Perioperative Pediatric Anesthesia Trauma Considerations

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Introduction

Trauma is the leading cause of death among children older than 1 year of age in the United States. Each year approximately 15,000 children die as a result of trauma. Additionally, over 100,000 pediatric patients suffer significant morbidity and disability from trauma. Unfortunately, despite dramatic increases in the number of educational programs and advances in injury prevention technology, this number remains consistent. In school aged children, motor vehicle and bicycle accidents are the most common causes of traumatic injury.

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The most common lethal injuries from blunt trauma are head trauma and severe intrathoracic injuries. Head injuries make up 80 % of isolated injuries and cause 70 % of all pediatric trauma deaths. Due to the compliant and non-calcified chest wall of pediatric patients, those with intrathoracic injuries may present without obvious rib fractures.

The complications from pediatric trauma impact anesthesiologists worldwide. Anesthesiologists are involved in many facets of pediatric trauma. Frequently, care of these patients takes place in adult emergency rooms or trauma centers, outside of the operating rooms. Unfortunately, very few anesthesiology residency programs teach about common traumatic injuries incurred by the pediatric population. It is vital to understand the subtle physiologic and anatomical differences and issues of this population, as compared to adults [1, 2].

Special Pediatric Anatomical and Physiologic Characteristics

Airway

Infants have large heads (prominent occiputs) relative to body size. This results in flexion of both the head relative to the neck, and the neck relative to the chest, when placed supine. Care must be taken to properly position these patients for intubation. Some practitioners place a roll or towel under the shoulders of these patients to

C.S. Scher (ed.), *Anesthesia for Trauma*, DOI 10.1007/978-1-4939-0909-4_15,

maximize the "sniffing position" for mask ventilation and intubation. The need for neck stabilization may further complicate management of these patients. The narrowest part of the airway in children is located at the subglottic area, whereas in the adult airway it is at the glottis. The larynx is located at C_2–C_5 in the pediatric population compared with a C_6 location in adults. The large tongue, short and U-shaped epiglottis, and anteriorly placed vocal cords can make airway management challenging, especially for the non-pediatric specialist [1].

When selecting an endotracheal tube, with or without a cuff, one must be cognizant of the delicate vocal cords, which may be easily damaged. Unfortunately, many pediatric patients do not conform to the many tables or formulas used when calculating the correct endotracheal tube size. This may result in large "leaks" when performing positive pressure ventilation. To achieve adequate positive pressure ventilation, some studies have shown a 30 % reintubation rate in patients under the age of 2. This, coupled with recent studies showing no increase in laryngeal injuries in pediatric patients ventilated with a cuffed endotracheal tube, has led to some advocating the use of "cuffed" endotracheal tubes in this group. One must remember that tracheal mucosal damage from increased cuff pressure or oversized endotracheal tubes is increased in hypotensive patients. Meticulous endotracheal cuff pressure monitoring may be required [1–3].

Circulation

Pediatric trauma patients may sustain significant blood loss (25 % of circulating blood volume) before a loss in central arterial pressure is seen. Therefore blood pressure can be an inaccurate measure of hypovolemia in this age group. Other measures such as heart rate, peripheral temperature, and capillary refill are more accurate measures of hypovolemia. Pediatric patients with cool extremities, delayed capillary refill (over 2 s), or tachycardia out of proportion for their age group provide a more accurate diagnosis of hypovolemia. Tables 15.1 and 15.2 list the normal systolic blood pressures, heart rate, and blood volumes of pediatric patients based on age [3].

Table 15.1 Hemodynamic parameters

Age	Systolic blood pressure (mmHg)	Heart rate (beats/min)
1 year	80	150
4 years	80	120
6 years	80–100	100
10 years	80–100	90

Table 15.2 Blood volume

Age	Blood volume (mL/kg)
3 months–1 year	70–80
1 year	70

Temperature Regulation

Pediatric patients have a larger surface area to body size ratio, less subcutaneous fat, thinner skin, and a higher metabolic rate than adults. In light of these differences, temperature should be monitored with vigilance. Ambient temperature should be adjusted to prevent hypothermia. Forced air convective warming devices and/or warm blankets can be applied to prevent or treat hypothermia after the initial trauma survey is completed. Although hypothermia can be beneficial in neurotrauma patients, it may precipitate decreases in cardiac and renal function. Hypothermia may also increase oxygen demand, cause hemostasis, acidosis, and increase the incidence of arrhythmias [1, 6].

Initial Resuscitation and Primary Survey

The initial survey requires quick identification of life-threatening injuries and prioritizing the delivery of treatment. The initial survey for pediatric trauma patients involves immediate assessment of the "ABCDEs" which is the protocol for Advanced Trauma Life Support. This enables efficient resuscitation and quick restoration of hemodynamic stability. The first hour, commonly referred to as the "Golden Hour," is critical. The following should be achieved within the initial hour to maximize outcome: primary survey, resuscitation, secondary survey, and definitive care.

