

# Trauma in Children

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## Introduction

Trauma is the leading cause of death in children worldwide. The causes of trauma and pattern of injury vary with age, with peaks in infancy and adolescence. Males are affected more frequently than females across all age groups except in infancy, where there is a 50:50 split. Blunt injury is responsible for >80% of fatalities. Falls from less than two metres and road traffic collisions (RTCs) are the most common mechanisms of injury in most age groups. Non-accidental injury (NAI) is the most frequent mechanism of injury in infants. There has been a substantial increase in penetrating trauma due to knife and gunshot injury in adolescents in recent years in the United Kingdom, particularly in urban areas. Currently, 10–20% of adolescent trauma is due to penetrating injury and responsible for 10–20% of paediatric trauma call activations in many major trauma centres (MTCs). Penetrating injuries have a high injury severity score (ISS) at presentation, increased activation of major haemorrhage protocols and a significant mortality of around 25%. The highest mortality (>50%) is seen with gunshot injuries to the head and injuries to the neck and thorax.

The incidence of major trauma in childhood increases in summer months, related to increased daylight hours and outdoor activities. Trauma calls are most common at the weekend and after school. Limb injuries are the most common and in isolation are not associated with high mortality. Traumatic brain injury (TBI) is the leading cause of disability and mortality, with the highest mortality seen in children with TBI combined with thoracic or abdominal trauma.

## Provision of Trauma Services

Management of paediatric trauma in the United Kingdom has been transformed with centralisation of services and the creation of regional networks. This followed recommendations from

several bodies, including the 2007 UK National Confidential Enquiry into Patient Outcome and Death (NCEPOD) report ‘Trauma: Who Cares?’, which found that care could be improved in more than 50% of cases.

Regional networks consist of a major trauma centre (MTC), which provides care to severely injured patients 24 hours a day, and linked local trauma units (TUs) that manage patients with less severe injuries. The ISS is used to describe trauma severity, with the highest score of 75 defining the most critically injured. Moderate injury is defined as an ISS of score of 9–15, and severe injury an ISS of >15. The ISS cannot be calculated at the scene at the time of injury. Pre-hospital triage is used to identify moderate and severe injuries to determine which cases should go directly to an MTC (see Table 39.1). If transfer times are long, cases may be taken to a local TU for rapid stabilisation prior to transfer. However, 30–50% of children bypass the pre-hospital triage system and are brought directly to hospital by parents or guardians. Care must be standardised and skills maintained across the whole paediatric network, especially the provision of life-saving interventions in local hospitals.

In the United Kingdom, there are currently 33 MTCs: 27 in England, four in Scotland, one in Wales and one in Northern Ireland. Twenty-one have paediatric services and are either paediatric only or co-located with adult services. Hospitals providing trauma care for children (MTCs and TUs) have dedicated standard operating procedures (SOPs) and up-to-date local guidelines. All units contribute data to the Trauma Audit and Research Network (TARN), which is a national UK audit that collects data on all children injured who are admitted to hospital for >3 days or admitted to intensive care and/or any mortality. Since the reconfiguration of services, practice between institutions has become more

**Table 39.1** Paediatric injuries triaged to major trauma centres

Haemodynamic instability not explained by anxiety or pain
Traumatic amputation
Signs of bruising to chest or abdomen
Glasgow coma score (GCS) <13
Penetrating injury
Open long bone/multiple long bone fractures
Pelvic fracture
Spinal injury with abnormal neurology
Skull fracture
Burn surface area >20 % if <12 years old or >30 % if >12 years old. Facial burns or circumferential burns
High-risk mechanism of injury – death of a same vehicle occupant, ejected from a vehicle, under a train, fall >2 floors (>20 feet), amputation above wrist or ankle or trapped under a vehicle (not a motorcycle)

standardised, and outcomes have improved, with a higher proportion of severely injured children surviving to hospital discharge.

## The Role of the Anaesthetist

The anaesthetist is an integral member of the trauma team and may be involved throughout the patient pathway, including in pre-hospital care. Trauma care in hospital begins with resuscitation and stabilisation in the emergency department (ED), potentially combined with transfer to radiology for diagnostic imaging, surgical interventions, procedures in interventional radiology (IR), provision of analgesia and postoperative care in the paediatric intensive care unit (PICU). Regional anaesthesia is increasingly important, particularly for complex polytrauma patients in the perioperative period.

## Trauma Calls, Primary Survey and Imaging

When there is a trauma call, there should be a team brief before the patient arrives, led by the trauma team leader (TTL). Everyone is identified

by name, role and the available patient information shared:

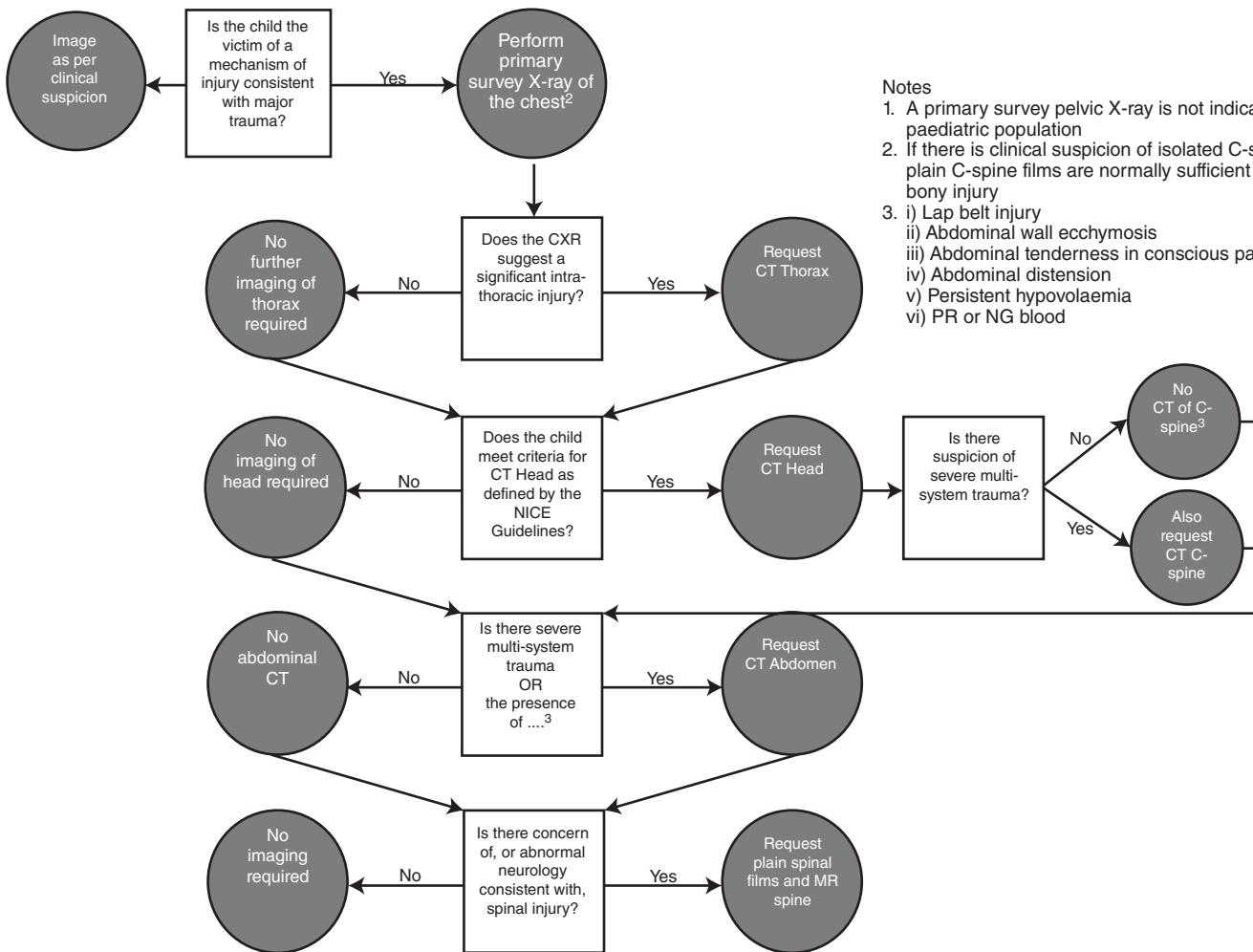
- Patient age and mechanism of injury
- Observations, including conscious level
- Obvious life-threatening injuries (including airway problems and uncontrolled haemorrhage)

