrical (and therefore battery) power it should be anticipated that there will be delays, such as to aircraft departures, arrivals, and even emergency diversions for clinical or aviation reasons. Secondary, or rechargeable, batteries are more commonly used especially in larger pieces of equipment with higher energy requirements such as patient monitors and ventilators. Smaller items of equipment may be designed to operate on primary, or disposable batteries and can operate for many hours. They are, however, usually less mission critical, have relatively low energy requirements and can usually be relied on to last many hours more than the transfer requires.

Rechargeable battery technology has improved significantly in the last couple of decades, largely due to the popularity of personal electronic devices such as laptops and mobile phones. Improvements have in turn enhanced the capability of medical transfer equipment. The main battery options commonly available are lead-acid, nickel cadmium (NiCd), nickel metal hydride (NiMH), and lithium-ion (Li-ion), each with their own particular advantages and disadvantages. A principle consideration is that of weight and size, both for ease of movement on the ground with the patient and in reducing the "footprint" onboard the aircraft.

The batteries with the highest energy density are Li-ion, commonly used in laptops. These would seem ideal as they provide a lot of stored energy for a relatively small and lightweight battery. Unfortunately, they pose a theoretical fire risk if abused and are treated as dangerous air cargo by many airlines [9]. Lead acid batteries have the lowest energy density, but are a tried and tested technology and have been in use for over a century. As this lower energy density suggests, they will be larger and heavier than other batteries and are thus not always the ideal choice for energy demanding medical equipment, and a possible handicap in transferring a patient. Of the remaining options, NiMH has a higher energy density than NiCd. The NiCd can suffer from memory effect, where its capacity is effectively "lost" over time. The newer generation NiMH batteries seem to have overcome the memory effect issue and are now taking much of market share traditionally held by NiCds.

Batteries work most efficiently within specific temperature ranges. The storage, use and charging of them in extremes of temperature are likely to decrease battery life and increase recharge times [10]. The extent of this will vary between battery types; ideally battery options would be varied dependant on environmental conditions. This is impractical, so attention must be paid to buy the most flexible option at the procurement stage. When not being used, most batteries will drop from their fully charged state. This self-discharge is obviously more significant the longer a battery is "sat on the shelf" and may be more pronounced in NiMH; for this reason, batteries should be either regularly checked or stored on a trickle-charger. Ultimately, each manufacturer will give the most appropriate advice for its own particular brand and this should be followed as strictly as practicable; some manufacturers advising a re-conditioning processes to prolong the life of the battery. This re-conditioning can often be carried out whilst the battery is in the equipment connected to a power supply.

28.6.4 Oxygen and Ventilators

Supplemental oxygen should be carried with the assumption that the patient's oxygen requirements will increase at altitude. Indeed, it should also be assumed that the patient may deteriorate and thus require supplemental oxygen in excess of that required by altitude and consequent pressure changes alone. The safest approach is to assume that a ventilated patient will require ventilation at an inspired oxygen concentration (FiO2) of 100%, and as with determining battery power consumption, delays should be anticipated. Sufficient oxygen must be carried; a diversion due to insufficient oxygen almost certainly indicates poor planning, carries a heavy financial burden and is rarely in the patient's interests.

Oxygen cylinders are treated as dangerous air cargo and must be handled and stored in accordance with the carriers instructions. The explosive nature of oxygen cylinders was seen in 2008 when a civilian Boeing 747 suffered a rapid depressurisation event secondary to failure of an oxygen cylinder in the cargo hold [11].

Integral to calculating oxygen consumption, users must know the quantity of oxygen consumed by the particular ventilator being used. This will vary depending on the technology utilised and whether gas or turbine driven; certain models of the latter are gas inefficient. At an FiO2 of 100%, the volume of gas used beyond the delivered minute volume, i.e. wasted, can range anywhere from 1 to 11 L/min [12].

