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CHAPTER 13.2

Out-of-Operating Room Procedures—Pediatric

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[1]Radiation Oncology

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[4]Radiation therapy, oncology, endoscopy, imaging

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Pediatric Radiation Therapy

Procedural Considerations

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Description: Modern pediatric radiation therapy (XRT) requires that the patient be in a stable and reproducible position for daily treatment. Sharply defined beams with secondary collimation are used to irradiate the tumor volume and to spare normal tissue. Patient movement may undermine techniques for sparing normal tissue and, while movement cannot be completely prevented, it must be minimized. In very young children, it is often impossible to prevent movement and achieve adequate cooperation for radiation treatment. In such cases, daily anesthesia is required. Close cooperation of the radiation oncology and anesthesia teams allows for safe and reproducible daily treatment. In general, children older than 3 or 4 years can be persuaded to lie still for radiation therapy. Children from 2.5–4 yr may cooperate during the treatment (which is usually < 15 min), but not for the treatment planning and simulation, in which an immobilization-stabilization device is made (often requiring 1–1.5 h). In most infants and young children (< 2.5 yr), anesthesia is essential.

The optimal position for XRT also must be optimal for the anesthesiologist. Ideally, the area to be treated is determined using 3-dimensional conformal techniques to optimize treatment and to minimize normal tissue exposure. This requires an imaging study

(e.g., CT scan), with the patient in the same position as will be used during the radiation treatment. A series of radiographs are taken at the treatment-planning appointment, which typically lasts 1–1.5 h and requires GA. It is essential that there be no patient movement between exposures; if the patient moves, the entire procedure must be repeated. After examining the radiographs, the area to be scanned is determined; then the patient is transported (anesthetized) to the CT suite for a 3-dimensional treatment-planning CT scan. Thereafter, the specific area can be determined and individual beam-shaping devices made.

Seven to 10 days following the initial planning session, the patient has a verification procedure, which usually is of shorter duration—often requiring only 30 min. of anesthesia time. The verification procedure consists of a series of radiographs using the beam-shaping devices, which simulate the treatment to be given. When this procedure is successfully completed, the anesthetized patient is moved to the treatment room. The child is put in the identical position achieved during the planning/verification procedures and treatment is administered.

The first day or two, and weekly thereafter, a verification x-ray (called a “port film”) is taken to confirm the accuracy of the treatment field. The treatment itself is only a few minutes in duration for each field; ideally, the entire procedure is completed within 15–30 min. A newer form of radiotherapy treatment planning and delivery known as intensity-modulated radiotherapy (IMRT) requires slightly longer treatment times due to the larger number and increased complexity of fields treated. A course of treatment may be only a few days, or may last for 5–6 wk, generally with treatment given 5 × per week. Occasionally, multiple (2–3) treatments per day are given at 4–8-h (usually 6 h) intervals. At the initial appointment, the patient's optimal position is determined, an immobilization device is constructed, and measurements are taken. The immobilization device is usually a body cradle or cast, and often a head/face mask is made for head and neck or brain treatment. Initially, temporary marks or Band-Aids are used; however, when the final positioning has been determined, a more permanent mark, such as a tattoo, is applied. Often, a head holder with a mask is applied to ensure the position for XRT.

In managing certain brain tumors (e.g., medulloblastoma, high-grade intratentorial ependymoma, germ cell tumors, and CNS leukemia), **cranial spinal irradiation** (CSI) is used. Conventionally, this procedure requires that the patient be placed in the prone position with the head flexed as much as possible to minimize a cervical lordosis. This positioning, however, creates special difficulties for the anesthesiologist. If the child is intubated for the setup, the radiation stabilization device must allow space for the ETT. If the child is not intubated, there must be adequate access to the airway. Newer techniques allow patients to be treated with CSI in the supine position, facilitating easier airway access for the anesthesiologist, more secure patient immobilization, and faster treatment times.

Fractionation: Pediatric protocols have been testing the efficacy of giving multiple fractions (treatments) of radiation 2–3 × per day, usually at 6-hour intervals, to allow higher total radiation doses to be administered with possible less normal-tissue morbidity. These schemes have been or are being evaluated for children with central nervous system tumors and total body irradiation (TBI) in preparation for bone marrow transplantation. Until proven to be of increased efficacy, such schemes should remain part of large protocol studies. The timing of radiotherapy may be at 4-, 6-, or 8-hour intervals 2–3 × per day, depending on the protocol. These studies provide several challenges for anesthesiologists, radiotherapists, and parents. Radiotherapy under anesthesia, however, has been successfully administered to infants undergoing multiple fractions per day. Attention must be given to potential malnutrition and/or dehydration from prolonged periods of npo status.