Trauma calls can be stratified by level of injury (mild, moderate or severe). Advanced trauma calls are for the most seriously injured, for example suspected or confirmed major haemorrhage, cardiac arrest at scene, serious head injury or polytrauma. Additional senior support should be available for these cases, including specific teams such as neurosurgery where there is a suspected serious head injury. An advanced trauma call should alert the theatre team that surgical intervention may be required, triggering a pause in theatre to allow the theatre coordinator to liaise with the trauma team to plan theatre allocation. The anaesthetic consultant should be called early if their presence is anticipated. Anaesthetic drugs should be prepared and airway equipment made ready. Once the patient arrives in hospital, there should be a structured handover from the pre-hospital team to the trauma team.

The primary survey is performed to identify and treat any life-threatening injuries. The anaesthetist simultaneously assesses the airway, adequacy of ventilation and conscious level.

In adult trauma, early whole-body CT within 60 minutes of arrival has been shown to improve survival. Children are sensitive to ionising radiation, and there are concerns that repeated exposure to X-ray may increase the lifetime risk of malignancy. It is recommended that only children suffering severe polytrauma should undergo whole body CT, with a more tailored approach for other cases.

Comprehensive guidelines are available from the National Institute for Health and Care Excellence (NICE) for head and neck imaging in TBI (see the section ‘Traumatic Brain Injury’), and the Royal College of Radiologists provide additional recommendations for imaging in chest, abdomen or pelvic injuries (see Figure 39.1). If an isolated cervical spine (C-spine) injury is suspected, cervical X-rays are normally sufficient to exclude bony injury. Chest X-ray (CXR) is a relatively sensitive screening tool and is performed as part of the primary survey in major trauma.



#### Notes

1. A primary survey pelvic X-ray is not indicated in the paediatric population
2. If there is clinical suspicion of isolated C-spine injury plain C-spine films are normally sufficient to exclude bony injury
3. i) Lap belt injury  
ii) Abdominal wall ecchymosis  
iii) Abdominal tenderness in conscious patient  
iv) Abdominal distension  
v) Persistent hypovolaemia  
vi) PR or NG blood

**Figure 39.1** Paediatric emergency department major trauma imaging decision tool.

Children with an abnormal CXR or severe mechanism of injury should undergo a computed tomography (CT) chest examination. Pelvic X-ray and focused assessment with sonography in trauma (FAST) scans have low sensitivity and are no longer recommended as part of the primary survey. The Royal College of Radiologists Paediatric Trauma Protocols recommend CT abdomen in major trauma or if there is suspicion of abdominal injury, for instance tenderness, ecchymosis, distension, a lap belt injury and/or blood per rectum or in the nasogastric (NG) tube.

Intravenous access should be obtained and standard blood tests taken: full blood count, group and cross-match, clotting, urea and electrolytes, liver function tests including lipase, blood gas and point of care coagulation testing in major trauma, if available.

The child may be awake, distressed and frightened, and it is essential to maintain good verbal and non-verbal communication at all times. Play therapists can provide useful distraction for procedures and increase cooperation, especially if parents are not present. Analgesia is sometimes necessary during the primary survey. Small boluses of opioid (fentanyl 0.5 mcg kg<sup>-1</sup> or morphine 25–50 mcg kg<sup>-1</sup>) or ketamine (0.5 mg kg<sup>-1</sup>) are suitable. The ED should have a sedation and pain relief protocol for children. Intranasal opioids such as fentanyl (2 mcg kg<sup>-1</sup>) or diamorphine (100 mcg kg<sup>-1</sup>) can be given whilst intravenous access is obtained. Even low doses can impair ventilation and cause hypotension, so opioids must be used carefully and titrated to effect.

## Airway Management

Airway patency must be checked as soon as the patient arrives in the ED. C-spine protection must be maintained if there is any suspicion of injury. Collars are often poorly fitting and not well tolerated in younger children. Manual in-line stabilisation or collar and blocks are used in preference if there is a suspicion of cervical spine injury. The anaesthetist should lead patient transfers or log-roll procedures carried out during the secondary survey.

The child should be monitored with continuous pulse oximetry, non-invasive blood pressure, electrocardiogram (ECG) monitoring and capnography (if intubated). Oxygen saturations can be unreliable if the child is cold, and blood pressure

readings may be inaccurate at extreme highs and lows (mean arterial pressure is more reliable). Initial steps in airway management involve the application of high-flow oxygen delivered via a non-rebreather mask and, if there is airway obstruction, basic airway manoeuvres to open the airway and restore patency:

- Apply gentle suction to clear the upper airway of blood, secretions and vomit. It is important not to cause further trauma or reflex vomiting.
- Open the airway with a jaw thrust to maintain C-spine immobilisation. Consider an oropharyngeal airway if there is a reduced conscious level.
- Decompress the stomach with a wide-bore orogastric or NG tube (ensure there are no concerns about base of skull fracture before NG placement).
- If the patient has already been intubated by the pre-hospital team, ensure correct tracheal tube position with capnography monitoring and auscultate the chest to ensure bilateral air entry. Document the grade of intubation, size and position of the tube. Tube position should be confirmed on imaging.
- Report any obvious scalp lacerations to the TTL. These can be a significant source of blood loss, especially in small children and infants.

