

19 Trauma in children

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Abdomen

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Intraperitoneal air mandates a laparoscopy or laparotomy . Penetrating wounds that have not entered the abdominal cavity should be cleaned and closed. The spleen and liver account for 70% of all visceral injuries caused by blunt trauma. In the haemodynamically stable child, most solid organ injuries can be managed without an operation, but if unstable despite appropriate transfusion, or only transiently responding, interventional radiology and embolisation or a laparotomy should be considered. Recurrent instability may reflect an inadequate initial resuscitation, and the need for a second transfusion does not mandate an operation. Following an abdominal solid organ injury , bed rest is advised until pain free, with mobilisation after a minimum of 1 night for grade I and II injuries and after a minimum of 2 nights for grade >III injuries . High-impact activities and contact sports should be limited for grade IV and V injuries for 6 /uni00A0 weeks. However, delayed haemorrhage can arise spontaneously several days after an injury and is thought to occur in a hyperosmolar setting when a haematoma breaks down. Discharged patients need to know to return to the hospital if unwell. Abdomen

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DAMAGE CONTROL SURGERY

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Damage control surgery aims to break the 'vicious cycle' of hypothermia, tissue hypoxia, coagulopathy and acidosis before later definitive repair. Anatomy is restored when the physiology is optimised. The principles are in sequence: (i) short operations aiming to control haemorrhage and limit contamination; (ii) ongoing correction of deranged physiology – acidosis, hypothermia, perfusion and organ function on intensive care; (iii) definitive surgical repair. In a trauma laparotomy, a midline incision is made from the xiphisternum to the pubic symphysis. Large clots are removed and the abdomen is packed in all four quadrants with large swabs to tamponade bleeding. If packing does not control bleeding, it is either inadequate packing, and more should be applied, or there is a significant arterial bleed, and so pressure should be applied to the aorta above the liver. Once bleeding is stemmed and the intravascular volume restored, the packs are removed systematically one quadrant at a time to find the source of the bleeding. Control is by vessel repair, ligation or removal of the organ or reapplication of the packs. Contamination is controlled by either repairing a simple bowel injury with a continuous suture or resection of multiple areas of perforated bowel with a clip-and-drop technique (either stapling or tying off the ends but not attempting primary anastomosis). Bile injuries are managed with a drain, and bladder injuries are oversewn and a urethral catheter placed. The abdomen is left open, allowing transfer to critical care for ongoing physiological correction before returning to theatre in the following days for further procedures. Summary box 19.1 Paediatric trauma

Use the Advanced Trauma Life Support (ATLS) guidelines Overextension of the neck can compromise the airway Cervical spine injury can be present without radiographic signs Intraosseous access is helpful in small children Lung contusion can occur without rib fractures In a stable child, abdominal injuries are best assessed by CT Blunt abdominal organ injury can usually be managed non-operatively Damage control surgery aims to correct physiology before definitive repair

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The choice of imaging depends on the mechanism of injury and the findings on examination. Cross-sectional imaging can be invaluable, but a head-to-toe computed tomography (CT) scan should only be performed with good reason to limit exposure to ionising radiation. Plain radiograph A chest radiograph is mandated in major trauma. The cervical spine is rarely injured, but if the injury mechanism leads to suspicion of cervical damage, then a cervical spine series is requested. Lateral and anteroposterior images must include the base of the skull and the C7-T1 junction. The odontoid or 'peg' projection can be difficult to obtain as the mouth needs to be open for the anteroposterior projection to see C1 (atlas) and C2 (axis). A pelvic radiograph is requested if a pelvic fracture is suspected. Suspected limb fractures initially undergo anteroposterior and lateral radiographs with CT reserved for those that are complex. CT scans A head CT scan should be performed within 1 hour if the GCS is <14 at the initial assessment or within 2 hours if the GCS is <15 after the injury. Other indications include a tense fontanelle, suspicion of an open or depressed skull fracture or a basal skull fracture, abnormal pupillary response, abnormal posturing, a focal neurological defect or concern about a non-accidental injury. A head CT scan should also be performed if there are three or more vomiting episodes, a witnessed loss of consciousness for >5 minutes or amnesia >5 minutes. A CT scan of the chest, abdomen and pelvis is performed if there is abdominal wall bruising (Figure 19.2), tenderness, distension, peritonitis, blood per rectum or blood in the naso-gastric tube. Some relative indications include an aspartate aminotransferase >200 U/L, amylase >100 U/L or micro-haematuria >5 erythrocytes/high-power field. Abdominal and pelvic CT should be single-volume dual-contrast to minimise radiation exposure using the Camp Bastion or Afghan protocol. A CT scan of the chest should be performed after a penetrating chest injury or a significant deceleration. However, most blunt chest injuries are detected on a chest radiograph; if the mediastinal silhouette is normal, a chest CT is not usually required. A focused abdominal sonography trauma (FAST) scan is not helpful in children as the findings can be difficult to interpret.

