Introduction

For the purpose of this chapter, infants are children between one month and twelve months of age. Most of them are healthy when they require surgery, but some can be quite ill. The function of many organs matures during this first year of life, and this must be taken into account when planning surgery. In some countries, many patients requiring anesthesia and surgery during the first year of life were born prematurely, and their surgery is to correct problems related to prematurity. This chapter discusses some common problems for which patients require surgery during the first year of life.

Overview of Physiologic Changes

The functions of many organs change during the first year of life and may be significantly different at 12-months of age than one-month of age. It is hoped that the information in this section will allow anesthetists to better understand events occurring during anesthesia and treat them appropriately.

Cardiovascular

For the first 6-12 months of life, heart rate is the major component of cardiac output. As the infant ages myocardial contractility becomes more important and heart rate less important (See Chapter 12). The cardiac myocytes of young infants are composed of 50% contractile elements and 50% water and ground glass substance. The contractile elements are arranged differently and contract less effectively. By about a year of age, contractile elements make up approximately 75% of myocyte volume; ground glass substance makes up the remaining 25%. Early in life, the excess ground glass substance makes the cardiac ventricles “stiffer” and less compliant. Consequently, giving fluid in excess of volumes needed to produce a normal blood volume only increases CO 15%, whereas in adults, it will increase it more than 100%. Increasing the infant’s heart rate (atropine, glycopyrolate), on the other hand, more than triples the CO of neonates. Drugs that decrease heart rate (fentanyl, propofol, halothane) decrease the infant’s CO to varying degrees. During anesthesia, decreases in CO seem to parallel decreases in oxygen consumption. Despite decreases in CO up to 50%, normal animals show no evidence of acidosis during anesthesia. The arterial blood pressure changes over the first year of life are shown in Table 8-1.
Table 8-1: Normal Arterial Blood Pressures and Heart Rates vs. Age

<table>
<thead>
<tr>
<th>AGE</th>
<th>Systolic (mmHg)</th>
<th>Diastolic (mmHg)</th>
<th>Mean (mmHg)</th>
<th>Heart Rate (BPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonate</td>
<td>70 ± 9</td>
<td>42 ± 12</td>
<td>55 ± 11</td>
<td>125 ± 25</td>
</tr>
<tr>
<td>1 Year</td>
<td>98 ± 4</td>
<td>53 ± 3</td>
<td>68 ± 3</td>
<td>90 ± 20</td>
</tr>
</tbody>
</table>

Of the three arterial blood pressures available (systolic, diastolic, and mean) mean arterial pressure is usually the most helpful in infants because it provides the “average” perfusion pressure to critical organs. Even if the arterial pressure tracing is damped, mean arterial pressure is usually correct. Arterial blood pressure can be measured in several ways (See Chapter 2). The easiest method is with an automatic blood pressure device (Figure 8-1); they are relatively expensive and sturdy. However, these devices tend to give higher arterial blood pressures, especially diastolic blood pressures, in infants than intravascular measurements.

Figure 8-1: An Automated Arterial Blood Pressure Monitor

This is an automated blood pressure monitor and cuff that measures pulse rate, and systolic and diastolic pressures. It can be fitted with a smaller cuff for use in neonates.
This figure shows the correct position of a blood pressure cuff in a child. The cuff width should also be 40% of the circumference of the upper arm at the mid point between the acromion and olecranon bones. Reprinted with permission from National Kidney Foundation, Inc. www.kidney.org

Arterial blood pressure can also be easily measured with a blood pressure cuff, an inflation bulb, and a manometer. This method works well for most patients, is portable, and can be easily taught to almost anyone. Position of the cuff on the arm or leg is important (Figure 8-2). Intra-arterial blood pressure measurements are important for sick infants because they provide beat-by-beat changes in arterial pressure. Intravascular catheters also allow the anesthetist to withdraw arterial blood for blood gases, pH and electrolyte determinations. There is a considerable amount of information available from the arterial pressure tracing besides the systolic, diastolic, and mean blood pressures. The upstroke (first part of the pressure wave) is an indication of myocardial contractility. The straighter (more vertical) the line, the better the myocardial contractility. On the other hand, if the line is bent over to the right (as in myocarditis and aortic valve stenosis), ejection of blood from the heart is delayed and decreased. The position of the dicrotic notch on the downslope of the pressure wave where the pressure increases slightly correlates with closure of the aortic valve at the end of systole. In normal adults and older children, the dicrotic notch appears in the upper one-third of the wave. In young children it is in the upper half. When the blood pressure is low or the peripheral vascular resistance is low, the
notch position is lower on the descending slope of the pressure wave. Several alterations of the pressure wave are associated with hypovolemia. The first is narrowing of the pressure wave. The second is lower position of the dicrotic notch on the down slope of the wave. Third is a decrease in the arterial blood pressure with inspiration, especially with mechanical ventilation (Figure 8-3). This change in pressure with ventilation is due to inspiratory pressure-induced decreases in venous blood return to the heart. During expiration pressure in the lungs decreases, and arterial pressure increases as blood returns to the heart. All of these features of the arterial pressure tracing can and should be used to determine the adequacy of the intravascular volume when it is possible to measure intra-arterial pressures. The blood volume of term babies is about 90ml/kg and decreases to 80ml/kg by one year of age.4

**Figure 8-3: Intravascular Arterial Pressure Tracings**

![Arterial Pressure Tracings](image)

_Figure A shows the arterial blood pressure tracing of hypovolemic infant. The arrows indicate inspiration. With each inspiration, the arterial blood pressure decreased >50%. During expiration the pressure was normal. Figure B shows the arterial pressure tracing from a normovolemic patient. Note that there was a <5% decrease in the systolic blood pressure with each breath (arrows)._5

**Pulmonary**

The lungs are not fully developed at birth, although they allow adequate oxygenation and ventilation for the baby’s needs. At birth there are only 40-50 million alveoli; by one year of age there are about 350 million.6 The normal respiratory rate at birth is higher than that at one year of age (Table 8-2).
Table 8-2: Normal Pulmonary Function: Neonate, Infant, Adult

<table>
<thead>
<tr>
<th>Variable</th>
<th>2-10 Weeks</th>
<th>9-12 Months</th>
<th>Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>4.7 ± 1.2</td>
<td>9.6 ± 1.2</td>
<td>70 ± 10</td>
</tr>
<tr>
<td>Heart Rate (bpm)</td>
<td>120-150</td>
<td>80-120</td>
<td>60-80</td>
</tr>
<tr>
<td>Vt (ml)</td>
<td>21 ± 1.8</td>
<td>23 ± 4.3</td>
<td>500 ± 50</td>
</tr>
<tr>
<td>Crs (ml/cm H₂O)</td>
<td>5.5 ± 1.65</td>
<td>11.5 ± 2.4</td>
<td>100 ± 20</td>
</tr>
<tr>
<td>Rrs cm (H₂O/ml/sec)</td>
<td>0.084 ± 0.021</td>
<td>0.042 ± 0.011</td>
<td>0.5-2.5</td>
</tr>
<tr>
<td>FRC (ml)</td>
<td>88.1 ± 26.8</td>
<td>178.4 ± 29.0</td>
<td>3000 ± 600</td>
</tr>
</tbody>
</table>

Kg = kilograms; ml = milliliters; Sec = seconds; Vt = tidal volume; Crs = compliance of respiratory system; Rrs = resistance of respiratory system; FRC = Functional residual volume. These are a compilation of data from Hanrahan JP, Brown RW, Carey VJ, Castile RG, Speizer FE, Tager IB. Am J Resp Care Med 1996;670-80; Nguyen TTD, Hoo Ah-F, Lum S, Wade A, Thia LP, Stock J Pediatr Pulmonol 2013;48:370-80.