The main indications for intubation are airway obstruction, respiratory inadequacy or a reduced conscious level (see Table 39.2).

The decision to intubate should be made at a senior level, by the anaesthetist and the TTL, with agreement from the rest of the trauma team. A simple neurological assessment should be carried out before intubation to document the Glasgow Coma Score (GCS), any focal neurological signs and pupillary responses.

## Induction of Anaesthesia

Induction of anaesthesia can obtund compensatory vasoconstriction and lead to significant haemodynamic instability in a child who is hypovolaemic. In TBI, this can cause a detrimental reduction in cerebral perfusion pressure (CPP). Choice and dose of induction agent should take into account the haemodynamics and neurology of the child. Ketamine is a sympathomimetic and maintains cardiovascular stability to a greater extent than other agents. It also has analgesic

**Table 39.2** Indications for intubation in paediatric trauma

Airway obstruction	
Severe TBI with reduced conscious level; causing loss of pharyngeal tone and airway protection	
Vomit or blood or secretions in the airway	
Penetrating neck trauma, expanding haematoma causing airway compression	
Direct airway trauma	
Maxillofacial trauma	
<b>Inadequate ventilation</b>	
Severe TBI; causing loss of ventilatory drive	
Intoxication	
<b>Respiratory failure (type 1 or 2)</b>	
Lung contusions	
Pneumothorax	
Haemothorax	
<b>Polytrauma</b>	
<b>Major haemorrhage</b>	
<b>Transfer to tertiary major trauma centre</b>	

properties and is the preferred induction agent in severe trauma. Propofol and thiopentone reduce myocardial contractility and vascular tone. This can cause cardiovascular collapse in a shocked patient. Opioids are used to obtund the response to laryngoscopy and reduce the amount of induction agent required. Short-acting opioids such as fentanyl cause less cardiovascular instability and histamine release compared to longer-acting drugs such as morphine. Large boluses of fentanyl can still cause haemodynamic compromise, and use should be titrated to effect. Rocuronium has largely replaced suxamethonium for muscle relaxation. It has a quick onset of action, avoids detrimental side effects of suxamethonium (raised intracranial pressure [ICP] and intraocular pressure [IOP]) and can be readily reversed with sugammadex. A frequently used induction technique is ketamine 1–2 mg kg<sup>-1</sup>, fentanyl 1–2 mcg kg<sup>-1</sup> and rocuronium 1–1.5 mg kg<sup>-1</sup>. Anaesthetic agents, common doses and side effects are shown in Table 39.3.

Gastric emptying is reduced from the time of injury, and children are at risk of aspiration following trauma. A modified rapid sequence induction (RSI) should be considered, with the child in a head-up position. Children are prone to desaturation at induction, which may be

exacerbated by chest injuries and/or pain, causing shallow breathing. The child should ideally be pre-oxygenated, although compliance may be a problem with younger or frightened children. Cricoid pressure can distort the anatomy and make the view difficult at laryngoscopy. There is limited evidence of benefit of cricoid pressure in children, and it should be removed if it interferes with the view of the glottis.

Intubation may be difficult in trauma due to C-spine immobilisation, facial and neck injuries and ongoing oropharyngeal bleeding. Video laryngoscopy should be considered in experienced hands, as it causes less C-spine movement, although the view may be obscured by bleeding. Intubation may be helped by removal of the cervical collar and blocks, and C-spine protection is maintained with manual in-line stabilisation (MILS). Suction should be on and ready to remove any debris obscuring the view at laryngoscopy. In severe maxillofacial or neck trauma, a potential difficult airway should be declared. Intubation should be performed by the most senior member of the anaesthetic team with an ENT surgeon in attendance. A supraglottic airway should be available as a rescue device to maintain oxygenation in failed intubation. Front of neck access is required in a ‘can’t intubate, can’t ventilate’ situation. Fortunately, this is rare in paediatrics, but formal tracheostomy is the technique of choice in this situation.

Correct position of the tracheal tube should be confirmed by capnography and auscultation, checking for bilateral air entry. High airway pressure, low tidal volume and reduced oxygen saturation may indicate ventilatory problems, potentially due to insufficient muscle relaxant, endobronchial intubation or light anaesthesia. Pulmonary causes need to be excluded, such as secretions plugging the airway or aspiration of blood or gastric contents. The former can usually be addressed with gentle suction with saline down the tracheal tube. In addition, there may be pulmonary injury with contusion or pneumothorax, in which case positive pressure ventilation may convert a simple pneumothorax to a tension pneumothorax. This is suggested by reduced breath sounds on the side of the pneumothorax, high airway pressures and potentially cardiovascular collapse. Needle decompression or thoracostomy is required followed by chest drain insertion.

Injury to the airway may be indicated by surgical emphysema following the start of positive

**Table 39.3** Anaesthetic agents used in trauma patients

Anaesthetic agent	Dose	Effects
Ketamine	1–2 mg kg <sup>-1</sup> (induction dose) 10–45 mcg kg <sup>-1</sup> (maintenance of sedation/anaesthesia)	Analgesia, sedation and anaesthesia. Preserves cardiovascular stability and CPP better than other induction agents.
Fentanyl	1–2 mcg kg <sup>-1</sup>	Sympatholytic and analgesic. Obtunds response to laryngoscopy. Can cause hypotension with bolus doses. Titrate to effect.
Propofol	1–2 mg kg <sup>-1</sup>	Anaesthesia and sedation. Causes haemodynamic instability in hypovolaemic shock. Not recommended in severe trauma.
Thiopentone	2–5 mg kg <sup>-1</sup>	Anaesthesia and sedation. Causes haemodynamic instability in hypovolaemic shock. Not recommended in severe trauma.
Alfentanil	10–20 mcg kg <sup>-1</sup>	Sympatholytic and analgesic. Obtunds response to laryngoscopy. Can cause hypotension with bolus doses. Titrate to effect
Morphine	0.1–0.2 mg kg <sup>-1</sup> (bolus dose) 10–40 mcg kg <sup>-1</sup> hour <sup>-1</sup> (maintenance of sedation/anaesthesia)	Analgesic. Can cause histamine release and hypotension. Used for sedation and maintenance of anaesthesia.
Rocuronium	1–1.5 mg kg <sup>-1</sup> (RSI dose) 0.5–1 mg kg <sup>-1</sup> (subsequent bolus doses)	Rapid onset within 60 seconds. Reversed with sugammadex. Has largely replaced suxamethonium.
Atracurium	0.5 mg kg <sup>-1</sup>	Slower onset of action. Can cause histamine release and hypotension. Not suitable for RSI.
Suxamethonium	1–2 mg kg <sup>-1</sup>	Rapid onset of action. Causes increased ICP and IOP. Largely replaced by rocuronium.
Volatile agents: sevoflurane/ isoflurane	Titrate to effect and MAC	Used in theatre for maintenance of anaesthesia. Cause vasodilation and hypotension.
Nitrous oxide	-	Not used in severe trauma. Causes cerebral vasodilation and increased ICP. Diffuses into and increases air-filled spaces rapidly. Can convert a simple pneumothorax to a tension.

pressure ventilation. Bronchoscopy will be needed to identify where the injury is and guide surgical planning. Instituting positive pressure ventilation may cause cardiovascular collapse in major haemorrhage. Blood transfusion should be ongoing if this is predicted.

