Operational Anaesthesia for the Management of Traumatic Brain Injury

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Abstract

The primary brain insult that occurs at the time of head injury, is determined by the degree of neuronal damage or death and so cannot be influenced by further treatment. The focus of immediate and ongoing care from the point of wounding to intensive care management at Role 4 should be to reduce or prevent any secondary brain injury. The interventions and triage decisions must be reassessed at every stage of the process, but should focus on appropriate airway management, maintenance of oxygenation and carbon dioxide levels and maintenance of adequate cerebral perfusion pressure. Early identification of raised intracranial pressure and appropriate surgical intervention are imperative. Concurrent injuries must also be managed appropriately. Attention to detail at every stage of the evacuation chain should allow the head-injured patient the best chance of recovery.

Introduction

Military patients sustaining severe traumatic brain injury (TBI) often pose particular challenges. The treatment of the injury can be highly complex, from the point of initial wounding, surgical intervention, intensive care and ultimately rehabilitation. It has been recognized that mild, moderate and severe brain injuries have become a major focus of military medical services during current operations due to the high levels of kinetic activity [1]. Changing patterns of head injury are being seen, with a penetrating injury now often also as a result of blast as well as direct ballistic injuries [1]. The management of traumatic brain injury raises many issues to be considered (Table 1). This article examines the management of brain injured patients through four phases of care from point of wounding through the deployed field medical facilities, aeromedical evacuation and UK based definitive care.

- Consideration of the injury mechanisms and potential structures at risk in blunt and penetrating trauma.
- Pre-hospital management and the time line to definitive care
- Peri-operative management of the trauma patient including intubation and approaches to fluid management.
- Clearance of the cervical spine in a sedated and ventilated trauma patient.
- Timing of fracture fixation and other injury management.
- Maintenance of blood pressure and cerebral perfusion pressure
- Timing of aeromedical evacuation to role 4 care
- Role 4 management and multi-modality monitoring
- Timing of neurosurgical interventions such as decompressive craniectomy
- Rehabilitation from injury

Table 1: Issues raised in the treatment of brain-injured patients.

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Pre-Hospital Management

This encompasses care at all levels from Care Under Fire (CUF) and Tactical Field Care (TFC) [2], to the Combat Medical Technician (CMT) or Regimental Medical Officer (RMO) at Role 1 and the Medical Emergency Response Team (MERT) retrieval. The level of intervention will depend on the stage of evacuation and medical skills present, but the medical care at all stages should be based on similar underlying principles.

The pre-hospital management of TBI aims to prevent secondary brain injury by provision of adequate oxygenation and cerebral perfusion and treatment of other significant injuries while ideally ensuring rapid transfer to a neurosurgical centre. It has been shown that even when surgical intervention is not required, all TBI patients do better when managed in a neurosurgical centre [3]. In the military setting, this may not be immediately possible, as current UK Role 2 or 3 facilities do not include a neurosurgical capability. However, all deployed general surgeons should be capable of performing a burr hole in order to decompress an extradural haematoma [2].

MERT physicians in the operational setting should be aware of the location of neurosurgical facilities in theatre, and should make appropriate triage decisions immediately, and transfer directly to the available neurosurgical facility if the operational tempo will allow.

Pre-hospital Resuscitation

In accordance with Brain Trauma Foundation (BTF) guidelines [4], pre-hospital assessment of a head injured patient should include assessment and treatment priorities as listed in Table 2.

Much of the civilian data for the pre-hospital management of TBI can be applied in the military setting. However, in some circumstances civilian guidelines will be impractical in the military setting, as discussed in the BTF Field management guidelines [5]. CUF, TFC and Role One management should be performed as described by Battlefield Advanced Trauma Life Support (BATLS) 2008 [2] and in the context of TBI the interventions in Table 3 should be focused on.

