

Chapter 43

MILITARY PEDIATRIC ANESTHESIA

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INTRODUCTION

Pediatric ballistic cases represent a significant proportion of the cases experienced at both Role 3 military hospitals in southwest Afghanistan, consistently providing 15% of the surgical workload. The patients' ages vary, the median being between 6 and 8 years of age; however, babies aged 6 months or less are not uncommon. This experience suggests that military anesthesiologists must be prepared to deal with this workload by updating their pediatric skills prior to deployment.

This chapter is a guide for those anesthetists without a normal pediatric practice. It gives a general descrip-

tion of managing the anesthetic components of pediatric trauma care. The preparation section provides some overall considerations, and the following sections are based on the primary survey as taught in the United Kingdom Battlefield Advanced Trauma Life Support course. No detailed consideration is offered regarding maintenance of anesthesia; neither is a particular anesthetic machine described in detail, because maintenance procedures and equipment change with the theater of operations and location. However, the clinical management of the pediatric trauma patient provided here is mostly based on recent experience in Afghanistan.

PREPARATION

Key Considerations

Injury Patterns

Children are smaller than adults, and their injury patterns are different. Expect injuries in a greater number of anatomical areas. In particular a child's head is proportionally larger than an adult's and more prone to injury.

Equipment

Calculate the drug dosages and equipment sizes and work out normal physiological values beforehand. This will help alleviate stress for the team. Weight prediction in Afghanistan is problematic (Tables 43-1, 43-2, 43-3, and 43-4; Figures 43-1 and 43-2; and Exhibit 43-1).

TABLE 43-1
NORMAL PHYSIOLOGICAL VALUES FOR CHILDREN

Age (years)	Heart Rate (beats/min)	Respiratory Rate (breaths/min)	Systolic Blood Pressure (mm Hg)
Newborn	130–170	40–60	60–70
< 1	110–160	30–40	70–90
2–5	95–140	25–30	80–100
6–12	80–120	20–25	90–110
> 12	60–100	15–20	100–120

Analgesia

Give children analgesia promptly. Be aware of the different administrative methods including intranasal (Tables 43-5 and 43-6).

TABLE 43-2
PEDIATRIC AIRWAY EQUIPMENT SIZES ACCORDING TO AGE

Age	Equipment						
	Facemask	Guedel Airway	Resuscitator	Laryngoscope	Tracheal Tube	Suction Catheter (French Gauge)	Laryngeal Mask
0–6 mo (1–6 kg)	0	000/00	Infant	Miller size 1	2.5–3.5	6	1
6–12 mo (4–9 kg)	1	0/1	Infant	Macintosh size 1	3.5–4.0	8	1.5
1–3 y (10–15 kg)	2	0/1	Infant	Macintosh size 2	4.0–5.0	10–12	2
4–7 y (16–20 kg)	3	1/2	Adult	Macintosh size 2	5.0–6.0	14	2
8–11 y (22–33 kg)	4	2	Adult	Macintosh size 3	5.5–7	14	2.5

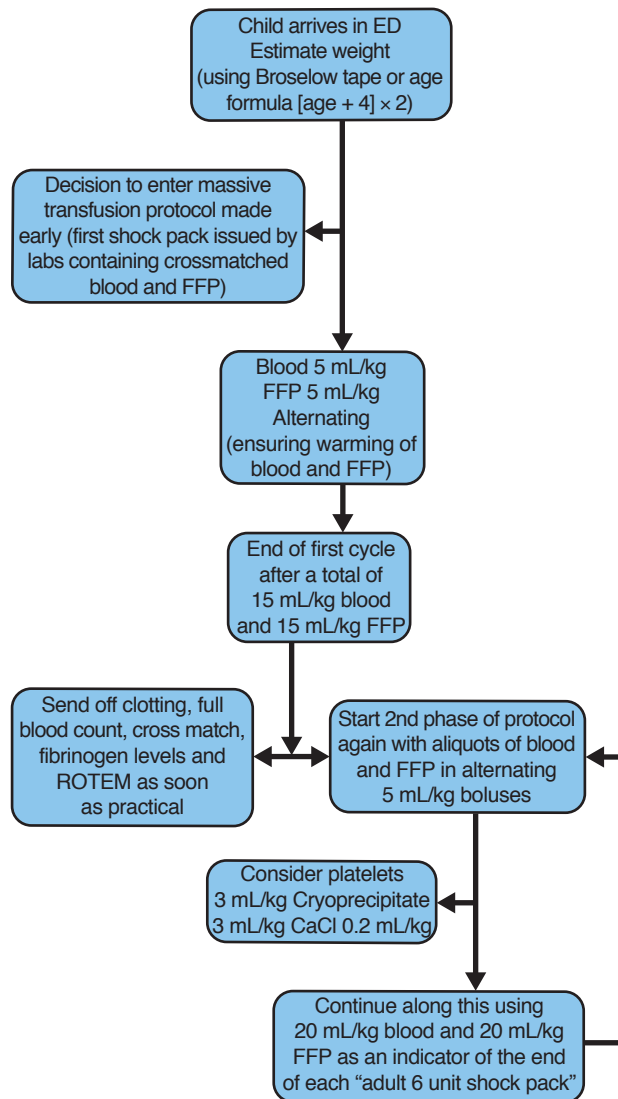


Figure 43-1. Pediatric massive hemorrhage resuscitation protocol.

