Chapter 1

Anatomy

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Introduction

The anatomical differences between the infant and the adult are numerous and can greatly affect the care of the infant and, most notably, the neonate. This chapter presents an overview of anatomical differences between the neonate and the adult, including general development, with a focus on the airway, body habitus, thermoregulation, and vascular cannulation.

General development

Airway

Respiratory development begins by the fourth week of gestation with a primitive pharynx, larynx, trachea, and bronchial bud. The trachea and the esophagus develop from the foregut, and then separate during division of the endoderm. If this separation fails, a tracheoesophageal fistula (TEF) lesion will result. With successive branching of the airways, the respiratory tree is formed. By 24 weeks gestation, respiratory bronchioles and primitive alveoli are present and surfactant begins to be produced. Adequate air exchange requires surfactants to maintain alveolar expansion and adequate lung exchange.[1] Even though surfactants can be administered after delivery, adequate air exchange for survival limits the viability of premature infants delivered before 23 weeks gestation. The alveoli continue to increase in number and size until 8 years of age, after which alveoli increase only in size.

Many morphological differences exist between the neonatal airway and the adult airway. In neonates, the epiglottis and tongue are relatively large. Other anatomical differences in the pediatric airway include large head, short neck, narrow nares, redundant soft tissues, and a high glottis. All these features can make mask ventilation and direct laryngoscopy a challenge.

Neonates are obligate nasal breathers, with about 22% of term infants being unable to breathe if the nares are occluded. Most infants gain the ability to compensate for nares occlusion with oral breathing by 5 months of age. The relatively large tongue of the neonate can result in upper airway obstruction, as can be seen in certain syndromes such as Beckwith–Wiedemann and Down syndrome. These anatomical differences along with the high oxygen consumption can make hypoxia more common and also more severe.

The anatomy of the airway changes with age. The glottis functions as an occlusive valve to protect the lower airway from the alimentary tract. The glottis is at the level of C3 in babies, moving caudad to the level of C4–5 in adults. The shape of the larynx also changes with age. Infants have a cricoid cartilage that is narrower than that of an adult. This creates a vocal cord aperture that is funnel shaped. As the child grows, the diameter of the cricoid cartilage also increases resulting in a cylindrical shape of the larynx by the age of 8 years. At the level of the cricoid, the cartilage forms a complete ring to prevent compression. The larynx at the subglottis is the narrowest portion of the respiratory system for all ages.

Delayed development in the neuromuscular tone of the supraglottic muscles can result in laryngomalacia with inward collapse of supraglottic structures, namely, the aryepiglottic folds or the anterior collapse of the arytenoid cartilages. As the neuromuscular tone improves during the first two years of life, symptoms also improve and often disappear completely.[2]

Body habitus

The degree of difference and variation between neonates and adults is striking. When compared to an adult, a newborn infant is 1/21 adult size in weight, 1/9 adult size in body surface area, and 1/3 adult size

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in length. It is thus essential to choose carefully the variable used to compare patients of different sizes.[3] For medication administration, the actual body weight is most commonly used. Drug dosing can also be based on ideal body weight or lean body mass. Most obese patients have increased total body weight as well as lean body mass. For these patients, ideal body weight has been shown to be the best measurement for dose calculation, but this is not often used in clinical practice. Calculations for fluids and doses of medications can be based on body surface area (BSA), which requires both a height and a weight measurement. The BSA can be estimated by Mosteller's calculation:[4]

$$\text{BSA } (m^2) = [\text{ht (cm)} \times \text{wt (kg)}/3600]^{½}$$

Body fluid compartment composition also varies with age, with an abrupt fall in total body water (TBW) and extracellular fluid levels (ECF) over the first year of life, reaching adult levels by 2 years of age.[5]

Water volume and blood composition

Total body water (TBW) varies inversely with age. While the newborn has 85% TBW, this percentage steadily decreases to the adult level of 65% TBW by 3 years of age. Males also have a higher TBW compared to females. The body's water can be divided into intracellular fluid (ICF), which contains 67% of the water distribution and extracellular fluid (ECF), which contains 33% of the water distribution. Diffusion across the cell membrane results in fluid exchange between the ECF and the ICF. Fluid will move from an area of low osmolality to an area of high osmolality. The body regulates ECF volume by varying renal sodium excretion and controls renal osmolality by varying water intake and excretion.