In terms of monitoring, transport ventilators should, as a minimum, have [7]:

- Disconnection and high pressure alarms
- Ability to deliver positive end expiratory pressure (PEEP)
- Variable FiO2
- Variable respiratory rate, inspiratory:expiratory (I:E) ratio and tidal volume

There are also a range of desirable characteristics, particularly for use in the military aviation environment during strategic aeromedical evacuation. They should be lightweight, simple to operate and ideally function without the mandatory need for compressed gas. In addition, the ability to efficiently ventilate both healthy and injured lungs as well as allowing spontaneous breaths (pressure support and continuous positive airway pressure (CPAP)) provides the necessary flexibility on long transfers [13]. Audible alarms remain essential but as with the alarms on the monitors the environment limits their usefulness. Therefore, constant vigilance by a dedicated member of staff is essential, particularly with regard to disconnection alarms during movement of the stretcher.

Some ventilators may require manual compensation for pressure changes due to altitude, or delivered tidal volumes will be significantly different to the set value [6]. Accompanying personnel must be aware of these issues. Equipment that will automatically compensate for altitude and meets both desirable and minimum specification is preferable and is widely available on the market.

28.6.5 Patient Preparation

Preparing the patient for aeromedical transfer follows many of the same general principles required for a road transfer and these are covered in suitable detail by the Intensive Care Society Guidelines [7]. It may be necessary depending on the context of the incident, to ensure the patient does not pose a risk to the transfer team from chemical or biological agents for example. In the case of large scale attacks this should be addressed by the initial response teams. If identified, then appropriate personal protective equipment should be worn and the patient decontaminated. However, less common agents may not be identified early therefore signs of illness in emergency service personnel should be taken seriously.

Where possible, the patient should be placed on a suitable transport ventilator in advance of the planned move in order to ensure they are stable on it. This should be followed up with an arterial blood gas prior to the move in order to confirm suitability of the settings. The patient should then be transferred onto a transport stretcher or gurney. A useful addition to this is the use of a transfer vacuum mattress, a sealed mattress that is similar to a beanbag in texture and composition. This can be moulded around the patient as air is pumped out of it, leaving a supportive rigid structure. This contours underneath and around the sides of the patient but leaves their front exposed. It has numerous benefits: it provides additional support in the case of spinal injury; it can help splint fractures, particularly of limbs; and it can effectively tie in loose lines. Care must be taken, however, to ensure that pressure areas are closely monitored; lines and cables must not press against exposed skin and in the case of longer transfers, the patient's position should regularly be changed.

The monitoring that has been used at the bedside should be changed for the monitors that will be used for the transfer. This opportunity should be used to ensure elements of the monitoring such as adhesive ECG electrodes, blood pressure cuff and pulse oximetry are adequately positioned and robust. Particular attention should be paid to the airway, invasive lines and nasogastric tubes. Any loose lines or cables should be secured. As a final step, the patient is secured to the stretcher using a harness. The RAF uses a specially designed 5-point harness for all aeromedical transfers. This is ideal for the strategic transfer of the critically-ill patient since it secures them for all stages of the evacuation: movement from Field Hospital to ambulance; ambulance to aircraft; and from aircraft to ambulance on arrival in the UK. Similar to the vacuum mattress it can also facilitate the securing of intravenous lines and cables. Consideration must be given to hearing protection for the patients during aeromedical transfer therefore foam plugs should be placed prior to the move.

The patient should also have their physiology optimised in readiness for flight where feasible. This should include correction of hypovolaemia as it is poorly tolerated once the patient is exposed to acceleration and deceleration forces of take-off and landing [7]. If the patient is loaded head first then blood will pool in the lower extremities on take-off. If they are loaded feet first, then there maybe elevation of the intra-cranial pressure. The critically injured patient may not be able to adapt to these rapid changes therefore they should be anticipated and treated accordingly.

For strategic aeromedical evacuation back to the UK, the patient should have no active bleeding and a haemoglobin level adequate for the journey. Blood products can be carried by the CCAST where deemed necessary and this may also include lyophilised plasma.

Other physiological factors to consider include correction of metabolic acidosis, seizure control and optimisation of intracranial pressure. Whilst such measures should be undertaken prior, the context of the evacuation may mean this is not possible. RAF CCAST has the capability to provide treatment *en route* beyond that of a simple transfer facility. It can initiate and continue advanced medical management throughout the evacuation chain until the patient reaches a definitive MTF. Where necessary they will request diversion to an appropriate facility if the patient deteriorates in-flight and needs more complex intervention.