Reproduced from: Bree S, Wood K, Nordmann GR, McNicholas J. The paediatric transfusion challenge on deployed operations. *J R Army Med Corps.* 2011;156(4 Suppl 1):S361–364. ED: emergency department; FFP: fresh frozen plasma; ROTEM: rotational thromboelastometry (TEM Innovations GmBH, Munich, Germany)

TABLE 43-3

ESTIMATION OF ENDOTRACHEAL TUBE SIZE AND LENGTH IN CHILDREN*

Age	Size	Length (cm)
6 months	3.5 tube	11
Term infant	3.0 tube	9
Premature	2.5 tube	7–8

* Size (internal diameter) = (age/4) + 4

Length (oral) = (age/2) + 12

Parents

The language barrier and the strange environment of a Western military hospital and its staff will cause children and their parents stress and anxiety in addition to that already caused by the child's injuries. Do not add separation anxiety to this. Involve the parents early to help alleviate this stress.

EXHIBIT 43-1

WEIGHT ESTIMATION FOR AFGHANISTAN LOCAL NATIONAL CHILDREN

Age = a
(a + 4) × 2 = b

Age: 1–5 y
Weight (kg) = b – 2 kg

Age: 6+ y
Weight (kg) = b – 4 kg

PEDIATRIC CONSIDERATIONS IN TRAUMA

- Trauma predominates. Although children do present with normal medical problems, in the military hospital in Afghanistan trauma predominates (94% of admissions due to trauma in one recent case series¹).
- Interaction is different. Responses to strangers and strange situations differ by age. Be aware of quiet children who will let you examine them uncomplainingly; they are potentially very sick.

Children less than 6 months old will tolerate separation easily; those aged 6 months to 4 years usually have a fear of strange environments and prominent separation anxiety; those in the 4- to 6-year age group are similar to those younger but communication is easier, which helps alleviate stress; and those 6 years and above tend to be increasingly more tolerant of changing situations.

PAEDIATRIC MASSIVE TRANSFUSION WORKSHEET

Age=
 Weight* = (age + 4) x 2 =
 Afghanistan LN Weight Age 1-S=weight* - 2kg =
 Age G+ Weight 4kg

pRBC = 5ml x weight (kg) =
 FFP = 5ml/kg =
 Platelets = 3ml/kg =
 Cryo = 3ml/kg =
 CaCl = 0.2ml/kg =
 Tranexamic Acid = 15mg/kg =

14
0.2
2.8

14
5
20
140
210

Unit Count	pRBC	FFP	Platelets	Cryo	CVP	THINK ABOUT
1	13'	13'				ROTEMI 7
2	11J	i<St>				iSTAT-:7 (O)IT
3	13" i(l:>					C
4	1:3")O	I(b				Call for
5	IV (tJ					---
6	IJY &O	11->				
7	C' J.v	11.rrb	D	D		Calcium -? -!
8	O -----	O -----				ROTEMI/STAT /
9	-O L! o	D \c				
10	D	D				TxA
11	D	D				Calcium
12	D	D				Call for Cryo/Pittt
13	D	D				
14	D	D	D	D		
15	D	D				Calcium
16	D	D				ROTEMI/STAT
17	D	D				
18	D	D				
19	D	D				Calcium
20	D	D				TxA
21	D	D	D	D		
22	D	D				ROTEMI/STAT
23	D	D				Calcium
24	D	D				
25	D	D				
26	D	D				
27	D	D				Calcium
28	D	D	D	D		
29	D	D				ROTEMI/STAT
30	D	D				TxA

Figure 43-2. Pediatric massive transfusion worksheet.

- Normal physiological values differ with age (see Table 43-1), but bradycardia and slow respiratory rate are always ominous.
- The primary and secondary surveys are no different for children (though be aware of the potentially different injury patterns).
- Children have a larger surface area for a given weight compared to adults, which leads to heat loss and hypothermia in addition to increased fluid loss. Keep them warm. Keep an eye on fluid balance.
- Neonates are more sensitive to drugs, more

TABLE 43-4

PEDIATRIC DRUG DOSES AND DATA FOR MASSIVE TRANSFUSION

	5kg	10kg	15kg	20kg	30kg	40kg	50kg	80kg
Ketamine iv/IM	10 / 50	20/ 100	30/ 150	40/ 200	60/ 300	80/ 400	100/ 500	160/ 800
Suxamethonium	10	20	30	40	60	80	100	160
Fent iv/in mcg	5/ 10	10/ 20	15/ 30	20/ 40	30/ 60	40/ 80	50/100	50/100
Vecuronium	0.5	1	1.5	2	3	4	5	10
Ket iv/ in Analgesia	1.5/ 15	2.5/ 30	4.0/ 45	5.0/ 60	7.5/ 90	10/ 120	12.5/ 150	20/ 240
M & M	0.5	1	1.5	2	3	4	5	8
Atropine (mcg)	100	200	300	400	600	600	600	600
Tube ETT	3.5	4	4.5	5.5	6.5	7	7	8
Blood/ FFP(5ml/kg)	25	50	75	100	150	200	250	1 unit
Platelets (3ml/kg)	15	30	45	60	90	120	150	1 bag
Cryo (3ml/kg)	15	30	45	60	90	120	150	1 bag
TXA (15mg/kg)	75	150	225	300	450	600	750	1.5g
CaCl 10% (ml)	1	2	3	4	6	8	10	10
Vital Signs								
	< 1yr	1-2yr	2 -5 yrs	5- 12yrs	>12 yrs			
HR (beats/min)	110-160	100-150	95-140	80- 120	60-100			
Systolic (mmHg)	70-90	80-95	80-100	90-110	100-120			

Cryo: cryoprecipitate; ETT: endotracheal tube; Fent: fentanyl; HR: heart rate; IM: intramuscular; IV: intravenous; Ket: ketamine; M & M: morphine and midazolam (mg); TXA: Tranexamic acid

prone to hypoglycaemia, and desaturate more quickly due to a smaller functional residual capacity.

ity. They are more prone to apnoea and bradycardia, particularly if hypoxic and hypercapnic.

ANATOMY AND PHYSIOLOGY

Specific differences between pediatric and adult anatomy and physiology affect the management of trauma in children.

