In pediatric anesthesia, four essential patient monitors are used for virtually every case (unless unusual circumstances preclude their use). They include pulse oximetry, capnography, electrocardiography (ECG), and blood pressure measurement. These monitors are components of the Basic Monitoring Standards of the American Society of Anesthesiologists (www.asahq.org/PublicationsAndServices/standards/02.html#2). Continuous auscultation via a precordial or esophageal stethoscope is strongly encouraged but not mandatory. Temperature monitoring (see Chapter 15) is indicated in all cases except those in which hypothermia or hyperthermia is deemed quite unlikely (e.g., myringotomy and tubes). Train-of-four nerve monitoring is recommended during use of a neuromuscular blocker (see Chapter 19). This chapter reviews the basic characteristics of these monitors, with an emphasis on the unique differences between adults and children.

Pulse Oximetry
Capnography
Electrocardiography
Blood Pressure Monitoring
Precordial or Esophageal Stethoscope

Pulse oximetry provides an estimate of the oxyhemoglobin saturation. It serves as an early warning signal of impending or actual hypoxemia, often prior to the onset of cyanosis, and frequently reminds anesthesiologists of the alarming rapidity with which infants develop hypoxemia. During rapid changes in oxygen saturation the value represented on the pulse oximeter lags behind the true oxyhemoglobin saturation, such that the recognition of hypoxemia may be delayed. In general, central probe locations (e.g., buccal) will have less of a delay than an upper extremity, which will have less of a delay than a lower extremity. Conversely, the reestablishment of normoxemia may be associated with a persistently low pulse oximetry value for up to 30 seconds or more.

Most oximetry manufacturers claim a maximum error between 2% and 4% when the true oxyhemoglobin saturation is greater than 70%. Below this value, the precision of the pulse oximeter decreases, and differs between manufacturers. Fetal hemoglobin, which is found in neonates and young infants, does not affect the accuracy of the pulse oximeter.

There are no outcome studies that demonstrate a proven benefit from the use of pulse oximetry. However, anesthesiologist-blinded studies have demonstrated that the use of pulse oximetry facilitates fewer episodes of hypoxemia results in an earlier recognition of hypoxemia. Therefore, pulse oximetry has evolved into a standard monitor during pediatric anesthesia and will never be subjected to rigorous outcome studies with a true control group (i.e., an anesthetic without a pulse oximeter).

Although the use of pulse oximetry in pediatric patients is associated with a relatively high rate of false-positive alarms, all alarms must be taken seriously until proven otherwise. When the oximeter detects a low oxyhemoglobin saturation, the anesthesiologist should immediately turn his or her attention to the adequacy of ventilation by simultaneously evaluating air entry, quality of the capnographic tracing (see later), and the quality of the pulse oximeter signal. In infants and small children, surgical personnel often unknowingly compress the oximeter probe by leaning on the hands or feet. This author prefers to put the oximeter probe on the upper extremity, which can be positioned above the head, when feasible. The audible tone on the oximeter should never be turned off since most anesthesiologists become accustomed to listening to the oxyhemoglobin saturation and becoming aware of a decrease in pitch, rather than continuously visualizing the numeric value.
CAPNOGRAPHY

Prior to 1998, capnography was considered a standard monitor by the ASA for the purpose of confirming the initial placement and continuous presence of an endotracheal tube. This section of the ASA monitoring standards was updated in 1998, and now indicates that capnography should be used to confirm adequate ventilation during airway management without an endotracheal tube (i.e., during laryngeal mask airway, facemask, or natural airway anesthesia). Specifically, these guidelines now state:

"Continual monitoring for the presence of expired carbon dioxide shall be performed unless invalidated by the nature of the patient, procedure or equipment. ...Continual end-tidal carbon dioxide analysis, in use from the time of endotracheal tube/laryngeal mask placement, until extubation/ removal or initiating transfer to a postoperative care location, shall be performed using a quantitative method such as capnography, capnometry or mass spectroscopy."

As in adults, capnography in pediatric anesthesia is used to confirm placement of an endotracheal tube in the correct tracheal position, and to continuously assess the adequacy of ventilation. Capnography also provides information about the respiratory rate, breathing pattern, and endotracheal tube patency, and indirectly about the degree of neuromuscular blockade. In pediatric patients, an abnormal increase in end-tidal carbon dioxide (P_{ET}CO_{2}) most commonly signifies hypoventilation, but rarely may also indicate the presence of increased carbon dioxide production as occurs with temperature elevation, or as an early sign of malignant hyperthermia. Conversely, an abnormally low end-tidal CO_{2} may indicate an increase in dead-space or suggest a state of low pulmonary perfusion. Sudden absence of the capnographic tracing indicates a breathing circuit disconnection, and the abnormal presence of inspired CO_{2} signifies the presence of a faulty unidirectional valve, an exhausted CO_{2} absorber or, when a semi-open circuit is being used, rebreathing secondary to an insufficient fresh gas flow.