A = Airway, B = Breathing

On arrival, the patient should be monitored with pulse oximetry and receive supplemental oxygen via nasal cannula or facemask while the initial survey is completed. Airway examination for signs of obstruction or compromise should take priority. This includes an inspection of the face, mouth, mandible, teeth, nose, and neck. It is imperative that one establishes, secures, and maintains a patent airway. Airway obstruction can result in hypoxemia, hypercarbia, and cardiac arrest.

Signs of blood, broken teeth, or edema when inspecting the airway may necessitate immediate airway intervention. In all patients with a closed head injury, it is assumed there is a cervical injury until proven otherwise. All trauma patients are considered to have "full stomachs." Measures should be taken to maintain C-spine precautions and minimize the risk of pulmonary aspiration.

The clinician should look, listen, and feel when assessing breathing and ventilation. Observation can reveal chest rise, an abnormal respiratory rate or pattern, nasal flaring, subcostal or intercostal retractions, and use of accessory muscles. Listening can identify stridor, grunting, or the presence or absence of breath sounds with auscultation. Lastly, one must feel to assess tracheal midline position or the presence of crepitus. A chin lift or jaw thrust can improve airway patency in patients with complete or partial airway obstruction. When executing these maneuvers, special care should be taken not to hyperextend the neck. Oral airway placement may be beneficial, but can lead to gagging and vomiting. This may precipitate pulmonary aspiration in the conscious patient.

The decision to intubate should be made as early as possible. One should not wait until a ventilation crisis occurs. Early intubation is advised in the following scenarios: (1) Patients with impending respiratory failure experiencing hypoventilation, apnea, or hypoxemia necessitating oral airway placement, or a flail chest. (2) Patients who have an initial Glasgow Coma Scale (GCS) score below 9. (3) Patients in shock who have not responded to appropriate fluid resuscitation. (4) Patients with significant burns or airway injury. Before intubation is attempted, airway equipment, drugs, suction, and personnel should be identified. Most emergency departments have an airway cart that contains emergency airway devices such as a fiberoptic bronchoscope, laryngeal mask airway, jet ventilation equipment, a light wand, and various laryngoscope blades and endotracheal tubes. If a difficult intubation is anticipated, a cricothyrotomy and tracheostomy kit and surgical personnel should be identified before proceeding with airway management.

C = Circulation

As previously mentioned, the most common cause of thoracic trauma is blunt trauma. Rib fractures are a poor predictor of major thoracic injury. The ribs are primarily cartilaginous structures and are extremely compliant, usually protecting against fractures. Commonly, pediatric trauma patients who have sustained multiple injuries present in hypovolemic shock. The pediatric patient is able to maintain a normal blood pressure despite a 25–40 % reduction in circulating blood volume. This compensation occurs through vasoconstriction and an increase in heart rate to sustain cardiac output. Therefore mental status, capillary refill, skin mottling, tachycardia, and peripheral skin temperature are more accurate indicators of circulatory status. A narrow pulse pressure and sustained tachycardia may indicate impending circulatory collapse.

Immediate restoration of systemic blood pressure is critical to maintain normal organ perfusion and function. Initial resuscitative efforts should involve administration of a warmed isotonic crystalloid solution. Many clinicians use warmed lactated ringers and initially infuse 20 mL/kg. This may be repeated once or twice. After this, if no increase in blood pressure is noted, then colloid and blood product administration should be considered. The first choice of blood products should be type-specific and fully cross-matched blood, given in 10–20 mL/kg boluses. If type-specific, fully cross-matched blood is not available, then type-specific, partially cross-matched, or type-specific uncross-matched blood is preferred. O Rh-negative blood is the next choice until type-specific blood is available. If the patient remains hemodynamically unstable after the above measures, then vasopressors (epinephrine) and/or inotropes (dopamine and dobutamine) may be indicated. After vasopressors and/or inotropes are used and there is still hemodynamic instability, tension pneumothorax, pericardial tamponade, myocardial contusion, or unrecognized internal bleeding should be considered.

Vascular access can be extremely challenging in the pediatric trauma patient presenting with hemodynamic instability. Peripheral access with a 24 gauge angiocatheter may be an adequate way to start resuscitation. When peripheral access is not possible, central access should be attempted. Cannulation of the external or internal jugular vein via direct venipuncture or Seldinger technique is acceptable. If there is no suspicion of intra-abdominal trauma or disruption of the inferior vena cava, femoral vein cannulation can be attempted. A central venous catheter should not be placed in the internal jugular vein if cerebral perfusion is in question. In the pediatric population subclavian venous catheter placement is associated with a higher incidence of pneumothorax and subclavian artery injury than in adults. The increasing use of ultrasound technology has made visualization and placement of central venous and arterial catheters easier in the pediatric population.

If intravenous access is not obtained after 2–3 min, one should place an intraosseous catheter. An intraosseous needle should be used; however, most large bore needles will suffice. Any nontraumatized long bone can be used for access, but the most common entry point is the tibia. The advised area of entry is the anteromedial aspect of the tibia 2 cm below the tibial tuberosity. Emissary veins that traverse the bony cortex may affect the flow rate. Intraosseous access should only be used temporarily, until venous access can be obtained.