Airway

Children have a large head relative to body size, which tends to flex the neck and exacerbate airway obstruction, potentially aggravating any cervical spine injury. Their small oral cavity with a relatively large tongue and tonsils predisposes them to airway obstruction, particularly if their consciousness level is reduced. The larynx is more cephalad (the glottis is at C3 in infants, C5-6 in adults), and the epiglottis is floppy and U-shaped, making visualization of larynx during intubation more difficult. The narrowest part of the airway is at the cricoid ring rather than the vocal cords, so trauma can be caused at this level if an inappropriately large endotracheal tube (ETT) is used. This may result in edema and increased airway resistance on extubation in the short term and possible

subglottic stenosis in the long term. The trachea is also short (4–5 cm in newborns, 7–8 cm at 18 months), making endobronchial intubation and tube displacement with movement more likely. Finally, it is important to remember that infants up to 6 months of age are obligate nasal breathers, which means the work of breathing can be significantly increased by nasal blood, secretions, or prongs.

Breathing

Children have increased oxygen consumption (6–8 mL/kg/min in neonates vs 4–6 mL/kg/min in adults) and thus require proportionately higher minute ventilation. Their functional residual capacity (FRC) is proportional to that in adults by size, but a high minute ventilation to FRC ratio results in more rapid desaturation in cases of apnea or airway obstruction. The FRC will be reduced by induction of anesthesia with barbiturates or inhalational agents but maintained or increased with ketamine. Children are more prone to

TABLE 43-5
PEDIATRIC ANALGESIC DRUG DOSES

Drug	Class of Analgesic	Routes of Administration	Doses
Paracetamol	Antipyretic analgesic	IV	5 mg/kg 6 hourly (< 50 kg) 10 mg/kg 6 hourly (< 6 mo)
		PO	115–20 mg/kg 6 hourly 10–15 mg/kg 6 hourly (< 6 mo)
Ibuprofen	NSAID	PO	10 mg/kg TDS (> 6 months) 5 mg/kg QDS (< 6 months)
Diclofenac	NSAID	PO/PR	1 mg/kg TDS (max dose 50 mg) Not suitable for infants < 6 mo
Ketorolac	NSAID	IV	0.5 mg/kg QDS (max dose 10 mg)
Codeine	Opioid	PO	1 mg/kg QDS
Tramadol	Opioid/5-HT antagonist	PO/IV	1 mg/kg QDS
Morphine	Opioid	PO	0.2–0.4 mg/kg 4 hourly (> 1 y) 0.1mg/kg 4-6 hourly (< 1 y)

IV: intravenous; NSAID: nonsteroidal antiinflammatory drug; PO: per os (by mouth); PR: per rectum; QDS: four times a day; TDS: three times a day

atelectasis, so continuous positive airway pressure (CPAP) is useful in maintaining alveolar recruitment in the neonate.

Ventilation in children is mainly diaphragmatic. For this reason, any abdominal distension from trauma or insufflation of air into stomach may cause respiratory difficulties. Pliable ribs also mean that fractures are less likely than in adults, but pulmonary contusions are more likely due to transmitted energy in blunt trauma.

MASSIVE HEMORRHAGE

Resuscitation of the circulation is a high priority in polytrauma. In children, signs must be compared with

TABLE 43-6
SUGGESTED DOSES OF KETAMINE AND FENTANYL IN ACUTE SEVERE PEDIATRIC TRAUMA

Drug	Route of Administration	Dose
Fentanyl	IV/IO	0.5 µg/kg initially then titrate
Ketamine	IV/IO	0.5 mg/kg initially then titrate
Fentanyl	Nasal	2 µg/kg
Ketamine	Nasal	1–3 mg/kg

IO: intraosseous; IV: intravenous

The increased mobility of mediastinal contents make tension pneumothoraces more likely than in adults.

Circulation

Children have higher resting cardiac outputs (350 mL/kg/min in neonates, 150 mL/kg/min at 2 months, falling gradually to adult levels of 75 mL/kg/min), with higher resting heart rates but lower blood pressures due to lower systemic vascular resistance (see Table 43-1). Their circulating blood volume is relatively higher than adults (90 mL/kg in neonates, 85 mL/kg in infants, 80 mL/kg in children). Because of the higher blood volume, combined with a vasoconstrictive response to blood loss, hypotension does not develop until over 35% of the blood volume is lost. Significant blood loss should therefore be suspected if the child has cold clammy skin, prolonged capillary refill time, and altered consciousness level. Finally, it should be remembered that small children have a bradycardic response to hypoxemia, which should be managed with oxygenation in the first instance rather than atropine.

Thermoregulation

Children have a higher surface area to body weight ratio, making them more susceptible to hypothermia than adults. Impaired temperature regulation under anesthesia and high thermal losses due to surgery make careful attention to temperature control essential.

normal physiological values. As part of coordinated trauma resuscitation, the anesthetist's first task is to

secure appropriate vascular access (discussed below). In the presence of significant hypovolemia, the best access in small children is intraosseus (IO), followed by supradiaphragmatic central venous access.

Hypovolemia

Poor perfusion secondary to hypovolemia can be indicated by central capillary refill time of over 2 seconds and differences between central and peripheral pulses and skin temperature. A change in mental status, specifically reduced reactivity and responsiveness, is a good indicator of cerebral perfusion and hence overall perfusion. Importantly, low blood pressure is a late sign and shows decompensation. Bradycardia is a preterminal sign.

Access

Vascular

Peripheral venous access. The best sites for peripheral access are the dorsum of the hand, radial aspect of the wrist, antecubital fossa, dorsolateral aspect of the foot, and saphenous vein. A 24-gauge catheter is appropriate for neonates and a 22-gauge catheter for young children. If access is difficult in young children, the palmar aspect of the wrist may provide a useful site, as may the scalp in neonates. In hypovolemic children, intravenous access may well be difficult and it may be necessary to resuscitate them through the IO route in the first instance.

