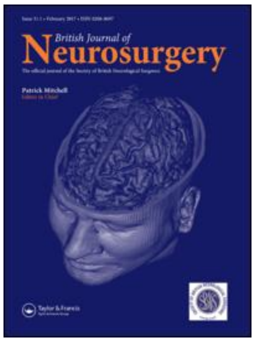

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REVIEW ARTICLE

Manchester Arena Attack: management of paediatric penetrating brain injuries

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ABSTRACT

Purpose: The Manchester Arena bombing on 22 May 2017 resulted in 22 deaths and over 160 casualties requiring medical attention. Given the threat of modern- era terrorist attacks in civilian environments, it is important that we are able to anticipate and appropriately manage neurological injuries associated with these events. This article describes our experience of managing paediatric neurosurgical blast injuries, from initial triage and operative management to longer-term considerations.
Materials and methods: Case study and literature review.
Results: Paediatric traumatic and penetrating brain injury patients often make a good neurological recovery despite low GCS at time of injury; this should be accounted for during triage and operative decision making in major trauma, mass casualty events. Conservative management of retained shrapnel is advocated in view of low long-term infection rates with retained shrapnel and worsened neurological outcome with shrapnel retrieval. All penetrating brain injuries should receive a prolonged course of broad-spectrum antibiotics and undergo long term follow-up imaging to monitor for the development of cerebral abscesses. MRI should never be utilised in penetrating brain injury cases, even in the absence of macroscopically visible fragments, due to the effect of MRI ferromagnetic field torque on shrapnel fragments. Anti-epileptic drugs should only be prescribed for the initial seven days after injury, as continuing beyond this does not incur any benefit in the reduction of long term post-traumatic epilepsy.
Conclusion: All receiving neurosurgical units should become familiar with optimum management of these thankfully rare, but complex injuries from their initial presentation to long term follow up considerations. All neurosurgical units should have well-rehearsed local plans to follow in the event of such incidents, ensuring timely deliverance of appropriate neurosurgical care in such extreme settings.

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Blast injury; trauma; neurosurgery

Introduction-Mass casualty incident

The Manchester Arena bombing on 22 May 2017 at an Ariana Grande concert resulted in 22 deaths and over 160 casualties requiring medical attention; the largest volume major incident to affect Greater Manchester emergency services since the Arndale Centre bombing in 1996, which injured 212. Initial reports of an explosion at the Manchester Arena were received at 22:31, and a major incident declared at 22:46. There were 19 fatalities at the scene, with three dying shortly after arrival to hospital.

The final patient arrived in Royal Manchester Children's (RMCH) Accident and Emergency by 03:30 and the major incident was stood down at 05:25.

Casualties were treated at eight locations across Greater Manchester; major trauma centres, local emergency hospitals (LEH) and walk-in centres and minor injury units using a modified physiological triage tool approach[1] (Table 1). Given the predominant teenage and young adult demographic of the concert, Royal Manchester Children's Hospital (RMCH) was anticipating a large 'P1' patient load; those with catastrophic haemorrhage requiring immediate input from the trauma team to ensure optimum survival chances (Figure 1). A total of 24 children attended RMCH, resulting in 19 paediatric trauma admissions, 6 of whom required critical care. This consisted of 13 children with P1 and P2 (serious or potentially life-threatening injuries but not suspected to deteriorate immediately) injuries, and 6 P3 'walking wounded' patients. We also received 5 accompanying adults who had sustained P3 injuries.

The first attender to RMCH arrived within 30 min of the blast detonation, and was transferred via police car rather than ambulance. The first attender to an LEH took a local bus. Of the 24 children that were triaged to RMCH, two required immediate neurosurgical attention. This may represent the nature of the blast with many patients sustaining overwhelming neurological injuries resulting in death at the scene. A third patient was identified as having a depressed skull fracture 48 hours post-blast during exploration of a scalp wound under anaesthesia. This child did not undergo CT head at time of initial presentation as CT criteria were not met.

UK trained neurosurgeons will experience managing traumatic brain injuries from high velocity road traffic accidents, falls, assaults and even gunshot wounds. However, most will not have managed multiple patients with injuries sustained from improvised explosive devices as these patterns of injury are rarely seen outside the battlefield. Although ballistic injuries account for less than 1% of UK trauma,[2] it is important that we are able to anticipate and appropriately manage the injuries associated with these events.

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Table 1. Patient distribution plan for mass casualty incident in Greater Manchester.