Because there are fewer alveoli and more connective tissue in the lungs of neonates, their lungs are stiffer, i.e., less compliant. As the infant grows, the lungs become more compliant, which takes less work to breathe. Neonates breathe 30-60 times a minute, and the one-year-old breathes 20-30 times per minute to maintain the same, normal PaCO₂. Tidal volume is about the same for everyone, infants and adults, about 7-10cc/kg. Therefore, for the PaCO₂ to be the same with a lower respiratory rate, the tidal volume of each breath must increase, which it does. Blood gases change during the first few months of age (Table 8-3).

Figure 8-3: Normal Blood Gases and pH -f Neonates and 1-Year Olds

<table>
<thead>
<tr>
<th>Variable</th>
<th>Neonate</th>
<th>Infant</th>
</tr>
</thead>
<tbody>
<tr>
<td>PaO₂ (mmHg)</td>
<td>55 - 85</td>
<td>85 - 100</td>
</tr>
<tr>
<td>PaCO₂ (mmHg)</td>
<td>35 - 45</td>
<td>35 - 45</td>
</tr>
<tr>
<td>pH</td>
<td>7.36 - 7.43</td>
<td>7.34 - 7.44</td>
</tr>
<tr>
<td>BE (meq/l)</td>
<td>-3 - +3</td>
<td>-2 - +2</td>
</tr>
<tr>
<td>SaO₂ percent</td>
<td>9 - 100</td>
<td>96 - 100</td>
</tr>
</tbody>
</table>

PaO₂ = partial pressure of oxygen; PaCO₂ = partial pressure of carbon dioxide; BE = base deficit (excess); meq/l = milliequivalents/liter. Partially modified from Siberry GK, Iannone R. The Harriet Lane Handbook, Mosby, St Louis, MO, 2000.

Because the chest walls of neonates is much more compliant than their lungs, neonates usually have atelectasis for much of the first month of life, and this is reflected in their PaO₂, i.e., the PaO₂ is lower in neonates and increases to adult levels by about a month of life as the ribs begin to calcify and they maintain a negative intrathoracic pressure at end-expiration. The neonate’s functional residual capacity (FRC - volume of gas remaining in the lung at the end of expiration) is smaller than that of older children and adults (neonates = 30ml/kg; one year old = 40 ml/kg).
Chapter 8: ANESTHESIA FOR INFANTS

This means that neonates and young infants have less total oxygen in their lungs at end-expiration (25cc in 1mo old; 84cc in 1yr old) [weight in kg x FRC in ml x 0.21% oxygen], if he/she is breathing room air. The infant’s oxygen consumption is about 10cc/kg, which means there is only enough oxygen for about 1-2min before they become hypoxic. Cardiac output (250-300cc/kg/min, in neonates and 70-80ml/kg in adults) also affects the rate of developing hypoxemia. Higher COs remove oxygen more quickly from the lung. The net result of a smaller FRC, higher oxygen consumption, and higher cardiac output is more rapid oxygen desaturation in young infants (often in about 1-2min). Oxygen desaturation occurs commonly in infants during the induction of anesthesia due to inadvertent hypoventilation or the administration of narcotics or inhaled anesthetics.

Renal

The urinary tract consists of two kidneys, two ureters, a urinary bladder and a urethra. Urine is produced by 10-12 weeks gestation See Chapter 3 for development of the urinary system and function. In utero, urine produced is excreted into the amniotic fluid. Failure to make or excrete urine and maintain a normal amniotic fluid volume causes compression of the infant’s chest and underdevelopment of the lungs. This often results in respiratory distress at birth and necessitates prolonged mechanical ventilation. Multiple sites in the urinary tract are prone to develop abnormalities and obstruction during fetal life. These include the urethra (urethral valves), the ureterovesico junctions (i.e., where the ureters enter the bladder), and the ureteropelvic-junction (where the ureters connect with the kidneys). In neonates, symptoms caused by urine blockage include: fever, not eating, irritability, diarrhea, vomiting, frequent urination, and the presence of dark, cloudy or bloody, foul-smelling urine. Untreated urinary tract obstructions can cause developmental abnormalities of the kidneys, or if severe enough, to not function at all.

Developmental genitourinary anomalies often require surgical repair during the first year of life. These include posterior urethral valve, ureteral obstruction, vesicoureteral reflux, cayliceal abnormalities, renal and adrenal tumors, and extrophy of the bladder. The following is a discussion of the types of surgery commonly seen in patients between one month and one year of age.

Posterior urethral valves (PUV) are present in about 1:8,000 live births, primarily in males. PUVs are the result of an abnormal membrane that crosses the opening from the urinary bladder to the urethra. This is the primary cause of bladder outlet obstruction in neonates. Symptoms include: low amniotic fluid volume, a distended bladder, and in some patients respiratory failure from hypoplastic lungs. The diagnosis of posterior urethral valves is frequently made by an ultrasound examination of the abdomen, which shows the distended bladder, hydronephrosis, a thick bladder wall, and bladder diverticula. A surgeon makes the diagnosis at cystoscopy when he/she visualizes the posterior urethral valve. The treatment of posterior urethral valves is relatively
simple. The abnormal tissue is ablated surgically during cystoscopy, which opens the urethra to urine flow.

_Ureterovesical-junction (UVJ) obstruction_ is due to insufficient lengthening of the ureter, which prevents normal formation of the ureterovesical valve at the junction of the ureter and the bladder. When this occurs, the open valve allows reflux of urine from the bladder into the ureter. This prevents normal kidney growth and functioning, placing the kidney and ureter at risk for developing postnatal urinary tract infections (UTIs). During physical examination, it may be possible to palpate an enlarged kidney. Some times, it is possible to palpate an enlarged ureter. The infant’s kidney is palpated by placing one hand behind the upper abdomen and the other on the abdomen just below the right costal margin (Figure 8-5). By moving the front hand back and forth and pressing gently downward, one can usually feel the kidney as a globular mass. If it is enlarged, it is easy to feel the kidney. An ultrasound of the abdomen will show the kidney and the obstruction. Treatment may include daily administration of antibiotics to prevent urinary tract infections, but surgery is the only definitive treatment of this lesion.

**Figure 8-5: Palpation of the Infant Kidney**

![Image of kidney palpation](ped10012 www.fotosearch.com)

*See text above for description of kidney palpation. With Permission.*

_Ureterocele_ is another form of UVJ obstruction. A portion of the ureter fails to develop normally where it enters the bladder, and this abnormality bulges into and obstructs urine flow into the bladder. As a result, the ureter dilates, and the kidney develops hydronephrosis. Surgery is the
primary treatment of this lesion.

*Ureteropelvic junction (UPJ) obstruction* is a condition in which blockage of the junction between the ureter and the kidney reduces/prevents urine flow from the kidney to the ureter. This results in hydronephrosis (distention of the kidney pelvis and calices with urine) and abnormal kidney maturity. The diagnosis is ultimately made by ultrasound, but can be suspected during physical examination by feeling a large kidney (See above). When available, radionuclide scans can be helpful, as is ultrasound. Antibiotics are usually given preoperatively to reduce the incidence of UTI.