Central venous access. If the massive hemorrhage protocol is being used, a large-gauge catheter in a central vein above the diaphragm is preferred. Using a single large-bore line (4–6 F depending on age), if available, will maximize filling rates. If multilumen central lines are the only available option, appropriate sizes are 3 F, 5-cm lines for infants; 4 or 5 F, 8-cm lines for toddlers; and 5 F, 10- to 12-cm lines for older children.

In hypovolemic children, the vessels collapse more easily than in adults. The use of ultrasound is strongly recommended, and anesthetists should become sufficiently skilled in its use before deploying. Direct vision of the needle and then wire in the correct vessel, extending into the superior vena cava, will minimize complications. The subclavian vein remains open for a longer time in hypovolemia; however, the internal jugular vein is the alternative and is more easily visualized with ultrasound. These vessels will completely occlude with the respiratory pattern in extremis, so consider IO filling before placing a central venous catheter.

Arterial

Arterial lines are used for continuous monitoring of blood pressure and for successive arterial blood gas measurement. The radial or femoral artery are the most common insertion sites. Because of the size of the vessels, complications become more frequent with radial cannulation in children under 5 years of age. Insertion of the catheter into the femoral artery has greater success in neonates and infants. Recommended catheter sizes are 24 gauge in neonates, 22 gauge in infants, and 20 gauge in older children. A catheter-over-needle technique is appropriate for the radial artery. A preferred technique is transfixion of the vessel: After observing blood in the clear plastic needle hub (or flashback), advance the cannula through the posterior wall of the artery. Then remove the needle and attach a syringe. Slowly withdraw the cannula while aspirating. Once aspiration without resistance is achieved, gradually advance the cannula within the artery. Inserting the catheter over the needle is also appropriate when approaching the femoral artery in infants, although the Seldinger technique can be used in older children.

Intraosseus Vascular

Use IO access for resuscitation when intravenous access is difficult; it is particularly useful as an early route for initial resuscitation of the hypovolemic child. For most children a 22-gauge, 15-mm needle is appropriate, but after inserting the needle into the bone, ensure there is 5 mm of needle visible above the skin on contact. If less than this is visible, use the next size up. Needles can be placed in either the tibia or humerus. Successful insertion is suggested by the loss of resistance as the needle passes from the cortex to the medulla. The needle will then remain upright unsupported. In the tibia, the IO needle should be inserted in the anterior surface of the proximal tibia, approximately 2 cm distal to the tuberosity and 2 cm medially. Insertion of the needle into the humeral head is slightly more difficult. With the arm adducted and hand across the groin, the greater tubercle of the humerus is found at the apex of an equilateral triangle, the base of which is a line between the coracoid and acromion of the scapula.

Blood samples can be taken at the time of insertion but not thereafter. All fluids and drugs given intravenously can be given via this route. A three-way tap and syringe will be needed to ensure fluids given are done at a sufficient rate.

Resuscitation

Most pediatric patients with ballistic trauma will

need blood products, and the majority will need a massive transfusion to ensure the patient is adequately resuscitated. Management of major hemorrhage occurs predominantly in the emergency department and continues into the operating room, but it may need to happen elsewhere. Because of their small circulating volumes, the threshold for initiating a massive transfusion protocol is lower in children than in adults (Exhibit 43-2; see Figure 43-1).

It is essential to deliver the fluids warmed and keep a close record of what has been given. This is particularly so in smaller patients. The worksheet in Figure 43-2 will aid this process. For pediatric cases, the anesthesiologist should give the fluid in a 50-mL syringe added to the setup illustrated in Figure 43-3. At the proximal

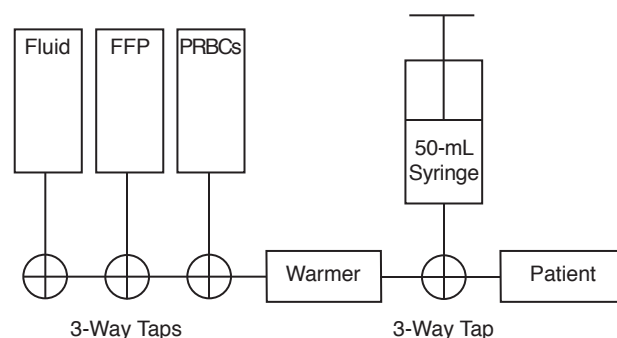


Figure 43-3. Massive transfusion equipment setup.
PRBCs: packed red blood cells
FFP: fresh frozen plasma

EXHIBIT 43-2

KEY POINTS OF THE UK PEDIATRIC MASSIVE TRANSFUSION PROTOCOL

- As with any pediatric case, calculate the patient's weight. This can be difficult; one method is shown in Exhibit 43-1.
- Initially order 1 U of PRBC and 1 U of FFP for every 20 kg of the child's weight. Eg, a 23-kg child will need 2 U blood and 2 U FFP initially. This will ensure a minimum of approximately 15 mL of blood per kg of weight.
- Give boluses of PRBC and FFP, alternating between the two, in volumes of 5 mL/kg each.
- Be aware that rapid transfusion of blood products through a large-bore central line has the accompanying risk of significant hyperkalemia.
- Keep track of blood and other products given by using the Pediatric Massive Transfusion Calculation Sheet (Figure 43-2).
- 15 mL/kg (3 boluses) of each product for the child equates to the first phase of transfusion for an adult (4 U of PRBC and 4 U of FFP).
- Use all clinical signs to help guide resuscitation, including arterial waveform, central venous pressure, blood pressure, and urine output. The variance of the arterial waveform with respiration in conjunction with its overall shape is a key guide.
- UK military research has shown that novel hybrid resuscitation is the best resuscitation model for blast injuries.¹ It entails resuscitating patients for the first hour after injury to achieve a palpable radial pulse in older children and a brachial pulse in children under 2 years of age. Thereafter aim to achieve a blood pressure that is normal for that age of child (Table 43-1). The exception to this is a child with head injury (see chapter text).
- Laboratory results are particularly useful:
 - Arterial blood gases (degree of acidosis) help guide whether resuscitation is adequate.
 - Rotational thromboelastometry (ROTEM [TEM Innovations GmbH, Munich, Germany]) will indicate degree of coagulopathy and need to vary blood product usage; variance from the 1:1 ratio of blood and FFP is usually not needed, however the ROTEM will guide need for platelets, cryoprecipitate, or antifibrinolytics.
- Platelets should be given initially at 3 mL/kg; however, ROTEM may indicate a requirement for more platelet transfusion. It takes up to 2 hours for transfused platelets to function adequately, and this may be reflected in a ROTEM suggesting further platelets despite an adequate platelet count.
- Hypocalcemia is common; the dose for calcium chloride 10% is 0.2 mL/kg.
- The treatment of fibrinolysis is tranexamic acid, 15 mg/kg. Current data suggests all patients qualifying for massive transfusion should receive this dose even without evidence of fibrinolysis.