Penetrating injuries have increased in the adolescent population in recent years. Penetrating neck trauma (injury extending below the platysma muscle) can be life threatening and cause

significant airway compromise. An expanding neck haematoma quickly obstructs the airway, necessitating definitive airway management in ED. Intubation may become increasingly difficult as oedema and swelling distort the laryngeal anatomy. If the patient is unstable (surgical emphysema, airway compromise, hemiparesis or a rapidly expanding pulsatile neck haematoma), they should be taken directly to theatre for airway management and surgery. If the patient is stable, a

**Table 39.4** Physiological values in children: normal values and values in severe trauma

Age (years)	Respiratory Rate (breaths per minute)	Heart rate (beats per minute)		Systolic BP (50th centile) (mmHg)	
		Normal	Suspect >40% blood loss	Normal	Suspect >40% blood loss
<1	30–40	110–160	>160	80–90	<70
1–2	25–35	100–150	>150	85–95	<80
2–5	25–30	95–140	>140	85–100	<80
5–12	20–25	80–120	>120	90–110	<90
<12	15–20	60–100	>100	100–120	<90

CT neck is often obtained to plan further management. Good decision-making at senior level is critical.

## Major Haemorrhage

The increase in penetrating trauma in adolescents has resulted in a rise in major haemorrhage trauma calls. Major haemorrhage occurs in 3–4% of paediatric trauma calls, with more than 50% of deaths occurring in the first 24 hours. Major haemorrhage is a cause of preventable death in trauma.

Haemorrhage can be concealed or obvious. Hospital definition of paediatric major haemorrhage is transfusion of 1–1.5 times the total blood volume (TBV) acutely or over a 24-hour period or ongoing losses of  $>2\text{ml kg}^{-1}\text{ min}^{-1}$ . These definitions work well in elective surgical settings, although less well in trauma. Pre-hospital definitions are important to allow teams time for preparation. In this situation, major haemorrhage is declared in the presence of confirmed or suspected haemorrhage, cardiac arrest at the scene and/or heart rate or blood pressure  $>20\%$  above or below normal for the age of the child. The emphasis is on the importance of ongoing clinical assessment and reassessment, particularly in a rapidly changing resuscitation situation.

Major haemorrhage is often ‘under-called’ in paediatric trauma. The reasons for this are multi-factorial. Children have excellent compensatory mechanisms and can lose 25–40% of TBV before a reduction in systolic blood pressure is seen. Hypotension is often a late pre-terminal sign. A prolonged capillary refill time and narrow pulse pressure are more reliable signs of early shock. The definition of major haemorrhage paediatric

trauma is not clear-cut, with the definition of haemodynamic instability depending on the age of the child. This and the fact that up to 50% of trauma presentations are self-referrals by parents or guardians, bypassing pre-hospital triage systems, can make paediatric major haemorrhage management more complex. Normal values for cardiorespiratory variables by age are shown in Table 39.4.

## Intravenous Access

Adequate intravenous access must be obtained on arrival (with formal laboratory blood tests as described in the section ‘Trauma Calls, Primary Survey and Imaging’). Access can be difficult in younger children or those in shock with cold peripheries. Excessive time should not be spent attempting IV access, and intraosseous (IO) access should be performed after two failed IV attempts. The tibial tuberosity is the most common site used. Other sites are the anterolateral surface of the femur and the tibia proximal to the medial malleolus. Limbs with fractures should be avoided. Flow rates are limited through an IO needle, and they can become dislodged easily. Intraosseous access is therefore only a temporary measure until more reliable access is obtained.

Blood products must be warmed before administration. Rapid infuser devices are used to simultaneously warm and deliver products quickly via the IV route. A rate of  $>100\text{ ml min}^{-1}$  is achieved by devices using a countercurrent exchange method and magnetic induction. It is important to set pressure alarms when using devices that are not exclusively paediatric. The cannula site should be checked regularly to ensure it is working. Maximum flow rates are limited by

**Table 39.5** Rates of flow and IV/IO access

IV/IO cannula/needle	Rates of flow (with gravity) ( $\text{ml min}^{-1}$ )	Rates of flow (with pressure) ( $\text{ml min}^{-1}$ )
14G cannula	236.1	384.3
16G cannula	154.7	334.4
18G cannula	98.1	153.1
20G cannula	64.4	105.1
22G cannula	35.7	71.4
25G IO needle	68.2	204.6

the size of the cannula (see Table 39.5). Rates of flow of  $>100 \text{ ml min}^{-1}$  are not possible through smaller gauge cannula (22G and 24G).

## Invasive Monitoring

Wide-bore cannulae are used for rapid resuscitation. If expertise allows, ultrasound-guided central venous access can be established for further monitoring and access. The site (femoral, internal jugular or subclavian) depends on access and preference of the practitioner. The presence of a pelvic binder and cervical collar limit femoral and internal jugular access respectively. The subclavian vein is associated with increased complications, including pneumothorax and inadvertent arterial puncture. The risk of pneumothorax is mitigated if there are thoracostomies. The size of central line depends on the age of the child (see Table 39.6).

Arterial access should be established early in major haemorrhage, but placement should not interfere or delay resuscitation. Arterial lines are used for gas sampling and point-of-care tests. The waveform provides information about blood pressure and vascular filling. A narrow waveform and wide variation in systolic pressure with respiration imply ongoing hypovolaemia.

## Damage Control Resuscitation

Coagulopathy begins at the time of injury. Tissue damage releases tissue factor and activates the clotting cascade. This leads to consumption of

**Table 39.6** Paediatric central line sizes

Age	Weight (kg)	Size
0–6 months	>10	4 Fr
6 months–4 years	10–20	4.5 Fr–5 Fr
4–12 years	20–40	5 Fr
>12 years	>40	7 Fr

clotting factors. Ongoing bleeding causes systemic hypoperfusion and tissue hypoxia. The resulting endothelial damage causes fibrinolysis and clot breakdown. The combination of this endogenous multi-factorial process is called acute traumatic coagulopathy (ATC). It can present on admission to hospital prior to transfusion. ATC is particularly pronounced where there is a high injury burden. Hypothermia, metabolic acidosis, haemodilution and hypocalcaemia are all modifiable factors that worsen ATC.

