Chapter 8

Monitoring of the Pediatric Patient

Michael R. King

A three-day-old, 3 kg female infant with transposition of the great arteries presents for an arterial switch operation. Transthoracic echo revealed an L-type transposition with an unrestrictive atrial shunt. The patient has been stable since birth in the neonatal intensive care unit receiving an alprostadil infusion.

Prior to the procedure, vitals include: temperature 37.2^{0}C, BP 63/42, HR 130 bpm, SpO_2 88% on room air.

What Are the American Society of Anesthesiologists (ASA) Standard Monitors?

The goals of monitoring are to have consistent feedback on the patient's oxygenation, ventilation, circulation, and body temperature. This is most commonly achieved with the ASA basic monitors: 3-lead electrocardiogram, pulse oximetry, non-invasive blood pressure, capnography, temperature probe for cases lasting longer than 30 minutes or shorter cases with expected temperature changes, and oxygen/inspired gas monitoring.

What Other Monitors May Be Useful for This Case?

Neonates undergoing congenital cardiac surgery require additional monitoring beyond the ASA basic monitors. At minimum, an arterial line will be needed for continuous blood pressure monitoring on bypass as well as to facilitate blood sampling. Many centers will also assess brain oxygenation with near-infrared spectroscopy (NIRS), central/right atrial pressures with a central venous catheter, and post-surgical anatomy and function with transesophageal echocardiography (TEE).

What Is Near-Infrared Spectroscopy and What Does It Monitor?

NIRS is a monitor of oxygenation in the cerebral vessels. Using technology similar to pulse oximetry, a probe is placed on the forehead which emits light in the near-infrared spectrum. The probe then subsequently analyzes scattering and absorption to assess oxyhemoglobin and deoxyhemoglobin saturations in the cerebral vasculature. During cardiac and other procedures, sudden changes in NIRS serve to alert the anesthesiologist to decreases in cerebral oxygenation or perfusion.

How Is NIRS Different from Pulse Oximetry?

Whereas pulse oximetry takes advantage of pulsatility to distinguish between arterial and venous blood, giving a reading that reflects arterial saturation, NIRS does not incorporate pulsatility and measures both venous and arterial hemoglobin saturations. Therefore, a normal NIRS saturation will be much lower than a pulse oximeter reading, often in the 70s or 80s when the arterial saturation is 100%. Thresholds for abnormal NIRS values are thus defined by a change greater than 20% or an absolute reading of $<$50%.

How Should a Noninvasive Blood Pressure Cuff Be Sized?

Choosing an appropriately sized cuff is important; a small cuff tends to overestimate blood pressure while an oversized cuff tends to underestimate it. Ideally a cuff should be 2/3rds to 3/4ths the width of the upper arm.

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What Is the Normal Blood Pressure in Children?

A crude estimate according to PALS may be obtained by the following formula:

$90 + (2 \times \text{age}) = 50\text{th percentile for age.}$

What Arteries Can Be Used for Invasive Blood Pressure Monitoring?

The most common arteries for arterial line placement include the radial, ulnar, femoral, dorsalis pedis, and posterior tibial arteries. In addition, in the newborn the umbilical arteries can be used for cannulation; these are most easily placed at birth, but can occasionally still be placed in the first several days of life.

What Techniques Can Be Used to Identify an Artery for Line Placement, and What Are the Limitations of Each?

Palpation is the simplest method of locating an artery for cannulation; however, numerous studies have demonstrated improved success with ultrasound utilization. Surgical cut-down allows for the direct visualization of the artery, but requires tissue dissection and may result in vessel laceration or hemorrhage.

Where Should the Tip of an Umbilical Artery Catheter Be Located? What Are Potential Complications of Its Migration?

Umbilical artery catheters should terminate high (T7–10) or low (below L2–3) to avoid thrombosis in one of the intra-abdominal branches off the aorta (Figure 8.1). Migration of the catheter into the femoral arteries can cause limb ischemia and migration proximally can occlude arteries leading to the kidneys, liver, or gastrointestinal tract. For umbilical vein catheters, the tip should lie at the junction of the inferior vena cava and right atrium (Figure 8.2).

