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Current trends in the management of major paediatric trauma

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Epidemiology

Trauma is the leading cause of death in children aged 1–14 years in the developed world. Traumatic injury is a major cause of disability. It has been said that inadequate evaluation (and, thus, inappropriate treatment) contributes to approximately 30% of early deaths in children with severe trauma.[1] Prompt and accurate assessment of injury severity and early initiation of critical care is important to prevent such deaths.

The most common causes of injury in children are falls, motor vehicle accidents, pedestrian accidents, bicycle accidents and child abuse. In children under 12 months of age, non-accidental injury is especially important. Head injury is the most common cause of morbidity and mortality in paediatric trauma due to the relatively large head size, less neck control and plasticity of brain tissues. The presence of a significant extracranial injury doubles the morbidity and mortality of children with head trauma. In the child with severe traumatic injury, multisystem trauma is typical. This is because of the small body mass, to which energy is imparted, resulting in a greater force applied per unit body area. This intense energy leads to more multisystem injuries.

Trauma systems for children

The trauma system for children in New South Wales (NSW) uses designated major paediatric trauma hospitals, together with regional trauma hospitals, to optimize the trauma care provided for children. This is supported by a statewide paediatric medical retrieval service, which ensures provision of expedient transfer of trauma patients to a major paediatric trauma hospital.[2]

Prehospital services have a key role in paediatric trauma care, as in adult trauma care. In NSW, the prehospital services are centrally coordinated, but are regionalized for metropolitan and rural areas. This allows for assessment at the scene by ambulance personnel and communication via radio to the receiving emergency department (ED). Airway obstruction and hypovolaemia remain the two most common prehospital reasons for preventable death in children.

Management of paediatric trauma requires the use of well-defined criteria to mobilize a 'trauma team' based on historical and physiological data. Activation of a trauma team ensures a high level of expertise is rapidly available. In rural centres, the trauma team should be composed of locally available expertise for rapid stabilization and prompt transfer to a major

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See Commentary, page 405.

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trauma centre, with advice sought from the major centre as early as possible.

The family should be involved quickly. Parents are encouraged to attend the resuscitation, but must be escorted at all times by a trauma social worker or a designated senior nurse. This is a key step in managing the child and parents.

Approach to major trauma

Staff need to be mindful of the many differences between children and adults in anatomy, physiology and psychology. This makes the assessment of the injured child and their injuries particularly unique (Table 1). The child with major trauma can be haemodynamically unpredictable. Injuries can cross the usual anatomical boundaries and, commonly, there is more than one injury. Knowledge of potential pathophysiology allows for better prediction of outcome. For example, head injury is characterized by age-related differences in pathobiology and pathophysiology, with the brain in children being less buoyant and plastic. Therefore, children with diffuse head injury are more prone to cerebral oedema, punctate haemorrhage and intracranial hypertension, problems often associated with transient seizures that can produce unexpected apnoea. Despite these features, and often a very low Glasgow Coma Scale (GCS) score on presentation, they often have a good outcome.[3]

The primary survey and resuscitation

The outcome of children with severe traumatic injury is related to both the mechanism and extent of injury, as well as to the success of initial resuscitation.[4] Good prognosis following initial resuscitation is suggested by: (i) slowing of the heart rate (< 130 b.p.m., with improvement in other physiological signs); (ii) increased pulse pressure (> 20 mmHg); (iii) return of normal skin colour; (iv) increased warmth of the extremities; (v) clearing of sensorium; (vi) increased systolic blood pressure (> 80 mmHg); and (vii) urinary output of 1–2 mL/kg per h.

The purpose of the primary survey in children, as in adults, is to diagnose and treat life-threatening conditions and to detect and correct abnormal physiology, hence avoiding a secondary insult. The priorities of the primary survey are shown in Table 2. The nuances of the primary survey as it relates to paediatrics are discussed below.