Table 15.3 Glasgow Coma Scale in children

Score	Variable
	Best motor response
6	Obeys commands
5	Localizes pain
4	Withdraws from pain
3	Abnormal flexion
2	Abnormal extension
1	Flaccidity
Score	Variable
	Best response
5	Appropriate words or social smiles, fixes, and follows
4	Cries but consolable
3	Persistently irritable
2	Restless agitated (moans only)
1	None
Score	Variable
	Eye opening responses
4	Spontaneous
3	Opens to voices
2	Opens to pain
1	None

Modified from Emerg Med Clin North Am, 16, Cantor RM, Leaming JM, Evaluation and management of pediatric major trauma, pp. 229–56, Copyright 1998, with permission from Elsevier

D = Disability

Head trauma is the major cause of death for pediatric trauma patients. The initial examination should include the mnemonic "AVPU" (awareness, response to verbal or pain stimuli, and unresponsiveness to stimuli), or the modified GCS (see Table 15.3) for assessment. The GCS can be unreliable in some pediatric patients. The GCS verbal responses have been modified for children in the hopes of improving predictability. However, in the absence of hypoxic-ischemic injury, the condition of most pediatric patients will improve despite a low GCS score [1].

An initial neurologic assessment sets a baseline for the patient so that trends in neurological function can be observed. Pediatric trauma patients may present with an unaltered mental status, no headaches and no vomiting. A CT scan should be performed despite the lack of these symptoms. Patients under the age of 18 months are able to accommodate an expanding intracranial mass because their fontanelles have not closed. However, if a fontanelle is bulging, immediate action should be undertaken. The large head to body size ratio in pediatric trauma patients predisposes them to flexion-extension injuries of the cervical spine between the second and third vertebrae. In half of patients with spinal cord injury, no radiologic abnormalities are noted. The patient with cervical spine injury may present with profound hypotension. Care to preserve neck stability and spinal cord perfusion should be taken [1, 2].

E = Exposure/Environmental Control

The pediatric trauma patient is frequently undressed to facilitate complete assessment. Patients can quickly become hypothermic due to their lack of subcutaneous tissue and their large surface area relative to body size. Clinicians should prepare to prevent hypothermia by increasing ambient temperature and using warm blankets to cover the patient after examination [7].

Preoperative Evaluation and Intraoperative Management

Secondary Survey

A secondary survey involves a thorough inspection of the patient and each organ system, with careful regard to the patient's hemodynamic status. Usually the anesthesiologist performs this preoperatively, with a thorough history and physical examination. However, pediatric trauma patients often present with urgent or emergent surgical needs. With limited time, a brief history outlined by the mnemonic "AMPLE" may be obtained for safe delivery of anesthesia. The anesthetist should talk with the patient (if he or she is capable of providing information), or others (family, paramedics, nurses, ED physicians) to determine the following:

A—allergies: Is the patient allergic to any medications, foods, and materials such as latex? If they do have allergies, what happened and how was it treated?

M—medications: What medications are they taking, both prescription and over the counter? If they are taking medications, how often, what dosage, what route, and the when was the last time the medication was taken?

P—past medical and surgical history: What medical conditions do they have? What surgeries have they had? What was their anesthetic experience? Any family history of anesthesia complications?

L—last oral intake: When was the last time they had anything to eat or drink? What did they eat or drink?

E—events related to the injury: What led up to or occurred just prior to the injury? [17]

Other information pertinent to patient care may include: What was the course of events and treatment given at the scene of the accident and in the emergency department? What crystalloid, colloid, or blood products have been given since the event? What are the laboratory, radiologic, and ancillary test results? [1]

Equipment

Having an operating room prepared and available for trauma is essential for taking care of severely injured children. The anesthesia machine should be checked daily. Pressure transducer lines should be set up and zeroed. Ventilators capable of volume control and pressure control ventilation should be available, as well as rapid infusers, warming devices, a cell saver machine, forced air warmers, a difficult airway cart with fiberoptic bronchoscopes, airway equipment of different sizes, an echocardiographic machine and probes, an ultrasound machine for vascular access, a direct telephone line to the clinical lab and blood bank, an emergency resuscitation cart with defibrillator and pacer, an arterial blood gas machine, a glucometer, crystalloid and colloid solutions, and emergency type O-negative blood. Additionally, the operating room ambient temperature should be raised to more than 28 °C for infants and small children [9].