Normal fluid management in the perioperative period includes administration of maintenance, preoperative deficit and replacement of ongoing losses. Maintenance requirements consist of replacing insensible losses through the skin and lungs, and urinary volume replacement.[6] Fluid requirements in infants are greater than adults because of greater surface-to-weight ratio and higher metabolic rate as well as reduced renal concentrating ability. In the newborn, day 1 maintenance fluids are decreased because of immature renal function that slowly improves during the first few days of life. For day 1 of life, $D_{10}W$ without added salt is administered at a rate of 80 ml/kg/day. By day 2 of life, sodium excretion from the kidney has begun and urine output improves, resulting in a change of maintenance fluids to include sodium replacement (2–3 mEq/dl NaCl). This is usually given in the form of $D_{10}W$ with 0.2 NS at a rate of 100 ml/kg/day. By day three of life, potassium replacement (1–2 mEq/dl KCl) is begun and total fluids are increased at a rate of 120 ml/kg/day. Outside of the neonatal period, the most commonly used formula for calculating hourly maintenance fluid perioperatively consists of the following calculation:[7]

"4–2–1 rule" for hourly maintenance fluid rate:
- 4 ml/kg/hr for the first 1–10 kg body weight plus
- 2 ml/kg/hr for each kg from 11–20 kg plus
- 1 ml/kg/hr for every kg > 20 kg

Maintenance fluids routinely provide dextrose, usually as 5% dextrose, and sodium supplementation as 0.2–0.45 NS. However, in the operating room routine dextrose administration is no longer advised in healthy children. Moreover, isotonic fluids have been shown to be significantly safer than hypotonic fluids for protection against postoperative hyponatremia in children.[8] Thus perioperative maintenance fluids are usually replaced with a balanced salt solution such as Ringer's lactate or 0.9% normal saline solution, except in patients at risk for hypoglycemia, such as neonates, children receiving hyperalimentation, and children with endocrinopathies.

Fluid deficits must also be replaced, and may be significant in the presence of prolonged fasting, fever, vomiting, or diarrhea. Preoperative fasting should be minimized to avoid significant dehydration or hypoglycemia in infants. Specific instructions should be given for infants to be encouraged to ingest clear fluids up until two hours before elective surgery.

Third-space losses from surgical trauma, burns or infection result in isotonic fluid transfer from the ECF to the interstitial compartment with resultant plasma volume depletion. These losses can be as high as 10 ml/kg/hr for major intra-abdominal surgery and even 50 ml/kg/hr for a premature infant undergoing surgery for necrotizing enterocolitis. These losses can be replaced with Ringer's lactate solution. Administration of fluid should be titrated to the clinical response, with maintenance of appropriate hemodynamic variables and a minimum urine output of 0.5–1 ml/kg/hr.

In addition to fluid replacement, blood loss needs to be closely monitored with prompt replacement as needed. Blood loss is initially replaced with a crystalloid such as lactated Ringer's as 3 ml per 1 ml

Table 1.1: Estimated blood volume

	Premature	Newborn	1 year	3 years	9 years	Adult
EBV (ml/kg)	100	90	80	75	70	65

blood lost to an acceptable minimal hematocrit, after which packed red cells should be administered. Factors that determine the maximum allowable blood loss (MABL) include the patient's estimated blood volume (EBV), body weight and starting hematocrit (HCT). Estimated blood volume decreases with age (see Table 1.1). The MABL can be calculated with the following formula:

$$MABL = EBV \times [HCT_{start} - HCT_{low}]/HCT_{start}$$

Thermoregulation

Under normal conditions, body temperature is one of the most accurately maintained physiologic parameters. The outer skin serves as a shell with the muscle compartment acting as a buffer. Thermoregulatory mechanisms including vasoconstriction can spare body heat and decrease heat loss up to 50%. In adults, shivering is a main component of this process. In infants and neonates, brown fat provides nonshivering thermogenesis. Brown fat can represent 2–6% of neonatal body weight and is found in the scapulae, axillae, mediastinum, adrenal glands, and the kidneys. Nonshivering thermogenesis from brown fat is the main thermoregulatory response to cold stress in the neonate and can double metabolic heat production during cold exposures.[9] This ability persists up to two years of age.