	Over 12 years					Under 12 years
P1	Salford Royal Infirmary 20	Manchester Royal Infirmary 20	Wythenshawe Hospital 20			Royal Manchester Children's Hospital 20
P2	Oldham Hospital 15	Stepping Hill Hospital 15	Royal Albert Edward Infrmary (Wigan) 15			Royal Bolton Hospital 10
P3 adults and Paediatrics						
P3	Tameside Hospital 40	North Manchester General Hospital 30	Rochdale Urgent Care Centre 10	Fairfield Hospital 20	Royal Bolton Hospital 20	WIC/MIU and mass casualty treatment centres

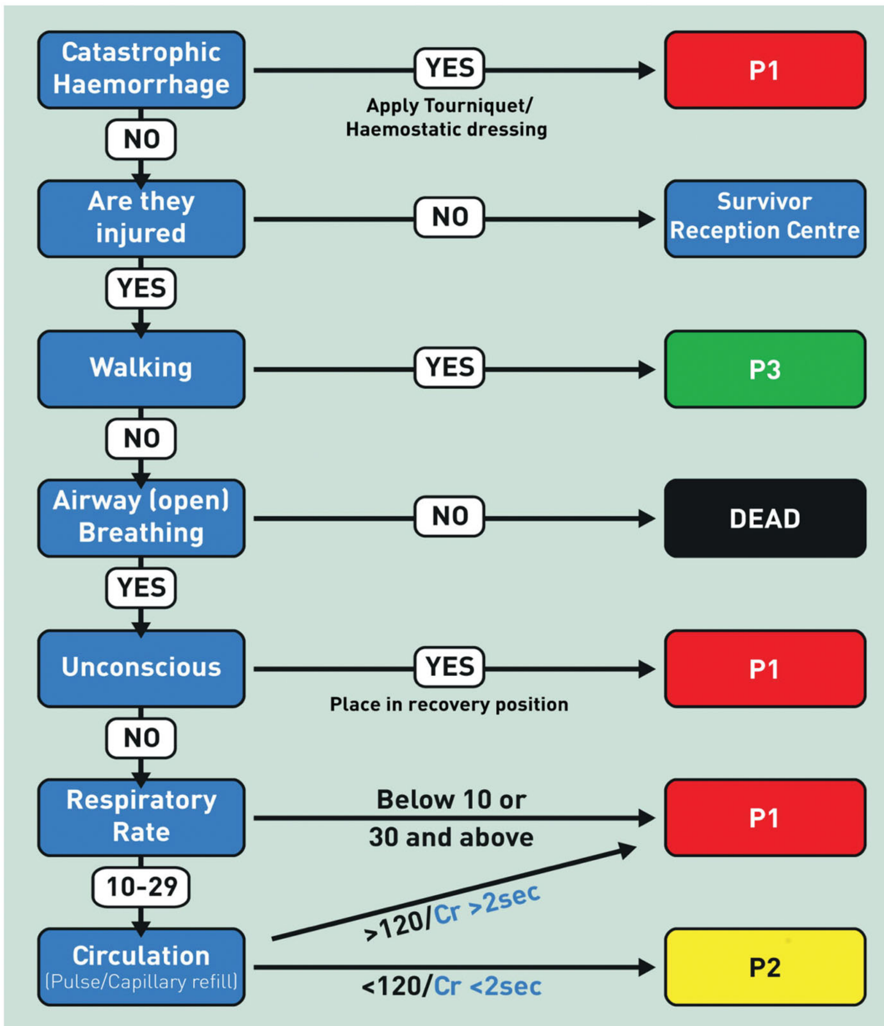

Figure 1. Priority triage and patient stream algorithm for major incident mass casualty events as per modified physiological triage tool (MPTT).[1] P1: catastrophic haemorrhage requiring immediate input from the trauma team to ensure optimum survival chances. P2: serious or potentially life-threatening injuries but not suspected to deteriorate immediately. P3: walking wounded.

This article describes our experience of managing paediatric neurosurgical blast injuries, from initial triage and operative management to long term considerations.

Blast injuries

At time of explosive device detonation, a solid is rapidly converted to an expanding hot gas forming a blast wave of compressed high-pressure air moving at supersonic speeds. The resulting blast winds can reach speeds of over 2000 km/h. Devices detonated in confined spaces cause the blast wave to be reflected from walls, amplifying the blast wave up to eight times.

The magnitude of injuries inflicted depends on distance of individuals from the blast, debris and shrapnel and the environment where the device was detonated. Improvised explosive devices (IEDs) packed with additional material such as glass shards, ball bearings and nails are malevolently designed to increase the severity of injuries.[3]

The pattern of injuries sustained from blast injuries are classically described as primary secondary, tertiary and quaternary injuries (Figure 2).