28.6.6 Administration

Whilst undertaking the preparation of the patient for transfer it is essential that attention is also paid to the administrative elements. This includes copies of medical notes, blood results and radiological investigations. The latter can often be stored in electronic form such as a CD and then uploaded to the imaging system of the destination medical facility. A passport is still required for evacuation back to the UK where immigration procedures will still be in force. In the event of aircraft diversion to anywhere apart from the UK, difficulties with the host nation would undoubtedly ensue if a patient's passport was not available. Any belongings must, however, be rigorously checked for any items of dangerous air cargo; in the transportation of military casualties a search for live ammunition is pertinent.

As with any patient transfer, arrangements for onward movements must be made including contact with the receiving hospital and advice on expected timelines. Transport from the airhead of arrival should be confirmed so the transfer team are confident that the plans are robust; delays stretch oxygen and battery resources and potentially impinge on patient safety, at a time when the accompanying medical team are already likely to be fatigued. As an example, RAF CCAST have well organised reception arrangements in the UK. This is coordinated by the aeromedical team at the Role 4 hospital in Birmingham and the Aeromedical Evacuation Control Centre (AECC) at RAF Brize Norton.

28.6.7 In-Flight Care

All aspects of care, drugs administered, and regular clinical observations should be recorded in-flight. As previously alluded to, many treatments can be initiated either before or during transfer. In the shorter, tactical, aeromedical transfer there will probably be little time to undertake significant elements of nursing care. Time is usually available in the longer strategic transfers. Pressure areas should be observed and the patient's position changed during transit; even if the patient does not have formal clearance from spinal injuries, at cruising altitude, most aircraft afford a suitably stable platform in which the patient can be safely log-rolled. Eye and mouth care are routine within a static intensive care facility and this should be viewed no differently during strategic aeromedical evacuation. It may be difficult to access water in some aircraft, particularly military cargo airframes, however cleansing wipes offer a good alternative for maintenance of patient hygiene. Hand hygiene is still paramount; universal precautions should be utilised where possible and an alcohol based skin cleanser used to augment hand-washing. The minimum standard achievable in helicopters, where water is absent, is likely to be the wearing of disposable gloves.

28.7 Operational Aspects of Aeromedical Evacuation

In the UK, a Strategic CCAST is maintained at a permanent 6 h' Notice to Move (NTM) readiness state. This means that the Team must be capable of being in the air within 6 h of notification of a mission. In reality there is usually more than 6 h notice but if there is an aircraft available and the patient will be ready to move then the team should be prepared for that. Tactical CCASTs may be on even shorter NTM restrictions as the operational tempo dictates. If the patient and the CCAST are co-located (as is frequently the case in established operations), the patient and equipment can be prepared and ready to board the aircraft in as little as 60–90 min from the notification of a mission.

Planning of CCAST missions will usually start long before the patient is ready to be transferred. If a patient is brought into the Emergency Department (ED) with obvious critical injuries, a Tactical CCAST may be notified that a transfer is likely to be required while the patient is still in the ED or the Operating Theatre. This transfer may be for specialist intervention (neurosurgery, cardiac surgery, specialist imaging) or evacuation. This gives the team the maximum time to prepare for the mission. Similarly, it takes time to task an aircraft for any mission and these administrative tasks can be started before the patient is ready for transfer. If a patient is obviously going to need a period of Intensive Care after their initial resuscitation in a field hospital then it is important to immediately start planning for their onward evacuation as intensive care beds are usually in very short supply in operational theatres and these patients use up large amounts of resources, both in equipment and in clinical time (each patient requires one-to-one nursing whilst on the intensive care unit). Both of these resources are often limited in the operational environment making rapid evacuation essential to maintain operational capability.

If a patient who initially requires intensive care improves rapidly in the deployed setting their level of dependency will be reduced and they may be transferred by general aeromedical evacuation teams rather than a CCAST. The level of medical support is determined by the clinical scenario prevailing at the time. If the patient has a medical (non-surgical) problem (such as angina or an uncomplicated pneumothorax) then it may be appropriate for a physician trained in aviation medicine to accompany the patient in addition to the FNO/FN and an FNA. Surgical patients are sometimes transferred with an anaesthetic escort as their in-flight problems are most likely to be related to pain management and the physiological effects (usually respiratory) of altitude. Advanced pain management techniques such as continuous peripheral nerve blockade have been utilised with good effect during aeromedical evacuation [14].