Assessment of:	Oxygenation Blood pressure
Treatment:	Maintenance of a patent airway Maintenance of adequate oxygenation and ventilation, Appropriate fluid resuscitation Treatment of cerebral herniation Appropriate triage and transport

Table 2: Priorities in the Pre-hospital assessment of brain-injured patients

BATLS Stage	CUF / TFC	Role 1
<C>	Prevention of further haemorrhage to maintain CPP.	Continue to reassess adequate haemorrhage control.
A	Maintenance of airway patency using adjuncts as necessary.	If the airway is not patent despite simple airway manoeuvres, a surgical airway should be performed as a definitive airway [2].
B	Optimisation of chest injuries causing pathology by needle decompression, & / or Aschermann or Bolan chest seal.	If ventilation is inadequate, aid with a bag valve mask either via face mask or surgical airway.
C	250ml fluid boluses to maintain a radial pulse.	250ml boluses of fluid should be given to maintain SBP of 90 if a BP cuff is available. Otherwise administer fluid boluses to maintain a good radial pulse, and verbal contact if the casualty is able to speak. If the casualty is hypotensive with no palpable radial pulse, hypertonic saline would be an appropriate pre-hospital resuscitation fluid.
D	Identification of head injury Assessment of the Glasgow Coma Scale (GCS) score and pupil size. Alerting the casevac chain to the type of injury and level of consciousness will prompt accurate allocation of casevac assets.	A drop in GCS would require expedition of evacuation to a neurosurgical facility where possible.

Table 3 Management during CUF / TFC and at Role One:

MERT and initial hospital resuscitation

These should be similar as MERT is a forward projection of the resuscitation facilities available at Role 2 or 3.

Airway

A definitive airway should be obtained with a Rapid Sequence Induction (RSI) if the patient is unconscious, has airway compromise or ventilatory failure. A number of patients with head injury and a relatively high GCS (9 – 14) may also require intubation. Most of these patients have cerebral agitation and it has been shown that patients with a significant mechanism of injury who have cerebral agitation have a high incidence of intracranial pathology. Patients with a skull fracture who are not orientated have a 1 in 4 risk of having an intracranial haematoma [6]. These patients require urgent management to prevent secondary brain damage, an expeditious CT scan and appropriate neurosurgical intervention.

A well-trained pre-hospital team such as the MERT, should have low intubation failure rates and should practice more permissive use of intubation without causing an increase in mortality. However, if the RSI procedure and ensuing mechanical ventilation are performed poorly, the negative effects have been shown to outweigh potential benefits [7]. Agitated patients with head injuries and additional injuries often require sedation and /or analgesia in order to gain control of the patient, therefore preventing secondary brain injury by adequately pre-oxygenating and performing a controlled RSI.

It is imperative that pre-hospital teams at Role 1 perform the basics well, and do not attempt to perform an RSI when they are not appropriately trained to do so. Basic airway management, appropriate administration of pre-hospital fluids to maintain a systolic of over 90mmHg (i.e. a good radial pulse) and rapid evacuation should be the focus of treatment. MERT personnel should be able to safely administer sedation and carry out an RSI when the patient's condition requires it.

Choice of Anaesthesia, Analgesia and Sedation by the MERT or in the Emergency Department

Current practice is commonly still to use etomidate as a pre-hospital induction agent for RSI in TBI, followed by morphine and midazolam to maintain analgesia and anaesthesia [8]. Traditionally ketamine has rarely been used in patients with TBI because of concerns that it causes a rise in intracranial pressure (ICP). However, there is emerging evidence that it in fact lowers ICP and maintains cerebral perfusion pressure (CPP) when used as an infusion on ITU [9-11] and there is evidence that it decreases ICP spikes and prevents spikes in response to procedures[12].

In hypotensive patients with TBI, ketamine is a more appropriate agent [13]. Especially in the presence of polytrauma, where brain injury and shock co-exist, and etomidate will reduce CBF as cerebral autoregulation is impaired and cerebral blood flow (CBF) is essentially CPP-related, the maintenance of hemodynamic stability will maintain CBF. In addition ketamine reduces cerebral oxygen consumption ($CMRO_2$) and so the overall balance of CBF and $CMRO_2$ in the presence of ketamine is favorable [13].