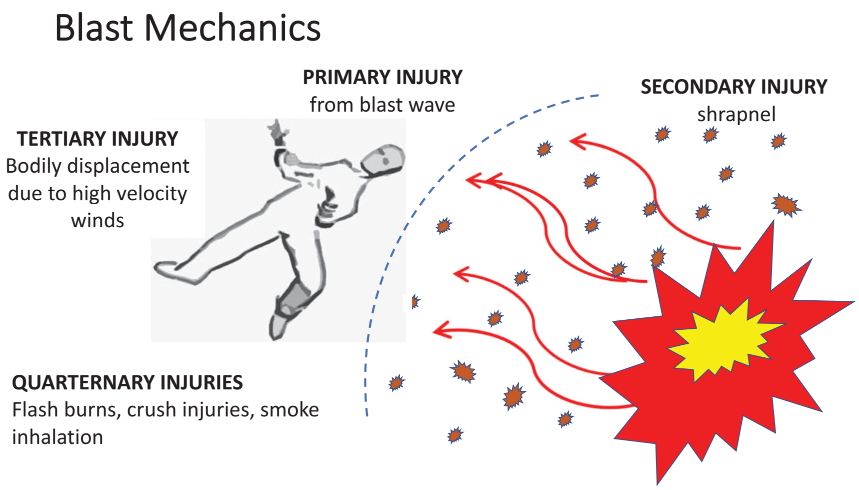

Figure 2. Schematic diagram of blast mechanics demonstrating primary, secondary, tertiary and quaternary blast injury patterns.

Primary injuries are caused by the supersonic high-pressure blast wave generated by the explosive device and subsequent drop in pressure immediately afterwards. This causes compression and shearing injuries as the blast wave propagates through tissue.

Secondary injuries are the most commonly encountered injury, as primary injuries frequently result in catastrophic injury and death. These are caused by propelled fragments from the bomb itself, implanting shrapnel or debris from the environment, resulting in blunt and penetrating injuries.

Tertiary injuries occur within the blast environment, including bodily displacement and injuries from damaged structures, whilst quaternary injuries are a result of burns and inhalation of smoke, dust and toxins.

Porcine models of blast related traumatic brain injury (TBI) identified that several factors are responsible for the extent of neurological damage sustained during primary injury. Each tissue encountered by the supersonic blast wave has different acoustic impedance, generating an impedance mis-match between different density tissues and causing spallation; disruption of the pressure wave propagation at the interface of different density mediums. This reflects the pressure wave, causing abrupt changes in intra-cranial pressure and bubble formation, especially at the brain: CSF interface. This results in cavitating injures to brain tissues, axonal disruption and microvascular damage, as well as associated penetrating and impact injuries from secondary and tertiary blast injuries.[4–6]

It is important to consider this constellation of injury mechanisms when managing blast victims, as injuries are frequently a result of a combination of multiple injury patterns.[7,8]

Case report

A 15-year-old was triaged as 'P1'and received basic resuscitation at the scene, arriving at our institution at 00:25. GCS at the scene was 8/15 (E1 V2 M5) with evidence of a severe head injury, extensive blood loss from scalp lacerations and airway compromise. The patient was intubated, and initial resuscitative measures continued prior to full body trauma CT. They received packed red cells and tranexamic acid in Accident and Emergency.

CT brain identified a 'through and through' pattern of injury from a shrapnel trajectory, extensive scalp fractures and evidence of retained shrapnel fragment within sub-galeal tissues (Figure 3).

They underwent insertion of an ICP monitor at approximately 01:00 plus management of bleeding scalp wounds in ITU whilst further resuscitation was continued. Early ICP measurements exceeded 40mmHg and the patient was transferred to theatre for immediate bi-frontal decompressive craniectomies and wound toileting. A piece of shrapnel in the form of a large metal nut was retrieved from left fronto-temporal soft tissue. They also underwent examination under anaesthetic of lower limb injuries by orthopaedic colleagues.

After a prolonged respiratory wean and tracheostomy placement, they were discharged from ICU to the neuro rehabilitation ward. They completed a 6-week course of broad-spectrum antibiotic cover. A ventriculoperitoneal shunt and cranioplasty were placed at 10 weeks and 5 months post-injury respectively to address concerns that they appeared to be suffering from syndrome of the trephined (Figure 4).[9] Neurologically their GCS is currently 15/15 (E4 V5 M6). They have a left upper limb spastic mono-paresis but are independently ambulant, fully conversant,attending school and are receiving ongoing psychological support. From an outcome scoring perspective, this would place the patient as a Glasgow Outcome Score (GOS) 4 (moderate disability), or Glasgow Outcome Score Extended (GOSE) of upper to lower moderate disability (independent at home and outside the home with some physical or mental disability).[10] They were discharged 9 months after the event.

Methods and materials

A Pubmed literature review was carried out using the following search terms: blast injury, penetrating blast injury, traumatic brain injury, shrapnel, retained shrapnel, paediatric traumatic brain injury.