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Total body irradiation (TBI): Although most TBI techniques are administered with the patient standing, infants and small children must lie prone and supine for the treatment. This positioning requires sedation and/or anesthesia. Retching and vomiting, sometimes provoked by the radiation, present an additional challenge for proper radiotherapy technique, as well as for anesthetic management.

Radiosurgery: The technique of using stereotactically localized radiosurgery with a highly collimated radiotherapy photon beam, as generated from a linear accelerator, is currently being employed for select patients with small CNS tumors or base-of-skull tumors. There is increasing enthusiasm for this technique for infants and children with recurrent posterior fossa and cerebral tumors, craniopharyngiomas, optic nerve and chiasmal gliomas, and small AVMs. Radiosurgery can be performed with a frame-based or frameless technique. Frame-based radiosurgery requires 6–10 h of continuous anesthesia while a patient undergoes application of a metal frame, CT localization, and multiport radiotherapy treatment. Newer technology, using image guidance, now allows frameless radiosurgery. This technique requires a 1–1.5-h treatment planning and simulation session followed by a single fraction or limited number of treatment sessions each lasting 1.5–2 h. These approaches require close coordination between the anesthesiologist, neurosurgeon, and radiotherapist.

Usual preop diagnosis: Leukemia; retinoblastoma; most of the solid tumors of childhood

Summary of Procedures

	Standard XRT/IMRT	TBI	Frameless Radiosurgery
Position	Supine or prone	Supine and prone	Supine or prone
Unique considerations	If prone: head flexed for maximal straightening of the C-spine.	May be repeated 2–3 9D at 4–6-h intervals.	Head extended for stabilization of airway.
Anesthesia time	Planning: 30–120 min Treatment: < 15 min (IMRT: 15–30 min)	45–60 min < 20 min	30–90 min 90–120 min
Postop care	PACU → home	PACU → room	PACU → home

Patient Population Characteristics

Age range	Usually ≥ 4 yr
Male:Female	1:1
Incidence	NA
Associated conditions:	**Brain tumors:** ↑ ICP is of concern in these patients. Postradiation edema following the first few treatments may further ↑ ICP, with potential for brain stem herniation. Some children with brain stem tumors are particularly difficult to anesthetize, perhaps because of disruption of nerve pathways in those areas of the brain stem that are affected by anesthetics. **Diabetes insipidus (DI):** It is often impossible to withhold fluids for 4-6 h prior to radiotherapy in an infant with symptomatic polydipsia from DI. **Neuroblastoma:** Neuroblastomas are capable of secreting catecholamines and related substances; hence, there is a potential for paroxysmal HTN during anesthesia induction. In these children, the principles of anesthetic management are similar to those for pheochromocytoma. **Retinoblastoma:** It is imperative that the patient be properly immobilized with no movement, as even a mm of change, as occurs with a sigh, may cause unnecessary radiation to the radiosensitive lens and anterior chamber. Optimal anesthesia prevents nystagmus and motion of the head. Even minimal lateral or rotary nystagmus may increase the risk of cataract induction.

Anesthetic Considerations

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Preprocedure

Orientation to the XRT suite, reassurance, positive reinforcement, and play therapy, can reduce the number of children requiring anesthesia for XRT; however, the majority of children ≥ 4 yrs will require anesthesia. A detailed *(Print pagebreak 1486)* preanesthesia visit is essential and is also an opportunity to gain the confidence of both child and parents. The majority of these patients will have received chemotherapy and should be evaluated for toxic side effects. The importance of NPO status needs to be stressed repeatedly, discussing the potential danger of emesis during treatment. Written instructions regarding preop protocols are extremely helpful in this context. For children with cancer, prolonged preop fasting for XRT once or twice daily could severely compromise an already marginal nutritional intake. Infants, children, and adolescents should be encouraged to drink clear liquids until 2 hours before treatment. Milk and solid foods should be held for an appropriate time interval (6 h). Reassessment before each

anesthetic is recommended because the patient's medical status may change during the course of radiation therapy. Some children will have Sx of ↑ ICP which must be taken into account when designing an anesthetic plan to avoid ↑ $PaCO_2$ and other factors that may further ↑ ICP.