FFP: fresh frozen plasma
PRBC: packed red blood cells
U: unit

1. Kirkman E, Watts S, Cooper G. Blast injury research models. *Philos Trans R Soc Lond B Biol Sci.* 2011;366:144–159.

end of the fluid warmer four 3-way taps should be attached in series to three to four bags of fluid and their giving sets. The three or four bags may contain any of the following; crystalloid, colloid, blood, or fresh frozen plasma. At the distal end of the fluid warmer, a further two 3-way taps should be attached in series: one for a 50 mL syringe (to use as the main “pump” for each fluid bolus) and the other for the addition of drugs. Distal to this should be a short connector to the

central line. The connector should be secured in some manner to the bed so it takes the weight of the 50-mL syringe and lines. Platelets should be given through a different giving set to a different line. The dose of 3 mL/kg is conservative and use of the whole bag should be considered. Appropriate monitoring is essential and invasive arterial and central venous pressure monitoring should both be used, but monitoring should not excessively delay necessary surgical intervention.

AIRWAY

The trauma anesthetist may need to manage a pediatric airway due to low consciousness level, as part of anesthesia for surgical intervention, or due to airway trauma.

Management of Airway Obstruction

Children may present with a reduced consciousness level and airway obstruction due either to head injury or hypovolemic shock. In all cases secretions, blood, vomit, and foreign bodies in the airway should be removed and oxygen delivered. To open the airway, the head should be placed into slight extension and the mandible pulled forward, taking care not to put pressure in the submental triangle, which will lead to posterior displacement of the tongue and worsening airway obstruction. When cervical spine injury is suspected, a suitably sized cervical collar or sandbags with head tape should be applied in the neutral position, and airway opening maneuvers should be restricted to pulling the mandible forward. If consciousness level is sufficiently depressed that a gag reflex is no longer present and the above maneuvers do not provide a satisfactory airway, a Guedel airway should be inserted (see Table 43-2 for sizing) and chin lift maintained. In small children, airways should be inserted with care and not inverted to prevent damage to the tissues of the oropharynx or tonsils.

Endotracheal Intubation

When endotracheal intubation is required, it should be performed once any hypoxia has been reversed by airway opening maneuvers and, if needed, mask ventilation. In children under 6 months of age, a straight-bladed laryngoscope should be used, lifting the epiglottis and withdrawing the laryngoscope slowly to reveal the laryngeal inlet. If the child is older than 6 months, a Macintosh blade should be used, placing the blade tip into the vallecula and lifting the laryngoscope to elevate the epiglottis and expose the vocal cords. Traditionally, uncuffed tubes are used in children up to the age of

8; however, recently interest in using cuffed tubes in children has been revived, and research is ongoing.

At present military modules contain uncuffed ETTs for pediatric use in sizes 3.5 to 6.0. The ETT may be sized against the child's nostril or fifth finger, or if age is known size may be calculated from the formulae in Table 43-3. Appropriate ETT length at the lips can be calculated from the formula: $(\text{age}/2) + 12$ cm. See Table 43-3 for children under 12 months of age. Because there is increased potential for inadvertent endobronchial intubation in children, it is essential that auscultation of both axillae is performed to ensure bilateral breath sounds. Tubes should be fixed securely to prevent movement. A common strategy is to use two “trouser-shaped” lengths of strong adhesive tape with a Guedel airway alongside the ETT to prevent lateral movement.

In all cases the ETT should pass through the glottis and cricoid without resistance, and there should be a small audible leak at inflating pressures of 20 cm H₂O. If there is no leak the ETT should be downsized to prevent damage to the airway mucosa; if there is a large leak the ETT should be upsized to allow satisfactory ventilation. If required a moistened throat pack can be used to reduce a leak or increase protection to the lower airways from ongoing hemorrhage. In children a nasogastric tube should be passed after the ETT is sited and secured unless contraindicated. If there is any question of damage to the cribriform plate an orogastric tube should be passed instead. The nasogastric or orogastric tubes reduce the gastric distension associated with acute trauma in children, which is exacerbated by swallowing large quantities of air when stressed and by facemask ventilation. Decompression reduces the risk of vomiting and aspiration, diaphragmatic splinting, and compression of the inferior vena cava. Caval compression may diminish venous return and cause hypotension, particularly where there is concurrent hypovolemia.