Results

Blast injury management

Triage

Paramedics attended the scene within 15 min of the major incident being called, providing field triage and basic life support care. Given the circumstances of the bomb and concerns of the threat of a second device, triage and initial assessment was based on a 'scoop and run' basis rather than in-field pre-hospital treatment despite evidence suggesting that outcomes for some

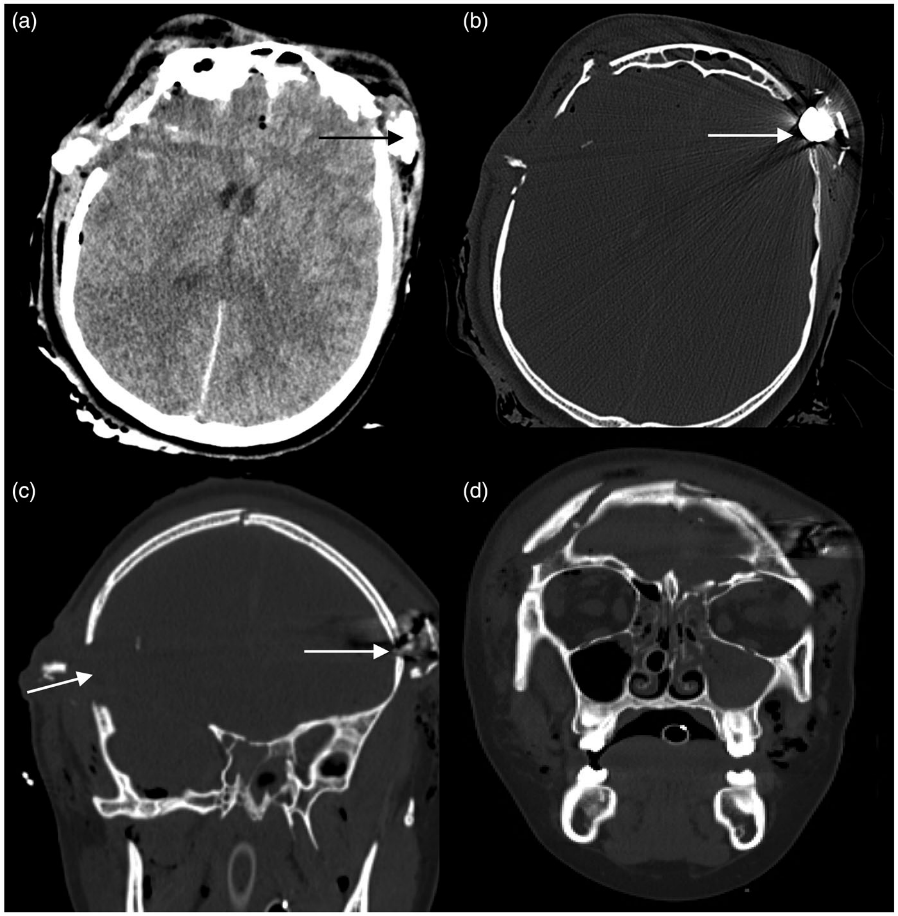

Figure 3. CT head at time of presentation. (a and b) axial non-contrast CT (b bone windowed) demonstrating 'through and through' pattern of shrapnel trajectory, plus retained shrapnel fragment in soft tissue (arrow). (c and d) (coronal bone windowed CT) demonstrating shrapnel entry and exit wounds (c, arrows) plus extent of skull fractures.

particular injuries (traumatic brain and thoracic injury) are better when pre-hospital ATLS treatment is utilised.[11–13]

NICE guidelines for the assessment and initial clinical management of major trauma injuries recommend transfer to designated regional paediatric major trauma centres as this is associated with improved survival outcomes.[14] NICE also recommends rapid control of catastrophic external haemorrhage and close adherence to major transfusion protocol with early haematology input in major trauma patients; this standard was readily met with our patients. However, the nature of the multiple injuries sustained by an IED blast meant that controlled volume resuscitation of major haemorrhage (due to extra-cranial injuries) to avoid clot disruption would potentially be at the detriment of maintaining normal cerebral perfusion and avoiding secondary traumatic brain injury, providing a challenging clinical situation. NICE also advocate avoiding full body trauma CT scans in favour of focussed anatomical assessment to limit radiation exposure, however given the unpredictable nature of blast and shrapnel injuries, most patients underwent pan-body CT imaging on arrival. Pre-hospital field triage was followed as per Figure 1.