General anesthesia disrupts thermoregulation by producing vasodilation by two mechanisms. It reduces the vasoconstriction threshold below core temperature, inhibiting centrally mediated thermoregulatory constriction, and also causes direct peripheral vasodilation.[10] This results in internal redistribution of body heat as the core temperature decreases with a proportional increase in peripheral tissue temperature. The body heat content remains constant. During the first few hours of anesthesia, redistribution contributes 65% of the total decrease in core temperature.[11]

In addition to redistribution of body heat during anesthesia, total body heat is lost through four mechanisms: radiation, conduction, convection, and evaporation. Heat transfer is minimal if the temperature of the body surface and the environment are similar but increase proportionally as the temperature difference increases.[9] **Radiation** is the transfer of heat from one surface to another without direct contact and results in 39% of the heat loss in a neonate. Radiation does not depend at all on the temperature of the intervening air. Radiant heat loss can be reduced by warming the room and by covering the patient. Because of the greater surface area to body mass ratio, infants have a greater radiative heat loss than adults. It is thus essential to increase the temperature of the operating room to help stabilize the temperature of small infants and especially neonates.[12] **Conduction** is the direct transfer of heat from the contact of one object to a second object, and accounts for about 3% of neonatal heat loss. Conductive losses can be avoided by warming the IV fluids and the table and by insulating the patient. Infants have less subcutaneous fat and a greater surface area to body ratio resulting in larger conductive heat losses than adults. **Evaporation** is the transfer of heat by vaporization of water and represents 24% of the neonatal heat loss. Evaporative losses include sensible losses such as sweating and insensible losses through the skin or surgical wound. Insensible loss from the skin in the adult is minimal but is significant in infants, particularly in the premature, who have less epidermal keratin, resulting in larger evaporative losses. Evaporative losses can be reduced by keeping the skin dry and by warming and humidifying gases in the breathing circuit. There is also substantial evaporative loss from within surgical incisions. **Convection** is the transfer of heat from an object to air or liquid and accounts for 34% of heat loss in the neonate. Convection removes heat to the environment, and is responsible for the wind-chill effect. Convection can be reduced by insulating barriers such as a plastic drape that prevent movement of air along the skin.

Anatomy for procedures

Airway management

Management of the pediatric airway begins with the adequate opening of the airway and effective bag-mask ventilation. The ability to maintain airway patency and ventilation can prevent an unexpected airway problem from becoming an airway emergency.

The neonatal airway can be particularly difficult with a relatively large tongue and redundant tissues. Maintaining a degree of mouth opening while placing a tight mask seal can compensate for the large tongue and redundant tissues and make bag-mask ventilation successful. For those who have not mastered the neonatal airway, insertion of an oral airway can achieve the same effect, if the patient is adequately anesthetized to tolerate insertion of an oral airway. Once a tight mask fit is achieved with a patent airway, the application of constant positive airway pressure (CPAP) can assist in achieving adequate ventilation.

Many airway tools exist to facilitate airway management in children. Many supraglottic airway devices exist but the most widely used is the laryngeal mask airway (LMA). Anatomical differences in the infant larynx can affect airway instrumentation with a supraglottic device. The shape of the infant larynx makes the LMA more difficult to position in infants less than 10 kg, resulting in more leaks and partial obstruction by the epiglottis, especially during positive-pressure ventilation. This occurs because the smaller LMA is a scaled-down version of the adult LMA, in which the anatomical differences of the larynx are not accounted for, making positioning more difficult.[13] Performing a jaw thrust during insertion of the LMA in an infant can minimize this complication. Although leak pressures in an LMA are rarely measured in clinical practice, maintaining the leak pressure at 40 cmH_2O can minimize leaks around the cuff as well as the incidence of sore throat.