Figure 19.2 Traumatic diaphragmatic rupture found in a child with abdominal wall bruising.

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Introduction

INTRODUCTION

Trauma is the leading cause of death in children over 1 year old, and blunt trauma is the most common mechanism. Prompt, guideline-driven management by a trauma team reduces complications and saves lives. For cranial injuries in children, see Chapter 28 ; for orthopaedic injuries in children, see Part 4, Trauma .

Learning objectives

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To be able to: Systematically assess an injured child • Give examples of how mechanisms of, and responses to, • injury differ from those in adults Distinguish the elements of the primary and secondary • surveys Explain when and how to transfuse blood products in • children Learning objectives

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Patterns of injury

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There are some well-recognised patterns of injury in children.

Lap belt If a child experiences a forced flexion over a lap belt in a car accident, the small bowel or its mesentery or the bladder's abdominal portion may get compressed against the spine. These tissues may fail up to 72 hours after the injury. Lumbar fractures may also be seen. In small children, the pancreas can be compressed by a lap belt.

Handlebar injury A child who falls onto the end of a bicycle handlebar may crush the pancreas, duodenum, small intestine or its mesentery against the spine. A duodenal haematoma may cause an obstruction, the pancreas may be injured or divided and contused intestine may perforate after a delay of a few days, so a period of observation is required. When this injury pattern is seen in a child under 3 years old, a non-accidental injury must be considered.

Straddle injury A child typically falls onto the side of a bath or a toy, causing a perineal injury that may involve the urethra or vagina.

Non-accidental injury Non-accidental injuries should be suspected when the reported mechanism of injury or its timing are unusual. Fractures, under 2 years old are often non-accidental. Bruises are remarkably difficult to date, but their shape and pattern may distinguish accidental from abusive bruising if they leave an imprint. Patterned bruises generally do not occur during regular play. Bruises over soft tissues in an immobile infant are suspicious, whereas those over bony prominences such as the knees elbows and the forehead in a mobile child are not. Bruises on the cheeks, neck, genitals, buttocks and back are unlikely to be accidental. Some benign entities may be confused with abusive bruises, such as Mongolian spots and haemangiomas. Children with idiopathic thrombocytopenic purpura or leukaemia may present with unexplained bruises in different stages of healing.

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Resuscitation

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All children initially receive high-flow oxygen, preferably via a non-rebreather mask; this can be stopped if there is cardio-respiratory stability after a period of observation. Intubation and ventilation are required if oxygenation is inadequate or if there is a low GCS, combative behaviour, an inability to cooperate, severe burns, prolonged seizures or imminent operative intervention. Ideally, seriously injured children require two large well-secured cannulae. Alongside the antecubital fossa, other suitable veins include the long saphenous at the ankle, the femoral, the external jugular and, in neonates, scalp veins. If intravenous access cannot be established, an intra-osseous needle can be placed in the tibia (Figure 19.1) or the humeral head, which has the benefit of being easily accessed by an anaesthetist.

age-adjusted cardiovascular parameters.