Capnography use in small children (<12 kg) has several drawbacks owing to the relatively large ratio of dead-space to tidal volume. Therefore, sampling proximal to the endotracheal tube often underestimates the true end-tidal CO_{2}. It is possible to measure end-tidal CO_{2} within the distal portion of the endotracheal tube using a device that resembles a thin straw, which is anchored to a breathing circuit extension piece by a Luer-lock mechanism (Fig. 14-1). Although the use of this device is associated with a more precise end-tidal CO_{2} value (Fig. 14-2), it may cause obstruction of a small endotracheal tube, or its sampling lumen may be blocked by secretions.

Although mainstream capnography may provide the most accurate reading, it adds bulk and dead-space to the circuit, both of which are undesirable when anesthetizing small infants. Therefore, side-stream capnography is most often employed for pediatric patients. Disadvantages of side-stream capnography in pediatric patients include the slow response time and, with some devices, a relatively large sampling volume. Recent innovations in capnography technology have allowed a sampling rate as low as 30 mL/min ("microstream technology").

The capnographic tracing of small infants is often characterized by a lack of an apparent alveolar plateau. This is usually a result of a higher respiratory rate, an excessively high sampling flow for the volume of CO_{2} produced, excessive dead-space in the breathing circuit, or an excessive leak around an uncuffed endotracheal tube.

ELECTROCARDIOGRAPHY

In pediatric anesthesia, the electrocardiogram (ECG) is most useful for diagnosing intraoperative rate-related
arrhythmias, the two most common of which are brady-cardia and supraventricular tachycardia (SVT). The ECG is much less prone to movement-related artifact than is the pulse oximeter. In small infants, hypoxemia-related bradycardia will often occur prior to the pulse oximeter signaling oxyhemoglobin desaturation. Conversely, resolution of hypoxemia is heralded by the transition from bradycardia to normal sinus rhythm. Premature ventricular contractions (PVCs) are commonly observed when halothane is used as the general anesthetic agent, especially during periods of hypercapnia and/or catecholamine release. More details about the electrical rhythm of the pediatric heart are given in Chapter 2.

**BLOOD PRESSURE MONITORING**

Nearly all pediatric surgical facilities in the United States are equipped with automated oscillometric blood pressure devices. Oscillometric measurement of systolic blood pressure usually correlates well with the Riva Rocci mercury column method, but it tends to underestimate the diastolic component in children. In most routine cases, measurement of blood pressure should be performed every 3–5 minutes throughout the period of general anesthesia. In children the blood pressure cuff is most commonly placed on the upper arm, but it can alternatively be placed on the forearm, thigh, or calf. However, there is inconsistent correlation of measurements obtained between upper and lower limbs.

The width of the blood pressure cuff should cover approximately two-thirds the total length of the upper arm (or other extremity portion to which it is applied). Too small a cuff is associated with falsely elevated blood pressure values, and too large a cuff is associated with falsely lowered blood pressure values.

**PRECORDIAL OR ESOPHAGEAL STETHOSCOPE**

Although not an essential monitor (by ASA standards), many pediatric anesthesiologists find that the precordial (or esophageal) stethoscope is indispensable during pediatric anesthesia. It is useful during all phases of general anesthesia, as well as during transport of the child between hospital locations. Continuous auscultation allows the anesthesiologist to immediately detect changes in the rate and character of heart and breath sounds, and it is often the first warning of a physiological alteration during pediatric anesthesia (e.g., right main bronchial intubation, wheezing). During administration of halothane, the character of the heart sounds is often used to judge the depth of anesthesia. During ligation of a patent ductus arteriosus (PDA), a precordial stethoscope can help the surgeon identify the correct structure since clamping the ductus will result in a disappearance of the murmur.

The precordial stethoscope is placed to the left of the sternum in the 3rd or 4th intercostal space. An esophageal stethoscope is placed in the mid-esophagus in intubated children. The proper method for accurate placement of the esophageal stethoscope is to listen while simultaneously advancing the device and placing it at the level where the heart and lung sounds are maximal. In small infants, unintentional placement of the esophageal stethoscope into the stomach can occur easily.

**ARTICLES TO KNOW**