Airway with cervical spine control

The anatomy of the airway in children is different to that of adults. In children, the airway is smaller and floppier and, in the young child, the disproportion between the cranium and mid-face makes it more likely that the airway will obstruct when the child is lying flat. Children also have a much higher

Table 1. Differences in paediatric anatomy and physiology

Anatomical/physiological characteristic	Clinical relevance
Small body size	Injuring forces dissipate over a small body mass, resulting in a high frequency of multiple organ injuries
Large body surface area:mass ratio	Places child at risk of hypothermia and dehydration
Relatively large size of head	Places child at particular risk of head injury and high cervical spine injury
Compliant, elastic paediatric skeleton	Injuries to internal organs are commonly seen without external signs of trauma or fracture (e.g. pulmonary contusions without rib fractures)
Airway characteristics	Tongue easily obstructs airway
Large tongue, small mouth	May obscure glottis during intubation
Epiglottis less stiff	Risk is oesophageal intubation
Larynx more cephalad and anterior	Uncuffed ETT are used in children < 8 years of age to avoid pressure necrosis
Cricoid cartilage at the narrowest part of airway	Risk is intubation of right main bronchus
Trachea is short	
Blood volume is 80 mL/kg	Guides intravenous resuscitation

ETT, endotracheal tube.

Table 2. Trauma resuscitation guidelines

	Immediate life-threatening injuries	Life-saving procedures
Airway	Obstructed airway	Oxygen; simple airway positioning manoeuvres
	Laryngeal/tracheal trauma	Oropharyngeal airway
	Faciomaxillary trauma	Endotracheal intubation
		Cricothyroidotomy
		Tracheostomy
Breathing	Tension pneumothorax	Intercostal cannula
	Flail chest	Intercostal tube
	Haemothorax	Endotracheal intubation
	Sucking chest wound (open pneumothorax)	Cover sucking chest wound on three sides
	Central depression of respiration	
Circulation	Haemorrhage	Pressure over bleeding sites
	Internal	Two large-bore i.v. cannulas
	External	Intra-osseous infusion
		Pericardiocentesis
	Cardiac tamponade/rupture	Emergency thoracotomy (penetrating trauma only)
Disability	Neurological dysfunction	Avoid secondary brain insult by optimizing ABC
Exposure	Hypothermia	Warming of patient
		Warming of all fluids
	Hypoglycaemia	Substrate as 10% glucose

ABC, airway, breathing and circulation.

respiratory rate and oxygen consumption, and smaller residual volume, and this may lead to earlier hypoxia. Establishment of an open airway should be initially attempted by using standard simple airway manoeuvres. In the setting of trauma and possible cervical spine injury, this should involve a jaw thrust with cervical spine immobilization and suction. The oropharyngeal airway may assist in maintaining this open airway. The oropharyngeal airway in children is inserted using a tongue depressor and placing it directly, rather than inserting the airway upside down and rotating 180°, as is performed in adults.

Intubation is not immediately necessary if a patent airway and adequate ventilation are achieved. However, in major paediatric trauma, rapid sequence intubation is often required. The size of the endotracheal tube (ETT) required can be estimated by looking at the size of the child's little finger or it can be calculated using the formula:

ETT internal diameter = age/4 + 4 (> 1 year)

The level at which the ETT should be taped at the lips can be estimated by watching the ETT pass between the vocal cords and advancing it approximately 3 cm. Alternatively, this can be calculated using the formula:

Level at lips + age/2 + 12 (> 1 year)

The choice of drugs for rapid sequence intubation will be a muscle relaxant and sedative and, in children under 2 years of age, we recommend the use of atropine to prevent the severe bradycardia that can occur on intubation. A detailed discussion of tracheal intubation is beyond the scope of the present paper.

Airway obstruction in children is rarely complete, the exception being facial burns, facial trauma and laryngeal injury. Children who are partially obstructed but are making good respiratory effort and are well saturated should be allowed to adopt a position of comfort while expert help is summoned in order to provide definitive treatment. In the obtunded patient, the insertion of a laryngeal mask airway (LMA) can provide an adequate airway, avoiding the need for cricothyrotomy. If airway obstruction is complete and LMA insertion is not possible, a needle cricothyrotomy should be considered. This is performed using a 14–18 gauge cannula connected to a three-way tap and oxygen at 15 L/min. Needle cricothyrotomy is a temporizing measure only and a definitive surgical tracheostomy should be completed within 2 h. Surgical cricothyrotomy is contraindicated in children under

11 years of age because it is fraught with difficulty and rarely gives a satisfactory result.