Rapid Sequence Intubation

The process of a rapid sequence intubation is de-

EXHIBIT 43-3

RAPID SEQUENCE INTUBATION

- Preoxygenate with 100% oxygen using a reservoir mask or anesthetic circuit for at least 2 minutes.
- Consider administering atropine (20 µg/kg IV) to dry oral secretions and prevent bradycardia from suxamethonium for children under 6 months of age.
- Administer an induction agent. In hypovolemia secondary to trauma the preferred agent is ketamine.
- Apply cricoid pressure using the thumb and index finger.
- Administer suxamethonium (2 mg/kg for children < 10 kg; 1 mg/kg for children > 10 kg) or rocuronium (0.6–1 mg/kg).
- Intubate.
- Confirm correct endotracheal tube placement with capnography followed by auscultation and observation of appropriate chest movement.
- Release cricoid pressure.
- Secure endotracheal tube.
- Obtain secondary confirmation of proper placement with chest radiograph or CT.

CT: computed tomography
IV: intravenous

scribed in Exhibit 43-3. Preparation is key: calculate weight, normal physiological values, doses of drug needed, and size of equipment. Table 43-4 is a calculation sheet currently used in Camp Bastion, Afghanistan, to aid this process.

Cricothyroidotomy and Tracheostomy

Both needle and surgical cricothyroidotomy and tracheostomy are difficult in children due to cephalad cricoid position and small cricothyroid membrane. Both procedures can give rise to serious complications and should only be used in life threatening situations.

EXHIBIT 43-4

CANNULA CRICOTHYROIDOTOMY IN CHILDREN

- Extend neck with roll under shoulders.
- Stabilize cricothyroid/trachea with non-dominant hand.
- Aim in caudad direction.
- Confirm position by aspiration of air.
- Connect to 4-bar oxygen source with flow-meter (match flow L/min to child's age) and Y connector.
- Set inflation: expiration = 1:4 seconds.
- Cautiously increase inflation pressures or oxygen flow rate by 1 L/min increments to achieve adequate chest expansion.
- Maintain upper airway patency, eg, with a Laryngeal Mask Airway (Teleflex, San Diego, CA).

The surgical and anesthetic teams need a skills assessment, and a joint plan should be made for managing this situation in advance. It is generally accepted that cricothyroidotomies should be converted to tracheostomies once a child is stabilized to reduce the risk of subglottic stenosis. Cannula cricothyroidotomy for children is described in Exhibit 43-4.

Facial Injuries and Burns

Facial injuries causing bleeding into the airway require immediate intubation for control of the airway. In all cases blood, secretions and foreign bodies should be removed and airway opening maneuvers performed, as described above, aiming to reverse any hypoxemia if possible before tracheal intubation. Airway burns should be suspected when a burn occurs in a closed space or when there is physical evidence of singed nasal hairs or eyebrows, carbonaceous sputum, wheeze, or change in cry or voice. In these cases early intubation is recommended before significant edema develops. An uncut tube should be used in anticipation of insidious facial swelling.

BREATHING

Assessment

Breathing should be assessed in all children as part of the primary survey and reassessed regularly, particularly after intubation. The chest wall should be examined for bruises and wounds. Due to children's highly compliant chest walls, significant intrathoracic

organ damage may occur with minimal external evidence of chest wall injury. Inspect and auscultate to ensure both sides of the chest are being adequately ventilated. The respiratory rate should be noted with reference to the normal values for the child's age (see Table 43-1). Look for central cyanosis and measure oxygen saturations—readings may be poor

EXHIBIT 43-5**CAUSES OF INADEQUATE VENTILATION FOLLOWING PEDIATRIC TRAUMA****Bilateral**

- Obstruction of upper respiratory tract
- Esophageal intubation
- Circumferential thoracic burns

Unilateral

- Pneumothorax
- Hemothorax
- Pulmonary contusion or laceration
- Intrapulmonary hemorrhage
- Flail segment
- Bronchial rupture
- Foreign body in bronchus
- Rupture of diaphragm
- Endobronchial intubation

in a hypovolemic, vascularly constricted child, so use clinical judgment and seek additional perfusion information from capillary, venous, or arterial blood gases. Additional information from imaging such as chest x-ray, focused assessment with sonography for trauma (FAST) and computed tomography (CT) will aid diagnosis but (CT in particular) should not delay prompt initial management. Causes of inadequate ventilation following pediatric trauma are detailed in Exhibit 43-5.

Management

The anesthetist's purpose is to maintain adequate

EXHIBIT 43-6**HOURLY FLUID MAINTENANCE REQUIREMENTS IN CHILDREN**

- First 10 kg: 4 mL/kg
- Second 10 kg: 2 mL/kg
- Thereafter: 1 mL/kg

Example: for a 34-kg child, use 74 mL/h (40 mL [first 10 kg] + 20 mL [second 10 kg] + 14 mL [last 14 kg])

oxygenation and ventilation and to manage hypovolemia or cardiovascular collapse caused by the injuries while permitting surgical management. In the first instance airway opening maneuvers, application of supplemental oxygen, and if required facemask ventilation should occur. Tension pneumothoraces require immediate drainage.

When intubation and ventilation are required, children should be ventilated to a tidal volume of 6 to 10 mL/kg with an age appropriate rate to maintain a normal PaCO_2 unless otherwise indicated. Peak end expiratory pressure (PEEP) should be started at 4 cm H_2O and increased as required, in addition to adjusting FiO_2 to maintain an adequate PaO_2 . It is usually recommended that children are ventilated in a pressure control mode (peak pressures normally 16–20 cm H_2O); however, volume control ventilation may be appropriate in the clinical circumstances. During intrathoracic procedures, particularly in very small children, hand ventilation may be optimal.

CIRCULATION**Fluid Management**

When blood products are not initially needed, fluid resuscitation should be initiated with 5 mL/kg boluses of Hartmann solution or Ringer lactate. Reassess the patient after each bolus to determine whether more fluid or a change to blood is required. Children, like adults, have a basic fluid maintenance requirement, which can be calculated using the equations shown in Exhibit 43-6.

Assessment of Circulation

Observation of mental status, heart rate, pulse quality, peripheral pulses, and temperature are the main indicators (see Massive Hemorrhage, above). Remember that a child can be in shock and still have a normal blood pressure; also be aware that inadequate resuscitation is common.