RSI technique

The RSI technique in head injury should minimise CO_2 increases and pharyngeal and laryngeal stimulation in an attempt to minimise ICP rises. Meticulous attention to oxygenation is also important as is the prevention of hyper and hypoventilation, which has been associated with poor outcomes [4,5,14].

Ventilation Aims

Ventilate to low normocapnia (end-tidal CO_2 of 30 mmHg, 4.0KPa) [4, 5]. This equates to a $PaCO_2$ of approximately 4.5KPa in normal individuals. This minimises the risk of cerebral vasodilation from high $PaCO_2$ and cerebral vasoconstriction from low $PaCO_2$.

Use of IV Fluids and CPP

After significant head trauma, the brain may lose the ability to autoregulate cerebral blood flow. A fall in mean arterial pressure (MAP) may therefore result in a reduction in cerebral oxygen delivery even if the ICP is normal. When active external haemorrhage has been stopped and splintage of limbs / pelvis has been maximised, then fluids should be administered to achieve a systolic blood pressure of 90mmHg. This can be increased to 100 to 120mmHg in isolated head injury. On the MERT or during in-hospital resuscitation, if hypotension is secondary to traumatic injuries, damage control resuscitation (DCR) should be commenced. Fluid replacement should be with red blood cells and fresh frozen plasma in a 1:1 ratio, rather than crystalloid to replace blood loss. [15] Hypertonic saline may also be an appropriate fluid for use in multitrauma patients with head injuries – this is discussed below.

Packaging

Compression of the jugular veins will reduce venous return from the head and neck which can increase ICP by an average of 4.5mmHg [16]; the cervical collar should be left slightly loose and cervical spine immobilisation maintained with head blocks and tape where possible. The neck veins can also be constricted by a tight tracheal tube tie, which should be checked and loosened if necessary. Ideally, the patient should be maintained and transported in a 20 degrees head up position to maximise venous drainage.

Control of ICP / impending herniation with hyperosmolar therapies

Mannitol

The TBF guidelines [4, 5] support the use of mannitol in response to herniation at doses of 1.4–2.1 g/kg if supported by the capacity to provide high fluid volume compensation for any ensuing urine loss.

In addition to the increased fluid requirement, however, mannitol is susceptible to cold and crystallizes in cold conditions, so is not practical in the military pre-hospital environment. A recent Cochrane review concluded that mannitol has a beneficial effect on ICP compared to pentobarbital, but may have a detrimental effect on mortality when compared to hypertonic saline. However, as that review highlights, there is a lack of pre-hospital evidence on its effectiveness [17].

Hypertonic Saline

Hypertonic saline (HTS) has been shown to lower ICP in severe head injuries and in multiple studies has been shown to improve neurological outcome in TBI [18-21] especially in paediatric patients [22-26]. It may have other beneficial effects such as increasing circulating volume, minimal alteration to coagulation and anti-inflammatory properties [27].

There are very few reports of any side effects due to its use. There are, however, some studies [28] showing no difference compared to isotonic solutions, although overall survival in these studies has been shown to be better than predicted, which may be due to an adequate pre-hospital resuscitation protocol. HTS use with the goal of maintaining adequate haemodynamic parameters during resuscitation may therefore still be beneficial, especially in military pre-hospital care where transporting large volumes of isotonic fluids is impractical[27].

5% Sodium chloride is used by some pre-hospital services. It is available as a 250ml or 500ml infusion bag and is stable through a range of temperatures. A suggested policy for administration of 5% Hypertonic saline [8] is 6 ml / kg (to a maximum of 350ml) of 5% HTS delivered by a well secured large bore peripheral (> 18 gauge) cannula over 10 minutes in patients with signs of actual or impending herniation resultant from severe head injury with either unilateral or bilateral pupil dilation and GCS < 8 (and usually 3) or progressive hypertension (systolic BP > 160mmHg) and bradycardia (pulse below 60).

The dose is given only once and regardless of blood pressure. In patients with multiple traumatic injuries, hypotension and head injury a bolus of HTS as above will help restore circulating volume and may protect against cerebral hypoperfusion and reduce oedema. For this indication it is suggested by the BTF guidelines that one or two boluses of 250ml of 5% HTS would be appropriate. [5].