Monitors and Monitoring

In the world of anesthesia there is no better monitor than a focused and vigilant pediatric anesthesiologist. Monitors provide clinically useful information that can aid the timely application of therapeutic interventions. The ASA standard monitors include the electrocardiogram (ECG), noninvasive blood pressure (at least every 5 min), pulse oximetry, temperature probe, capnography, and an oxygen analyzer with a low oxygen concentration limit alarm in use. These monitors should be used for every pediatric patient. Additionally, a nerve stimulator is recommended to assess neuromuscular blockade, as well as an esophageal or precordial stethoscope to continuously monitor breath sounds. The pulse oximeter measures arterial oxygen saturation and gauges the adequacy of oxygenation and tissue perfusion. It may become unreliable when there is vasoconstriction due to hypovolemia, hypothermia, or shock. Other factors that influence the accuracy of pulse oximetry are patient movement, ambient light, dysfunctional hemoglobin (carboxyhemoglobin), and an altered relationship between $PaCO_2$ and SaO_2 (shift in the oxyhemoglobin dissociation curve) [4].

Capnography, or exhaled CO_2 monitoring, is helpful with: (1) determining endotracheal tube placement, (2) assessing ventilation, (3) estimating the $PaCO_2$ (the concentration of expired CO_2 is normally within 2–3 mmHg of that in the arterial blood), (4) gauging the adequacy of ventilation and the effectiveness of CPR, and (5) evaluating dead space [5].

In the mechanically ventilated neonate or young infant, the dead space volume between the breathing circuit and the ETT may be relatively more significant than in an adult, resulting in higher dead space to tidal volume ratio and less accurate, lower, $ETCO_2$ value. Decreases in the $ETCO_2$ value can be due to hyperventilation, hypothermia, low cardiac output, pulmonary embolism, accidental disconnection of the circuit, mainstem tracheal intubation, or cardiac arrest. Therefore, monitoring the trend of $ETCO_2$ as well as the actual $ETCO_2$ value is very important in infants and young children.

Temperature monitoring is mandatory in all children due to their immature thermoregulation, disproportionately greater body surface area to body mass ratio, and fluid and heat loss from exposed surgical sites. Hypothermia in children is associated with many adverse effects, such as increased oxygen consumption, a left shift of the oxyhemoglobin dissociation curve, coagulopathy with prolonged bleeding, metabolic and lactic acidosis, hypoglycemia, apnea, depressed myocardial contractility, arrhythmias, impaired drug metabolism, delayed emergence from anesthesia, and increased mortality. For these reasons, continuous temperature monitoring is mandatory in the care of an injured child [6].

Other monitors to consider include an arterial line, a central venous catheter, a urinary catheter, and an ICP monitoring device. In addition, continuous hemoglobin analysis and near-infrared spectroscopy are being increasingly used in pediatric anesthesia, and may soon have an important role in the care of the pediatric trauma patients. Invasive arterial blood pressure measurement is very useful, but urgent surgery should not be delayed if attempts to place an arterial line are unsuccessful. An arterial line provides access to obtain blood samples for analysis. It also provides continuous and accurate blood pressure measurement, useful when large changes in blood pressure are expected intraoperatively.

The most common reason for emergent or urgent surgery in the pediatric trauma patient is hemodynamic instability, often due to penetrating chest injury or acute bleeding in the head [16]. When transporting an unstable trauma patient, extra care should be placed in securing airways, lines, and monitors. An inventory of lines and monitors should be done immediately upon arrival to the OR. When transferring the patient to the OR table, cervical spine precautions should be maintained. The continuation of resuscitation fluids is imperative during placement of invasive monitors or establishment of additional IV access.

As with any trauma case, the pediatric anesthesiologist's primary responsibility is to focus first on the airway, breathing, and circulation. If the patient is already intubated, correct placement of the ET tube should be confirmed by equal and bilateral breath sounds, symmetrical chest expansion, and a normal $ETCO_2$ waveform on the capnogram, or a color change on the portable $ETCO_2$ detector. Once these are confirmed, mechanical ventilation can be safely initiated to ensure adequate ventilation and oxygenation.

Many infants and children who suffer trauma come to the OR conscious or semiconscious, receiving supplemental oxygen through a face mask or nasal cannula. For most of these patients, endotracheal intubation is often a necessity, so a reasonable and safe plan to secure the airway should be formulated. Before intubation, one should always have an emergency airway tray (including fiberoptic bronchoscope, laryngeal mask airway, light wand, jet ventilation, and appropriate blades and tubes). In addition, familiarity and knowledge of the American Society of Anesthesiologists (ASA) difficult airway algorithm is a necessity.

Anesthesiologists should presume that all trauma patients have full stomachs and a high likelihood of cervical spine injuries. Rapid sequence IV induction and intubation with manual in line cervical spine stabilization is usually indicated. By performing a rapid sequence induction then intubation, the time between loss of airway reflexes and intubation is minimized [10]. Preoxygenation of the patient with 100 % oxygen for four maximal breaths or 3–5 min of normal breathing, followed by intravenous injection of an anesthetic induction agent and a muscle relaxant while cricoid pressure is applied, reduces the risk of aspiration of gastric contents. As soon as the neuromuscular blocking agent takes effect, direct laryngoscopy is performed while in line cervical spine stabilization is maintained. Endotracheal tube placement is confirmed by the presence of continuous $ETCO_2$ capnography waves, auscultation of bilateral equal breath sounds, and the absence of gastric sounds in the stomach. Cricoid pressure is only discontinued when ETT placement is confirmed and its cuff is inflated. A modified rapid sequence induction is an option when dealing with a combative or uncooperative child. With a combative child, another option is to perform an inhalational induction and apply cricoid pressure as the child loses consciousness. Before choosing a particular induction technique, the risk and benefits of each should be considered, specifically regarding aspiration and exacerbation of injuries due to excessive movement. During induction and intubation, the oxygen saturation of pediatric patients will decrease more quickly than in adults. This is related to their higher metabolic rate and low oxygen reserves (decreased functional residual capacity). Therefore, preoxygenation is very important [11, 12].