Acute traumatic coagulopathy and the modifiable factors create a vicious cycle called trauma-induced coagulopathy (TIC). The principles of damage control resuscitation are to reduce TIC:

- *Haemostatic resuscitation.* Replacing ongoing blood losses with blood products, guided by major transfusion protocols and point-of-care testing (see the following section). This reduces haemodilution and coagulopathy. Crystalloid and colloid are avoided. They increase transfusion requirements, coagulopathy, multi-organ failure and mortality.
- *Temperature control.* Correction of hypothermia. Measure core temperature and minimise exposure. Active warming with fluid warmers and warming blankets. Increase environmental temperature.
- *Permissive hypotensive resuscitation.* There is little evidence for this strategy in children; however, targeting a mean arterial pressure (MAP) at the lower end of normal for the age of the child is common practice. A higher MAP may be necessary in coexisting TBI.
- *Wound management and damage control surgery.* Apply direct pressure to the wound. Pelvic binders and tourniquets reduce bleeding. Damage control surgery (DCS) is aimed at wound decontamination and control of bleeding, with definitive surgery after a period of stability in PICU.

**Table 39.7** Biochemical electrolyte correction

Electrolyte abnormality	Management
Hypocalcaemia ( $\text{Ca}^{2+} > 1.0 \text{ mmol l}^{-1}$ )	Calcium gluconate (or chloride) 10% 0.5 ml $\text{kg}^{-1}$ up to 20 ml maximum. Give over 15 minutes. Aim for ionised calcium $> 1.0 \text{ mmol l}^{-1}$ . Repeat as necessary.
Hyperkalaemia $\text{K}^+ 6.0\text{--}7.0 \text{ mmol l}^{-1}$ or ECG changes are present (tented T waves, wide QRS, prolonged PR interval or absent/small P waves).	<b>For cardiac protection</b> Calcium gluconate (or chloride) 10% 0.5 ml $\text{kg}^{-1}$ up to 20 ml maximum. Give over 15 minutes. <b>To reduce serum potassium</b> Insulin infusion 0.05–0.1 units $\text{kg hour}^{-1}$ . Monitor blood glucose levels. Nebulised salbutamol 2.5 mg ( $<25 \text{ kg}$ ) or 5 mg ( $>25 \text{ kg}$ ) Repeat as necessary Continue cardiac monitoring Consider 8.4% sodium bicarbonate 1–2 ml $\text{kg}^{-1}$ in severe metabolic acidosis Consider dialysis for refractory hyperkalaemia

- **Electrolyte correction.** Calcium is integral to the clotting pathway. Ionised calcium should be kept greater than  $1.0 \text{ mmol l}^{-1}$ . Potassium levels increase with metabolic acidosis and transfusion and should be corrected if  $>7.0 \text{ mmol l}^{-1}$  or with ECG changes (see Table 39.7).

## Haemostatic Resuscitation

Red blood cells (RBC) and fresh frozen plasma (FFP) are given initially in a 1:1 ratio with additional platelets and cryoprecipitate guided by major haemorrhage protocols and point-of-care testing. An initial bolus of  $10\text{--}20 \text{ ml kg}^{-1}$  of RBC (in  $5 \text{ ml kg}^{-1}$  aliquots) should be given in major haemorrhage. O-negative blood is given in the emergency setting whilst waiting for cross-matched blood. Group specific blood is preferred; this takes approximately 15 minutes to obtain, whilst a full cross-match takes 40–45 minutes. The volume of FFP/octaplas is matched for every  $10\text{--}20 \text{ ml kg}^{-1}$  of RBC given.

Tranexamic acid  $15 \text{ mg kg}^{-1}$  over 10 minutes (maximum 1 g) should be given within three hours of injury. Adult practice is to give a larger dose of 2 g of tranexamic acid, and paediatric practice may change to reflect this. The CRASH-2 (Clinical Randomisation of an Antifibrinolytic in Significant Haemorrhage) trial found this higher

dose reduced death from haemorrhage but was less likely to be effective given more than three hours after injury and may increase the relative risk of death. If bleeding persists platelets ( $15 \text{ ml kg}^{-1}$ ) and cryoprecipitate ( $10 \text{ ml kg}^{-1}$ ) should be given. As a guide, platelets should be given after every  $30 \text{ ml kg}^{-1}$  of RBC or if indicated by laboratory results (platelet value  $<100 \times 10^9 \text{ l}^{-1}$ ) or point of care coagulation testing. Cryoprecipitate should be given if fibrinogen is  $<1.5 \text{ g l}^{-1}$  or if indicated by point-of-care testing. Consider using adult major haemorrhage protocols in children  $>50 \text{ kg}$ .

Point-of-care testing is used to guide ongoing transfusion requirements and is performed at the bedside. Thromboelastometry (ROTEM®) and thromboelastography (TEG®) are examples of point-of-care tests that help to identify factors leading to ongoing bleeding and allow specific tailored resuscitation. They measure the viscoelastic properties of whole blood from initiation of coagulation to fibrinolysis. The median and reference range for normal values vary depending on the age of the child. Local protocols should be used to interpret ROTEM® and TEG® values. An example ROTEM® algorithm for a child  $>50 \text{ kg}$  is as follows:

- Clotting time, extrinsic assay (EXTEM CT)  $>80 \text{ s}$  – give four units of FFP
- Fibrinogen assay at 5 minutes (FIBTEM A5)  $<10 \text{ mm}$  – give two pools of cryoprecipitate

- Clot amplitude at 5 minutes (EXTEM A5) < 40 mm and FIBTEM A5  $\geq$  10 mm – give one pool of platelets
- Maximum lysis, extrinsic assay (EXTEM ML) >15% – give 1 g of tranexamic acid and four units of FFP

## Theatre Conduct in Damage Control Surgery

Leadership and theatre preparation are important in DCS:

- The theatre team leader should be identified and roles allocated. A runner should be identified to take samples to the laboratory and collect blood products, and a scribe be appointed to document events.
- The ED team leader should conduct a formal handover to the theatre team.
- The operating table should be arranged in a crucifix layout (+/- extended arm boards depending on age of child) for ease of access to the patient.
- Blood bank must be informed that the patient is now in theatre.
- The airway and resuscitation trolley should be moved into theatre.
- Equipment including chest drain, thoracotomy kit, invasive lines, ultrasound, rapid infuser devices and fluid warmer should be in theatre.
- Theatre temperature should be increased.
- The World Health Organisation (WHO) trauma checklist should be performed.