Some comparisons can be made with a military approach to triage of a mass casualty suspected terrorist incident, where conditions are often austere and unpredictable and evacuation of casualties to a safe environment is a priority. However, one of the primary objectives of military triage is to identify wounded soldiers who can be treated rapidly and return to the battlefield, as opposed to saving maximum number of lives, often creating ethical and practical difficulties when managing mass casualty incidents.[15] The reported favourable outcomes for penetrating brain injuries (PBI) in military patients may simply represent early field triage and survivability assessments and patient selection rather than effectiveness of intervention.[16]

When applied to our incident, this approach could potentially mean the more severely injured children and young adults may not have been identified as to be actively resuscitated, despite the often-favourable outcomes in paediatric trauma, particularly traumatic brain injury. 'Good' neurological recovery has been reported in up to 40% of children with a severe traumatic brain injury and GCS of <5 at time of presentation, and up to 70% of children with prolonged traumatic coma make an acceptable neurological recovery at 1 year.[17–21] Another challenging aspect particular to this case was accurate patient identification upon arrival in hospital; most teenagers, the predominant audience at this event, do not routinely carry formal identification. This made the correct identification of critically unwell P1 patients prior to major surgical intervention and attempting to contact next of kin extremely difficult. The identification of one of our patients was confirmed using photographs taken in A + E, after a parent unable to locate their child at the scene presented to the department describing characteristics matching this child. Although an unorthodox technique that would certainly have no place in routine clinical setting, this allowed identification of a critically unwell child and full consent to be taken from a responsible parent prior to high risk, life-saving surgery. This also allowed the parent to spend a short period of time with their child prior to transfer to theatre.

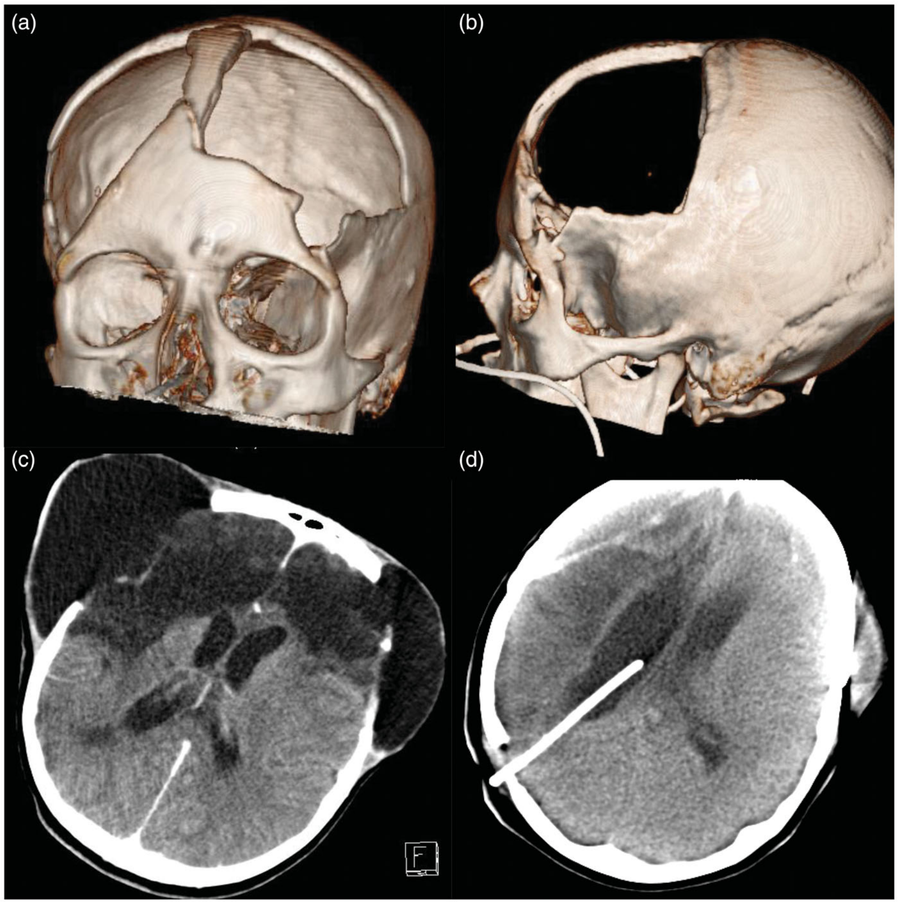

Figure 4. Bi-frontal decompressive craniectomy and external hydrocephalus (images taken 4 months after injury). (a and b) CT 3d reconstruction demonstrating extent of bi-frontal decompressive craniectomy. (c) axial CT demonstrating significant external hydrocephalus prior to shunt placement and evidence of frontal (left) and fronto-temporal (right) gliosis post-injury. (d) resolution of external hydrocephalus post insertion of bi-frontal cranioplasty and ventriculoperitoneal shunt.

Where needed, RMCH made special compensation to accommodate and admit the injured parents of our paediatric patients, with medical input from teams at Manchester Royal Infirmary, our adult hospital based at the same site. As well as providing emotional support for our paediatric patients at such a challenging time, this also allowed patient-parents to remain fully up to date with their children's condition whilst receiving requisite specialist medical care.

