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Trauma anaesthesia in paediatrics

P Mogane

Department of Anaesthesia, School of Clinical Medicine, Faculty of Health Sciences, Chris Hani Baragwanath Academic Hospital, University of the Witwatersrand, South Africa
Corresponding author, email: *moganep@gmail.com*

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Introduction

Paediatric trauma is the leading cause of global death and disability in children older than one year,[1,2] accounting for 40% of all childhood deaths.[3] In South Africa, injuries in children younger than 15 years are predominantly caused by road traffic accidents and intentional injuries.[3] Despite the overwhelming nature of this problem, relatively little attention is given to this major source of sickness and death in children.[4]

Consideration has to be given to multiple issues which may influence the outcome of the patient, including: airway management, particularly in the presence of a cervical spine injury; the possibilities of a full stomach and the need for rapid sequence intubation; haemodynamic status, particularly in the presence of a traumatic brain injury (TBI); and the potential for significant haemorrhage and transfusion. The topic of trauma anaesthesia within the paediatric population is expansive and involves many topics which cannot be covered in this paper (e.g. non-accidental injury [NAI], burns, near-drowning, detailed advanced trauma life support [ATLS] principles and TBI management).

Epidemiology of paediatric trauma

Falls, road traffic injuries (RTI) and burns are frequent mechanisms of childhood injuries.[3] Risk factors include male gender and specific age distributions (e.g. burns predominantly involve children 1–2 years of age, RTIs occur in unsupervised/unrestrained 3–6-year-olds, toddlers often have falls, and older children are usually involved in road accidents and sports injuries).[3] More than half of these injuries take place within the child's home or school.

Paediatric trauma deaths have a trimodal distribution with 50% dying at the scene either from severe TBI or haemorrhage; a further 30% dying within the first few hours ("golden hour"); and late deaths which occur days to weeks after the initial injury due to inadequate initial resuscitation, management, sepsis and multi-organ failure.[5] Up to 30% of these deaths are preventable by rapid identification and early aggressive treatment of the cause.

In most cases, head injury accounts for 75% of trauma injuries in children in the UK,[5] with C-spine injury being very uncommon at < 2%.[5] Thoracic injuries occur in 3% of children with blunt trauma and are the next significant cause of mortality in children. Intra-abdominal injuries occur more frequently at 10% and are the leading cause of initially unrecognised fatal injury and haemorrhage; second only to airway problems as the most frequent cause of preventable death.[5] Most trauma injuries are sustained by blunt (85%) versus penetrating (15%) mechanism.[6] Skeletal injuries occur in 10–15% of paediatric trauma patients; these are rarely life-threatening and can often be managed without surgery.

Anatomical and physiological differences relevant to trauma (See Table I)

Basic Advanced Trauma Life Support principles

The survival of children who sustain major trauma is dependent on good prehospital care, appropriate triage and effective resuscitation. This is best performed by following the organised and systematic approach outlined in the Advanced Trauma Life Support (ATLS) principles. These involve the initial stages of resuscitation, stabilisation and further definitive management. Universal precautions, particularly in this era of COVID-19, should be practiced. The Paediatric Trauma Score (Table II) was developed to facilitate the initial assessment and triage of injured children by categorising the overall severity of their injuries.[2] Anaesthetists can provide better intraoperative care if they understand the management of the trauma patient in the emergency department.

The **primary survey** refers to the "ABCDE" sequence. As part of this, a Broselow tape to estimate the weight (can be used up to an age of 12 years/36 kg) and a colour-coded paediatric resuscitation trolley should be readily available. There should be continuous monitoring of vital signs, which is essential for the ongoing assessment of response to interventions. Indications for intubation or ventilation include airway obstruction not relieved by simple manoeuvres; a TBI with compromised airway; inadequate breathing; Glasgow Coma Scale (GCS ≤ 8); severe maxillofacial trauma and inhalational injury.[7] The trachea should be intubated using some form of rapid sequence induction

Table I: Anatomical and physiological differences relevant to trauma[1,5,7]