## Transfusion Endpoints in DCS

This varies depending on local protocols. Common targets used are as follows:

- Haemoglobin 80–100 g l<sup>-1</sup> or haematocrit >0.3.
- Fibrinogen >1.5 g l<sup>-1</sup>.
- Ionised calcium >1.0 mmol l<sup>-1</sup>.
- PT <1.5 (less sensitive in the context of major haemorrhage).
- Platelets >75–100  $\times$  10<sup>9</sup> l<sup>-1</sup>.
- Blood gas – improving lactate and metabolic acidosis.
- Clinical endpoints – normal heart rate/blood pressure/capillary refill time/warm peripheries. Values at the higher end of normal should be used in patients with coexisting TBI.

## Other Causes of Shock in Trauma

Haemorrhage is the most common cause of shock in trauma patients. It is important to consider other causes that may be coexistent:

- Neurogenic
- Spinal trauma, massive TBI
- Obstructive shock
- Tension pneumothorax
- Cardiac tamponade

## Vasopressors and Inotropes

The evidence for the use of vasopressors in haemorrhagic shock in children is limited. There may be a role for short-term use in refractory hypotension, in failure to respond to fluid resuscitation and in spinal injury. Inotropes are often needed in conjunction with vasopressors, titrated to effect. Supranormal blood pressures will exacerbate bleeding and disrupt clot formation.

## Traumatic Brain Injury

Traumatic brain injury is the leading cause of mortality and morbidity in paediatric trauma. Non-accidental injury should always be considered in children <2 years. The severity of TBI is classified using the GCS, with a modified GCS for use in younger pre-verbal children (see Table 39.8). A GCS score of 3–15 is allocated depending on the child's best eye, verbal and motor responses at the time of injury. TBI is classified as mild (GCS 13–15), moderate (GCS 9–12) or severe (GCS  $\leq$  8). Initial motor score correlates with prognosis.

Neurological status can be assessed in awake children by assessment of conscious level, pupillary responses and presence of localising signs. Children with a GCS  $\leq$  8 or who are agitated require intubation and ventilation for airway and neuroprotection. Intracranial pressure (ICP) monitoring is recommended in children with severe TBI and GCS < 8 and/or who are intubated and ventilated.

The NICE 2014 guidance (updated in 2019) recommends a CT head is performed within one hour in children if there is any of the following: suspicion of NAI; depressed, basal or 'open' skull fracture; GCS < 14 (or < 15 in infants); focal neurological signs; post-traumatic seizure in the absence of epilepsy history; or any bruise or swelling >5 cm in an infant. A CT head is also

**Table 39.8** Paediatric Glasgow coma scale

GCS	Score	Infants	Older children
4	Eye opening	Spontaneously	Spontaneously
3		Verbal	Verbal
2		Pain	Pain
1		No response	No response
5	Speech	Babbles and coos normally	Orientated
4		Spontaneous irritable cries	Confused
3		Cries to pain	Inappropriate words
2		Moans to pain	Incomprehensible sounds
1		No response	No response
6	Best motor response	Normal spontaneous movement	Follows commands
5		Withdraws to touch	Localises pain
4		Withdraws to pain	Withdraws from pain
3		Abnormal flexion to pain	Abnormal flexion from pain
2		Extension to pain	Extension to pain
1		No response	No response

indicated in the presence of more than one of the following: amnesia for >5 minutes, loss of consciousness for >5 minutes, a severe mechanism of injury, three or more discrete episodes of vomiting and/or persistent drowsiness. A C-spine CT is performed with the CT head in the context of major polytrauma. Radiological clearance of the C-spine allows removal of a collar. This can reduce venous engorgement and help with ICP management.

The outcome after TBI depends on the extent of the initial intracranial insult (the primary injury) and development of any secondary injury. Secondary injury is exacerbated by hypotension, hypoxia and cerebral oedema. Careful management is required to provide neuroprotection and reduce secondary injury.

Neuroprotection involves control of factors that increase ICP or reduce cerebral perfusion pressure (CPP) ( $\text{CPP} = \text{MAP} - \text{ICP}$ ). CPP should be maintained at a minimum of 40 mmHg; infants >40–50 mmHg, children >50–60 mmHg and adolescents >60 mmHg (as per adult guidelines). Vasopressor infusions should be used to achieve adequate CPP, with noradrenaline, ideally given centrally, as the first line. Temperature should be controlled to ensure normothermia and the

ventilation set to achieve arterial carbon dioxide ( $\text{PaCO}_2$ ) of 4.5–5.5 kPa. Arterial sampling is recommended to validate the end-tidal carbon dioxide ( $\text{ETCO}_2$ ) readings, as there can be a discrepancy between  $\text{ETCO}_2$  and  $\text{PaCO}_2$ , particularly in smaller children. Hyperthermia and high  $\text{PaCO}_2$  cause cerebral vasodilation and increase ICP. Hyperventilation and a low  $\text{PaCO}_2$  cause cerebral vasoconstriction, which can lead to ischaemia and infarction. Simple measures to reduce ICP involve nursing the patient in a head-up position and ensuring tracheal tube is secured appropriately with tapes, avoiding compression of neck veins.

Intracranial lesions causing a mass effect (acute subdural or extradural haematoma) require urgent neurosurgery and should be operated on ideally within four hours of injury. This is a time-critical emergency, and urgent transfer is required if the child is not at a neurosurgical centre; potentially by the local team, rather than waiting for the retrieval team. A refractory ICP >20 mmHg despite maximum medical therapy and signs of impending herniation are indications for decompressive craniectomy.

Anaesthesia for emergency neurosurgery should aim to maintain neuroprotection. Blood

loss can be significant and require transfusion, particularly in smaller children and infants with open cranial sutures. Blood should be available in theatre, and adequate IV access available (ideally two wide-bore cannulas). Invasive lines should not delay surgery and can be sited intraoperatively if required. Cardiovascular instability may occur following the first burr hole or incision of the dura. It is possible to extubate children with isolated uncomplicated head injury at the end of surgery, which also aids neurological assessment. Children with more severe head injuries or poly-trauma will usually require postoperative PICU care. Cerebral oedema often increases in the first 24–48 hours postoperatively.

Maintaining ICP <20 mmHg improves outcomes. Hypertonic saline (3%) is recommended in preference to mannitol to control ICP if required. A bolus of 3–5 ml kg<sup>-1</sup> is given over 10–20 minutes to treat sustained ICP >20 mmHg or if there are signs of impending herniation. Sedation and analgesia can be used to treat raised ICP. Boluses of sedative drugs risk hypotension and cerebral hypoperfusion and should be used with caution. Propofol is not recommended for prolonged sedation or treatment of raised ICP in children.