Imaging in severe and penetrating brain injuries

Computed topography is the current imaging standard for all suspected penetrating brain injuries, permitting the identification of retained shrapnel fragments and their trajectories, assessment of fractures, bone fragments and haematomas. Angiography, whether CT or catheter, should be obtained when vascular injury is suspected, which is likely to represent a large proportion of these patients, particularly in those with ballistic entry points in close proximity to the Sylvian fissure.

MRI should not be widely used for imaging of both confirmed and suspected shrapnel injuries due to the effects of MRI field torque on ferromagnetic retained fragments. This is particularly relevant in the context of terrorist IEDs when an assortment of different materials could have been utilised as shrapnel fragments. This principal should be applied to both macroscopically visible fragments and the presumed shower of microscopic shrapnel material deposited at time of blast injury. Assessment of the magnetic field effect of military bullets at both 1.5 and 3 Tesla MRI, identified that bullets containing steel core and steel or nickel jacket exhibited substantial magnetic field interactions above what would be considered safe in vivo.[22] Most shrapnel MRI safety studies concern retained ballistics, and whilst [23] suggests only a small risk dependent on shape and size, this theory cannot be safely extrapolated to retained shrapnel of unknown origin due to varying shapes, sizes and materials of these objects.[24] Forensic analysis of the shrapnel operatively retrieved from the Manchester blast victims identified steel, zinc, carbon and wooden screws and nuts.

The American College of Radiology white paper on MRI safety recommends the 'serious consideration of risk versus benefit of MRI' in cases of retained shrapnel, although this statement did not consider intra-cranial fragments.[25]

Severe traumatic and penetrating brain injuries; when to operate

Penetrating brain injuries (PBI) are generally associated with a poor outcome, with a significant association with increasing age and co-morbidities.[26] The high morbidity rates associated with civilian PBIs reflects the high velocity gunshot wounds associated with homicide and suicide.[16]

There is significant variability within the literature amongst neurosurgeons regarding appropriate intervention for severe traumatic and PBI patients, largely based on their initial GCS at the scene. When considering gun-shot wounds outcomes (mortality rates of 23–92%) it is not recommended to offer surgical treatment in the absence of a mass causing haematoma for patients with initial GCS 3–5/15 due to significant association with poor outcome.[27] Bi- or multi-lobar penetrating brain injuries have significantly worse outcomes compared to supra-tentorial uni-lobe injuries.[27] This can be attributed to destruction of diencephalic and mesencephalic structures, extensive cerebral oedema and elevated intra-cranial pressure, mass causing lesions and mass haemorrhage from major vessel injury, principles that can all be applied when considering shrapnel and blast injuries.[28]

Shrapnel injuries however, are usually relatively low velocity injuries and therefore do not cause as extensive cerebral damage as seen with high velocity bullets, suggesting a better survival profile. This is seen in surviving military intracranial missile injuries, which are predominantly a low velocity pattern.[29–31]

Timely identification of traumatic brain injuries and field resuscitation to address hypotension, hypoxia and coagulopathy may limit the impact of secondary brain injury and improve outcome.[32–34] Aggressive resuscitation (IV blood products, hyperosmolar therapy, prothrombin complex) of civilian gun-shot wound patients is associated with increase in survival from 10% to 46% and also a 20% survival rate with GCS $\geq$ 13/15.[35] DuBose[36] compared the outcome of isolated severe traumatic brain injuries in matched military and civilian cases, finding a significantly higher rate of operative intervention, in military patients when compared to civilians. The overall mortality rate was also significantly better in military patients. Although there are many confounding factors, including quicker transfer to theatre in military injuries,[29] between these population groups, this suggests that early and aggressive intervention for traumatic and penetrating brain injuries is associated with an improved outcome profile.

Extent of surgical debridement and management of retained shrapnel

Current initial management of traumatic and penetrating brain injuries is based upon principles developed during WWI and WWII, consisting of; debridement of both entrance and exit wounds; removal of necrotic tissue, haematoma, and bone fragments; removal of intracranial bone and metal fragments where accessible, and foreign material including hair and clothing; closure of the dura, with reconstruction if necessary.[29,37,38]

Prior to modern era antibiotic therapy, aggressive surgical debridement and removal of all in-driven fragments was considered essential to avoid infection. This mandate was advocated by Cushing in World War I and practiced from WWII through to the Vietnamese conflicts, although remained untested against any alternative treatment regimens. Of note, the survival rate of traumatic and penetrating brain injuries improved significantly following the introduction of broad-spectrum antibiotic cover, but then plateaued between WWII and Vietnamese conflicts.