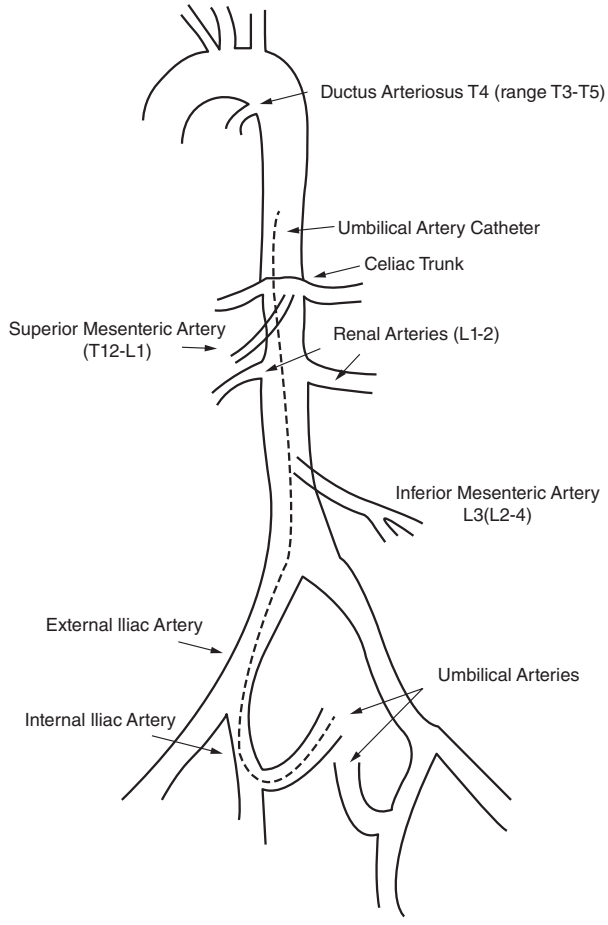

Figure 8.1 High placement of an umbilical artery catheter in relation to intraabdominal aortic branches. Illustration by Adam C. Adler, MD

How Is the Depth of Insertion Calculated for Umbilical Catheters?

In small neonates, <1,500 grams, a 3.5F catheter should be used. In larger neonates >1,500 grams a 3.5 or 5F catheter may be used.

Arterial: The depth of insertion for a "high" placement can be assessed by:

$$\text{Depth of Insertion} = (\text{weight (kg)} \times 3) + 9\ \text{cm}.$$

Venous:

$$\text{Depth of Insertion} = \frac{(\text{weight (kg)} \times 3) + 9\ \text{cm}}{2}$$

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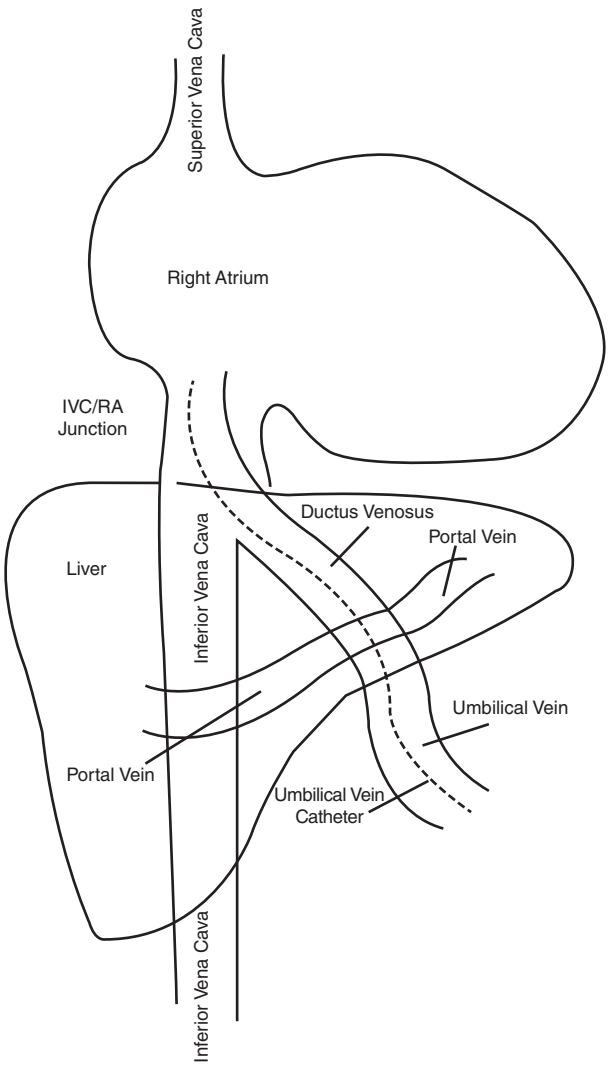

Figure 8.2 Correct placement of an umbilical venous catheter in relation to the hepatic vessels. Illustration by Adam C. Adler, MD

What Vessels Can Be Utilized for Central Line Placement?