Further Management At Role 2+ / Role 3

Initial management of <C> ABCD should be as before for airway and ventilation. Rapid infusion of blood products in hypotensive multitrauma patients to maintain a systolic BP of over 100mmHg should be via a central, usually subclavian, trauma line, inserted on arrival in the Emergency Department (ED) and damage control resuscitation (DCR) should continue [15].

There must be a rapid decision to proceed to CT scanning to look for intracranial haematoma and cervical spine clearance, or to go directly to theatre in the case of co-existing injuries requiring immediate surgical treatment.

If the patient is haemodynamically stable, with no immediate need for surgical treatment, then a CT scan to exclude intracranial pathology, most importantly an extradural haematoma, should be performed as a priority. If intracranial pathology is detected in a stable patient, including intracranial or intraocular foreign bodies, as is often seen from IED blasts, then the images should be transmitted to the nearest neurosurgical facility. In Afghanistan at the time of writing, this is the US Role 3 facility at Kandahar Airfield. A neurosurgical opinion should be urgently sought, whilst the Tactical Critical care Air Support Team (CCAST) prepares to transport the patient.

Intra- Operative Anaesthetic Management Of TBI

Conduct of anaesthesia in the TBI patient should aim to preserve normal brain parenchymal homeostasis to reduce the risk of secondary brain injury (Table 4) [14, 29].

Any injury causing persistent hypotension should be addressed immediately and if intracranial space-occupying lesions are present, these should be evacuated simultaneously. Limb-saving peripheral vascular surgery should be performed urgently. Subsequent, operative treatment of long bone and other fractures can be delayed until the head injury has been stabilized [30].

GENERAL PRINCIPLES
Maintenance of Mean Arterial Blood Pressure
Control of Intracranial Pressure
Maintenance of adequate Oxygenation
Avoidance of hyper/hypocapnia
Glycaemic Control
Avoidance of Iatrogenic Injury

Table 4: Physiological aims of anaesthesia for traumatic brain injury [4]

Monitoring

As with all military trauma patients, in addition to standard monitoring for anaesthesia, invasive arterial blood pressure, central venous pressure and core temperature monitoring should be initiated. Near-patient testing for blood gas analysis, blood glucose and coagulation is routinely available in the role 2E facility.

Maintenance of anaesthesia

After intubation, normoxia and low normal carbon dioxide should be the aim ($ETCO_2$ 4.0-4.5 kPa). Hyperventilation should be preserved for herniation syndromes only. A systolic blood pressure of <90mmHg is an independent predictor of poor outcome in head injury and as a result, maintenance of the patient's cerebral perfusion pressure at an approximate target of 70mmHg should be the goal. This can be achieved with isotonic fluids and vasopressors as required, although it is often a difficult balance during ongoing catastrophic haemorrhage. No clear data supporting either crystalloid or colloid use exists in neurotrauma. A patient's blood product requirement will be titrated to clinical and thromboelastometry findings in the military major trauma setting.

Hyperthermia and seizure activity should be avoided as these result in increased cerebral metabolic oxygen requirement and cerebral ischaemia. Core temperature monitoring is required and temperatures should not be kept below 37°C.

Elevation of the surgical table head to reduce venous congestion (20-30°) should be implemented. Use of a reinforced endotracheal tube, eye tapes and padding and checking the breathing system's integrity are important.

Intensive Care Management

On admission to the intensive care unit (ICU) the patient needs to be fully re-evaluated as quickly as possible so that all injuries are recognized by tertiary survey [31]. This should be performed in all trauma patients, regardless of whether or not they require critical care management. The goal is to identify all injuries; missed injuries can have a significant impact on morbidity and mortality, and trauma patients with TBI are at the greatest risk for having missed injuries. Items to be specifically included are the acquisition of a complete and accurate history, performance of a thorough physical examination, review of all imaging studies, and laboratory data, and ordering of additional tests as indicated. Repeated limb compartment checks and continued presence of distal pulses must be recorded in all patients with limb injuries. A thorough examination of the eyes and ears is also indicated as this is a frequently overlooked aspect of the trauma examination.