Refractory ICP >20 mmHg can be managed with high-dose barbiturate therapy. Prophylactic seizure treatment is recommended to reduce the occurrence of early post-traumatic seizures (PTS) within seven days, with either phenytoin or levetiracetam. Steroids and hypothermia are no longer recommended to reduce ICP or improve outcome in TBI.

The CRASH-3 trial published in 2019 demonstrated a reduction in head injury-related mortality in adults with mild and moderate TBI who received tranexamic acid within three hours of injury, but there have been no publications relating to children yet.

## Chest Trauma

Thoracic injuries account for less than 10% of paediatric injuries but have a high mortality. Eighty-five per cent are blunt trauma, mainly caused by road traffic accidents. Penetrating chest injuries are more likely to cause traumatic cardiac arrest. NAI must be considered in younger children with rib fractures.

A small body surface area and increased compliance of the chest wall make children more

vulnerable to thoracic injury. The ribs have not undergone complete ossification, and large amounts of energy from impact are transmitted readily, with risk of serious injury to underlying intrathoracic structures. The presence of rib fractures suggests severe injury, particularly in young children. Small mediastinal shifts can cause significant ventilatory and cardiovascular compromise.

Pulmonary contusions are the most common form of thoracic injury. This may cause varying degrees of hypoxia and respiratory distress, depending on severity. Life-threatening major thoracic injuries include tension pneumothorax, cardiac tamponade, massive haemothorax, airway injury and aortic rupture. These should be identified and treated rapidly during the primary survey. A CXR in ED is a good screening tool. Anterior pneumothoraces are often not seen on CXR. A CT chest is not performed routinely in children but is indicated following a serious mechanism of injury or where the initial CXR is abnormal.

Positive pressure ventilation can convert a simple pneumothorax to a tension pneumothorax, and a chest drain should be sited if this is anticipated. Ketamine or short-acting opioids can be used for sedation for chest drain insertion. Low chest wall penetrating injuries can rupture the diaphragm, resulting in intraperitoneal injury.

The majority of simple chest injuries can be managed conservatively with early effective analgesia, high-flow oxygen and chest physiotherapy. A chest drain is often the only intervention needed. Severe injuries require surgical intervention in theatre and management on PICU post-operatively. Deterioration post-induction of anaesthesia should be anticipated if haemostatic resuscitation is ongoing. Major haemorrhage should be managed as detailed in the section 'Major Haemorrhage'.

Emergency thoracotomy is performed to control massive haemorrhage usually associated with penetrating injury. The surgeon can cannulate the right atrium for rapid volume replacement if other access has not been possible. If the patient is too unstable for transfer to theatre or has a traumatic cardiac arrest, a resuscitative thoracotomy can be performed in ED. Transfer to theatre to achieve definitive vascular control should occur as soon as return of spontaneous circulation (ROSC) is achieved.

## Traumatic Cardiac Arrest and Resuscitative Thoracotomy

The Paediatric Emergency Research in the United Kingdom and Ireland (PERUKI) Consensus Statement on management of paediatric traumatic cardiac arrest states 'good airway management with a supraglottic airway device (SAD) or tracheal tube (TT) to maintain oxygenation and ventilation, rapid volume replacement with warmed blood products and a resuscitative thoracotomy in penetrating trauma, improve survival'. The PERUKI group suggests the following life-saving interventions are used initially in paediatric traumatic arrest, in preference to chest compressions and defibrillation:

- External haemorrhage control
- Oxygenation and ventilation
- Bilateral thoracostomies
- Haemostatic resuscitation with warmed blood products
- Use of a pelvic binder

These interventions are not recommended in traumatic arrest secondary to hypoxia (drowning or asphyxiation). There is no consensus regarding the role of adrenaline in a paediatric traumatic cardiac arrest, and the normal Advanced Paediatric Life Support algorithm should be followed. Cautious use of adrenaline to avoid hypertension and exacerbation of bleeding is advised following ROSC.

Resuscitative thoracotomy is well established in the adult trauma algorithm and improves survival. Most evidence for resuscitative thoracotomy in paediatrics is in adolescents with penetrating chest injury. Evidence for benefit is less clear in blunt injuries. Indications are a penetrating chest injury causing traumatic cardiac arrest or peri-arrest in ED or five minutes prior to arrival. The aim is to control massive haemorrhage (and to clamp the aorta when needed) to provide internal cardiac massage and to relieve any underlying cardiac tamponade. Aggressive haemostatic resuscitation should begin whilst preparations for thoracotomy are made.

Decisions regarding when to stop resuscitation are guided by duration of cardiac arrest and response to the aforementioned interventions.

## Rarer Thoracic Injuries

### Aortic Rupture

This is very rare and due to rapid deceleration injuries. Death at the scene is common due to

massive haemorrhage into the left side of the chest. Children who survive present in shock and require massive transfusion. A widened mediastinum is seen on CXR. A transoesophageal echo (TOE) is useful to define the injury. Emergency cardiothoracic surgery is needed to repair or replace the damaged aorta.

### Tracheobronchial Injury

This occurs in < 3% of thoracic injuries. Children present with subcutaneous emphysema, airway obstruction and hypoxia. A classic sign is an air leak and persistent pneumothorax despite chest drain. Lung isolation reduces the air leak and improves ventilation and oxygenation. This is achieved with placement of the tracheal tube beyond the level of injury, a bronchial blocker or double-lumen tube (DLT), although DLTs are only available for children >10 years old. Airway placement should be confirmed with flexible bronchoscopy, although any significant airway bleeding will preclude use. Definitive management is with thoracic surgery to repair the fistula.

### Diaphragmatic Rupture

This rare injury occurs more frequently on the left side of the chest. Abdominal viscera can herniate into the thoracic cavity, causing respiratory distress and mediastinal movement. An NG tube should be sited to decompress the gastrointestinal (GI) tract. Surgical correction may be required.

### Intra-abdominal and Pelvic Trauma

Children are vulnerable to abdominal injuries. The liver and spleen are relatively unprotected, as they are larger and extend below the thoracic cage. The anterior-posterior diameter of the abdomen is smaller, and energy forces can be widely dissipated within the intra-abdominal structures. Injuries to the abdomen can involve the solid organs (liver, spleen and pancreas) or hollow viscera (bowel and bladder) or be vascular in nature. The spleen is the most common solid organ injured.