Diagnosis of urinary tract obstruction is most easily made by ultrasound. It is also important to search for abnormalities in serum electrolytes. Whether electrolyte abnormalities occur or not depends on whether one or both kidneys are obstructed. Compensation by a non-obstructed kidney may lead to normal serum electrolytes. If both sides of the urinary tract are involved (e.g., posterior urethral valves), both kidneys may be abnormal. These patients may well have electrolyte abnormalities. Acidosis or hyperkalemia (K+ >5meq/l) increase both the number of arrhythmias during anesthesia and the risk of cardiac arrest. The likelihood of cardiac arrest happening increases when serum K+ concentrations exceed 6meq/l. Hypernatremia (elevated sodium concentration) occurs when patients cannot excrete normal amounts of sodium (Na+) due to the renal failure and blockage. Hypermagnesemia may also occur. If it does it may affect the central nervous system, muscles, heart and blood vessels (hypotension, bradycardia), and in severe cases it may causes coma and cardiac arrest. If possible, electrolyte abnormalities should be corrected preoperatively. However, this is not always possible.

Definitive treatment of urinary tract anomalies is usually surgical, usually when the patient is less than one year old. Because of their young age, these patients require general anesthesia, even though some bladder procedures can often be done endoscopically. When the patient has no IV preoperatively, one can be inserted after the induction of anesthesia with inhaled anesthetics (halothane, sevoflurane). If the patient has an IV, anesthesia can be induced with oxygen, propofol 2-3mg/kg or sodium pentothal 4-6mg/kg IV. Because these procedures are frequently lengthy, it is better to intubate the trachea and control ventilation during surgery when possible. Surgical retraction and positioning of the patient for surgery often make spontaneous breathing ineffective.

Intraoperative noninvasive arterial blood pressure, ECG, and SaO2, and temperature are adequate monitoring for most of these patients. However, it may be necessary to measure electrolyte concentrations intraoperatively in some patients. Temperature measurement is important because manipulation of infected kidneys, ureters, and the urinary bladder may lead to hyperthermia with temperatures of >40°C. When this occurs, the anesthetists must quickly determine if the fever is due to seeding the circulation with bacteria or to malignant hyperthermia *(See Chapter 23).*
Fluid and electrolyte administration can be complicated for these patients, especially if they have fluid retention or electrolyte abnormalities. Some of these infants have fluid retention and edema because there urine output is low. It is important to determine this preoperatively so that fluid administration can be adjusted to compensate for any hypovolemia present (See Chapter 14). An enlarged liver suggests right ventricular failure. This should lead the anesthetist to cautiously give intraoperative fluids and not cause further volume overload and worsening right ventricular failure. Fluids should be limited to only those amounts that are necessary to maintain normal perfusion and arterial blood pressure.

If the child has hyperkalemia, mild hyperventilation may reduce the serum \( K^+ \) concentration slightly, but may also increase the likelihood of a seizure, especially if the patient is hypocalcemic. The pH should be maintained within the normal range when possible. On the other hand, hypoventilation will make existing hyperkalemia worse, because extracellular hydrogen ion (\( H^+ \)) is exchanged for intracellular potassium, which raises serum potassium concentrations even higher. If the serum ionized calcium concentration is reduced, it may be necessary to give calcium gluconate or calcium chloride to correct the abnormality. Hypocalcemia plus hyperventilation may lead to seizures. Hyperventilation must be avoided. Being able to measure end-tidal CO\(_2\) is very helpful for maintain ETCO\(_2\) concentrations.

Anesthetists should plan for treatment of postoperative pain (See Chapters 20 and 21). The simplest and most effective method of relieving pain is with a caudal or epidural anesthetic that is placed after the patient is asleep. As long as the patient is cared for in a monitored unit postoperatively, a catheter can be placed in the caudal or epidural spaces and the patient can be given repeated doses of local anesthetic and preservative free morphine or fentanyl (See Chapter 21) in the intensive care unit (ICU). If this cannot be done, pain can be relieved with narcotics, if available, nonsteroidal ant-inflammatory drugs (NSAIDs), or acetaminophen, tramadol (See Chapters 18 and 20).

**Ear Nose and Throat**

Tonsillectomy and/or adenoidectomy (T & A) are two of the most common ear, nose, and throat procedures done in infants. They are usually performed because the infant has chronic tonsillitis or enlarged tonsils and adenoids that obstruct her/his airway. Infants with severe obstruction may develop sleep apnea and may go on to develop pulmonary hypertension.

*Sleep apnea* occurs in two percent of infants with enlarged tonsils.\(^7\) Patients with this condition pause their breathing or stop breathing all together for varying amounts of time or have shallow or infrequent breathing when asleep. Apnea is defined as cessation of breathing for 20 seconds or more. Periodic breathing occurs when breathing stops for <15 seconds. Repeated apneic periods may lead to hypoxemia and acidosis, pulmonary vasoconstriction, and eventually pulmonary hypotension. In rare cases it may lead to right ventricular failure. If it is believed that
the patient has pulmonary hypertension, the anesthetist must determine the degree of pulmonary artery obstruction present and whether it is fixed or not. If it is fixed, the pulmonary vessels fail to dilate with breathing 100% oxygen or nitric oxide, or with respiratory alkalosis. There are three types of apnea: central (CSA), obstructive (OSA), and mixed.

CSA is characterized by a lack of respiratory effort due to lack of central nervous system signaling to initiate breathing. This is the least common type of OSA. Ondine’s Curse (failure to breath when asleep) is one form of CSA and is usually fatal.

OSA is relatively common and is caused by relaxation of the pharynx and the genioglossis and hyoglossal muscles. This causes airway obstruction that is made worse during inspiration and leads to snoring. As with most upper airway obstructions, the tongue “falls back” in the throat and partially obstructs the airway. During inspiration, the patient attempts to overcome the obstruction by generating more negative pleural pressures. The increased negative pressure “pulls” the tongue against the pharyngeal wall, increasing airway obstruction. Because there is little or no air movement, PaCO2 increases and SaO2 decreases. The increased CO2 awakens the patient and he/she begins to breath. Patients with OSA often make respiratory motions (the chest moves) during inspiration, but little or no gas moves into the lungs. Children with OSA have excessive sleepiness during the day, difficulty with school (if they are school age) and enuresis (bed wetting). They are often belligerent and hard to get along with. Measuring and recording SaO2 throughout a night is useful for the diagnosis of obstructive sleep apnea. Hypoxemia, sleep deprivation, obesity, exposure to cigarette smoke makes OSA worse. Treatment may include decreasing exposure to cigarette smoke, weight loss, sleeping upright or on side, nasal continuous positive airway pressure (CPAP), or other methods of keeping the pharynx open during sleep. Tonsillectomy and adenoidectomy are often the best choice. Patients with sleep apnea will usually not be immediately better after T & A. It may take months for their sleep apnea to go away. Thus, the patient must be observed carefully for signs of OSA, and if the patient was using CPAP preoperatively, he/she should continue to do so after surgery.

Mixed sleep apnea is characterized by the presence of both OSA and CSA simultaneously. Many of these patients have abnormal response to CO2 and may not awaken as easily form apnea.