The modified rapid sequence induction and intubation has three defining features: (1) oxygen administration before induction, (2) the use of cricoid pressure, and (3) an attempt to ventilate the patient before securing the airway. Inflation pressures should be kept between 15 and 20 cm H_2O to minimize the possibility of gastric distention, regurgitation, and aspiration. Suction should be immediately available in the event of passive regurgitation or vomiting. Oxygenation should be attempted after each failed intubation attempt [10].

When dealing with a difficult airway, particularly when direct laryngoscopy appears to be difficult, the anesthesiologist should have several options for airway maintenance and protection. Spontaneous ventilation may be maintained while an inhalational agent is used to deepen the level of anesthesia in preparation for a fiberoptic intubation. In a non-emergent situation, for children with a limited mouth opening, limited neck movement (common in trauma victims in a cervical collar), or a congenital syndrome associated with a difficult airway, the fiberoptic bronchoscope is a powerful tool. Another helpful adjunct with these patients can be a video-assisted laryngoscope. It may allow for good visualization of the airway with less neck movement. In emergency situations, blind placement of a supraglottic device such as a laryngeal mask airway (LMA) is common. The LMA does not protect the airway from aspiration, but it can be used as a conduit to facilitate either blind or fiberoptic intubation of the trachea. The “Fastrach LMA” is another supraglottic device that is useful when direct visualization of the laryngeal inlet is not possible. However, this device is not yet available for use in small children. Additionally, the lightwand or light-assisted device can be very helpful. This is a rigid stylet with a light at its tip. It uses the technique of transtracheal illumination for blind intubation of the trachea in older children. Advantages to using this in the trauma patient are ease of learning how to use the device, and minimizing neck movement in a patient with a potential cervical spine injury [11, 12].

Induction Agents

When initiating induction of a trauma patient several factors have to be considered. The hemodynamic status is a major concern. Other concerns include the potential side effects of induction agents. A hypovolemic child is particularly sensitive to the vasodepressor and negative inotropic effects of volatile anesthetics, some induction agents, and drugs that promote histamine release. A safe induction technique may include providing small incremental doses of the selected agents. The reduced doses of induction agents are effective because the hypovolemic child has a decreased volume of distribution, while blood flow to the heart and brain are maintained. Also, fluid resuscitation can cause hemodilution resulting in a reduction of drug binding serum proteins. Almost any induction agent can be used in pediatric trauma as long as the agents are titrated carefully to minimize potential deleterious effects.

Sodium thiopental (at this time not commercially available) can be given in the dose of 3–6 mg/kg intravenously. Its dose should be titrated carefully as its side effects include venodilation and myocardial depression. Additionally, thiopental is rapid acting, lowers intraocular pressure (IOP), and does not cause pain on injection. It is a good choice for induction of pediatric patients with head injury and increased intracranial pressure (ICP) as it causes a dose-dependent decrease in ICP, cerebral oxygen consumption, cerebral blood flow (CBF), and reduces epileptiform activity.

Propofol can be given in a dose of 2–3 mg/kg IV. One of its major side effects is more pronounced hypotension than thiopenthal, especially in hypovolemic patients. Propofol also causes pain on injection, especially when given in smaller caliber vessels. To decrease the pain on injection, lidocaine 0.5–1 mg/kg IV can be given prior to propofol. Propofol decreases ICP and CBF, and has antiemetic, anticonvulsant, and antipruritic properties.

Ketamine can be given in a dose of 1–3 mg/kg IV. Due to its high lipid solubility, it can also be given intramuscularly in trauma patients. It has some very favorable effects during induction of a hypovolemic, hypotensive, hemorrhaging child who needs emergent surgery. As an induction agent, ketamine can elevate blood pressure while providing analgesia and amnesia. It can provide complete anesthesia given as an infusion after induction. Ketamine can produce significant but transient increases in systemic blood pressure, heart rate, and cardiac output via centrally mediated sympathetic stimulation. However, ketamine is a direct myocardial depressant. This effect is usually masked by its stimulation of the sympathetic nervous system. Doses of ketamine used for induction minimally affect the central ventilatory drive, and do not depress upper airway reflexes. Ketamine causes increased salivation that can be attenuated by giving anticholinergic premedication such as glycopyrrolate 0.01 mg/kg IV, or atropine 0.1–0.2 mg/kg IV. Ketamine can cause dose-dependent increases in ICP, CBF, and cerebral oxygen consumption. Therefore it is usually avoided in patients with intracranial pathology, especially those with increased ICP [1, 3].