Cervical spine

Children with possible cervical spine injury should be immobilized appropriately using in-line axial bimanual immobilization or a hard cervical collar of appropriate size, sandbags and adhesive tape strap-ping the head and trunk to a spinal board. In young infants, a rolled-up towel under the shoulder can overcome spinal malalignment due the protrusion of the occiput.[5]

X-Rays of the cervical spine in the awake child under 5 years of age consist of two static cervical spine X-rays (anteroposterior and lateral) and, if necessary, a fine-cut axial computed tomography (CT) scan. The open-mouth odontoid (OMO) view in young children is frequently of poor quality and is unsatisfactory for reporting. It is performed to exclude a fracture of the dens, which almost exclusively occurs through the synchondosis in children under 5 years of age and is easily seen on a good lateral film.[6,7] Obtaining adequate flexion–extension films in children under 5 years of age is difficult; false-negative reporting is common and should not be relied on to clear the cervical spine.[8] A more detailed assessment of cervical spine injury in children is given in (Fig. 1).[8,9]

Breathing

The administration of high-flow supplemental oxygen (12 L/min) via a reservoir oxygen facemask is given to all children with significant injury. Assisted ventilation with a bag–valve–mask device is required if spontaneous ventilation is inadequate.

Tension pneumothorax may be well tolerated in small children due to increased tissue elasticity. Once clinical signs develop, this suggests that the airway pressure has increased to levels that will result in imminent cardiovascular collapse. Tension pneumothorax is relieved by inserting a 14–18 gauge over-the-needle catheter into the affected side. In children, use the second intercostal space, mid-clavicular line, while in the small infant use the fourth intercostal space, anterior axillary line, thus avoiding complications due to limited space during resuscitation due to small body size. The pneumothorax must then be definitively treated by inserting a chest tube. Traumatic asphyxia is a syndrome of cervicofacial cyanosis, subconjunctival haemorrhages, venous engorgement and petechiae of the head and neck. Although it is rare, traumatic asphyxia is commonly associated with other injuries, such as blunt pulmonary injury, and may result in unexpected clinical deterioration if not diagnosed early in the primary survey.[10]

Circulation

Shock is a syndrome that results from tissue perfusion that is inadequate to meet metabolic needs. In children, it may exist with normal blood pressure. Although cardiac output falls in children in an almost linear fashion as blood volume is depleted, blood pressure is unchanged because of increased vascular resistance and tachycardia, which maintain cardiac output. When cardiac reserve is depleted, hypotension occurs. A bradycardia indicates a grave situation. Hypotension is, therefore, a late and often sudden sign of cardiovascular decompensation. After life-threatening conditions, such as cardiac tamponade, are excluded, a persistent tachycardia may be the only indication that there is occult blood loss with persistent shock.

The child's initial vasoconstrictive response to hypovolaemia is why intravenous access can be difficult. If no intravascular access is established after 60–90 s, or three attempts in an unstable child, try the intra-osseous route. Insert the intra-osseous needle in the proximal tibia or distal femur, directing the needle away from the epiphyseal plate. Fluids and drugs can be given with the assistance of a pressure-infusion device. Avoid the intra-osseous route in the presence of a tibial or femoral fracture, inferior vena cava disruption or a vascular injury in the affected leg.

All intravenous (i.v.) fluids should be administered warmed to 37°C to reduce the occurrence of hypothermia. If a patient fails to improve after two fluid boluses of 20 mL/kg each, then blood (whole blood 20 mL/kg or packed cells 10 mL/kg) is required. If packed cells are used, the volume is made up using saline, plasma or 5% albumin. If the child is stable and blood is available within 10–15 min, wait for fully cross-matched blood. If the child is unstable, type-specific blood may have to be used. If a delay of even a few minutes is critical, group O-negative blood is given.