The small size of infants and children also makes regional anesthesia of the airway more difficult. Most laryngeal nerve block techniques normally performed in adults are not commonly used in children. One exception is the subcutaneous lateral approach which allows bilateral subcutaneous administration of local anesthetic just lateral to the hyoid bone.[14]

Intubation can be challenging in the infant, whose large occiput and large tongue can hinder the alignment of the oral, pharyngeal and tracheal axes during direct laryngoscopy (DL). Placement of a shoulder roll can assist in aligning these axes. The infant epiglottis is narrow and angled away from the axis of the trachea, making a straight blade preferable for tracheal intubation in an infant or neonate. Despite these anatomic challenges, direct laryngoscopy is successful in the majority of infants and children. When laryngoscopy is difficult, the use of muscle relaxant to facilitate intubation in infants and children in conjunction with sevoflurane anesthetic is associated with fewer adverse respiratory events and should be considered while investigating the use of other advanced airway devices.[15]

The videolaryngoscope (VL) can provide improved view of the glottis specifically when the oral, pharyngeal and tracheal axes are not well aligned. In this misalignment, the epiglottis partially obstructs the glottic view or, in the worst case scenario, even the epiglottis is unable to be visualized under DL. In these patients, the VL has been shown to be a successful rescue technique for unsuccessful DL. Moreover, utilizing a VL blade smaller than that based on weight can further improve the visualization. Thus, changing to a smaller VL blade can clinically improve successful intubation in the infant or child with a difficult airway.[16]

Difficult airway: Although data is limited for the incidence of the difficult pediatric airway, it has been calculated to be anywhere from 0.58% up to 3%, which is significantly less than the 9–13% often reported in adults.[17] Both younger age and ASA III/IV status is associated with difficult laryngoscopy. Many studies have found a significantly higher risk of difficult intubation in infants under one year of age with a rate as high as 5%. Similar to adults, being overweight alone is not a predictor for difficult airway but, unlike adults, being underweight in children is associated with a difficult airway. The Mallampati score is less useful in the uncooperative pediatric patient or infant. However, in the cooperative pediatric patient, the Mallampati score can be a helpful tool to predict difficult laryngoscopy.[18] Despite many available videolaryngoscopic devices, fiberoptic intubation remains the gold standard for securing the difficult airway for both the adult and pediatric airway.

Should a surgical airway be needed in an emergency, needle cricothyroidotomy may be more difficult in the infant because of less room between the chin and the cricothyroid membrane. Caution must be given to correct placement as the target is small and the trachea is compressible making passage through the back wall of the trachea and into the esophagus a calculated risk in this procedure.[19]

Vascular cannulation

Successful cannulation of central veins requires a thorough understanding of the anatomy of relevant structures. Central access in infants can be technically more difficult due to the small vein size, and the variable anatomy. As with many pediatric procedures, once the vessel is identified, the actual cannulation can be hindered by difficulty threading the guidewire into the vessel and by kinking or dislodging of small-caliber guidewires when threading the catheter over the guidewire.

The decision to place a central venous line should be given serious thought before placing the line as the complications can be devastating. Due to the smaller caliber of the vessels in infants and children, thrombus formation and vessel occlusion are increased risks. Many other complications exist depending on the site chosen for central access and will be discussed with the individual sites. Despite the risk, central venous access is often required in infants and children for central venous pressure monitoring, administration of vasoactive medications, and hyperalimentation. The most commonly used sites for central venous cannulation in infants and children include the umbilical vein, the subclavian vein, the internal jugular vein, the femoral vein, and percutaneous intravenous access (PICC). Preferred sites depend upon the age of the patient, the type of surgery and practitioner preference. In neonates, undergoing cardiac surgery, central access is represented by all sites, including internal jugular/subclavian (38.8%), femoral (27.2%) and umbilical/central (32.9%). For infants out of the neonatal period undergoing cardiac surgery, internal jugular/subclavian is the site of choice with 70.5% of infants having access from these sites.[20]