Etomidate can be given in a dose of 0.2–0.3 mg/kg IV. Advantages of using etomidate are that it is a short acting, potent, non-barbiturate sedative hypnotic, providing hemodynamic stability due to its minimal effects on the cardiovascular system. Etomidate is a potent cerebral vasoconstrictor, decreasing ICP and CBF. Other side effects of etomidate include spontaneous movements (characterized as myoclonus), and it has both anticonvulsant and proconvulsant properties. It can cause adrenocortical suppression, especially after a prolonged continuous infusion [13].

Neuromuscular Blockers

For muscle relaxation, either a depolarizing or a nondepolarizing muscle relaxant can be used. Succinylcholine can be given in a dose of 1.5–2 mg/kg IV. It is a depolarizing muscle relaxant, and may be the best choice for rapid sequence induction and intubation due to its rapid onset of 30–60 s and its short duration of 5–10 min. Its short duration makes it a valuable tool in the event that endotracheal intubation is unexpectedly difficult and bag mask ventilation becomes inadequate. This can allow for the return of potentially life-saving spontaneous respiratory efforts quickly. Infants require larger doses of succinylcholine, typically 2–3 mg/kg IV. This is due to their large volume of distribution. Caution must be taken when administering succinylcholine, especially when given repeatedly, because children are more susceptible than adults to cardiac arrhythmias, hyperkalemia, rhabdomyolysis, myoglobinuria, malignant hyperthermia, and even sinus arrest from succinylcholine. Thus, atropine 0.01–0.02 mg/kg IV (0.1 mg minimum) is often given to children prior to succinylcholine. Other side effects of succinylcholine include increased IOP and ICP, and elevated intragastric and esophageal sphincter pressures. Hyperkalemic cardiac arrest after succinylcholine administration has occurred in children with undiagnosed neuromuscular disorders. Succinylcholine is therefore *contraindicated* in patients with muscular dystrophies, and also in pediatric patients with burns more than 24 h old, denervation injuries, hyperkalemia, disuse atrophy, neuromuscular disorders, prolonged immobility, and a history of malignant hyperthermia.

Nondepolarizing muscle relaxants, such as rocuronium, may also be used for induction. At higher doses of 0.9–1.2 mg/kg IV, rocuronium provides rapid onset of neuromuscular blockade for intubation within 45–90 s. However, larger doses of rocuronium usually prolong its duration of action (up to 90 min). Rocuronium does not cause histamine release. If being given with thiopental, the intravenous line should be flushed before giving rocuronium, as rocuronium precipitates with thiopental. Another nondepolarizing muscle relaxant is vecuronium, which also does not cause histamine release or adverse hemodynamic effects. When given in a dose of 0.25 mg/kg IV, it provides good intubating conditions in 60–90 s. Vecuronium is an acidic compound that can be inactivated by alkaline solutions such as thiopental. Therefore thiopental should be flushed from the intravenous line before administering vecuronium.

Fluids and Blood Replacement

Large amounts of intravenous fluids may be required. They serve one of four purposes in trauma patients: (a) maintenance, (b) to balance ongoing losses, (c) to treat hypovolemia, and (d) to serve as replacement for volume deficits. In general, the non-glucose containing, isotonic crystalloid solutions are the fluids of choice for replacement of fluid losses associated with major surgery, hemorrhagic shock, and trauma. These solutions can rapidly restore circulating blood volume and preserve vital organ perfusion.

Calculating the preoperative deficit may be difficult in pediatric trauma patients. Patients undergoing emergency surgery may have larger fluid deficits related to fever, vomiting, third space loss, or blood loss. Often intraoperatively large deficits must be replaced; therefore fluid warmers should be used. This helps avoid hypothermia. An accurate estimate of fluid loss is often impossible; therefore fluid replacement should be guided by cardiovascular response and urine output.

Maintenance fluids for pediatric patients should be calculated using the 4-2-1 formula. For example, the required maintenance fluid for a 26 kg child would be 4 mL/kg/h for the first 10 kg, plus an additional 2 mL/kg/h for the next 10–20 kg, plus 1 mL/kg/h for weight greater than 20 kg, for a total of 66 mL/h (40 + 20 + 6). Again, non-glucose containing, isotonic crystalloid solutions are the fluids of choice for maintenance. Glucose containing solutions may be necessary in cases of hypoglycemia, or if the patient is at risk for hypoglycemia, such as a neonate with limited glycogen reserves.

Preoperative and intraoperative fluid losses are mostly isotonic, and are commonly replaced by lactated ringers or 0.9 % normal saline solution. Lactated ringers solution is slightly hypotonic (273 mOsm/L, sodium 130 mEq/L, chloride 108 mEq/L) and contains electrolytes. It is thought to be the most physiologic solution, especially when given in large amounts. Normal saline (308 mOsm/L, sodium 154 mEq/L, chloride 154 mEq/L) may also be used, but can lead to hyperchloremic metabolic acidosis when given in large amounts. Albumin 5 % is the most common colloid used in pediatric patients, but disagreement exists as to the efficacy of this therapy versus isotonic crystalloid administration.