Initially, 10 mL/kg of a warmed isotonic fluid is given. Total blood volume (TBV) is around 85 mL/kg in a neonate, rising to 100 mL/kg at 1 month and then falling to 75–80 mL/kg in a child. Major haemorrhage is defined as loss of 50% of TBV in <3 hours, 100% in 24 hours or >20% in <1 hour, but is challenging to assess, especially in blunt trauma. Hospitals should have a major haemorrhage protocol. If the capillary refill is >2 seconds and the child has lost mainly blood, then blood is given, using O rhesus-negative blood until type-specific or cross-matched blood is available. Severe trauma-induced coagulopathy is best managed by correcting specific coagulation factors and using point-of-care testing thromboelastography (TEG) and thromboelastometry (ROTEM), but if these are not available the following are given: packed cells 20 mL/kg, fresh-frozen plasma 20 mL/kg, platelets 10 mL/kg and cryoprecipitate 5 mL/kg, and repeated maintaining these ratios and aiming for a haemoglobin level >80 g/L, platelets >75 $\times 10^9$ /L, fibrinogen >1.5 g/L and activated partial thromboplastin time (APTT)/prothrombin time (PT) <1.5 $\times$ normal midpoint. If the major haemorrhage occurred within 3 hours, a slow tranexamic acid bolus of 15 mg/kg followed by an infusion (15 mg/kg over 8 hours) should be given.

1–3 cm Figure 19.1 The intraosseous needle is inserted into the proximal tibia's medullary cavity about 1–3 cm below the tibial tuberosity.

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intra- osseous needle can be placed in the tibia (Figure 19.1) or the - humeral head, which has the benefit of being easily accessed by an anaesthetist. age-adjusted cardiovascular parameters. Initially , 10 /uni00A0 mL/kg of a warmed isotonic fluid is given. Total blood volume (TBV) is around 85 /uni00A0 mL/kg in a neonate, rising to 100 /uni00A0 mL/kg at 1 /uni00A0 month and then falling to 75–80 /uni00A0 mL/kg in a child. Major haemorrhage is defined as loss of 50% of TBV in <3 /uni00A0 hours, 100% in 24 /uni00A0 hours or >20% in <1 /uni00A0 hour, but is challenging to assess, especially in blunt trauma. Hospitals should have a major haemorrhage protocol. If the capillary refill is >2 /uni00A0 seconds and the child has lost mainly blood, then blood is given, using O rhesus-negative blood until type-specific or cross-matched blood is available. Severe trauma-induced coagulopathy is best managed by correcting specific coagulation factors and using point-of-care testing thromboelastography (TEG) and thromboelastometry (ROTEM), but if these are not available the following are given: packed cells 20 /uni00A0 mL/kg, fresh-frozen plasma 20 /uni00A0 mL/kg, platelets 10 /uni00A0 mL/kg and cryoprecipitate 5 /uni00A0 mL/kg, and repeated maintaining these ratios and aiming for 9 a haemoglobin level >80 /uni00A0 g/L, platelets >75 /uni00A0 $\times$ /uni00A0 10 /L, fibrinogen >1.5 /uni00A0 g/L and activated partial thromboplastin time (APTT)/ prothrombin time (PT) <1.5 /uni00A0 $\times$ /uni00A0 normal midpoint. If the major haemorrhage occurred within 3 /uni00A0 hours, a slow tranexamic acid bolus of 15 /uni00A0 mg/kg followed by an infusion (15 /uni00A0 mg/kg over 8 /uni00A0 hours) should be given.

1–3 cm Figure 19.1 The intraosseous needle is inserted into the proximal tibia's medullary cavity about 1–3 cm below the tibial tuberosity.

Resuscitation

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(APTT)/ prothrombin time (PT) $<1.5 \times$ normal midpoint. If the major haemorrhage occurred within 3 hours, a slow tranexamic acid bolus of 15 mg/kg followed by an infusion (15 mg/kg over 8 hours) should be given.

1-3 cm Figure 19.1 The intraosseous needle is inserted into the proximal tibia's medullary cavity about 1-3 cm below the tibial tuberosity.