Anatomical and physiological differences	Anaesthetic implications
Neurological • Relatively large head, thinner cranial bones, higher centre of gravity • Cartilaginous vertebral bodies, elastic ligaments, horizontal facet joints, underdeveloped neck musculature and large head → • Subluxation and dislocation are common	• Higher incidence of TBI, tolerate expanding intracranial haematoma • Increased spinal mobility, rare to have spinal cord injury; if these occur, it is a high spinal cord injury (C1–C3); fulcrum of spinal flexion is C2–C3 in children and C5–C6 in an older child • Up to 50% of spinal cord injuries in children < 10 years of age may exist without radiological evidence (SCIWORA), children > 10 years of age usually have fractures
Airway • Large protuberant occiput creating natural flexion, large tongue, anterior and cephalad larynx • Aerophagia, gastric inflation with assisted ventilation, traumatic gastric paresis	• Careful positioning, the potential for difficult airway particularly if a C-spine injury • May need to consider versions of controlled or modified RSI, consider inserting a nasogastric tube to decompress the stomach • May need to avoid nasotracheal intubation, particularly if a base of skull fracture is suspected
Respiratory • ↑ RR, ↑ oxygen consumption, ↓ FRC, ↑CC • Increased chest wall compliance • Elastic ribs • Diaphragm easily fatigued and displaced	• Assess, establish and maintain airway urgently, early desaturation and decompensation • High possibility of collapse and hypoxia • Rarely have rib fractures, but impact of energy may be transferred to inner organs (pulmonary contusion most common)
Cardiac • Cardiac output is rate-dependent; during major haemorrhage, child compensates by constriction and ↑ SVR • Smaller vessels, more subcutaneous tissue	• Tachycardia is the first sign of hypovolaemia; hypotension is a late sign of haemorrhage that may not occur until > 25–40% of EBV is lost. Do not delay fluid resuscitation • Approximated 5th percentile systolic pressure: • SBP (5th percentile) = 70 mmHg + 2 X (age in years) • Vascular access may be difficult; consider intraosseous (ideally < 6 years of age)/ central venous cannulation or cut-down
Abdominal • Dimensions of the torso with pliable ribs and easily displaced diaphragm, increase vulnerability of intra-abdominal organs	• Most frequently injured organ in descending order: spleen, liver, renal, intestine then pancreas
Other • Large head and organs, large surface area to body mass ratio	• Prone to hypothermia

TBI – traumatic brain injury, SCIWORA – spinal cord injury without radiographic abnormality, RSI – rapid sequence intubation, RR – respiratory rate, FRC – functional reserve capacity, CC – closing capacity, SVR – systemic vascular resistance, EBV – estimated blood volume

Table II: Paediatric Trauma Score[8]

Component	Score		
	+2	+1	-1
Weight	> 20 kg	10–20 kg	< 10 kg
Airway	Patent (Normal)	Maintainable (Oral or nasal airway)	Not maintainable (Intubated or tracheostomy)
Systolic blood pressure (BP)	> 90 mmHg	50–90 mmHg	< 50 mmHg
Level of consciousness (LOC)	Awake	Obtunded/any LOC	Unresponsive/comatose
Open wounds	None	Minor	Major or penetrating; burns > 10%
Fractures/skeletal trauma	None	Minor (e.g. closed fracture)	Open or multiple fractures
Total score			
9–12 Minor trauma (< 1% mortality) 6–8 Potentially life threatening 0–5 Life threatening (50% mortality) < 0 Usually fatal (98% mortality)			

(RSI) technique with manual in-line stabilisation applied, as deemed necessary.[2] Assessment of the child's neurological status includes the paediatric GCS (Table III), which is modified for age-appropriate verbal development and should be used for children under 2 years of age. Children older than 2 years can be evaluated using the standard GCS measurement.[6]

The previous ATLS guidelines recommended giving three boluses of 20 ml/kg of a balanced crystalloid as part of **initial resuscitation**; however, currently, it is advised that if the patient hasn't stabilised after the second 20 ml/kg bolus of crystalloid, a transfusion 10–20 ml/kg of packed red blood cells (PRBCs) should be prepared.[7] After that, a **secondary survey** can be initiated; diagnostic testing is completed during this period. Once the child has stabilised and all injuries are identified, **definitive care** can take place.

Table III: The paediatric Glasgow Coma Scale (GCS)[5]

Standard GCS	Score	Paediatric
Eye-opening		
Spontaneous	4	Spontaneous
To speech	3	To speech
To pain	2	To pain
None	1	None
Verbal response		
Orientated	5	Age-appropriate
Confused	4	Irritable, cries
Inappropriate words	3	Cries to pain
Incomprehensible	2	Moans to pain
None	1	None
Motor response		
Obeys commands	6	Spontaneous movement
Localises to pain	5	Withdraws to touch
Withdraws to pain	4	Withdraws to pain
Abnormal flexion	3	Abnormal flexion
Extensor response	2	Extensor response
None	1	None

The anaesthetist may be involved in the initial stabilisation in the emergency room; provision of sedation, analgesia and monitoring for imaging; emergency surgical procedures such as craniotomy or laparotomy; semi-elective surgeries such as long bone fixation; and intensive care management and pain control during hospitalisation.[1]

Anaesthetic management of the paediatric trauma patient

Preoperative evaluation and airway management

If the situation permits, the child should be thoroughly assessed, considering that the entire process is a significant source of fear and anxiety for both the children and their families.[2] Evidence suggests that the gastric residual volume in children undergoing emergency surgery is greater than those undergoing elective surgery. The anaesthetist should consider these children as having a full stomach and should take appropriate measures to reduce the risk of aspiration. This may include variations on the RSI techniques.