Blood loss should be replaced with 3 mL of crystalloid for every 1 mL of blood loss, in combination with 1 mL colloid given for every 1 mL of blood loss, to maintain normovolemia. The hematocrit should be monitored in cases with moderate (4–6 mL/kg/h) or greater blood loss. When a predetermined lower limit of hematocrit has been reached, blood products should be given. Acceptable low hematocrit values vary with age. Premature infants normally have a hematocrit of 40–45 %, with an acceptable low level of 35–40 %. A normal hematocrit for a newborn is 45–65 %, and an acceptable low hematocrit is 35–40 % for this age. A normal hematocrit for a 3-month-old is 30–42 %, and an acceptable low hematocrit is 25 %. A normal hematocrit for a 1-year-old is 34–42 %, with an acceptable low hematocrit of 20–25 %. Children 6 years old or older have a normal hematocrit between 35 and 43 %, and an acceptable low hematocrit of 20–25 %. Red blood cell transfusion is indicated to increase the intravascular oxygen carrying capacity, as well as volume. The use of other blood products such as platelets, fresh frozen plasma (FFP), cryoprecipitate, or other factors should be guided by coagulation studies and clinical signs of coagulopathy. Other factors that influence the decision to transfuse include preoperative hematocrit, estimated blood volume, comorbidities, rate of ongoing blood loss, and the clinical response of the patient to volume resuscitation.

The formula to calculate maximum allowable blood loss is: MABL = EBV X (initial hematocrit-target hematocrit)/initial hematocrit. To calculate the amount of PRBCs needed to reach the target hematocrit value, the following formula can be used: Volume of PRBCs (mL) = EBV X (desired hematocrit-present hematocrit)/ hematocrit of PRBC (typically 60 %). Transfusion of 10–15 mL/kg of PRBCs should increase the hemoglobin concentration by 2–3 g/dL.

Platelets and FFP should be given when blood loss is greater than one to two blood volumes, or when the results of coagulation studies are abnormal. Administration of 5–10 mL/kg of platelet concentrate should increase platelets by 50,000–100,000 per dL. FFP is typically given to correct coagulopathy due to insufficient coagulation factors. Administration of 10–15 mL/kg of FFP will increase factor levels by 15–20 %. Cryoprecipitate is most commonly used as a source of fibrinogen, factor VIII, and factor XIII. Administration of 1 unit of cryoprecipitate for every 5 kg to a maximum of 4 units is typically adequate for correcting coagulopathy due to low levels of fibrinogen.

Recombinant factor VIIa is approved by the FDA for the treatment and prevention of bleeding in patients with factor VII deficiency, and for hemophiliacs with inhibitors to factors VIII and IX. Over the last decade, there have been multiple reports of recombinant factor VIIa being used effectively in controlling life-threatening traumatic and intraoperative bleeding unresponsive to conventional intervention. However, concern remains about potential thromboembolic complications [14].

Postoperative Care of Pediatric Trauma Patients

The percentage of injured children that go on to have surgery is considered low, as one study reported fewer than 15 % of pediatric trauma patients require surgery. Despite this, it is important to realize that those pediatric patients requiring surgery are often critically injured. One study cited that 86 % of pediatric trauma patients at risk for mortality had at least one surgical diagnosis, and that surgical pediatric trauma patients required longer ICU stays (2). Even though pediatric and adult trauma patients undergo similar surgeries to treat their injuries, there are considerable differences in physiology (especially in regards to cardiac and pulmonary physiology) that make postoperative care of pediatric trauma patients much different than in adults.

The challenge of caring for pediatric trauma patients in the postoperative period begins with transport. As stated previously, pediatric trauma patients who require surgery have a higher mortality risk and will often require recovery in an intensive care unit. The transport of pediatric trauma patients to intensive care units is often challenging. The pediatric intensive care units (PICU) are sometimes located a considerable distance from the operating rooms in the hospital. The clinician transporting the patient should focus on airway management, breathing, and the cardiovascular status of the patient. Due to the patient's critical condition, monitors, resuscitative drugs, and airway equipment, as well as other medical equipment, should be on hand during transport to ensure proper care and stability.

Regarding airway management and maintenance of ventilation, the anesthesiologist must decide whether to keep the patient intubated, or to extubate in the operating room. If the patient is extubated in the OR, then supplies for laryngoscopy and intubation should accompany the patient to the PICU in case intervention is needed during transport. In addition to airway supplies, an oxygen source, properly fitting face mask, and a self-inflating bag with reservoir should be transported with the patient should ventilation become inadequate. It is not ideal to intubate a patient during transport from the OR. Bag-mask ventilation is an acceptable method for ventilation, and is frequently used by clinicians when transporting patients to the PICU. If respiratory difficulty occurs during transport, it is advisable to provide bag-mask ventilation until arrival in the PICU. The PICU provides a better setting for intubation if needed.