However, long term follow-up of military penetrating brain injuries has identified that retained fragments can be managed less aggressively (with appropriate antibiotic cover) and achieve a comparably good outcome with similar infection profiles when compared to more aggressive resection. This implies that tempering surgical debridement to preserve neural tissue should be encouraged, and that extensive surgical management is not best practice despite historic supporting literature.[39–42]

The American guidelines for penetrating brain injuries reviewed multiple military case series, confirming that multiple craniotomies to remove retained shrapnel and bone fragments was detrimental to overall outcome.[16,40,43,44]

Rare cases of abscess formation around retained fragments have been reported up to 7 years post PBI, demonstrating the need for appropriate antimicrobial cover and follow up imaging.[45] There are also documented cases of migrating intra-cranial shrapnel fragments, again supporting the argument for regular follow-up imaging. Migration of intra-cranial fragments, attributed to loss of normal brain substance, arterial pulsations and gravity, has been reported within and between supra- and infra-tentorial compartments, and also from supratentorial brain parenchyma into the 4th ventricle.[46]

The Journal of Trauma therefore recommends the following approach to penetrating brain injuries; small entrance wounds with no significant intracranial pathology should receive local wound care only, extensive wounds should undergo debridement of non-viable tissue permitting primary closure or skin-graft. Debridement of necrotic brain tissue and removal of mass causing lesions is performed in the event of ‘significant intra-cranial pathology’ only. Active debridement of missile tract and removal of shrapnel fragments is no longer recommended, although it should be noted that this is based on class III evidence.

Traumatic and penetrating brain injuries and infection

Infection is a well-documented early and late complication of traumatic brain injury, and usually associated with penetrating debris such as shrapnel, skin, hair and bone particles. In the setting of a planned attack, consideration should be given to the deliberate contamination of the device with bacteria and blood-borne viruses.

Infection associated with TBI ranges from 5% to 23%, and can take the form of superficial wound infections, osteomyelitis, extra-dural and subdural empyemas, ventriculitis, cerebritis and cerebral abscesses.[47–49] The British Society for Antimicrobial Chemotherapy (BSAC) reviewed prophylactic and therapeutic antibiotic use in civilian and military penetrating brain injuries. Across various different conflict zones, the most commonly encountered organisms isolated from wound cultures, brain tracts and bones fragments were gram positive bacteria including *S. epidermidis* (coagulase negative) and *S. Aureus (coagulase positive)*, and less commonly gram-negative species such as *Acinetobacter.*[29]

Given the potential gravity of CNS infection secondary to PBI most of the studies reviewed by BSAC utilised a broad-spectrum antibiotic regimen, covering coagulase negative staphylococcus, other staphylococci species, gram negative bacilli and also anaerobes where indicated. Antimicrobials used included chloramphenicol, ampicillin, ceftriaxone, gentamicin and metronidazole. From this, BSAC recommended IV co-amoxiclav or cefuroxime and metronidazole for a minimum of 5 days. At our institution, microbiology and virology strategy was based on a worst-case scenario basis; assuming that penetrating brain injuries were at risk of exposure to faeculant matter and blood-borne viruses from deliberately contaminated shrapnel. Our PBI patients received an extended course of ceftriaxone and metronidazole, providing broad spectrum cover with good CNS penetration. At time of submission, neither patient had experienced a CNS infection. All children who presented to RMCH underwent screening for blood-borne viruses at transmission, and at 3, 6- and 12-months post event. Given that some patients underwent massive red blood cell transfusions, serum conversion may be delayed hence the need for extended testing. All our patients also received an accelerated hepatitis B vaccination program.

Serum procalcitonin was utilised a biomarker for infection and sepsis, providing a more specific and reactive assessment of infection in the context of multi-system injured patients and SIRS response to trauma when compared to CRP.[50–52]

Cerebral abscesses have been identified in up to 3% of traumatic brain injuries and carry a high mortality rate of up to 50%.[53] They usually occur around retained material, and develop 2–4 weeks after injury, although much later onset abscesses have been reported. Abscess secondary to traumatic brain injury are also more likely to spread when compared to non-traumatic abscesses, causing a diffuse brain and ventricular infection. This is likely due to damaged and devitalised brain tissue being unable to produce a collagen rich capsular wall and contain the infection within the abscess limits.[31] Due to potential latent abscess formation around retained fragments, regular surveillance scanning is advocated.