The most common diagnoses are: primary CNS tumor (28–33%), retinoblastoma (9–26%), acute leukemia (9–26%), neuroblastoma (2–18%), lymphoma (8%), rhabdomyosarcoma (5–7%), Wilms' tumor (5%), and Ewings (5%). The total number of treatments can range from 1–65 (median 20–24). Many patients require a mold of the head and neck. The prone position was required during 19–21% of treatments. Children can range in age from infants to adolescents, with a median age of 2.4–3.8 yr.

Respiratory	Careful evaluation for respiratory compromise due to chemotherapy. Patients with Sx of URI (rhinorrhea, cough, fever) are commonly seen during XRT treatment. If Sxs are significant, XRT should be delayed and the patient should be evaluated by primary service. Fortunately, most children can be managed without the use of an ETT, which itself can increase the risk of oxygen desaturation, laryngospasm, and bronchospasm. As always, the benefit of XRT vs. delaying treatment must be balanced against the risks of anesthesia. **Tests:** As indicated from H&P.
Cardiac	Careful evaluation for cardiac compromise due to chemotherapy. **Tests:** As indicated from H&P
Neurologic	Patients with intracranial tumors may have ↑ ICP. Postradiation edema following the first few treatments may further ↑ ICP. Sx include irritability, HA, N/V, and papilledema. Suspicion of ↑ ICP mandates ET intubation and controlled ventilation to induce hypocarbia.
Laboratory	Tests as indicated from H&P.
Premedication	Usually unnecessary in this patient group. Parents usually present for induction and majority of patients have some form of central venous access or heplock in situ. If inhalational induction necessary, midazolam 0.5–0.75 mg/kg po may be helpful. Inappropriate sedation may cause respiratory or cardiovascular depression and prolong recovery.

Intraprocedure

Anesthetic technique: Provision of anesthesia to children at sites remote from the OR is challenging. During XRT, patients must remain immobile so that the tumor can be reliably irradiated while minimizing damage to uninvolved tissue. Anesthetic goals should include: patient immobility, rapid onset, brief duration of action, and prompt recovery. The anesthetic should allow maintenance of a patent airway and spontaneous ventilation in a variety of body positions. Ketamine is a potent sialogogue and can cause nystagmus, which prevents precision radiation of retinoblastomas. It may cause prolonged or unpleasant emergence and should be avoided in patients with ↑ ICP. Choice of anesthetic technique may be limited by equipment or logistical issues. Anesthesia machines may not be available in all XRT suites.

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Induction	**IV:** Propofol (2–4 mg/kg), titrated slowly to effect. Intubation is usually unnecessary, except for patients with ↑ ICP or those with potential for airway obstruction. **Inhalation:** Mask induction with sevoflurane is appropriate in children without iv access, and may be preferred by some children. Again, intubation is usually unnecessary. The airway can almost always be maintained by careful positioning and extension of the neck. It is essential that this same degree of extension/flexion be maintained for each treatment. A molded immobilization device may be placed over the patient's head and neck.
Maintenance	**IV:** Propofol (100–250 mcg/kg/min) by continuous infusion. Supplemental O_2should be administered via nasal prongs. **Inhalation:** Sevoflurane in O_2 Patients awaken rapidly following cessation of propofol infusion or sevoflurane.

Emergence	Extubate patient fully awake, unless there is the possibility of ↑ ICP, in which case a deep extubation may be appropriate. XRT can cause nausea/vomiting so antiemetics should be given (ondansetron 0.1–0.15 mg/kg). Avoid dexamethasone (may conflict with chemotherapy protocols and in rare cases may cause tumor lysis syndrome).	
Blood and fluid requirements	IV: NS/LR:	Majority of children receiving radiotherapy have some form of central venous access. Maintenance.
Monitoring	Standard monitors (see p. D-1).	A critical problem is the lack of access to the patient and monitors during XRT. A video camera with a zoom lens can focus on the monitors and a second camera is trained on the patient. In XRT suites with a viewing window, a small marker may be placed on the chest so that the rise and fall of chest motion is seen easily. Respiration also may be assessed by direct visualization.
Positioning	and pad pressure points eyes.	Careful positioning 2° possible chemotherapy induced peripheral neuropathy.
Complications	Airway obstruction Patient movement	Respiratory obstruction may occur; it usually responds to nasal or oral airways and careful repositioning. In rare instances, intubation may be required for persistent airway obstruction. Deepen anesthesia.