Children have small blood volumes and cannot afford to loose large amounts of blood if haemodynamic instability is to be avoided. Occult blood loss from the head and neck region, in particular from scalp lacerations, can result in haemodynamic

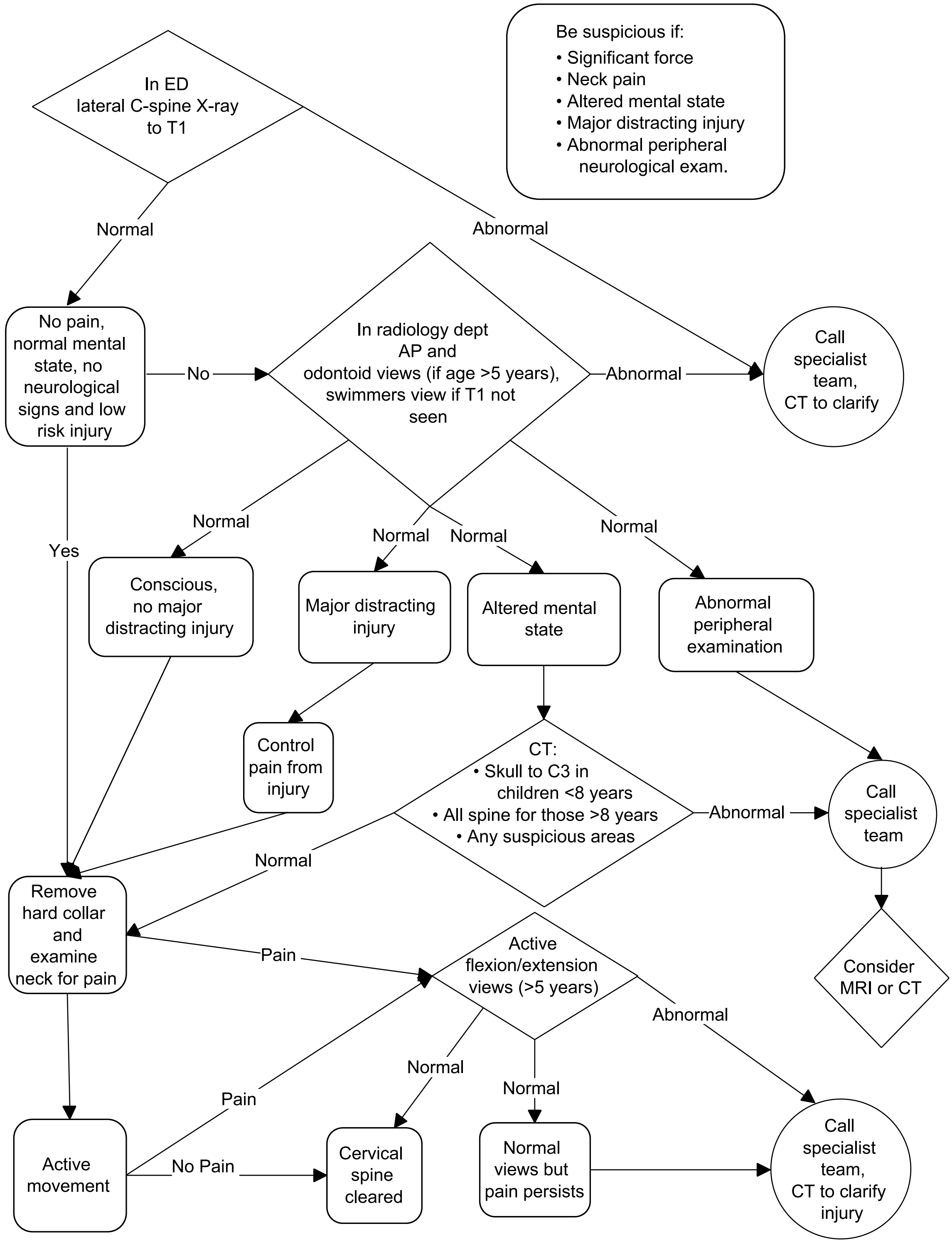

Figure 1. Paediatric cervical spine assessment. C-spine, cervical spine; CT, computed tomography; ED, emergency department; MRI, magnetic resonance imaging.

instability. Aggressive control of haemorrhage (direct pressure to external bleeding sites) is indicated. In children with multisystem trauma, stabilizing fractures of the femur may be crucial for pain relief and control of bleeding. Thomas splints are not available in appropriate sizes for smaller children. Where haemodynamic instability is of concern, a medical antishock trousers (MAST) suit of appropriate size should be used.

A haemodynamically unstable child should never be sent to CT scan to define the site of bleeding. The only option is surgical intervention.