History and Physical Examination

Performing an effective history and physical examination is important in all patients, but is especially important in those undergoing T & A. What symptoms is the patient having? Why is the patient having surgery? Is it because he/she has repeated tonsillitis, or is it because he/she has sleep apnea (See above)? Does he/she have difficulty drinking/eating and swallowing? Does he/she have difficulty exercising (if old enough)? If so, is it due to airway obstruction? Can the patient open her/his mouth – how far? Are the tonsils enlarged (touching each other)? Can the patient breath through her/his nose when their mouth is closed, or are her/his adenoids so large
Anesthesia Care of Pediatric Patients (George A. Gregory & Dean B. Andropoulos)

they obstruct the airway? In infants, closing the child’s mouth and placing a few strands of cotton in front of a nostril helps evaluate whether the child can breath through her/his nose. If the cotton moves with breathing, the nose is not obstructed. Then test the other nostril. Is the second heart sound louder than the first sound? This occurs when there is an element of pulmonary hypertension. Is the liver enlarged? It should normally be 1-2cm below the right costal margin. If it is larger than this, it may be due to an element of right ventricular failure that is the result of pulmonary hypertension. Infants with pulmonary hypertension seldom have enlarged neck veins, as adult do. Are the pulses normal or are they decreased? This could indicate some degree of myocardial failure. Is the child well hydrated and making urine (See Chapter 1)? If the patient has some heart failure and is hypovolemic, cardiac output will be inadequate when the patient is anesthetized. Is the patient’s blood pressure normal for age (See Appendix 1)? Are the breath sounds normal or are they decreased due to airway obstruction?

Anesthesia is usually induced with inhaled anesthetics and the concentration of anesthetic increased over several minutes. A positive end-expiratory pressure of 5-10cmH₂O is used to open the pharynx and prevent the tongue for obstructing the airway. CPAP prevents the airway from completely collapsing and causing total airway obstruction at very light levels of anesthesia. If necessary an oral airway can be inserted, assuming the anesthetist can get it between the enlarged tonsils. Inserting a nasal airway is usually is not a good idea in patients who have enlarged adenoids because doing so may dislodge a portion of the soft, infected adenoids. When this occurs, there may be significant bleeding that will make ventilation of the patient’s lungs more difficult and may make it more difficult to see the glottis and intubate the trachea. An oral RAE tube (See Chapter 7) is used when available, because this removes the tube from the surgeon’s field and makes it easier for her/him to see. The surgeon must take care not to touch the tracheal tube with a cautery to avoid initiating an airway fire.

Three things are need for an airway fire to occur: 1) Oxygen >30% or nitrous oxide; 2) Something that will burn (tracheal tube or sponges; 3) A spark (cautery). All of these are present during a T & A. Use of a cuffed tracheal tube reduces the amount of oxygen leaking around the tracheal tube and decreases the concentration of oxygen in the posterior pharynx to that of room air. If there is a leak of anesthesia gases around the tracheal tube during ventilation, the concentration of oxygen in the pharynx may increase when more than room air (21% oxygen) is used for the carrier gas, and this will be a potential source of combustion. If possible the inspired oxygen should be kept below 30 percent throughout surgery because this reduces the likelihood of fire. In all cases, the surgeon should not touch the tracheal tube with an electrocautery. If a fire occurs, Figure 8-6 shows actions that should be taken. Survival of these patients depends on rapid treatment of the problem and on the extent of the burn.
Table 8-6: Outline for Action During a Tracheal Fire

- Fire
- Inform anesthetist/surgeon/Nurses
- Stop Ventilation - Disconnect Circuit
- Remove Tracheal Tube - Extinguish Fire
- Ventilate Lungs With 100% Oxygen Bag-and-Mask
- Direct Laryngoscopy To Remove Debris
- Bronchoscopy/Bronchial Lavage
- Reintubate Trachea/Extensive Burn Consider Tracheostomy
- Chest X-ray - Assess for Inhalation of Smoke
- Mechanical Ventilation
- Brief Course of High Dose Steroids

This plan of treatment should be understood by everyone in the operating room and be initiated immediately.8

Young children are frequent victims of otitis media and require incision and drainage of the middle ear and/or placement of ear tubes to equalize the pressure inside the middle ear with that in Eustachian tubes. Both procedures are quick and are easily done with an inhaled anesthetic delivered through a facemask. It is important that the head not move while incisions are made in the eardrum or when tubes are being inserted. This is especially important if the surgeon is performing the procedure with the aid of a microscope. Very slight movements are magnified by the microscope, which makes it difficult for the surgeon.
Tracheostomy is sometimes required in infants. If possible, a tracheal tube or LMA is inserted to control the airway during surgery because the complication rate of tracheostomy is lower when this is done. Infants have small necks. Thus, there is a greater chance of injuring the carotid artery or jugular vein during tracheostomy. For this reason, it is important to have a good IV for this procedure. Occasionally, air dissects along the pre-tracheal fascia and causes a pneumothorax or a pneumomediastinum.

Stridor is common in infants due to abnormalities of their larynx and trachea. Stridor is a high-pitched musical breath sound that is caused by turbulent airflow in the larynx, trachea, or bronchi. It is the result of narrow or obstructed airways and can be inspiratory, expiratory, or both. However, it is usually heard during inspiration, often when a patient has croup. Epiglottitis, a foreign body in the airway, or uncommonly laryngeal tumors can be the cause of stridor in infants. Glossoptosis (a tongue that is too large for the mouth) or a small mandible (Pierre Robin Syndrome) may also cause Stridor.

Neurosurgery

Neurosurgery is not commonly required during the first year of life, except in a few instances (See Chapter 10). One of these instances is treatment for hydrocephalus.

Hydrocephalus occurs when there is a disturbance in the balance of cerebral spinal fluid (CSF) production and removal. Under normal circumstances the balance between these two variables results in a relatively constant volume of CSF and a relatively constant intracranial pressure (ICP). When this balance is disrupted, the volume of CSF and the ICP increase. If the increase in pressure is excessive, it interferes with cerebral blood flow (CBF) and with tissue oxygenation and nutrition. Symptoms of increased ICP in an infant include irritability, inability to console the infant, vomiting, and when the pressure is high, somnolence. If this goes on for a period of time, the baby may stop breathing and have a cardiac arrest. Removal of excess CSF from the brain is the only treatment of hydrocephalus. However, the excess CSF should not be removed by spinal tap, as a sudden decrease in ICP below the brain may cause the increased pressure in the brain to force the brainstem through the foramen magnum, causing apnea, unstable cardiac conditions, and death. Placing an intraventricular to peritoneum shunt is the definitive treatment for hydrocephalus. This requires a small craniotomy to place a pressure relief valve into the ventricle through the brain. The external portion of the pressure valve is connected to a catheter that is passed subcutaneously into the peritoneal cavity where excess CSF is drained. This CSF is absorbed from the peritoneal cavity. As a temporizing measure, the neurosurgeon can place a catheter transdermally into a cerebral ventricle. The catheter is connected to a sterile bag. A stopcock in the system is intermittently turned to drain CSF.
Anesthesia is usually provided by sevoflurane or by intravenous narcotics and propofol. Both drugs can depress respiration and increase the PaCO₂, which will increase the ICP further. Therefore, it is prudent to ventilate the patient’s lungs to maintain a normal PaCO₂. When available, the best way to maintain the PaCO₂ normal is by measuring end-tidal CO₂. If the child’s PaCO₂ was elevated for some time, he/she may have compensated for the increased CO₂ by accumulating sodium bicarbonate in the blood. If this occurred, it is easy to hyperventilate these small children and make them very alkalotic, which will markedly reduce cerebral blood flow. If the alkalosis goes on for very long, CNS injury may occur. Care must also be taken keep the arterial blood pressure at or near the preoperative pressure to help maintain adequate CBF. Having an elevated ICP and a decreased arterial blood pressure will cause marked cerebral hypoperfusion and CNS injury. The SaO₂ should be kept above 96 percent by increasing the inspired oxygen concentration (FiO₂) if needed. Sudden decreases in ICP may lead to hypotension, for reasons not clearly identified. At the end of surgery, removal of the tracheal tube occurs when the patient is breathing adequately and maintaining a normal (for the patient) end-tidal CO₂ or PaCO₂. Pain is usually not a significant component following a VP shunt and can
be treated with NSAIDS or acetaminophen. It is better to avoid administering narcotics to these patients for pain because it may increase the incidence of apnea after surgery. The surgeon can place long-lasting local anesthetics (Marcaine 0.25%) in the scalp and abdominal incisions.