Civilian aeromedical evacuation teams also provide a critical care repatriation service and responsible for transfer of British citizens from overseas medical facilities. They are usually commercial organisations based out of regional airports and use dedicated aircraft such as Bombardier Challenger and Learjet. The larger companies may have extensive medical and logistics links in other countries to facilitate patient moves. They often work in liaison with travel insurance companies when tourists are involved and international corporations who have globally based employees. Costs can be in excess of £100,000 for a long haul critical care transfer.

28.8 Aviation Physiology

This section is not intended to provide comprehensive coverage of aviation physiology. It will give a brief overview of the effects of changes in the composition of ambient air and the pressure and volume changes associated with an ascent to altitude.

For the purposes of this chapter, the atmosphere can be considered to have a constant relative composition of gases, namely:

- Nitrogen 78%
- Oxygen 20.9%
- Argon ~1%
- Carbon Dioxide 0.04%
- Neon, helium, methane, krypton, and hydrogen, all of which comprise less than 0.01%
- Water vapour

Water vapour is the only component whose percentage varies significantly over the altitude range concerned, being between 1% and 4% at the surface but averaging 0.4% over the whole atmosphere. Pressure varies inversely with altitude, decreasing to approximately 50% at 18,000 ft and to a quarter at about 33,700 ft. Table 28.1 gives the pressures in kilopascals and millimeters of Mercury (mmHg for various altitudes above sea level. For the remainder of this chapter, feet will be used to

Table 28.1 Pressure changes with altitude

Altitude (ft)	Altitude (m)	Pressure (kPa)	Pressure (mmHg)
0	0	101.3	760
1000	305	97.7	733
2500	762	92.5	694
5000	1524	84.3	632
10,000	3048	69.7	523
20,000	6096	46.6	349
30,000	9144	30.1	226
36,090	11,000	22.6	170

Reproduced from Ryan's ballistic trauma 3rd Edition

measure altitude as this is the unit generally used in aviation. Similarly, kPa will be used as the standard unit for pressure. The US uses mmHg to measure physiological pressures and these will be included for completeness where appropriate.

28.8.1 Hypoxia

An inspired oxygen concentration (FiO2) of 21% roughly corresponds to an arterial oxygen tension (PaO2) of 13.3 kPa (100 mmHg) due to a variety of physiological reasons that mean that not all the inspired oxygen reaches the alveolar capillaries. One reason for this is that inspired oxygen is humidified, either by evaporation from the respiratory epithelium or by humidification systems within the ventilator circuit in the intubated patient. This water vapour has a constant pressure of 6.3 kPa (47 mmHg) irrespective of altitude and should be removed from the total pressure prior to performing the partial pressure calculation. Thus inspired air has a partial pressure of $(101.3 - 6.3) \times 0.21 = 20$ kPa at sea level but has a partial pressure at 36,000 ft of $(22.6 - 6.3) \times 0.21 = 3.4$ kPa and not 4.8 kPa as might be expected from dry air.

The relative increase in significance of this water vapour further impairs the body's ability to cope with increasing altitude and mandates supplementary oxygen for all but low level flights. Furthermore, any physiological derangement of the patient's respiratory function becomes far more significant at altitude. A patient who requires 60% oxygen at sea level in order to maintain a normal PaO2 will require 90% oxygen at 10,000 ft. It is therefore not difficult to see how the patient may deteriorate quickly in flight if the changes in respiratory physiology are not anticipated and managed appropriately.

28.8.2 Effects of Gas Expansion

Another major consideration caused by altitude is the change in the volume and pressure of gases trapped within the patient, for example, in a pneumothorax, a pneumocranium, or in a paralytic ileus. Boyle's Law states that for a fixed amount of gas at a constant temperature, the volume is inversely proportional to the pressure. Care must therefore be taken to ensure that all trapped air is ventilated before flight, by means of a nasogastric tube for the stomach or a chest drain for the thorax. Patients with eye injuries and those with bowel anastomosis are also at risk of adverse effect from pressure changes. The aircraft cabin maybe typically pressurised to 8000 ft and therefore expansion of contained gas by around 10% is to be expected [15].