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The secondary survey is performed after resuscitation and stabilisation. The history is reviewed and a complete clinical examination is performed to assess for other injuries. SECONDARY SURVEY

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Spleen There is a risk of splenic pseudoaneurysm after splenic trauma, which is unrelated to the severity of the injury (Table 19.1 Therefore, a follow-up ultrasound is recommended. Claude Couinaud , 1922–2008, French surgeon and anatomist, described the segmental anatomy of the liver. - - , - - Liver The grades of liver trauma are given in Table 19.2 . Bile leaks). are rare and often resolve after drainage rather than repair but should be discussed with a paediatric liver surgeon.

Grade	Injury type	Description of injury
I	Haematoma	Subcapsular, <10% surface area
II	Laceration	Capsular tear, <1 /uni00A0 cm parenchymal depth
III	Haematoma	Subcapsular, 10–50% surface area, intraparenchymal, <5 /uni00A0 cm in diameter
IV	Laceration	Capsular tear, 1–3 /uni00A0 cm parenchymal depth not involving a trabecular vessel
V	Haematoma	Subcapsular, >50% surface area or expanding; ruptured subcapsular or parenchymal haematoma, intraparenchymal haematoma ≥ 5 /uni00A0 cm or expanding
VI	Laceration	>3 /uni00A0 cm parenchymal depth or involving a trabecular vessel
VII	Laceration	Involving segmental or hilar vessels producing major devascularisation (>25%)
VIII	Laceration	Completely shattered spleen
IX	Vascular	Devascularised by a hilar injury

TABLE 19.2 Liver injury scale.

Grade	Injury type	Description of injury
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V	Laceration	>3 /uni00A0 cm parenchymal depth or involving a trabecular vessel
VI	Laceration	Parenchymal disruption involving 25–75% of hepatic lobe or 1–3 Couinaud segments in a single lobe
VII	Laceration	Parenchymal disruption involving >75% of hepatic lobe or >3 Couinaud segments within a single lobe
VIII	Vascular	Juxtahepatic venous injuries
IX	Vascular	Hepatic avulsion

Pancreatic trauma may lead to a pancreatic pseudocyst, which requires endoscopic drainage into the stomach. For distal lacerations in the pancreatic tail, some surgeons prefer an early distal pancreatectomy rather than non-operative management. Proximal pancreatic duct injuries in older children can be stented. **Renal** After severe renal injuries, hypertension can develop, which may need treatment. A dimercaptosuccinic acid (DMSA) scan is used to assess function in those with hypertension or following grade IV or V injuries (Table 19.3). **Duodenum** A duodenal haematoma has a risk of late perforation, which may be retroperitoneal. Therefore, a second abdominal CT scan or a contrast study should be considered if there is dete rioration or recovery is particularly slow . **Bowel** There are three mechanisms: the bowel wall may fail instantly if pressure rises rapidly in a trapped loop, it may fail up to 72 /uni00A0 hours after a direct crush injury or it may become ischaemic following a mesenteric injury damaging its blood supply . In straddle injuries and pelvic fractures there may be blood at the urethral meatus. Urethral catheterisation can aggravate a urethral injury , and so a suprapubic catheter should be placed.

TABLE 19.3 Renal injury scale. Grade Injury type Description of injury I Contusion Microscopic or gross haematuria. Normal imaging Haematoma Subcapsular, not expanding and without parenchymal laceration II Haematoma Non-expanding peri-renal haematoma confined to the retroperitoneum Laceration <1.0 cm parenchymal depth without extravasation of urine III Laceration

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hypertension or following grade IV or V injuries (Table 19.3). Duodenum A duodenal haematoma has a risk of late perforation, which may be retroperitoneal. Therefore, a second abdominal CT scan or a contrast study should be considered if there is deterioration or recovery is particularly slow . Bowel There are three mechanisms: the bowel wall may fail instantly if pressure rises rapidly in a trapped loop, it may fail up to 72 hours after a direct crush injury or it may become ischaemic following a mesenteric injury damaging its blood supply . In straddle injuries and pelvic fractures there may be blood at the urethral meatus. Urethral catheterisation can aggravate a urethral injury , and so a suprapubic catheter should be placed.