Spinal cord injuries are rare in children, with the most common (60–80%) location being the C-spine. However, there are potential long-term side effects of increasing doses of radiation with imaging to exclude these injuries. In light of this, most paediatric algorithms are less aggressive in terms of imaging. The Pediatric Trauma Society supports the Level 2 recommendations of Rozelle et al.,[9] which reports that C-spine imaging is not recommended for injured children over 3 years of age who are alert, have no neurological deficit, have no midline cervical tenderness, have no painful distracting injury, do not have unexplained hypotension and are not intoxicated. Children younger than 3 years of age must meet the above criteria as well as a GCS > 13/15, they should not have been involved in a motor vehicle accident (MVA) or a fall of more than 3 meters (10 feet) or non-accidental injury (NAI).[6]

Radiation exposure produced by CT scans in the paediatric population is not trivial. Studies have found that this may result in a threefold increased risk for brain tumours and leukaemia.[10] Subsequently, "clinical benefits should outweigh the small absolute risks, radiation doses from CT scans ought to be kept as low as possible and alternative procedures, which do not involve ionising radiation, should be considered if appropriate".[10] Up to 50% of spinal cord injuries are due to subluxation and dislocation of the tissue resulting in spinal cord injury without radiographic abnormality (SCIWORA), which can only be visualised using magnetic resonance imaging (MRI) which may require anaesthesia in a preferably stable patient.[2]

The **anaesthesia induction** and medication selection are dependent on the child's injury, the presence or absence of TBI, haemodynamic stability, and the clinician's skill and preference. The routine considerations of anaesthetising a paediatric patient should be taken, including age-appropriate equipment, standard ASA monitors, preferably a functional IV line (this allows for pre-induction resuscitation if necessary) and appropriate assistance. Alternative approaches to **airway management** should be considered when a difficult airway/ventilation is anticipated.[2] Many of the patients will present to theatre already intubated; in this case, it is the responsibility of the anaesthetist to assess and confirm correct endotracheal tube placement (tube size, cuffed/uncuffed, presence of any leak, depth of tube, breath sounds, ventilation and oxygenation).

Haemorrhage and damage control resuscitation

Transfusion guidelines for all blood components should be weight- and age-appropriate, based on both laboratory and physiological/clinical criteria, and use restrictive transfusion thresholds for allogeneic red blood cell transfusion when supported by published evidence and expert consensus.

Damage control resuscitation is the strategy of treating massive haemorrhage with the transfusion of blood components with the closest resemblance of whole blood.[8] Evidence to support practices in the paediatric population is emerging and sparse, high-quality studies are needed to determine the triggers and effects of balanced resuscitation in the bleeding paediatric trauma patient.[11] Crystalloid predominant resuscitation negatively affects mortality, length of hospital and intensive care stay, and increased ventilator days;[11] and is subsequently discouraged.

Massive transfusion protocols/balanced transfusion

No universal definition of massive transfusion in the paediatric population exists. Diab et al.[12] suggested the following dynamic definition of massive transfusion in children and neonates: "transfusion of > 50% of total body volume (TBV) in 3 hrs, transfusion > 100% TBV in 24 hrs or transfusion support to replace ongoing blood loss of > 10% TBV per min". Neff et al.[13] concluded that 40 ml/kg of all blood products administered within 24 hours is critical in defining massive blood transfusion in children and should be used in future clinical research. Other definitions have