Real-time ultrasound guidance has been definitively shown to be beneficial in adults, but pediatric data is less clear-cut. The use of real-time ultrasound in adults has been shown to decrease risks of cannulation failure, arterial puncture, hematoma, and hemothorax.[21] Although pediatric studies exist, data to evaluate outcomes in pediatric patients remain limited. Current evidence in the pediatric literature supports ultrasound use especially with inexperienced operators. For inexperienced operators,[22] ultrasound guidance versus landmark techniques can improve successful cannulation and decrease the number of needle passes needed to cannulate the vessel. In the pediatric intensive care setting, ultrasound guidance has been shown to decrease the time needed for residents to cannulate a vessel but does not offer such a benefit for experienced providers.[23]

Umbilical vein: The umbilical cord contains two umbilical arteries and one umbilical vein. The umbilical vein can be used in a neonate up to one week of age, after which atresia of the vessel makes cannulation unlikely. Use of this vessel has its limitations because of significant complications including necrotizing enterocolitis, thrombus in the vena cava or thrombus in the portal vein. Signs of umbilical vein thrombus formation include renal dysfunction and systemic hypertension. Umbilical vein cannulation can be life-saving, especially in the resuscitation of a newborn in distress at the time of delivery. Skilled practitioners can place such an umbilical line within minutes, providing much needed vascular access.[24]

Femoral vein: Femoral vein cannulation may be preferred in some patients when hemothorax, pneumothorax or local hematoma is of concern or when access is required without interfering with the airway. However, femoral venous access has been reported to have a higher incidence of thrombosis and infections as long-term complications. Femoral head necrosis is another risk, especially in the premature infant, and is avoided if possible in the premature infant. The femoral vein lies midway between the anterior superior iliac spine and the symphysis pubis and can be accessed just below the inguinal ligament at the inguinal crease. The femoral vein is medial to the femoral artery. Appropriate positioning can improve both cross-sectional area of the femoral vein and minimize overlap with the artery. This includes reverse Trendelenburg, external rotation of the hip and 60° abduction of the leg.[25] Although two-dimensional ultrasound is not required for femoral vein cannulation, ultrasound has been shown to improve the overall success rate, decrease the incidence of arterial puncture, decrease the incidence of hematoma, and decrease the number of needle passes for successful cannulation. The use of ultrasound guidance by trainees for femoral cannulation decreases the time of insertion, markedly improves first attempt success, and lowers the median number of passes for success.[22]

Upper body central cannulation: Upper body central lines in the internal jugular veins or the subclavian veins can be placed in neonates, infants, and small children. Upper body central lines provide reliable vascular access and accurate central venous pressure monitoring with a decreased risk of infection when compared to lower body central lines.[26] However, these vessels are sometimes avoided in small children with single-ventricle cardiac physiology due to a potential risk of stenosis or thrombosis of the