Unfortunately, VP shunts become obstructed and require replacement. Catheter infections are also common, which necessitates removal of the shunt, placement of an external drain, and treatment with antibiotics until the infection has cleared. Then a new VP shunt can be paced.

**Arterial-venous malformations (AVM)** are relatively uncommon lesions in infants. Abnormally developed intracranial vessels, both arterial and venous, cause these malformations. At times blood flow through these abnormal vessels is so extensive that patients develop high-output heart failure (gallop rhythm, hepatomegaly, and a murmur or bruit heard over the anterior fontanel. The echocardiogram of patients with high-output failure, if available, will shows cardiac ventricular dysfunction and dilatation of the right atrium. The heart rate is elevated and the pulses are often diminished, due to the heart failure. Pulmonary edema may occur. Treatment of AVMs includes injecting material into the vessels to occlude them and reduce the high output failure.

Anesthesia for patients who have an AVM and high-output failure requires close attention to the patient’s cardiovascular system. How is the heart failure being treated? Is the patient receiving diuretics, and is her/his fluid intake being limited? If either is true, the patient may be intravascular volume depleted and in heart failure. Is the patient receiving vasoactive drugs, such as dopamine hydrochloride, to improve myocardial function? If so, the drug should be continued during anesthesia and the dose adjusted as needed. When the arterial-venous malformation is partially or totally occluded by the procedure, cardiac output will decrease towards normal and the dose of dopamine or other vasoactive drugs may have to be decreased rather rapidly. Inserting an arterial catheter to measure beat-to-beat variation in arterial blood pressure is important and should be done when possible. This catheter not only allows measurement of arterial blood pressure but also permits the anesthetist to obtain blood for determining acid-base status and blood gases. Arterial blood gases should be maintained as normal as possible because acidosis or alkalosis may worsen any heart failure present. It is common for radiologists to use large volumes of “flush” solution and dye during the procedure, which may worsen the heart failure before the vessels are occluded. It is important to keep track of the volume of blood taken out and of fluid and dye given. Continuous measurement of urine output is also important, as an excess of dye can either increase urine output and cause hypovolemia or decrease renal function. It is usually necessary to mechanically ventilate the patient’s lungs during and after surgery. Using a PEEP of 5-10cmH2O usually improves oxygenation.

**Tethered spinal cord** is a common complication of spina bifida and is often repaired during the first year of life (**See Chapter 10**). A tethered spinal cord occurs when tissue attachments prevent the spinal cord from moving in the spinal column. As the child grows, this lack of movement
stretches the spinal cord, and this may cause neuologic symptoms; including pain and incontinence; it may also cause scoliosis. Patients with a tethered spinal cord frequently have dimpled skin over the lower spine; some children have fatty tumors on the lower back. Deformities of the feet are common, as is progressive leg weakness.

Excision of spinal tumors and correction of myelomeningocel are uncommon in this age group (See Chapter 10).

**Pulmonary**

There are a few reasons that infants require anesthesia for thoracic surgery during the first year of life. These include: Bronchogenic lung sequestration, congenital lobar emphysema, and bronchogenic cysts, which will not be discussed here (See Chapter 11).

At times, infants require *bronchoscopy* for diagnosis of tracheal or laryngomalacia, to remove foreign bodies, and for tumors. Patients requiring bronchoscopy commonly have respiratory distress, including intercostal, substernal, sternal, and suprasternal retractions; tachypnea; grunting respirations; wheezing; and occasionally cyanosis. The retractions are evidence of increased work of breathing. Grunting respiration is evidence of loss of FRC and occurs because the baby is attempting to increase FRC by rapidly taking in a breath and exhaling slowly through partially closed vocal cords. Grunting is heard during exhalation. Tachypnea, rather than deeper inspirations, occurs because it is less work for a child with a relatively unstable chest wall to breath rapidly and shallowly than it is to take deeper breaths. Taking deep breaths tends to increase chest distortion and decrease effective breathing. Rapid breathing also helps maintain FRC by decreasing the amount of time available during expiration to empty the lung of gas. This improves oxygenation.
There are two forms of bronchoscopy, fiberoptic and rigid (Figure 8-8).

**Figure 8-8: Types of Bronchoscopes**

![Types of Bronchoscopes](Image)

On the left is a **fiberoptic bronchoscope**, which is compared to a rigid scope (middle of image). The fiberoptic scope easily passes through an appropriate size tracheal tube. The light is very bright and the optics provide very clear images of the airways. This device is useful for observing movement of the airways during breathing. On the right are images of **rigid bronchoscopes** with three graspers above for obtaining tissue or removing foreign bodies from the airways. Below (in order) are the light source and two bronchoscopes of different sizes. There is a connector for delivering oxygen or connecting a ventilator to the device to breath for the patient during bronchoscopy.

**Fiberoptic bronchoscopy** (Figure 8-8 on left) is often used to evaluate dynamic changes in the airway. The simplest way to do this is to insert an LMA and place the bronchoscope through the LMA while the patient inhales anesthesia and oxygen. The vocal cords are easily identified through the laryngeal end of the LMA and this allows the bronchoscopist to visualize the vocal cords and determine if they move normally during spontaneous breathing. Once the vocal cords have been examined, local anesthesia (2% lidocaine sprayed through an atomizer – max dose 7mg/kg with epinephrine and 4mg/kg without epinephrine) can be sprayed on the vocal cords and the bronchoscope can then be advanced through the vocal cord into the trachea to determine if the airway moves normally during inspiration or collapses.
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*Rigid bronchoscopy (Figure 8-8 on right)* uses a rigid metal tube and a light source. It is especially useful for biopsying tumors and for removing foreign bodies from the airway. Aspiration of foreign bodies occurs in this age group of patients because they place things into their mouths and have relatively poor control of swallowing. Peanuts are common foreign bodies that infants aspirate. Once aspirated, peanuts swell and obstruct airways. They may not be easy to remove in tact because they disintegrate when touched with a grasper.