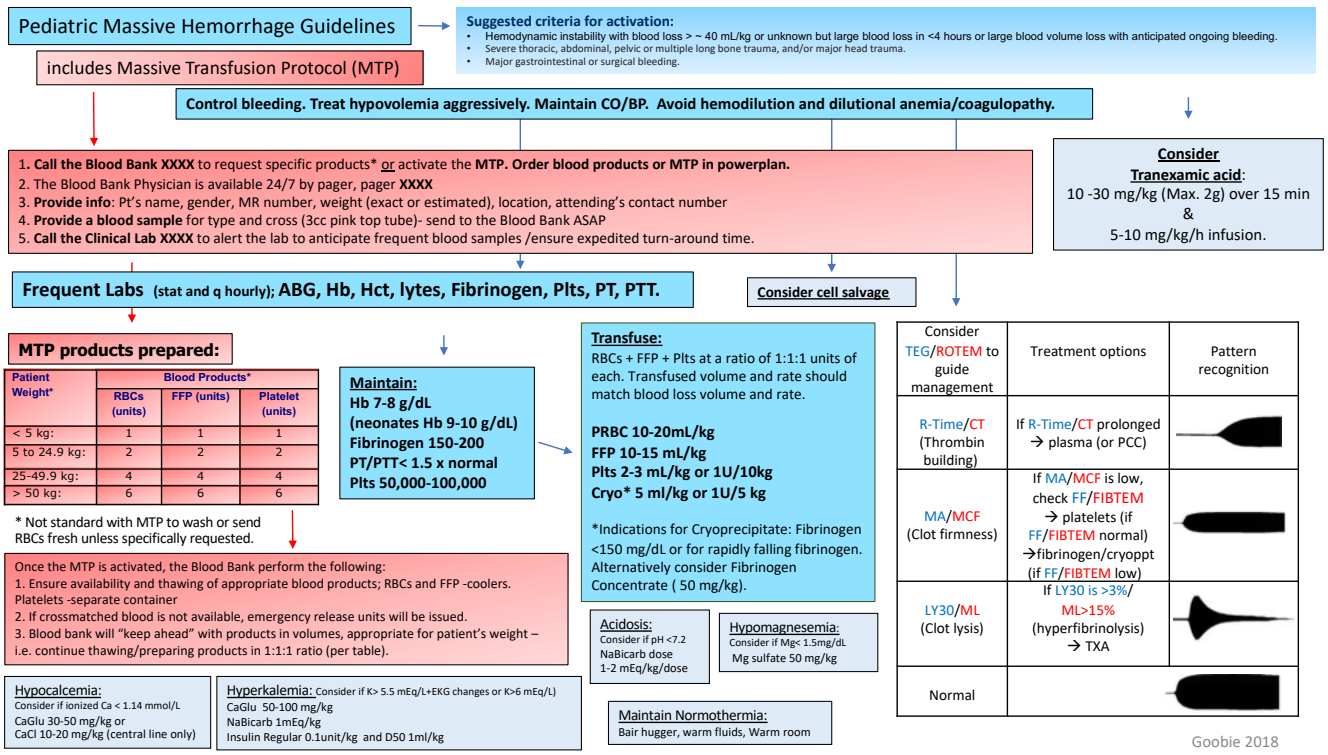

Figure 1: A sample of a Paediatric Massive Haemorrhage Guideline[15,16]

Note: The SASA Perioperative Patient Blood Management guidelines approve of a "restrictive" approach in children > 3 months of age; the transfusion of 10 ml/kg of PRBC to increase the Hb by 2 g/dl, cryoprecipitate should be given at 5–10 ml/kg, platelets 10–20 ml/kg, fresh frozen plasma (FFP)/fresh dried plasma (FDP) at 10–15 ml/kg and TXA given at a loading dose 15 mg/kg followed by an infusion 2 mg/kg/h.[17]

included expected transfusion requirements of 40 ml/kg in 12 hours or 80 ml/kg within 24 hours.[14]

Protocols involving early and liberal use of a fixed ratio of red blood cells:fresh frozen plasma (FFP):platelets have been used, with most suggesting 1:1:1, while occasionally 2:1:1 has also been described.[8,15] Literature has indicated that mortality rates are not significantly altered by implementing major transfusion protocols vs giving blood products at the clinician's discretion.[6] Further work in this field has started emerging. The majority of the existing studies are retrospective in nature and the level of evidence is low.[11] Additional high-quality research is required.

Early administration of blood products in a ratio that approximates whole blood is beneficial to patients.[18] There are no guidelines on what is the ideal massive transfusion protocol in children. However, one needs to consider the patient's volume status, tissue oxygenation, haemorrhage control and coagulation abnormalities. Large-volume blood product administration also affects potassium, ionised calcium, acid-base balance and hypothermia.[18]

Trauma-induced coagulopathy (TIC) is multifactorial, involving haemodilution, hypothermia, consumption of clotting factors and metabolic derangements. Acidosis and hypothermia commonly coexist with coagulopathy resulting in the "deadly triad". Management involves early identification and the transfusion of blood products. As trauma care has evolved, research has led to new therapies and techniques. These include massive transfusion protocols (MTP), tranexamic acid (TXA) and recombinant factor VIIa (rFVIIa) usage.[19] Current literature has predominantly focussed on the adult population.