Cervical spine clearance

The cervical spine CT scan should be reported by the deployed radiologist immediately. This will enable the neck to be cleared where possible, prior to any further positioning or movement in the operating theatre. If this has not already taken place, then it should occur as soon as possible on admission to the intensive care unit. The presence of a severe head injury or focal neurological deficit increases the relative risk of a cervical spine injury by a factor of 8.5 and 58 respectively. When the patient is unable to be fully evaluated within 24hrs, prolonged immobilisation shifts the risk-benefit analysis from waiting for an opportunity to do a full clinical evaluation, to a non-clinical clearance, given that the 95% will not have a cervical injury. Some units combine cervical plain films (lateral, anteroposterior and odontoid views) with sagittal reconstructions of the entire cervical spine CT [32].

Use of a protocol using CT scanning alone for blunt trauma patients who were obtunded has shown the risk of missing a cervical spine injury is 0.04% [33]. It is currently becoming accepted practice to perform a whole cervical spine helical CT scan for assessment of cervical spine injury in the unconscious trauma patient. CT scanning has a sensitivity of 98.1%, a specificity of 98.8%, and a negative predictive value of 99.7%. In contrast, an adequate lateral cervical spine film has a sensitivity of 53.3%, and unstable injuries will be missed. It must be remembered however, that no imaging modality will have 100% sensitivity, and there will always be injuries missed by any given protocol [34].

Ongoing ICU care

Intracranial pressure monitoring is not currently routinely available at UK Role 3, although patients with external ventricular drains *in situ* can often have the ICP measured by appropriately trained staff. In the absence of ICP monitoring, maintenance of CPP is based on the maintenance of an adequate MAP of 90mmHg , thereafter ICU management at Role 3 should follow the same principles as described for Role 4. A suggested checklist for head injured patients at Role 3 and 4 is given in Table 5. A strategic CCAST move should be urgently arranged to transfer the patient back to the neurosurgical ICU at Role 4.

Aeromedical Evacuation to Role 4

Definitive specialist neurosurgical intervention, invasive intracranial and circulatory monitoring and advanced ICU care are best provided in a Role 4 facility in the UK. The transfer to a Role 4 facility must never involve a 'step down' in care, which could be detrimental to neurological outcome. Evidence supports the transfer of TBI patients by dedicated, highly trained teams, with the appropriate equipment to reduce risk of secondary injury [35, 36].

The CCAST is a specialist team whose primary role is the transfer of severely injured or critically ill patients, providing continual care in a safe environment, with no reduction in care standards. All transfers of severely head injured patients are potentially hazardous. Full primary, secondary and tertiary surveys and review of all documentation and investigations are required prior to transfer. The timing of this transfer may vary from case to case, with the ideal being retrieval to a UK Role 4 facility within, or as close as possible to 24 hours from injury.

Care during aeromedical evacuation of patients with traumatic brain injury follows the same principles as standard ICU care with a few additional factors to consider, namely the stressors related to altitude, noise and vibration. Reduced atmospheric pressure

• Head Injury	Traumatic brain injury guidelines followed? Tertiary survey completed? Cervical Spine cleared? Surgical plan robust?
• Infection control	Strict adherence to hand hygiene? Field-placed venous access lines changed? Assess need for current central venous access? Appropriate antibiotics?
• Ventilated patients	Head-of-bed elevation? $EtCO_2$ in 4.0-5.0 range? ICP/MAP/CPP all within agreed limits Oral care protocol? Is a weaning plan appropriate? Sedation and analgesia protocol? Cooling required? Is paralysis justified? Pressure area protection optimised?
• Deep vein thrombosis prophylaxis optimised?	
• Stress ulcer prophylaxis required?	
• Glycaemic control best and safest for circumstance?	
• Nutrition optimal?	
• Candidate for evacuation?	Safe for transport? CCAST arrangements? Records ready?
• Rehabilitation plan commenced	