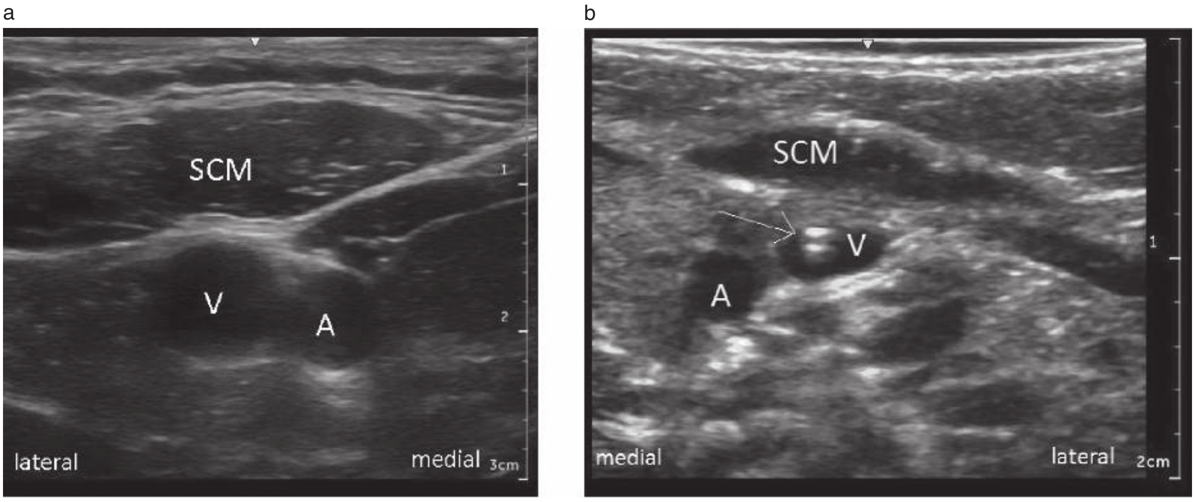

Figure 1.1 Ultrasound pictures of the internal jugular vessels. **Figure 1.1a.** shows the left neck vessels in a 3-year-old. **Figure 1.1b.** shows the right neck vessels in a newborn. A = carotid artery, V = internal jugular vein, SCM = sternocleidomastoid muscle. The arrow is pointing to the central line within the IJ lumen after cannulation. IJ = internal jugular.

superior vena cava. Stenosis or thrombosis of vessels in the upper body can result in "superior vena cava syndrome," a post-thrombotic syndrome with marked elevated pressures in the head and neck, facial swelling, and headaches. However, studies have shown minimal risk of clinically significant catheter-associated vessel thrombosis or stenosis in patients with single-ventricle physiology, especially when the right internal jugular access is used.[20]

Subclavian vein: The subclavian vein can be accessed via an infraclavicular approach using the landmarks of the lower border of the clavicle just lateral to the intersection of the clavicle with the first rib. This is also the lowest part of the "bend" of the clavicle. Complications such as pneumothorax and arterial puncture can be avoided with a flat angle of approach so the needle stays adjacent to the clavicle to avoid unwanted structures.

Internal jugular vein: The internal jugular anatomy has easily identified landmarks both anatomically and via ultrasound. Cannulation success rate can be improved with optimal positioning. This includes Trendelenburg position with the table tilted down 15^{o} and passive leg elevation of 50^{o} to increase the cross-sectional area of the IJ vessel.[27] The head should be turned only 45^{o} from midline, as extreme turning of the head will cause more overlap of the internal jugular (IJ) and carotid, making carotid puncture more likely. Ultrasound is recommended for improved cannulation success. The straighter course of the right internal jugular vein towards the heart makes this the preferred site of access with less difficulty passing the guidewire and catheter into the heart and a lower thrombotic risk to the patient from catheter placement. Figure 1.1 depicts the anatomical view of the left and right neck anatomy. Figure 1.1a shows the ultrasound view of the left neck in a 3-year-old child. Note the depth of the vessels at 2 cm and the well-developed sternocleidomastoid muscle. Figure 1.1b shows the right neck in a newborn. Note the vessels are shallower at a depth of 1 cm with a less developed sternocleidomastoid muscle. The cross-sectional areas of the vessels in the neonate are smaller than those seen in the older child.

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Chapter 2

Anesthesia equipment

Hoa N. Luu

In this chapter, we will review anesthesia equipment as it relates to respiration. The one major focus would be on the breathing circuits that connect the anesthesia machine to the patient. Another focus is ventilation devices and ventilation techniques used.

The anesthesia machine is a huge subject that we will briefly discuss in this chapter. You should be aware that there is no dedicated anesthesia machine for the pediatric patient but we use the normal adult anesthesia machine. Thus, when providing anesthesia to the pediatric patient it is important for us to know the limitations of the anesthesia machine.

When connecting the patient to the anesthesia machine, we are all familiar with the standard semi-closed circle absorber system used in adults. With this breathing system, the use of two unidirectional valves allows for the anesthetic gases to flow in one direction and prevent rebreathing of carbon dioxide with the carbon dioxide absorber. This circle system allows for rebreathing of the anesthetic gas mixture, thus, cutting the cost by minimizing waste of anesthetic gases and conserving heat and moisture. The limitations of this system are that it is more bulky in size and there is increased resistance in the circuit if the patient is breathing spontaneously. In the pediatric patient, there are more options. While these options are rarely used today, except at some children's hospital operating rooms, it is important for us to learn about because they are continued to be used for transporting pediatric patients in the hospital.