Factor VIIa is indicated for haemorrhage resulting from shortages of factors VII and IX. The activation results in the formation of a complex with tissue factor at the site of the injury, thus activating factors IX and X. Activated factor X converts prothrombin to thrombin, subsequently allowing the conversion of fibrinogen to fibrin, ending in local haemostasis. The drug is dosed at 40–100 µg/kg, which can be administered every 2 hours until haemostasis is achieved.[6,19] In severe haemorrhage, the interval for maintenance dosages is 3–6 hours. Literature suggests that rFVIIa may not be beneficial when given early in the setting of haemorrhage as acidosis (pH < 7.2), thrombocytopaenia (platelets < 100 000) and hypotension (systolic ≤ 90) were indicators of poor response to rFVIIa.[6] The most severe side effect is potential thromboembolism and cost.

Desmopressin (DDAVP) was found to raise the levels of factor VIII and vWF and improve platelet adhesion to vessel walls. Another short-lived effect is the release of tissue plasminogen activator. The recommended dose is 0.3 µg/kg that can be administered intravenously (IV), subcutaneously or intranasally.[19] The benefits are reduced cost, increased availability, diversity of usage and meeting religious requests.

Tranexamic acid (TXA) usage in the paediatric population has been studied in the cardiac, spinal and craniofacial surgery settings.[15] The clinical randomisation of an antifibrinolytic in significant haemorrhage 3 (CRASH-3) trial assessed the effects

of early (< 3 hours) administration of a short course of TXA in adult trauma patients, particularly those with TBI.[14,20] It showed that this drug reduced the risk of death from bleeding with no apparent increase in fatal or non-fatal vascular occlusive events. Similar observations have been made in the paediatric population. Late usage (> 8 hours) has been associated with increased mortality and no adverse safety/medication-related complications.[11,19]

Tranexamic acid has a relatively low cost, ease of administration, a low side effect profile and is readily available, particularly in low- and middle-income countries, where there is decreased availability of blood products. There are various dosage regimes suggested ranging from a one-time 20 mg/kg dose to 1 g IV over 10 minutes followed by an infusion of 1 g over 8 hours[18] (in children more than 12 years old). For children younger than 12 years, the dosing recommendation is a loading dose of 15 mg/kg (max 1 g) over 10 minutes followed by 2 mg/kg/h for at least 8 hours or until bleeding ends.[6]

Prothrombin complex concentrate contains 25–30 times the concentration of clotting factors as FFP. Three-factor concentrate (factor II, IX, X) and four-factor concentrate (includes factor VII) exist. There is level 2C evidence for its use in patients with massive bleeding, with a recommended dose of 20–50 units/kg with a risk of thromboembolism at doses > 50 mg/kg.[6]

Coagulation tests, including the thrombo-elastogram (TEG), rotational thromboelastometry (RoTEM) and impedance aggregometry, should be used early to evaluate and better inform the management of TIC in children older than 1 year.[8]

Permissive hypotension/hypotensive or controlled resuscitation

Permissive hypotension is a concept that has evolved in the management of adult trauma patients. This practice has not gained wide acceptance in the management of paediatric patients as baseline blood pressures are close to the limits of cerebral autoregulation.[8] Some authors advocate extreme vigilance, questioning the non-validated theoretical benefits of such an approach in children.[11]

Pain management

There needs to be careful titration of analgesia and sedation without opioid-related sequelae, including respiratory depression and hypotension, and involves appropriate monitoring at all times. Consideration should be given to the usage of both pharmacological and non-pharmacological interventions. The intranasal route of administration, especially where oral or IV routes are not alternatives, should always be kept in mind. The role of regional anaesthesia to avoid opioid-related side effects and ensure patient comfort should become part of regular practice.

Future directions in paediatric trauma

A coordinated multidisciplinary approach is required to define the problem and solve it. This may include the involvement of clinicians in management from the prehospital setting and the usage of retrieval teams. There has been an increasing interest in identifying tissue-specific biomarkers that reflect the severity and prognosis of injury,[2] and further development and evolution of damage control surgery and MTPs, particularly in the paediatric population.

Prevention and public education are important areas of ongoing research in paediatric anaesthesia. One such initiative is the Childsafe campaign (www.childsafe.org.za) by the Child Accident Prevention Foundation of Southern Africa, a member of Safe Kids Worldwide. There needs to be continued teamwork, family and clinician support and debrief throughout this critical period of managing trauma in the paediatric population.

ORCID

P Mogane https://orcid.org/0000-0002-5523-4539

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