Table 5: Intensive Care Unit checklist for the brain-injured patient

causes a reduction in PAO_2 and subsequently a reduction in PaO_2. Any gas present in enclosed spaces with no ability to vent to the atmosphere will expand and cause compression of adjacent structures. If this gas lies within sensitive areas such as within the cranium, the increase in pressure may have a deleterious effect. Noise prevents any effective auscultation and equipment alarms are unable to be heard and communication between crew members is degraded. Vibration can affect equipment and initial studies suggest that the risk of micro aspiration in intubated patients may beincreased (Unpublished data – K Birch). All these factors must be considered and efforts made tominimize their impact.

Haemodynamic Monitoring and Management

Invasive monitoring of arterial blood pressure is important to ensure maintenance of adequate systemic blood pressure. Treatment should be titrated to aim for a CPP of 60-70mmHg. If the ICP is not known, as ICP monitors are not currently sited at UK Role 2 or 3 facilities, and there are issues with accurately measuring ICP during flight, aiming for a MAP of 70-80mmHg would suffice. If augmentation of blood pressure is necessary, infusions of vasopressor agents or inotropes may be considered. Volume status of the patient should be assessed via a central venous catheter and/or by measuring hourly urine output. The aim is for a euvolaemic, normosmolar state with a haematocrit of around 0.3. If there is evidence of active bleeding or risk of a fall of heamoglobin concentration in flight, blood for transfusion should be carried.

Respiratory Monitoring and Management

The majority of patients with traumatic brain injury require intubation and ventilation to ensure a secure airway (if GCS ≤8/15), adequate oxygenation and control of $PaCO_2$. Low levels of Positive End Expiratory Pressure (PEEP) should be employed during ventilation and $PaCO_2$ maintained within the normal range (4-0-5.0KPa). Equipment to be able to measure arterial blood gases during flight should be carried for transfer.

Sedation and Muscle Relaxation

The level of sedation required for head injured patients will depend on the injury and the systemic physiological condition of the patient. Increased doses of sedation, narcotics and/or benzodiazepines may be required during transfer due to increased stimulation due to noise and vibration on the aircraft. Routine use of muscle relaxants is not recommended, however if use is required, monitoring of the degree of neuromuscular blockade is mandatory.

Patient Positioning

Ideally a 30-45° head up attitude should be sustained as part of the ventilatory care bundle and neurological management. The head should be maintained in a neutral position. The type and flying attitude of the aircraft will dictate if the patient is loaded head or feet first.

Metabolic Treatment

One should aim to maintain the patient's biochemical parameters to as near normal as possible during transfer. If the ICP is known or believed to be significantly elevated, therapy such as increasing serum sodium concentration and use of mannitol (used in conjunction with other therapeutic measures) can be considered. The brain is an obligate glucose user so hypoglycaemia, as well as hyperglycemia must be avoided during transfer [37].

Hyperthermia is a recognized cause of secondary cerebral insult, therefore normothermia, or in certain circumstances therapeutic hypothermia, should be maintained [38, 39]. This may require active or passive cooling methods.

Nutrition

Ideally early enteral feeding is initiated for patients suffering traumatic brain injury. However the potential risk of increased microaspiration in intubated patients during flight requires discontinuation of nasogastric or orogastric feeding during aeromedical transfer.

Role 4 Treatment of TBI

Intensive care treatment is aimed at lessening the impact of secondary injury by controlling ICP. Maintenance of a CPP greater than 60 mm Hg is now widely recognized as a vital component of management of traumatic brain injury. A single recording of a hypotensive episode (SBP of < 90) is generally associated with a doubling of mortality and a marked increase in morbidity from a given head injury [40]. The highest blood sugar occurring in the first 24 hours of ICU care is linearly correlated with mortality [41]. Fever should be prevented in TBI patients, as it will merely increase the $CMRO_2$. For the patient with TBI, a

CPP of 60–70 mmHg is generally sufficient to maintain cerebral oxygenation. Excessive hyperventilation of patients with TBI will cause ischaemia if CO_2 reactivity is preserved. The interpretation of a given ICP measurement must be made in the light of the underlying pathology and the speed of its evolution. Current evidence suggests that 20–25 mmHg is the upper threshold above which treatment to lower ICP should be started. The management of hypotension must include not only fluid replacement but also identification of the cause. There is minimal evidence for the routine use of anticonvulsants to prevent seizures.