Before we discuss the Mapleson systems, we will first talk about what practical options we have when a pediatric patient comes to the operating room. While some argue that the standard adult circuit can still be used, most hospitals do have the modified pediatric circuit. This modified pediatric circuit would consist of a shorter, stiffer, and smaller-diameter tubing and smaller rebreathing bag. The advantage of having this modified circuit would be having a decreased compression volume that means less compliance of the circuit. In addition, smaller CO_2 canisters can be used to minimize resistance to breathing.

Now we will learn about the Mapleson circuits that are semiclosed rebreathing systems. There are six different types of Mapleson circuits (A to F) that we are familiar with (Figure 2.1). Each circuit is different from the others by the location of its components. The five components are fresh gas inflow, expiratory valve, corrugated tubing, reservoir bag, and an adaptor for a face mask or endotracheal tube.

Depending on the locations of the components and mode of ventilation, it affects the amount of rebreathing that occurs. For simplicity, I like to divide the Mapleson circuits into three groups so it will help you remember the location of the components in each circuit. We will discuss the Mapleson systems as three groups as well because it will help us memorize which circuits are better for spontaneous or controlled ventilation.

The Mapleson A circuit has the expiratory valve close to the patient with the corrugated tubing separating away the fresh gas inflow and reservoir bag at the end. The Mapleson A circuit is the most efficient circuit for spontaneous ventilation because there is no rebreathing when the fresh gas flow is more than 80% of the minute ventilation. However, it is the least efficient circuit for controlled ventilation so it would require a much larger fresh gas flow to prevent rebreathing. We do not use the Mapleson A circuit today in the operating room because of the proximal location of the valve to the patient. It is potentially hazardous because the weight of the valve could inadvertently extubate an endotracheal tube.

Both Mapleson B and C circuits have the expiratory valve close to the patient with the fresh gas inflow

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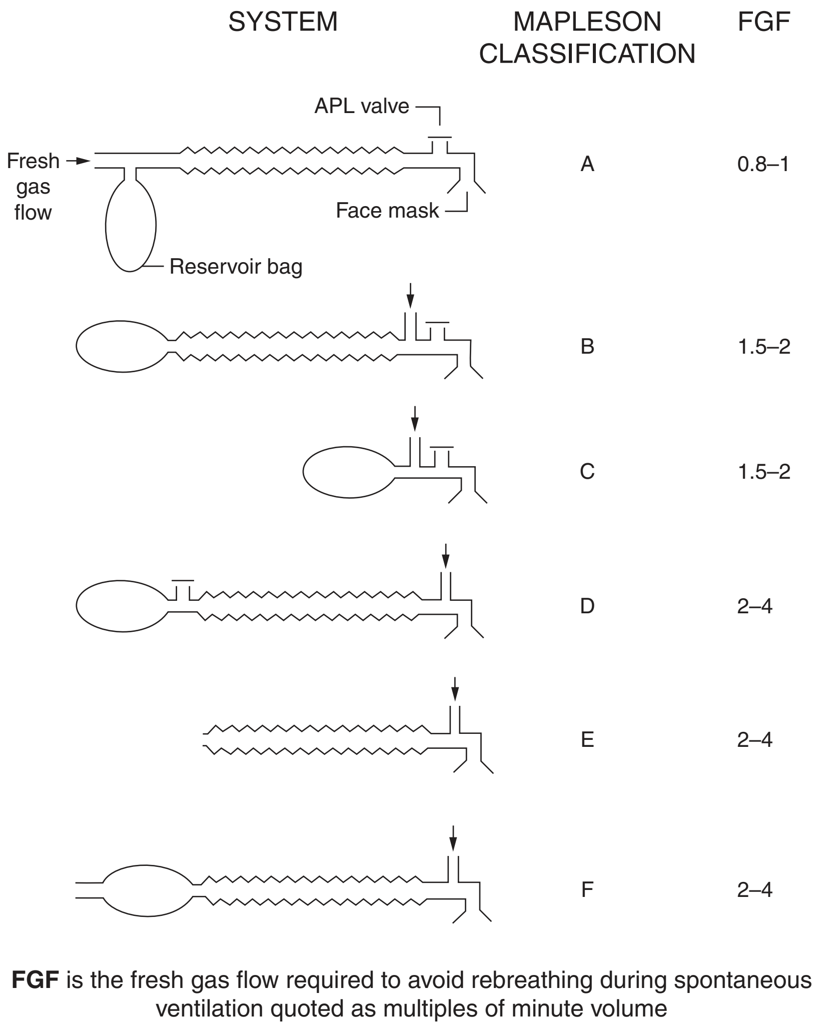