Maintaining adequate circulation should begin with ensuring that the patient has adequate intravascular access before transport. Supplies such as intravascular catheters of appropriate gauge, intraosseous needles, and isotonic fluids with proper pediatric drip chambers and tubing should be transported with the patient in case intravascular access is lost and emergency medications need to be administered. Key drugs for the management of a pediatric trauma patient include etomidate, ketamine, succinylcholine, vecuronium, cisatracurium, lorazepam, midazolam, fentanyl, morphine, dopamine, dobutamine, epinephrine, atropine, albuterol, and racemic epinephrine.

Portable monitors used to transport patients to the ICU should be able to measure blood pressure, pulse oximetry, and provide a 5-lead EKG tracing. Some monitors may be equipped with defibrillation pads or devices to measure blood glucose. Ultimately it is at the discretion of the anesthesiologist as to which supplies, monitors, and medications are needed for patient transport. It may not be practical to travel with all of the drugs and supplies previously listed [9].

Hemodynamic monitoring in pediatric patients may be more challenging than in adults. One must realize hemodynamic values vary based on the age of the pediatric patient (see Table 15.1). Even more challenging is determining whether pediatric trauma patients are experiencing bleeding related to their injury or surgery, or, more importantly, are in hypovolemic shock. In adults, blood pressure and heart rate are more sensitive values used for diagnosing hypovolemic shock. On the other hand, as previously mentioned, children can maintain normal, age-specific blood pressures despite significant blood loss. For this reason, it is advisable to place an arterial line in all pediatric trauma patients for close blood pressure monitoring. An arterial line also allows for arterial blood gases and other labs to be easily obtained in the postoperative setting. A quick way to determine the normal systolic blood pressure of a child is to multiply the patient's age in years by

2 and then add 80. For newborns, the normal systolic blood pressure is approximately equal to their age in gestational weeks (i.e., 40 mmHg for a term infant). If hypovolemic shock is suspected in the postoperative setting, then a protocol for resuscitation should be followed, especially if the patient has become hypotensive. A bolus of 20 mL/kg of crystalloid should be given twice before initiating transfusion of type-specific, cross-matched PRBCs or O-negative type blood. If there is no improvement, then FFP and platelets should immediately follow the transfusion of blood [19].

Postoperatively, pediatric trauma patients may need to remain intubated with ventilator support. Thoracic trauma is common in pediatric trauma patients. The lung is often injured, even in the absence of rib fractures, due to the very compliant chest wall that allows direct transfer of energy to the lungs. Oxygenation may be compromised, and pediatric patients may present like adult patients present with acute lung injury (ALI) or acute respiratory distress syndrome (ARDS). Pediatric patients presenting with an ARDS-like picture should be treated with the treatment strategy of low tidal volumes (6 mL/kg) [15]. In addition to the lung protective strategy of low tidal volumes, specialized modes of ventilation have been used to help patients recover. High frequency (or oscillator) ventilation allows for continuous airway pressure and low tidal volumes with very high respiratory rates to help maximize the patient's oxygenation. The inspiration to expiration ratio can also be inversed, giving the patient more time in the inspiration phase, allowing permissive hypercapnia [18, 21–23]. When all ventilation modes fail, a trial of extracorporeal membrane oxygenation (ECMO) may allow the heart and lungs time to recover [8].

Postoperatively, we may find that not all of the injuries suffered during trauma were necessarily corrected with surgery. Other injuries may have been stabilized before surgery and require ongoing monitoring and care. The most notable of these injuries are possible cervical spine fractures. Several protocols have been suggested for cervical spine clearance, but there are no procedural or diagnostic standards. The care of patients with possible cervical spine fracture focuses on keeping the head in a neutral position. However, pediatric patients have larger heads than adults, and when lying supine a child's head is often slightly flexed. Extra padding behind the back, or specialized backboards, along with a cervical collar, can help keep the head in a neutral position. Other anatomic differences between children and adults include more flexible interspinous ligaments and joint capsules, vertebral bodies that will slide forward with flexion, flat facet joints, and a different head to neck ratio. Due to a disproportionately larger head, the greater laxity of interspinous ligaments, and flatter facet joints, cervical spine injuries in children are most likely to occur in the first three cervical vertebrae.

As we have continual postoperative hemodynamic monitoring for pediatric trauma patients who may have ongoing internal bleeding, the patient should also be continually observed to identify any undiagnosed fractures. Some pediatric patients may have difficulty communicating effectively due to age. This, coupled with the possibility of distracting injuries, may allow for an undiagnosed fracture to appear postoperatively. Children are at risk for multiple injuries based on their smaller body size. When caring for the pediatric trauma patient postoperatively, it should not be assumed that all of their injuries have been addressed. Bony fractures can also be more difficult to diagnose in pediatric patients due to the presence of growth plates. Given the previous statements, one should pay close attention to the patient's complaints of pain and their ability to move extremities or ambulate [1, 3].

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