Penetrating brain injury will, by definition, breach the dura and be associated with CSF leak at both exit and entry sites as well as distant sites due to blow out fractures and dural tears.[54] CSF leak has been identified as an independent risk factor for developing infection, alongside sinus breach and ventricular injury.[55] 70% of infections around retained fragments are associated with persisting CSF leaks, suggesting that this, rather than retained fragments is the source of infection, further supported by the low infection rates seen in conservatively managed shrapnel.[41,42,56,57]

The American Journal of Trauma advocates surgical closure of persisting CSF leaks, or leaks that do not settle with temporary CSF diversion via external ventricular or lumbar drains. Ideally, dural closure should be achieved at time of primary surgery, although in reality this is not always practical.

Seizure prophylaxis

The incidence of post-traumatic epilepsy (PTE) is higher in penetrating brain injury than non-penetrating injury (30–50% versus 4–42%), with up to 10% of PBI sufferers experiencing seizures in the first week and 80% experiencing seizures within the initial two years post injury. However, it has also been reported that 95% of seizure free PBI patients will remain so if they do not have any seizures in the first 3 years post injury. PTE management can be viewed as either therapeutic treatment of seizures post-PBI, or prophylactic; preventing seizure onset after PBI. Interestingly, incidence of early and late PTE has remained relatively constant despite advances in surgical techniques and neuro-critical care.[58–64]

There is limited evidence to advocate continuing prophylactic anticonvulsants beyond the first week post injury in PBIs. Anti-epileptic medication can prevent early PTE but extending prophylactic medication beyond one week does not impact on late seizure occurrence. Multiple studies assessed factors influencing late onset epilepsy post TBI, identifying that focal motor deficit, GCS, Glasgow Outcome Score (GOS), parietal vertex injuries, tract haematomas, infection and retained metal fragments are associated with late seizure development.[59,61,64] However, class I studies including small numbers of PBI patients, have failed to demonstrate that continuing AEDs beyond one-week post-injury prevents late seizure development, implying that their continued use cannot be justified against their associated side effect profiles.[63–65] An extensive 2017 literature review of early and late PTE in the context of TBI confirmed that phenytoin and levetiracetam offer similar protection against early onset PTE compared to placebo and that there is no benefit with regard to the onset of late PTE.[66] Strazzer *et al.* specifically looked at PTE in children and young adults, further confirming that there is no role for long term anti-epileptic prophylaxis.[67]

This practice is adopted at our institution; with traumatic brain injury patients receiving a seven-day prophylactic course of phenytoin or sodium valproate.

Staff management in the mass casualty incident setting

NHS England define a major incident as ‘any occurrence that presents serious threat to the health of the community or causes such numbers or types of casualties, as to require special arrangements to be implemented’. Although all hospitals, particularly those designated as major trauma centres have well documented major incident plans with a pre-defined approach to managing trauma workload and allocation of staff, dealing with a suspected terrorist blast injury major incident presented its own set of unique problems and considerations. The Greater Manchester casualty capability plan for major incidents pre-defined allocations of both paediatric and adult P1–P3 cases to appropriate units in the region, planning for up to 300 casualties. A regional major incident simulation exercise was performed a few months prior to the attack, with the scenario involving a suicide bomber at a large shopping complex. This provided a practical, real time overview of local response times and personnel and resource management across our major trauma centres and P2 and P3 receiving units.

From a neurosurgical standpoint, due to the malicious nature of the blast and the large capacity venue, we were concerned about number of patients potentially requiring immediate neurosurgical attention following imaging and resuscitation. The responsible coordinating neurosurgical consultant on-call made the decision to call all paediatric neurosurgery consultants and two registrars into the department, rather than only the allocated on-call team. This created a team of six neurosurgeons ready to operate across three simultaneous theatres, plus a lead consultant assessing new patients in Accident and Emergency. This decision was made in the knowledge that consultant cover may be compromised the following day, but providing timely and effective emergency neurosurgical input was our immediate priority. These supplementary neurosurgery team members were dismissed once the major incident had been stood down, and no further neurosurgical procedures were anticipated.

In view of the general inexperience of managing ballistic injuries in the civilian population, advice and guidance was sought from military surgeons based at Royal Centre for Defence Medicine, Queen Elizabeth Hospital Birmingham. This expertise, guidance, case discussions and support proved during their site visits proved invaluable, and it has been proposed that a similar approach will be adopted in the event of any future incidents.[68]

All hospital personnel involved in the blast, either immediately or in the following weeks, had open access to in-house psychiatry and psychology services for debrief and counselling sessions. As a department, we organised individual debrief meetings at day two post incident to acknowledge the significance of such a challenging event, and ensure all team members felt comfortable accessing support services.

Discussion

Blast injuries present a challenging constellation of neurosurgical and extra-cranial injuries with unique management considerations, in both the immediate and long term follow up periods.

Given the potential threat of improvised explosive device terrorist attacks on civilian targets and the resulting mass casualties, all receiving neurosurgical units should become familiar with optimum management of these complex injuries and have well-rehearsed local plans to follow in the event of such incidents.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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