Anesthesia for bronchoscopy is provided in one of several ways. Inhalational anesthesia is often used because it tends to depress respiratory reflexes and reduce coughing, gagging, and laryngospasm when the scope is inserted. Because a fairly deep level of anesthesia is required to block airway reflexes, hypotension may occur and may require treatment with drugs such as ephedrine (100-200mcg/kg). The dose may have to be repeated. To get around this problem, some anesthetists give muscle relaxants and paralyze the patient. While paralyzed, the patient’s lungs must be ventilated through the bronchoscope. This is accomplished during rigid bronchoscopy by adding oxygen to the side port of the bronchoscope and intermittently occluding the end of the bronchoscope with a finger. When the bronchoscope is occluded, the oxygen flowing into the lungs expands the chest and gives a “breath”. Removing the finger from the end of the bronchoscope allows exhalation. During fiberoptic bronchoscopy, the bronchoscope is inserted through the LMA or tracheal tube and the lungs are ventilated with a mechanical ventilator or Jackson-Reese system. A biopsied tumor may cause airway bleeding. If this occurs it may be necessary to quickly advance a tracheal tube into the opposite main stem bronchus and provide one-lung ventilation.

*Laryngotracheal polyps* are benign airway lesions that can obstruct the larynx, trachea, and bronchi, depending on their location. They may be due to the human papilloma virus or airway trauma (tracheal intubation, tracheostomy). The lesions are often recurrent and can severely obstruct the airway, especially when more than 50% of the airway is occluded. Symptoms of obstruction include: dyspnea (difficult or labored breathing), occasionally cyanosis, inspiratory retractions, use of accessory muscles of breathing (intercostal muscles, nasal flaring), wheezing or decreased breath sounds, stridor.

These polyps are usually removed surgically. In developed countries, this is done with a laser and then covered with podophyllin to suppress polyp regrowth. When no laser is available, they are removed with a cautery and then threatened with podophyllin. If it is necessary to intubate the trachea to treat these lesions, the tracheal tube should be taped with aluminum foil tape to reduce the possibility of an airway fire; <30% oxygen should also be used during laser or cautery use (See Above). Induction of anesthesia in children with airway polyps can lead to total airway obstruction. Many practitioners permit these patients to breathe spontaneously throughout the procedure once the airway is secured. If possible, the tracheal tube should not pass through the polyps (except in an emergency) or the polyps may be pushed deeper into the airway and seed
new areas. Positive pressure ventilation may do the same. If it is possible for the surgeon to remove a large portion of the polyps, there will be less airway obstruction at the end of surgery. If so the tracheal tube can be removed before the patient awakens from anesthesia.

**Abdominal Surgery**

Infants often undergo abdominal surgery for inguinal hernia repair, urology procedures, necrotizing enterocolitis (NEC), imperforate anus, Hirschprung’s disease, duodenal atresia, bowel obstructions, and pyloric stenosis.

**Inguinal Hernias**

Inguinal hernias occur in 0.8% - 4% percent of children born at term and about 10% of those born prematurely. Hernias are more common in males. Fifteen-twenty percent of inguinal hernias are bilateral. They can be either symptomatic or asymptomatic. An inguinal hernia is diagnosed when a bulge is found in the labia, scrotum, or groin that gets larger with crying, upright position, or moving. If a hernia cannot be reduced (incarcerated) or the blood supply is obstructed (strangulated), the hernia is accompanied by pain. Incarceration occurs in about 15% of all patients with hernias and in nearly 30% of infants with hernias. Strangulated hernias are often associated with a bowel obstruction. Surgeons try to reduce hernias (i.e., return them to the abdomen) to rule out the presence of strangulation or to prevent it from happening. Narcotics are given to treat the pain, and the child is placed in a head down (Trendelenburg) position while gentle pressure is applied over the hernia. This reduces the hernia into the abdomen in about 75% of instances. Children with strangulated hernias often have evidence of bowel obstruction (vomiting, abdominal distention, fever, and/or abdominal pain). If the hernia cannot be reduced, urgent surgery is required to relieve the obstruction and prevent bowel death.

Anesthesia for patients with strangulated or incarcerated inguinal hernias is not different from that for patients with other bowel obstructions. They should be considered to have a full stomach and to be at risk for vomiting and aspiration of gastric contents. Sufficient suctioning should be available to quickly remove any material found in the mouth. If possible, a nasogastric or orogastric tube should be inserted before inducing anesthesia to remove as much gastric fluid and material as possible, although suctioning will not remove everything from the stomach. When possible, anesthesia should be induced in a head up position while holding cricoid pressure. Pressure is applied over the crycothyroid cartilage in a backward, upward direction (Figure 8-9).
Figure 8-9: Cricoid Pressure

Cricoid pressure is applied over the cricoid cartilage in a backward and upward direction. This figure shows a completely occluded esophagus with this maneuver. However, cricoid pressure fails to occlude the esophagus in about 15% of patients due to anatomic variations in the position of the esophagus. From: intranet.tdmu.edu.ua

If excessive cricoid pressure is exerted, the soft trachea may also be obstructed, making it more difficult to breathe for the patient or intubate the trachea. In addition, excessive pressure may make it difficult or impossible for the patient to breathe spontaneously. There is continuing debate about whether or not anesthetists should ventilate the patient’s lungs when cricoid pressure is being applied. If there is a delay in accomplishing tracheal intubation, the patient’s lungs should be gently ventilated with oxygen by bag-and-mask to maintain oxygenation. If excessive cricoid pressure prevents insertion of the tracheal tube, cricoid pressure is relaxed slightly to allow the tracheal tube to be inserted.

There is debate about whether anesthesia should be induced by mask or by rapid-sequence if the inguinal hernia is incarcerated or strangulated. If the patient has an IV, he/she can be oxygenated for 3-5 minutes while breathing spontaneously, following which propofol 3mg/kg and
succinylcholine 1-2 mg/kg are given intravenously. The succinylcholine should be preceded by 30mcg/kg of atropine to prevent succinylcholine-induced bradycardia and decreased cardiac output. As soon as the patient stops breathing, a tracheal tube is inserted and the lungs are ventilated with oxygen. When the anesthetist is certain the tracheal tube is in the correct position and the lungs can be ventilated adequately, cricoid pressure can be released. If the patient has no evidence of bowel obstruction, anesthesia can be induced via a mask and an IV can be inserted.

Caudal anesthesia can also be used to provide excellent pain relief after surgery in patients who have hernias without a bowel obstruction (See Chapter 21). Spinal anesthesia has been used with great success for infants with inguinal hernias. However, the pain relief provided by spinal anesthesia lasts a shorter time than a caudal anesthetic. When a spinal or epidural anesthetic is used, it is often helps to have the infant suck on a nipple stuffed with cotton and soaked with glucose during surgery. This prevents her/him from crying, straining and pushing bowel out through the wound, making it difficult for the surgeon to perform the surgery. The child can also be sedated during the surgery.

At the end of surgery, the patient can be awakened and the tracheal tube removed. For postoperative pain relief, ilioinguinal nerve blocks (See Chapter 21) can be preformed or the surgeon can infiltrate the wound with local anesthetic. NSAIDS can also be used. Postoperative narcotics are seldom needed.

Either open or endoscopic surgery is used to repair inguinal hernias. Endoscopic repairs usually cause less postoperative pain, but they have a higher rate of recurrence. One advantage of an endoscopic procedure is the ease with which the surgeon can explore the opposite side to see if there is a hernia on that side also. This is important because up to 60% of patient have a patent processus vaginalis. For either repair, it is common to insert an LMA or intubate the trachea of patients undergoing inguinal hernia repair.