DISABILITY**Neurological Injuries****Assessment**

Calculate the Glasgow Coma Score. It is imperative

to do this prior to anesthetising (Exhibit 43-7). Consider whether the patient is exhibiting signs of neurological deficit. A brief but comprehensive neurologic examination is very important. Specific concerns that can be quickly answered include: Is there posturing, and if

EXHIBIT 43-7

GLASGOW CHILDREN'S COMA SCORE*

Eye opening	Score
Spontaneous	4
To verbal stimulus	3
To painful stimulus	2
No response to pain	1
Best motor response	
Obeys verbal command	6
Localizes to pain	5
Withdraws from painful stimulus	4
Abnormal flexion to pain	3
Abnormal extension to pain	2
No response to pain	1
Best verbal response	
Alert, babbles, coos; words appropriate for age	5
Spontaneous irritable cry, less than usual words	4
Cries only to pain	3
Moans to pain	2
No response to pain	1

*For children under 4 years of age.

so, what kind? The motor component of the Glasgow Coma Score is important and should be recorded. Address neurogenic shock by assessing for hypotension, warm peripheries, and flushed skin. Spinal shock is evidenced by absent deep tendon reflexes, hypotonia, flaccid sphincters, and priapism. Signs of increased intracranial pressure should be sought. These include headache, vomiting, altered mental status, and pupillary dilation. Evidence of Cushing signs, irregular respiratory pattern, hypertension, and bradycardia should also be noted.

Management

It is important to minimize secondary brain injury with the following measures: elevate the head of the bed to 15 to 30 degrees; avoid hypoxia, hypercarbia, and hypotension; avoid seizures; control fever aggressively; control glucose, avoiding hyperglycemia and hypoglycemia; avoid hyponatremia; control shivering;

maintain adequate analgesia; avoid coughing and straining; tape the ETT; and maintain neutral head alignment. In the presence of elevated intracranial pressure, consider administering mannitol (0.25–1.0 g/kg) or hypertonic saline (3% sodium chloride, 2–4 mL/kg) to decrease intracranial pressure and help restore intravascular volume.

Traumatic brain injury with altered consciousness or CT changes should be discussed with a neurosurgeon at an early stage. Relevant guidelines should be followed for CT scanning and referral.

Preoperative Sedation

Preoperative sedation is rarely needed, particularly if the patient is in extremis. Oral midazolam (0.25–0.5 mg/kg to a maximum of 15 mg) in flavored paracetamol solution (20 mg/kg) will work well as a premedication or added with ketamine (2 mg/kg) for short procedures (eg, change of dressing).

Anesthesia

Maintenance of Anesthesia

Military hospital personnel prefer using volatile inhalational anesthesia for maintenance of anesthesia in children due to concerns about potential “propofol infusion syndrome” (after case reports of fatal metabolic acidosis and cardiac failure in children), as well as its advantages in ensuring therapeutic concentrations of anesthetic when there is ongoing blood loss. Intravenous anesthesia, however, is preferred when transferring patients. Propofol is not recommended for anesthesia maintenance in children under 3 years of age, although it can be used for brief periods when needed because propofol infusion syndrome is associated with prolonged infusions. Various infusion regimes are available, although infusion pumps are currently not available in Afghanistan. A useful infusion starting point is 13 mg/kg/h for the first 10 minutes, reducing the dose to 11 mg/kg/h for the next 10 minutes, and then maintaining the dose at 9 mg/kg/h.

Sevoflurane is the most common volatile agent used in children, particularly for inhalational induction, although its use carries a risk of apnea at higher concentrations. The appropriate minimum alveolar concentrations for the most common inhalational agents, isoflurane and sevoflurane, are detailed in Table 43-7.

Regional Anesthesia

Administration of regional anesthesia is as relevant to children as to adults, though with differences in

TABLE 43-7

AGE-APPROPRIATE MINIMUM ALVEOLAR CONCENTRATION

Age	Isoflurane	Sevoflurane
Preterm	1.3	Unknown*
Neonate	1.6	3.3
Infant	1.9	3.2
Child	1.6	2.5
Adult	1.16	2.0

*Commonly used in the United Kingdom, but minimum alveolar concentration has not been determined.

volumes of local anesthetic, depth of needle insertion, and needle sizes. Administration requires expertise but satisfactory analgesia may be achieved with opioids by the nonspecialist. further below.

Equipment

Due to children's physiological differences and smaller sizes, pediatric circuits must have less dead space and reduced resistance. The preferred anesthetic circuits are therefore the Mapleson F and circle systems. The Mapleson F (also called the Jackson-Rees modification to the Ayre's T-piece) is the most common circuit used for children under 20 kg. It is simple and lightweight with low resistance and minimal dead space. Partial occlusion of the open-ended 500-mL bag can enable the application of PEEP and CPAP. Monitor end tidal carbon dioxide continuously and change fresh gas flows appropriately to maintain normocapnia. When using a circle system for children, the circuit must be narrower (15 mm is appropriate) to reduce the compression volume, and the connections (particularly distally) must be smaller to minimize dead space. The narrow-bore circle circuit can be used for older children (>20 kg) providing the reservoir bag is changed from a 500-mL bag to one holding 1 or 2 liters, as appropriate.

Analgesia**Acute Pain**

For minor injuries, pediatric pain can be managed according to the World Health Organization pain ladder (see Chapter 18, Multimodal Analgesia for Specific Injury Patterns, Figure 18-1). Table 43-8 contains doses of commonly used formulations in operations. Atten-

tion should also be paid to adjunctive measures such as splinting and immobilization, reassurance, and distraction.