Raised ICP after severe TBI is frequent in relation to altered cerebral compliance. Information obtained by ICP monitoring allows early detection of high ICP and goal directed therapy. ICP monitoring allows informed therapeutic decisions. Protocols need to be agreed jointly between the neurosurgical and intensive care medical team. There are a number of protocols for the prevention of secondary brain injury following major trauma. They are generally directed at the maintenance of CPP to ensure adequate cerebral blood flow. The Brain Trauma Foundation [42] found that mortality increased as the average CPP fell below 70 mm Hg, and that aggressive therapy was required to control ICP and systemic arterial pressure. A number of historical trials have suggested that the mortality for patients with head injuries on a neurosurgical ICU is reduced by the implementation of a target CPP-guided protocol but there are no prospective randomised trials comparing goal-directed therapy with previous conventional head injury management.

The European Society of Intensive Care Medicine has published guidance on the use of monitoring in neurological injuries [43]:

1. There are insufficient data to recommend ICP monitoring and management as standard care in all brain-injury patients. Nevertheless, the evidence is "good enough" to recommend ICP monitoring of patients with severe injuries who are at increased risk of intracranial hypertension.
2. Which patients are at "high risk" of ICP elevation is a matter of controversy. We recommend ICP should be monitored in all salvageable patients with a severe TBI (i.e. Glasgow Coma Scale Score ≤ 8) and an abnormal CT scan.
3. The management of raised ICP should follow BTF guidelines with care to exclude surgical lesions, including haematoma,contusion and hydrocephalus. Local protocols should be developed that conform to international guidelines and include neurosurgical consultation.

Invasive ICP Monitors

Invasive ICP monitors have been used on neuro-intensive care units in head injured patients for many years and they have become a standard of care either as external ventricular drains (EVD) or monitoring bolts. All evidence suggests that morbidity of head injured patients is improved if treated on a neuro-intensive care unit. Whilst not risk-free, the incidence of adverse events from inserting intra-cranial pressure monitoring equipment is small and it should be safe to use in the field. However it is clear that it is not the monitor itself which makes the difference, and it has been pointed out that all military intensivists and ITU nurses would need significant pre-deployment exposure to these patients for all of the clinical governance issues to be covered [44].

The use of brain tissue oxygenation (PO_2) monitors is gaining acceptance at established neuro-intensive care units. There is now evidence that the combined use of ICP and brain tissue oxygenation monitoring can be associated with reduced mortality in TBI when compared with ICP monitoring alone [45].

Other considerations

General supportive measures are as important as specialised neuro-intensive care or surgical interventions. Sepsis is a major threat in this group of patients and efforts should be made to prevent and treat infections. Infection control and hand-washing in particular have a major role to play, in this respect. Early feeding and thrombo-embolic prophylaxis are also important. Chest and limb physiotherapy should be performed at least daily on patients who are unconscious. Successful outcome is often measured in terms of mortality but from the patients perspective a return to a functionally useful life and full employment is usually what they want. Intensive care only forms one link in the chain of survival and as such the goal should be viewed as enabling the patient to benefit from the rehabilitation phase, which commences in and follows discharge from ICU [46].

Conclusion

The principles of TBI management remain consistant throughout all levels of care. From the point of injury, the aim should be to prevent secondary brain damage by optimizing oxygenation, ventilation, cerebral perfusion pressure and adequate sedation and analgesia. Coexisting injuries must also be managed simultaneously in order to optimize cerebral perfusion and ventilation. The recognition of TBI must trigger appropriate triage decisions at all levels of the casevac chain. Timely CT scanning, neurosurgical intervention, appropriate critical care transfer and management including monitoring of the intracranial pressure will allow optimization of the patient's chances of recovery and rehabilitation.

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