**Appendectomy**

Appendicitis is uncommon in infants, but when it occurs, it has potentially serious consequences for the patient because the appendix has ruptured in 80% of <1 year-old infants at the time of surgery. The younger the patient, the more likely perforation is to have occurred. This is due to the fact that infants cannot communicate their symptoms to their parents or surgeons and because their symptoms are more vague than those of older children. The most common presenting symptoms in infants are fever, diarrhea, and abdominal tenderness rather than the classic symptoms of appendicitis in older patients (anorexia, nausea and vomiting, periumbilical pain followed by right lower quadrant pain). However, the infant’s symptoms can also be caused by intussusception of the bowel, respiratory illness, infections, and gastrointestinal disorders. The vagueness of these symptoms delays the diagnosis and causes the high (85%) incidence of
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perforated appendix. It also leads to an approximately 20% rate of normal appendix at appendectomy surgery.

Management of appendicitis includes hydration (they frequently do not drink sufficient fluids), broad-spectrum antibiotics to cover both gram positive and gram-negative organisms, and treatment for pain (if needed). Antibiotics are usually given after surgery until the child is afebrile for two days. In many countries appendectomies are done laparoscopically, although 10-20% of these procedures must be converted to open laparotomy.

Because these children have a “full stomach” and are vomiting, anesthesia is induced by rapid sequence induction when possible. It can also be induced by mask induction while holding cricoid pressure, remembering that cricoid pressure is ineffective in 15-20% of patients. If possible, a nasogastric tube should be inserted to drain as much gas and fluid from the stomach as possible before inducing anesthesia. Suctioning the stomach may reduce the risk of gastric aspiration but does not remove all of the gastric fluid. Some liquid and solid food (if there is any) may remain in the stomach and can be aspirated. Since many infants have a perforated appendix, they may be septic and require a significant amount of fluid administration to maintain a normal arterial blood pressure. Occasionally vasopressors may also be required. Surgical manipulation of infected material may make sepsis worse. Postoperative pain can be treated with narcotics, but usually they are treated with narcotics and Tylenol or Ketorolac to reduce the total dose of narcotics given. Epidural anesthesia/analgesia can be used, but there is concern about doing so in septic patients.

Meckel’s diverticulum is a congenital small sac off of the distal ileum. While they are relatively common and can be found in two percent of people, they are usually asymptomatic. If symptoms occur, they usually do so before two years of age and consist of painless rectal bleeding, intestinal obstruction, volvulus, and intussusception of the bowel. At times the symptoms are difficult to differentiate from those of appendicitis. When available, the diagnosis is made by a technetium-99 scan, or it can be made at colonoscopy. Ultrasonography and CT scan may also be helpful. When symptomatic, surgery is the treatment for a Meckel’s diverticulum. The anesthesia considerations are similar to those for appendectomy.

Intussusception is a condition in which one segment of intestine (usually large bowel, especially in infants) turns into (invaginates) the intestinal lumen next to it causing bowel obstruction (Figure 8-10). However, intussusception does occur in small bowel, especially when a gastrojejunal tube that is too long is in place. The tip of the tube serves as a lead point for the intussusception. Intussusceptions usually occur in the first year of life, although it can occur later.13 If treated early the outcomes are very good. If treatment is delayed, intussusception can be fatal. Small bowel intussusceptions tend to self-correct if not caused by a gastrojejunal tube; large bowel obstructions do not. About 30% of infants with intussusception have concurrent a viral upper respiratory tract infection (URI).
These patients often arrive at hospital with bilious vomiting if the patient has a bowel obstruction; colicky, intermittent pain; current jelly type stool (blood, mucus, sloughed cells); and diarrhea. They may be dehydrated from vomiting and lack of fluid intake (See Chapter 1). On physical examination, a sausage shaped mass can be felt (between spasms) in the right lower quadrant of the abdomen in about 40% of patients. Treatment of intussusception is either nonsurgical or surgical. Nonsurgical treatment consists of filling the bowel with water, barium, or gas to force the intussuscepted bowel out of the other bowel and corrects the obstruction. If this does not work, the patient must undergo surgery to relieve the obstruction. Occasionally a portion of bowel must be resected. After air reduction, one study found a 10% incidence of recurrence of intussusception. Over all, >90% of nonoperative reductions of intussusceptions were successful. Sedation is required for this procedure because distending the bowel with air is very painful.

**Figure 8-10: Intussusception of the Bowel**

*This abdominal X-ray shows small bowel dilatation and little gas in the right lower and upper quadrants of the abdomen. The sausage shaped, air filled bowel in the right lower quadrant is the intussusception. Courtesy of Hanmin Lee, MD*

**Malrotation and Volvulus of the Bowel.** At 8-10 weeks gestation the bowel returns to the abdomen from the umbilical coelom, rotates counter clockwise and fixes in place in the right and
left side upper quadrant. If this does not happen, the bowel is free in the abdomen. This allows malrotation of the bowel, which allows the bowel to be rotate around a narrow mesentery, and this puts the child at risk for volvulus (twisting of the bowel) and occlusion of the bowel’s blood supply. This is one of the few true emergencies in pediatric surgery. Failure to correctly diagnose the patient’s condition and appropriately treat it is often fatal.

Despite the fact that approximately 1 in 500 people have malrotation of their bowel, only a small portion of them develops a volvulus. When they do, it usually occurs in the first few weeks of life. Volvulus can be divided into acute and chronic. The acute form is of most concern for the anesthetist because the entire midgut may be ischemic. Failure to unwind the bowel leads to intestinal necrosis and death. Patients with a volvulus appear with bilious vomiting, metabolic acidosis, lactatemia, oliguria, haematochezia, hypotension and shock with progressing ischemia. However, there may be no acidosis preoperatively if the vessels are obstructed and acid cannot get into the circulation. When the bowel is untwisted and blood flow returns, however, the patient may suddenly have severe metabolic acidosis and may undergo cardiac arrest and death.

Anesthesia for infants with torsion of the bowel is similar to that all patients with a bowel obstruction and a full stomach. These infants may also be quite intravascular volume depleted from decreased fluid intake and extravasation of fluid into the bowel. Careful preoperative evaluation of intravascular volume and appropriate correction of preoperative hypovolemia is necessary to prevent hypotension and death with the induction of anesthesia. Sometimes large volumes of fluid >40ml/kg are required to correct volume losses. Many of these patients also have clotting abnormalities from diffuse intravascular coagulation (DIC). When possible, clotting studies should be done pre- and intra-operatively. Monitoring of these patients during anesthesia and surgery includes frequent determination of arterial blood pressure (with an arterial line if possible – See Chapter 2), ECG, SaO₂, and body temperature. Once the torsion is relieved, the patient may become severely hypotensive and require additional volume and vasopressor administration. Some patients develop hypocalcemia and require calcium administration, especially when there is evidence of reduced cardiac output and tissue perfusion. Because fluid and glucose intake have been compromised, some patients may be hypoglycemic. Consequently, it is important to measure blood glucose concentrations during surgery and initiate appropriate treatment when needed. If hypokalemia is detected, it should not be treated until the acidosis is controlled, unless there is evidence of hypokalemia on ECG (decreased T-wave amplitude, ST-segment depression and T-wave inversion, presence of a U wave). If sodium bicarbonate is given to partially correct metabolic acidosis, this should be done carefully while ventilation is increased to eliminate the CO₂ produced. Remember, each milliliter of bicarbonate produces 25cc of CO₂ when fully reacted with acid. This must be removed, in great part by the lungs.