Management strategy is guided by the haemodynamic status and the American Association for the Surgery of Trauma Organ Injury Scale (OIS), which describes and grades the severity of traumatic organ injuries based on initial CT imaging. Classification grades for the liver, kidney and spleen are most frequently used. Between 80–95%

of abdominal injuries can be managed conservatively, especially blunt injuries. This has the advantage of avoiding morbidity associated with high-risk surgery and preserves organ function. This is particularly important in splenic injury to preserve immune function and avoid post-splenectomy sepsis. Risk factors for failure of conservative management are a high ISS at presentation, a high organ injury grade and multiple organ injuries. Early identification of failure of conservative management is key.

## Trauma Laparotomy

Indications for a trauma laparotomy are haemodynamic instability, abnormal findings on CT (free air or fluid), peritonitis and/or evisceration or omental herniation. Massive traumatic haemorrhage should be anticipated and managed as detailed in the section 'Major Haemorrhage'. The surgeon should be scrubbed in the operating theatre prior to induction of anaesthesia. Fentanyl or ketamine can be used for induction as outlined previously. The tamponade effect of retroperitoneal or intra-abdominal bleeding is lost on surgical opening; in extreme cases, this can cause hypovolaemic cardiac arrest.

Complex abdominal injuries require initial DCS to control bleeding, decontaminate the area (in cases of intestinal perforation) and stabilise the child. Definitive surgery should be planned after a period of stability in PICU. There is a risk of abdominal compartment syndrome following abdominal injuries. Clinical signs include increased ventilation pressures, hypotension, reduced urine output and a rising lactate. Intra-abdominal pressures should be measured in PICU to aid early identification.

## Interventional Radiology

IR is a well-established component of the adult trauma algorithm. Advances in endovascular techniques and equipment and increasing experience of interventional radiologists with smaller children have made interventional procedures an important option in paediatric trauma. Most reports are in adolescents, with increasing case reports in younger children.

IR procedures, mainly embolisation, may be performed as a primary procedure or when conservative management fails. Indications include extravasation of contrast on CT and/or ongoing

bleeding. This is suggested by a persistent tachycardia (despite sufficient analgesia) and a falling haemoglobin with ongoing requirement for blood transfusion. Main techniques for embolisation are with a coil or a gelfoam slurry. Complications include failure to control bleeding and conversion to an open technique, infarction distal to the embolisation site, infection and post-procedure re-bleeding. Anaesthesia for IR can be challenging in a remote site. Monitoring and IV lines require careful positioning for accessibility during the procedure. Extensions to IV lines are often needed. The theatre team must be ready if conversion to an open technique is required. This is invariably due to massive haemorrhage.

## Pelvic Injury

Pelvic injury is rare in children, the management is mainly conservative and there is a good prognosis. Pelvic fractures in adolescents can cause a massive retroperitoneal haemorrhage. A pelvic binder is used to tamponade the bleeding and prevent further fracture movement until definitive intervention. The binder may remain in place for up to 24 hours. Movement should be by limited log-rolls restricted to 15–30° only to preserve clot stability. Active arterial bleeding will benefit from embolisation of pelvic or iliac vessels in IR. Removal of the binder in IR to allow for cannulation of femoral vessels can cause further haemorrhage and haemodynamic instability. The binder should be released slowly with blood products available for transfusion. Retroperitoneal packing can be used to manage venous bleeding in centres where IR is not immediately available. Perineal, rectal and urinary tract injuries should be anticipated when there is a pelvic fracture.

## Penetrating Abdominal Trauma

Penetrating abdominal trauma is increasingly common in children and adolescents. The principles of management are similar to those for blunt trauma, although surgery is required more often. A CT scan can be performed if the child is haemodynamically stable, with the anaesthetist present in case of deterioration. Patients with stab injuries and a normal CT scan can undergo a period of close observation, but patients with gunshot injuries often require immediate surgery. The patient must be examined for an exit wound in gunshot injuries, and diaphragmatic, cardiac or

thoracic injury considered in all penetrating injuries. Diaphragmatic injury on CT is not obvious, and exclusion with laparoscopic surgery is sometimes required, although it should be avoided if there is haemodynamic instability.

## Limb Trauma

Mortality associated with isolated limb trauma is uncommon. Stabilisation of long bone fractures reduces blood loss and provides analgesia. This is achieved with external fixation devices or application of a cast to more distal fractures. Occasionally emergency surgery is needed when there is compromise to the limb. Displaced supracondylar fractures can cause damage to the brachial artery or nerve injury (median or radial). Concerning neurovascular signs are increased pallor, changes in sensation, muscle weakness and reduced or absent peripheral pulses. Neurovascular compromise must not be missed in the context of a polytrauma patient with other distracting significant injuries. Open fractures should be closed as an emergency to reduce the risk of infection.

## Anaesthesia for Minor Trauma

Most minor trauma cases can be managed semi-electively. The exception is where there is neurovascular compromise to the affected limb or an infection risk from an open fracture (see the previous section). Common minor injuries include facial lacerations, nailbed injuries and limb fractures or dislocations. Immobilisation combined with oral paracetamol and ibuprofen often provides sufficient analgesia, and in most cases children can go home and have the surgery the next day as a day-case procedure under general anaesthesia.

The anaesthetist is occasionally asked to provide IV procedural sedation in the emergency department at the time the child presents. This is usually to facilitate sutures for a laceration, relocation of a dislocated limb (for example, shoulder or elbow) or removal of a foreign body (commonly from the ear or nose in young children). The

anaesthetist will be responsible for providing the sedation, managing the patient's airway and monitoring the child whilst the sedation wears off. Intravenous ketamine 1–2 mg kg<sup>-1</sup> (titrated to effect) is most often used. Intravenous ketamine provides 10–20 minutes of 'surgical' sedation with complete recovery around 40 minutes after administration. This has the advantage of treating the problem in one hospital visit and avoids the need for a general anaesthetic and day-case surgery. The child should be discharged home with appropriate verbal and written advice following the sedation.

## Violence Reduction Strategies

The rise in interpersonal violence in adolescents makes violence reduction strategies increasingly important. Adolescents who suffer penetrating trauma are a vulnerable group, often young males from deprived backgrounds. Up to 40% of cases will re-present with a more severe injury. Usual safeguarding measures aimed at younger children may not be sufficient to provide the protection needed, and specialist violence reduction teams should be involved.

Risk factors should be identified whilst the patient is in hospital. The following should trigger referral to a violence reduction team:

- The history is not consistent with the injury.
- The patient has presented to hospital before with a similar injury pattern.
- The patient and/or their family are concerned for their safety on discharge.

An independent caseworker should be assigned through the local authority before discharge home. Examples of teams in London are the St Giles SOS project, Oasis Youth Support and Redthread. Caseworkers, who have an insight into the nature of how and why these children get injured, have an important role in building rapport and trust with individuals. The aim is to implement suitable safeguarding measures to prevent subsequent violence.

## Further Reading

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