Central venous catheters are most often placed in the internal jugular, femoral, or subclavian arteries. Peripherally inserted central lines (a.k.a., "PICC lines") can be placed through peripheral veins in the arms or legs for central medication administration and phlebotomy; however, their length and small cross-sectional area often dampen signals for central venous pressure. Similar to arterial line placement, the umbilical vein can be used for cannulation in newborns. For the catheter to reach a central location it must pass through the ductus venosus, which closes a few days after birth.

Where Should the Tip of a Central Venous Catheter Lie for Accurate Central Venous Pressure Measurement?

Central venous pressure (CVP) is measured at the junction of the superior vena cava and right atrium. Central lines placed in the inferior vena cava, such as femoral lines, may have the accuracy of their CVP readings affected by changes in intra-abdominal pressure.

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What Is the Role of Pulmonary Artery Catheterization in Pediatrics?

Pulmonary artery catheters are rarely used in children, but can provide information on right heart pressures which may be particularly useful in patients with pulmonary hypertension. The ability to sample mixed venous oxygen saturation can also be useful in the management of shock. Due to small patient size, relative to available catheters, their use is virtually nonexistent in infants and neonates.

Would You Use Transesophageal Echocardiography (TEE) for This Patient? What Are Potential Complications of Its Use?

TEE provides a wealth of information at the termination of cardiopulmonary bypass in congenital heart surgery. It can be used to diagnose residual shunts, patency of valves, repaired vessels or grafts, and, of particular concern in the arterial switch operation due to the relocation of the coronary arteries, wall motion abnormalities suggestive of ischemia. Care must be taken with insertion and removal of a TEE probe in neonates as the small size of the oropharynx often puts the probe in contact with the endotracheal tube, which can lead to accidental extubation or mainstem intubation. Although rare, esophageal perforation is also a known complication. More commonly, tracheal compression may occur, leading to difficulty with ventilation (high peak inspiratory pressures), especially in neonates.

What Are Potential Sources of Error in Pulse Oximeter Readings in Neonates?

In the neonate with a patent ductus arteriosus, any site monitored distal to the ductus will report a decreased saturation if a right-to-left shunt is present. In these patients it is helpful to monitor a preductal saturation in the right arm as well as a post-ductal saturation in the left arm or legs. It is notable that pulse oximeters, depending on the brand, are calibrated for best accuracy at higher saturations, typically above 70%. A pulse oximeter may therefore be less accurate in a child with cyanotic heart disease. Fetal hemoglobin and hyperbilirubinemia do not affect pulse oximeter accuracy. Common sources of error in adults, such as methylene blue, indigo carmine, and methemoglobinemia will also affect neonates.

What Are Potential Sources of an Increased Arterial to End-Tidal Carbon Dioxide Gradient in This Patient?

In all neonates and infants with small tidal volumes, increases in dead space cause dilution of the exhaled breath as measured by capnography. This can be mitigated by placing the capnography sampling site, whether sidestream sampling or mainstream sampling, as close to the endotracheal tube as possible to minimize dead space.

Where Would You Monitor Temperature on This Patient?

Temperature is typically monitored at two sites for cases involving cardiopulmonary bypass. It is essential to monitor the temperature of the brain, as cooling is used for protection from cerebral ischemia. The nasopharynx is most commonly selected. The tympanic membrane has also been used, but is less practical. A "shell" temperature site – one that reflects the body tissues that are not in the vessel-rich group – is also typically monitored. Options for this include the bladder, skin, or rectum. While esophageal probes are useful for core temperature monitoring in most general cases, in cardiac surgery, especially where deliberate hypothermia or hypothermic circulatory arrest will occur, nasopharyngeal temperature monitoring is preferred (as a surrogate for intracranial temperature).

What Properties of Neonates Limit the Utility of Neuromuscular Blockade Monitoring?

Neonates, especially those that are premature, have immature neuromuscular junctions. As a result, neuromuscular junction monitors may reveal decreased signals even at baseline. Some neonates will have fade on a train-of-four test at baseline, and may lack sustained tetany in response to a continuous stimulus. For these reasons, the neonate should also be observed clinically for signs of full neuromuscular function recovery if muscle relaxants have been used.

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Suggested Reading

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