For more severe injuries, rapid-acting analgesics, usually ketamine or fentanyl, should be carefully titrated to response. In cases where intravenous access is difficult or not obtained, or in mass casualty situations, intranasal ketamine and fentanyl have been shown to be rapid acting and effective, and may be of particular use in the prehospital care setting (see Table 43-6). For the most severe injuries, it may be more appropriate to move quickly to anesthesia induction to manage pain, maintain the airway, and facilitate resuscitation and damage control surgery.

Postoperative Pain Management

High quality postoperative pain management should be encouraged to support early mobilization and rapid transfer to a facility equipped for definitive care. Rigorous intraoperative and postoperative attention to an analgesic regime based on the World Health Organization pain ladder lays the foundations for good postoperative pain control. For children old enough to use patient-controlled analgesia, the standard field unit can be used with a morphine solution containing 20 µg/kg/mL and standard settings (eg, 1-mL bolus with 5-minute lockout and no

TABLE 43-8

DRUG DOSING FOR PEDIATRIC SINGLE-INJECTION PERIPHERAL NERVE BLOCK*

Block	Dose Range (mL/kg)	Midrange Dose (mL/kg)	Maximum Volume (mL)
Parascapular	0.2–1.0	0.5	20
Infracavicular	0.2–1.0	0.5	20
Axillary	0.2–0.5	0.3	20
Paravertebral	0.5–1.0	0.7	5
Femoral	0.2–0.6	0.4	17
Proximal sciatic	0.3–1.0	0.5	20
Popliteal	0.2–0.4	0.3	15
Lumbar plexus	0.3–1.0	0.5	20

*Children < 8 y: 0.2% ropivacaine or 0.25% bupivacaine. Children > 8 y: 0.5% ropivacaine or 0.5% bupivacaine. Do not exceed maximum recommended doses of local anesthetic.

Reproduced from: Buckenmaier C, Bleckner L. *Military Advanced Regional Anesthesia and Analgesia Handbook*. Washington, DC: Borden Institute; 2009: Table 30-4.

continuous infusion). A morphine infusion is needed for smaller children. These patients must be cared for in the critical care unit until adequate enteral opioids are tolerated.

When the situation permits, analgesia with local anesthetics (ie, infiltration by a surgeon, nerve blocks/catheters, caudal anesthetics, or epidurals) should be performed to reduce the need for systemic pain medications. As with adult regional anesthesia coagulation screening, platelets count and thromboelastometry (where available) should be normal before placing catheters or performing neuraxial blockade. In the complex trauma patient, siting of epidurals and nerve catheters in the days following initial resuscitation and stabilization may facilitate early extubation and reduce complications from prolonged ventilation and sedation.

Epidural Anesthesia

Epidural anesthesia in infants and neonates is a subspecialist practice and should be undertaken only by those with sufficient experience. In children weighing more than 10 kg, a 19-gauge adult-length Tuohy

needle with a 21-gauge catheter is appropriate. A standard aseptic and syringe loss of resistance to saline technique is used. At lumbar levels the epidural space is roughly at a depth of 1 mm per kilogram of body weight for children between the ages of 6 months and 10 years. At least 4 cm of catheter should be left in the extradural space. If used for surgical anesthesia, 0.75 mL/kg of 0.25% plain levobupivacaine should produce an adequate block. Postoperatively, levobupivacaine 0.125% should be administered at a rate of 0.1 to 0.4 mL/kg/h, with a maximum rate of 15 mL/h.

Caudal Anesthesia

Caudal anesthesia is an easy-to-learn technique providing good postoperative analgesia. A dose of 0.5 mL/kg 0.25% levobupivacaine provides sufficient anesthesia to block levels L₅–S₅, and a dose of 1.0 mL/kg 0.25% levobupivacaine will block T₉–S₅ (maximum dose: 20 mL). Duration of action can be prolonged by adding preservative-free ketamine (0.5 mg/kg) or clonidine (1–2 µg/kg), although this dose has possible side effects of hypotension and sedation. See Table 43-8 for pediatric dosing with individual blocks.

EXPOSURE

Injuries

As with adults, a thorough secondary survey is imperative. Remember that children are at greater risk of suffering injuries in more anatomical areas compared to adults.

Hypothermia

Use all methods available to treat hypothermia and maintain normothermia. Heated mattresses, forced air warmers, and fluid warmers should be used in all trauma cases.

Hypoglycemia

Neonates and in particular preterm infants are particularly vulnerable to hypoglycemia during periods of trauma due to low carbohydrate reserves. During the acute trauma phase, blood sugars should be monitored

regularly and hypoglycemia treated with 5 to 10 mL/kg of 10% dextrose (500 mg–1 g/kg). Hypoglycemia in the neonate is not clearly defined (in neonatal intensive care units it is usual to delay treating at-risk neonates who are otherwise healthy until their blood glucose falls below 2.0 mmol/L). However it would be pragmatic during an acute trauma episode to treat blood sugars below 3.0 mmol/L (54 mg/dL). Fluid requirements change very rapidly in the first week of life, from 60 mL/kg/day at birth to 150 mL/kg/day. As a rough guide, neonates who are not obtaining nutrition from other sources should be given 90 mL/kg/day of 10% dextrose (6 mg/kg/min) as maintenance carbohydrate intake.

Older infants and children rarely suffer from hypoglycemia, but if they do it should be treated with boluses of 5 to 10 mL/kg of 10% dextrose. Hyperglycemia is frequently present in pediatric trauma patients and is associated with increased morbidity and mortality.

SUMMARY

Children will always be victims in war. In the present theater of operations for the UK and US military, pediatric patients having suffered from ballistic trauma remain a significant proportion of

the surgical workload. Military anesthetists should endeavor to update their pediatric experience prior to deploying to war zones so both their skills and knowledge is up to date. This chapter is an adjunct

to this training. It is intended to be a valuable source of information to help nonpediatric anesthesiologists cope with the challenges of caring for the injured child.

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