Choice of fluid for resuscitation

Much remains to be learnt about fluid resuscitation in children. The choice of colloid over crystalloid has been reported to increase mortality, although evidence is weak and remains unproven in critically ill children.[11] In children, blunt trauma is the rule and the liberal use of fluids is the current accepted practice, titrating this to the clinical response of the child.

Mortality in injured children is associated with an Injury Severity Scale ≥ 25, a GCS score ≤ 7 or a Paediatric Trauma Scale ≤ 4. The amount of emergency blood transfusion required is singularly the most important independent predictive factor of outcome in children because blood transfused in amounts ≥ 20 mL/kg significantly increases the risk of coagulopathy and multisystem organ failure. There is a need for better end-points of resuscitation in children if adverse outcomes from fluid mismanagement are to be avoided. Traditionally, normal pulse rate and systolic blood pressure for age and urine output > 1 mL/kg per h usually signify adequate fluid resuscitation. Metabolic end-points, such as base excess and lactate, can augment traditional signs of successful resuscitation[12] and may be useful measures in the injured child (Table 3). Physicians must be aware that the excessive use of chloride-containing fluids can cause hyperchloraemic acidosis, resulting in persistently abnormal base excess. This can cause fluid overload if not recognized.

There are some special situations in which care should be taken with fluid resuscitation. We have perceived an increase in penetrating trauma in children, which has raised the issue of delayed resuscitation in this group. The aim is to promote clot stabilization in a more physiological environment and allow surgical intervention to occur in a controlled way.[13] Delayed resuscitation in paediatric penetrating trauma should only be considered if surgical intervention is imminent. However, it remains to be shown whether this approach improves patient outcome.

Table 3. Metabolic end-points useful initially in resuscitation[12]

	Mild	Moderate	Severe
Base excess	2 to −5	−6 to −14	< −15
Lactate (mmol/L)	< 2	2–4	> 4

Fluid therapy must also be carefully considered in the management of traumatic brain injury (TBI) in children. The aim is to prevent secondary insult from systemic hypotension, hypoxia and intracranial hypertension. Optimization of cerebral perfusion pressure (CPP; the difference between mean arterial pressure (MAP) and intracranial pressure (ICP)) is a therapeutic aim in the management of brain-injured patients. It is believed that neurological outcome improves if CPP is maintained at levels of 60–70 mmH_2O. Hypotension is the single most important correctable cause of secondary brain injury with a direct affect on CPP. Appropriate use of fluids and the early introduction of inotropes in maintaining MAP of at least 70 mmHg, to avoid fluid overload, is recommended.[14]

Disability or attention to central nervous system disorder

To quickly assess paediatric disability in the primary survey use the AVPU mnemonic: the child will either be **A**lert, responsive to **V**erbal stimuli, responsive to **P**ainful stimuli or **U**nresponsive. A score of ‘P’ or ‘U’ suggests a GCS score < 8 and requires urgent attention and further assessment. Note pupillary size and reaction to light.

Exposure and things not to forget

1. Undress the child fully to examine the entire body.
2. Children are prone to hypothermia. Monitor core temperature via a rectal probe. Expose the child only as long as it takes to complete the physical examination. Maintain normothermia by using warmed i.v. fluids, blood warmers, warm blankets and overhead heating lamps.
3. Agitation and/or pain needs aggressive management. Adequate analgesia must be provided early

and is most appropriately provided through the use of intravenous opiates. Intravenous morphine should be titrated carefully to relieve severe pain, commencing with a dose of 0.1–0.2 mg/kg. The treatment of pain allows for better clinical assessment and helps prevent secondary insult due to agitation caused by pain.

4. Ensure adequate monitoring of children: respiratory rate, blood pressure, oxygen saturation, heart rate and peripheral perfusion.
5. Check all hardware on children who have been transported to hospital.
6. Psychological support must be provided early to family and child by an appropriate member of the trauma team, assisted by the team social worker.