If there are concerns that the resultant pressure changes will cause clinical deterioration, then a lower cabin altitude restriction can be applied. This is achieved by taking a feed from the compressors in the aircraft engines but it has the implication of reducing fuel economy. A sea level cabin altitude will also reduce the maximum operational ceiling for the aircraft as only a certain difference in pressure between the cabin and the outside air can safely be maintained. This reduced ceiling (to maybe 25,000 ft) reduces the possible speed achievable in flight and increases drag, further reducing fuel economy. Flight planning is affected as lower airspace is under different restrictions and some mountain ranges cannot be crossed at this altitude, requiring alternative routing. All these considerations may mean that a flight that could have been completed without refuelling may now require at least one stop for fuel thereby further increasing the length of the flight. Therefore, the request for altitude restrictions should be carefully considered.

Air is also contained within the sinuses of the face (predominantly the maxillary and frontal sinuses), the middle ear, teeth, and abscess cavities. Obstructed sinuses and eustachian tubes (due to a simple cold or similar upper respiratory tract condition) will not be able to equalise pressures via the usual routes on descent and cause excruciating facial and ear pain. On ascent the increased pressure relative to the outside environment is usually sufficient to overcome any obstruction (this is the cause of your ears “popping” in aircraft). People for routine aeromedical evacuation who cannot clear their ears should not be flown unless absolutely necessary. Vasoconstrictor nasal sprays such as xylometazoline can improve symptoms but their effect is slow and these should not be relied upon except in extreme cases. Dental pain may also occur in flight for due to expansion of air trapped between a deep cavity filling and the tooth substance on ascent.

As has been discussed above, these considerations primarily apply to fixed wing aircraft. Rotary wing aircraft cannot be effectively pressurised and so the likely altitude of flight must be considered when calculating oxygen requirements and considering pressure effects.

References

1. Metcalfe D, Perry D, Bouamra O, Woodford M, Edwards A, Salim A, et al. Regionalisation of major trauma services in England: a post-implementation analysis. Lancet. 2016;387:S73.
2. MacGoey P, Lamb CM, Navarro AP, Brooks AJ. Damage control: the modern paradigm. Trauma. 2016;18(3):165–77. 1460408616629507.
3. Doughty H, Glasgow S, Kristoffersen E. Mass casualty events: blood transfusion emergency preparedness across the continuum of care. Transfusion. 2016;56(S2):S208–16.

4. Harrisson SE, Kirkman E, Mahoney P. Lessons learnt from explosive attacks. J R Army Med Corps. 2007;153(4):278–82.
5. Kehoe A, Jones A, Marcus S, Nordmann G, Pope C, Reavley P, et al. Current controversies in military pre-hospital critical care. J R Army Med Corps. 2011;157(Suppl 3):S305–9.
6. McGuire N. Monitoring in the field. Br J Anaesth. 2006;97(1):46–56.
7. Intensive Care Society. Guidelines for the transport of the critically ill adult. 3rd ed. London: Intensive Care Society; 2011.
8. Graham KC, Cvach M. Monitor alarm fatigue: standardizing use of physiological monitors and decreasing nuisance alarms. Am J Crit Care. 2010;19(1):28–34.
9. CAA. Dealing with in-flight lithium battery fires in portable electronic devices, Civil Aviation Authority Safety Regulation Group, CAA Paper 2003/4.
10. Dell RM, Rand DAJ. Understanding batteries. Cambridge: Royal Society of Chemistry; 2001.
11. ATSB. ATSB Transport Safety Report – Aviation Occurrence Investigation AO-2008-053. Canberra: Australian Transport Safety Bureau.
12. Josephs S, Lyons E, Branson R. Assessment of oxygen consumption from standard E cylinders by fluidic, turbine and compressor style portable mechanical ventilators. Crit Care. 2006;10(Suppl 1):63.
13. Chipman DW, Caramez MP, Miyoshi E, Kratohvil JP, Kacmarek RM. Performance comparison of 15 transport ventilators. Respir Care. 2007;52(6):740–51.
14. Flutter C, Ruth M, Aldington D. Pain management during Royal Air Force strategic aeromedical evacuations. J R Army Med Corps. 2009;155(1):61–3.
15. Essebag V, Halabi AR, Churchill-Smith M, Lutchmedial S. Air medical transport of cardiac patients. Chest. 2003;124(5):1937–45.