Inhaled anesthetics are more likely to cause severe hypotension in these sick infants than divided doses of fentanyl 30-50mcg/kg or morphine 200-300mcg/kg. Since these patients are paralyzed
with muscle relaxants during surgery, use a narcotic based anesthetic is appropriate. This combination of drugs tends to better maintain cardiac output, arterial blood pressure, and tissue perfusion in sick infants. Mechanical ventilation will probably be required postoperatively. While it is possible to use spinal or epidural anesthesia for these cases, this is probably not a good idea because the patients are often septic. Postoperative pain relief is required and can usually be accomplished with low dose fentanyl or morphine (See Chapter 20).

**Pyloric Stenosis:** Pyloric stenosis is found in 2:1000 live births and usually occurs during the first two months of life. It is due to thickening of the pyloric muscle. During contraction of the stomach and pylorus muscle, the pylori’s contracts and narrows, causing a bowel obstruction. The most common symptom is non-bilious forceful vomiting, often several feet. The diagnosis is easily made by ultrasound when available. In about half of the patients, it is possible to feel and “olive” sized firm mass just to the right of the midline near the costal margin. Peristaltic waves can be seen moving across the upper abdomen of some infants after feeding. Despite frequent vomiting, these patients usually appear hungry and eat well. The vomiting leads to inadequate fluid intake, dehydration, lethargy, decreased number of bowel movements, and constipation in sicker patients whose diagnosis is delayed. If not diagnosed and treated early, vomiting causes the loss of Na⁺, K⁺, Hall⁻ (Hydrochloric acid) alkalosis and dehydration Na⁺ and fluid retention in exchange for K⁺ paradoxical academia alkalosis and dehydration more loss of Na⁺, K⁺, Hall⁻ with additional vomiting. If these electrolyte abnormalities are present, a nasogastric tube should be inserted and connected to intermittent suction when possible. The electrolyte abnormalities should be corrected before proceeding with surgery. Care should be taken to avoid hyperventilating these already alkaloid patients because this will worsen their alkalosis, decrease cerebral blood flow more, and cause hypotension. Correction of pyloric stenosis is not an emergency. The surgery should only be done when the patient’s condition is stable.

Pyloric stenosis is done either open or endoscopically. In many countries almost all of these repairs are done endoscopically because it shortens hospital stay. However, both types of surgery require tracheal intubation for airway protection. All of these patients require an IV preoperatively. This allows the anesthetist to do a rapid sequence induction of anesthesia while cricoid pressure is being held (See Above). If an open procedure is done, a caudal anesthetic is helpful for the treatment of postoperative pain (See Chapter 21). If the procedure is done endoscopically, this is not necessary. Pain in the latter group of patients is easily controlled with Tylenol, ketorolac, etc.

**Hirsch rung’s disease** is a disorder of the bowel (mostly large intestine) that occurs in about 1:5000 births (Figure 8-13). It is caused by abnormal development and absence of the nerve supply (ganglion cells) to parts (or rarely all) of the colon that prevents affected colon from relaxing and pushing stool through. As a consequence, patients have severe constipation. The obstruction usually occurs in the colon closest to the anus but can occur anywhere in the colon or
the entire colon may be involved. It occurs four times more often in males and is more common in white than in non-white babies.

**Figure 8-11: Hirschprung’s Disease**

*This figure shows the underdeveloped area of colon that lacks ganglion cells and relaxes poorly. The area of bowel above it is dilated. Courtesy of Hanmin Lee, MD*

Diagnosis of Hirschprung’s disease is based on both clinical and biopsy information. Failure to have a meconium stool within the first 48h after birth suggests this diagnosis, as does presence of megacolon on X-ray. The enlarged segment of bowel is found proximal to the aganglionic segment of bowel. Following digital examination of the child’s rectum, there may be an “explosive” stool. Vomiting may also occur. The gold standard for diagnosis of Hirschprung’s disease is biopsy of the affected segment of colon. The diagnosis is made when no ganglion cells are found in the biopsied material.

Treatment consists of performing a colostomy to relieve the bowel obstruction and to allow the child to grow, although some surgeons now do corrective surgery in very young infants. When those caring for the infant think the patient is in the best condition possible, the surgeon resects the abnormal portion of bowel and connects normal bowel to the anus by one of several techniques (Swenson, Soave, Duhamel, Boley). Fifteen percent of patients do not receive full bowel control from these procedures and must have enemas and other procedures each day to have a stool. Anesthesia for these patients is similar to that for any patient with a bowel
obstruction (see above).

In infants, *abdominal masses* can be of many origins (Table 8-7).

**Table 8-7: Causes of Abdominal Masses in infants**

<table>
<thead>
<tr>
<th>Neoplastic Tumors</th>
<th>Infectious</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hepatocellular Carcinoma</td>
<td>Hydatid Cyst</td>
<td>Impacted Feces</td>
</tr>
<tr>
<td>Hepatoblastoma</td>
<td>Toxic Megacolon</td>
<td>Mesenteric Cysts</td>
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<tr>
<td>Neuroblastoma</td>
<td>Retroperitoneal Intra-abdominal Abscess</td>
<td>Intussusception Volvulus</td>
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<td>Wilms Tumor</td>
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<td>Teratomas</td>
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<tr>
<td>Lymphoma</td>
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<tr>
<td>Rabdomyosarcoma</td>
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*Neuroblastomas* are neural crest tumors in the adrenal glands and paraspinal ganglia. They are the most common abdominal tumor of infancy and can be life threatening. Slightly more boys have this tumor than girls. Upwards of 75% of patients have metastasis to bone marrow, liver, lymph nodes, and skin. Presentation of neuroblastoma depends on site of the primary tumor, the presence of metastasis, and tumor size. Some patients present early with pain and malaise, but most, especially those with a sizable mass, present with abdominal pain, weight loss, abdominal distention, anemia, and failure to thrive. About one fourth of patients have catecholamine producing tumors and hypertension. Intra-thoracic neuroblastomas may cause Horner’s syndrome (ptosis, miosis, enophthalmos, anhydrosis) on the affected side. Some patients have diarrhea, hypokalemia, and occasionally hypovolemia.

The diagnosis of neuroblastoma is primarily made when high levels of serum and urine catecholamines are present and an abdominal mass is present on physical examination, plain X-rays of the abdomen, CT scan, ultrasound, and MRI. Treatment of neuroblastoma includes surgery and chemotherapy. Surgery is effective if the tumor is a localized and has not metastasized. However, about half of the tumors have metastasized at the time of presentation. Tumors that have metastasized are first treated with chemotherapy to reduce tumor size and then with surgery.

Following a complete history and physical examination, evaluation of laboratory data (especially the Hgb and K⁺), standard monitoring of heart rate, arterial pressure, ECG, and SaO₂, general
tracheal anesthesia is induced. If there is evidence of vomiting or upper bowel obstruction, induction of anesthesia should be by rapid sequence. Adequate intravenous access is needed to treat the excessive blood loss seen with tumors that involve major blood vessels or are very large. If significant blood loss is thought to be likely, intravascular arterial pressure monitoring is very useful (See Chapter 2). Depending on the site and size of the incision, patients can have significant pain after surgery. Epidural analgesia is often very helpful. Postoperative pain can also be treated with narcotics and NSIDS.

Conclusion

Infants have varied problems from uncomplicated to very complicated that must be understood before the induction of anesthesia to prevent problems during anesthesia. Appropriate correction of intravascular volume and electrolytes before the induction of anesthesia is important. Monitoring aids in detecting changes early and providing therapy to prevent untoward events.

References