Secondary survey: Paediatric priorities

The important aspects of the secondary survey with respect to paediatric trauma are:

1. Continuing resuscitation and monitoring. Any deterioration mandates immediate return to the airway, breathing and circulation (ABC). Remember, blunt abdominal injury is the second-most frequent cause of preventable death in paediatric trauma after airway problems.
2. History. An AMPLE history should be obtained from the child (if possible), family, ambulance personnel, friends and bystanders using the mnemonic:
   - A: Allergies
   - M: Medication
   - P: Past history
   - L: Last ate; Last tetanus
   - E: Event
3. Head-to-toe examination. Perform a systematic head-to-toe, front-and-back examination to detect any injuries not noted in the primary survey. A formal assessment of the child's neurological state should now be performed, including documentation of the paediatric coma score (Table 4). The need to perform a digital rectal examination on a paediatric trauma patient should be assessed on an individual basis by the attending surgical trauma team member.
4. Investigations. Blood specimens should already have been collected during the resuscitation phase. Hypoglycaemia may be present and a bedside blood sugar level should be performed at this time. In terms of radiological investigations, a standard trauma series is required (i.e. chest X-ray, lateral cervical spine X-ray and pelvic X-ray). Further radiological investigation will be determined by clinical assessment. An electrocardiogram should be performed in cases of chest trauma with suspected myocardial contusion.

Table 4. Paediatric Glasgow Coma Scale scores.

Response	Score
Eye opening (all ages)	
Spontaneously	4
Response to voice	3
Response to pain	2
No reponse	1
Best motor response	
> 1 year	
Obeys commands	6
Localizes pain	5
Flexion withdrawal	4
Decorticate posturing	3
Decerebrate posturing	2
No response	1
< 1 year	
Spontaneously	6
Localizes pain	5
Flexion withdrawal	4
Decorticate posturing	3
Decerebrate posturing	2
No response	1
Best verbal response	
> 5 years	
Oriented and appropriate	5
Disoriented conversation	4
Inappropriate words	3
Incomprehensible sounds	2
No response	1
2–5 years	
Appropriate words	5
Inappropriate words	4
Cries and/or screams	3
Grunts	2
No response	1
0–23 months	
Smiles, coos	5
Cries but consolable	4
Persistant cries and/or screams	3
Grunts	2
No response	1

Entries given for eye opening, best motor response in children > 1 year of age and best verbal response for children > 5 years of age are the traditional Glasgow Coma Scale.

Observation and re-evaluation

Abdominal trauma is the leading cause of initially unrecognized fatal injury in children. Unique anatomical features predispose children to a variety of abdominal injuries. Particular injury mechanisms lead to specific injuries that can be difficult to identify (e.g. lap belt injury).[15] Abdominal signs of injury may be absent. If abdominal trauma is considered likely in a stable child, consider observation and serial evaluations. This should be done only if the child is haemodynamically stable. The focus should be on increasing tenderness and distension during serial abdominal examinations. Gastric tube decompression may aid examination. Aspiration of blood suggests significant injury. Serial testing of urine for blood may detect occult renal injury.[16] Diagnostic peritoneal lavage has no role in paediatric trauma.

Definitive care and disposition

After completion of the secondary survey, reassess the child's response to resuscitation and prioritize injuries according to immediate threats to life and then those with potential morbidity. Urgent laparotomy in the child with an abdominal injury should be considered if:

1. The child remains hypotensive despite 40 mL/kg i.v. fluid resuscitation over a 6 h period (i.e. half the blood volume).
2. A hollow viscus injury is suspected (e.g. free air on chest or abdominal X-ray).
3. Diaphragmatic rupture is detected on chest X-ray or abdominal CT scan.
4. Significant gastrointestinal haemorrhage is detected by nasogastric tube or rectal examination.

Analgesia continues to be an important consideration throughout the child's stay in the ED. Regional nerve block of the femoral nerve is of value for fractured femur. Nitrous oxide may be useful, especially in orthopaedic injuries, but should be avoid in TBI, pneumothorax or eye injuries. Methoxyfluorane is proving valuable in managing pain in children with orthopaedic and eye injuries (G Browne, pers. obs.).

The management of major paediatric trauma requires a multidisciplinary approach so that medical care is tailored to meet the specific needs of the injured child and, in addition, attends to the needs of their family. An understanding of the different pathobiology, pathophysiology and the unique way in which children can present with major trauma will allow this multidisciplinary team to achieve the best possible patient outcome.

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