Figure 2.1 Mapleson circuits. APL = ??

nearby as well. The difference is that there is a corrugated tube separating the reservoir bag in Mapleson B while there is no corrugated tube in Mapleson C. Both of these circuits are seldom used today because of the proximity of the expiratory valve to the patient and high fresh gas flow required to prevent rebreathing.

The Mapleson D, E, and F circuits have the fresh gas inflow close to the patient. In the Mapleson D circuit, the expiratory valve is between the corrugated tube and reservoir bag. While the Mapleson D does require a little more fresh gas flow to prevent rebreathing than Mapleson A during spontaneous ventilation, it is the most efficient circuit during controlled ventilation. Bearing in mind both modes of ventilation, Mapleson D requires the lowest fresh gas flow rate; thus, explains it is the most commonly used Mapleson circuit. Mapleson E is the basically the Ayre T-piece while the Mapleson F is a modified Ayre T-piece with reservoir bag and tubing. They are grouped together also because they have similar rebreathing characteristics.

To help determine which circuits are better for spontaneous or controlled ventilation, there is a mnemonic that is easy to remember. For spontaneous ventilation, it's "**A**ll **D**ogs **C**an **B**ite." (A > DEF > CB) Thus, there is the least rebreathing in Mapleson A. For controlled ventilation, it's "**D**og **B**ites **C**an **A**che." (DEF > BC > A) Thus, there is the least rebreathing in Mapleson D, E, and F. To remember which phrase goes with which mode of ventilation, I just modify the first one to "**A**ll **D**ogs **C**an **B**ite **S**pontanously."

Now we will discuss ventilation devices. The focus will be devices we particularly use once the airway is secured. The discussion of airway management will be

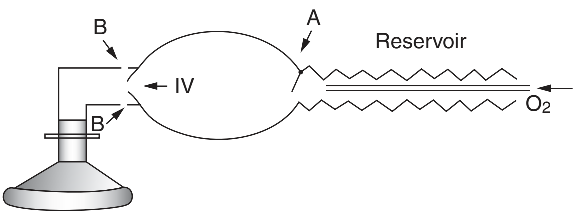

Figure 2.2 Self-inflating bag.

discussed later in the book. In that section, you will learn about the devices and techniques for both mask ventilation and endotracheal intubation.

As you can see, we have already talked about the most important ventilation device which is our anesthesia machine and the different circuits to connect it to the patient. But what happens when there is a machine failure or malfunction? The answer brings us to the last device we will discuss: the self-inflating bag (Figure 2.2).

The self-inflating bag can provide positive-pressure ventilation to ventilate the patient's lungs with room air or air enriched with oxygen if an oxygen supply is available. The Mapleson circuit would require compressed gas, thus, you would not be able to ventilate the patient with the circuit alone. You do not need to worry about rebreathing with the self-inflating bag because there is an one-way valve (B) near the patient which opens at expiration and closes at inspiration. When you squeeze the bag, the air within it would flow to the adaptor that connects to the face mask or endotracheal tube since the valve (A) would be closed. When the self-inflating bag re-expands, the valve (A) would open allowing the gas in the reservoir tubing to fill the bag. This gas can just be room air or be oxygen-enriched air if it is connected to an oxygen source. Thus, it is very important to have a self-inflating bag and alternate oxygen source prior to the start of every anesthesia case.

I hope you have a better understanding of the anesthesia equipment regarding breathing circuits now so you can address the limitations when caring for the pediatric patient.

Further reading

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