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Spinal cord injury without radiological abnormalit

Spinal cord injury without radiological abnormality (SCIWORA)

Cervical hyperextension can occur during a rear impact in a car accident or from a frontal impact to the head. If such a mechanism dissipates a lot of energy, the spinal cord can be damaged even though a cervical radiograph may look normal. Compared with adults, children have a proportionally heavier head and weaker cervical muscles, which together with more elastic spinal ligaments and horizontal facet joints permit displacement without fracture and spontaneous anatomical resolution. A myelopathy can follow a contusion or follow control ischaemia from temporary vertebral artery occlusion. If an older child gives a history of transient paraesthesia, numbness or paralysis, cervical immobilisation should be continued, and - magnetic resonance imaging obtained. Immobilisation of the Part 4, cervical spine can be with blocks and tapes or, if tolerated, a collar. - Spinal cord injury without radiological abnormality (SCIWORA)

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Injured children are assessed using the Advanced Trauma Life Support (ATLS) structured cABCDE approach: of catastrophic bleeding with pressure, A irway with C-spine control, B reathing with oxygen, C irculation with further control of haemorrhage, D isability , E xposure and Environ ment. In contrast to managing trauma in adults (see Trauma), the following should be considered:

- /uni25CF A – overextension of the neck can cause airway obstruc tion; a neutral position is used for infants and a ‘sni ffi ng the morning air’ position for older children.
- /uni25CF B – hypoxia is usually the cause of cardiac arrest in chil dren; if easily reversed, the cardiac rhythm returns.
- /uni25CF C – hypotension occurs comparatively late after 20% of the circulating volume is lost.
- /uni25CF D – an age-dependent modified Glasgow Coma Scale (GCS) is used.
- /uni25CF E – small children lose heat rapidly , with hypothermia exacerbating any coagulopathy . If their weight in kilograms is unknown, it can be estimated from $2 \times (\text{age in years} + 4)$. In cardiac arrest, the four Hs and four Ts are considered: H ypoxia, H ypovolaemia, H ypothermia/Hyperthermia, H yperkalaemia/hypokalaemia, T ension pneumothorax, car diac T amponade, T oxins, T hrombus.

Describe some common patterns of injury in children • Request appropriate investigations for an injured child • Outline the non-operative management of solid organ • injuries Outline the principles of the trauma laparotomy and the • clamshell thoracotomy Explain the principle of damage control surgery •

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Trauma-induced coagulopathy

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Tissue damage releases factors that encourage coagulation but acidosis and hypothermia prolong it; therefore, blood products should be warmed. For each 1°C fall in temperature, factor activity falls by 10%. Below 34°C clotting times are prolonged, and platelets pool in the spleen and have poor adherence and aggregation. Poor perfusion increases thrombomodulin, which binds to thrombin and activates protein C, so inhibiting cofactors V and VIII. Activated protein C can deplete plasminogen activator inhibitor-1, which results in the formation of plasmin. Leonardo Gigli, 1863–1908, Florentine surgeon and obstetrician. and, if this falls below 0.6 mmol/L, platelets are less effective. Haemostasis is immature in neonates with procoagulant and anticoagulant proteins, remaining low until 6 months old. Fibrinogen is qualitatively dysfunctional, existing in a fetal form for 6–12 months after birth and contributing to an increased risk of bleeding. Burns can also cause a consumptive coagulopathy with microangiopathic haemolysis. Children are more susceptible to hypothermia than adults: wet clothes should be removed early and warming blankets used. Children are more likely to become hypoglycaemic after a major injury as they mobilise glycogen poorly – blood sugar should be monitored in the significantly injured child, especially if they are nil by mouth. A nasogastric tube and a urinary catheter should be considered for children who have had a major abdominal or head injury or are unconscious or ventilated. An orogastric tube is used if there is suspicion of a basal frontal skull fracture and a suprapubic catheter if a urethral injury is suspected.

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