Postprocedure

Complications	PONV	Many patients have chemotherapy induced nausea, which may be exacerbated by anesthesia, XRT, and stress.
	Central line sepsis	Patients may be immunocompromised following chemotherapy. Attention to sterility during access of the central venous line is critical, because repeated use by multiple health care providers ↑ risk of catheter contamination. Aseptic preparation of anesthetic iv medications, especially propofol, is important.
	Cerebral edema	In patients with ↑ ICP, XRT can provoke an acute ↑ ICP, with consequent ↑ HA, ↑ N/V, ↓ consciousness, and cardiac arrest. These patients should be monitored × 24-h post-XRT.
Pain management	Standard approaches	Radiation treatments are not associated with pain, but narcotics may be useful in relieving pain associated with neoplastic disease.

Suggested Readings

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Pediatric Cardiac Catheterization and Electrophysiology

Procedural Considerations

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Cardiac catheterization and electrophysiology testing have evolved over the recent decades from purely diagnostic tools to combined diagnostic and therapeutic procedures. Although the use of anesthesiologists and GA varies from institution to institution, higher levels of sedation are required at a minimum for critically ill patients, those requiring complex interventional strategies, small

children who must remain totally still, and when TEE is used for image-guided therapy. A thorough review of diagnostic and interventional cardiac catheterization and electrophysiology is not possible in this chapter, and the interested reader is referred to the multiple textbooks available on the subject.

The placement of anesthesia equipment for these procedures must allow for: (a) proper positioning of the patient, (b) easy access to the head and neck and/or groin for the physician performing the procedure, and (c) rotation and angulation of the imaging equipment. The goal of sedation in all of these procedures is to provide a nontraumatic, safe environment for the patient. Many patients can be cared for adequately and safely using conscious sedation; however, there is a subset of pediatric patients who may require GA. This group may include patients with complex congenital heart disease, ventricular dysfunction, or airway abnormalities. It is important to understand that certain anesthetic agents may alter cardiac conduction, making arrhythmia inducibility more difficult. Catecholamine-dependent arrhythmias, such as an automatic atrial tachycardia, may be impossible to induce with the patient under GA. Furthermore, the arrhythmia itself may complicate anesthetic care, by causing sudden decreases in BP due to excessively rapid rates. In patients undergoing radiofrequency ablation (RFA) in areas close to other critical structures of the heart, GA may be necessary to keep the patient motionless during application of energy.

Vascular Access

The modified **Seldinger technique** of cannulating blood vessels percutaneously is used to establish vascular access for cardiac catheterization. (The femoral, IJ, and subclavian veins are most commonly used for venous access.) Transhepatic access to the IVC has been used safely and successfully in patients without femoral venous access. The femoral artery is most commonly used, although the carotid and axillary arteries may be used for specific procedures or when there is bilateral femoral artery occlusion. In newborns, the umbilical artery and vein may be used. Access may be especially difficult in patients who have undergone multiple previous procedures. In the most severe cases, *(Print pagebreak 1489)* **reconstructive transcatheter techniques,** including **balloon angioplasty** and **stent implantation** to rehabilitate the vessels, have been used to allow future catheter-based diagnostic and therapeutic interventions.

Infiltration of the skin and the subcutaneous tissues with a local anesthetic agent to reduce pain is used when the procedure is being performed under conscious sedation. With GA, infiltration of a local anesthetic agent may be deferred to the end of the procedure to alleviate pain and discomfort at vascular access sites during recovery.

Hemodynamic Data

O_2 sat measurements are made routinely in the various cardiac chambers, vena cavae, and great vessels. These measurements are used to calculate the systemic flow (CO, Q_S), pulmonary flow (Q_P), the ratio of the pulmonary-to-systemic flow (Q_P:Q_S), and PVR and SVR.

It is ideal to obtain the data with the patient awake and breathing spontaneously in room air. This is rarely possible in pediatric patients. The use of light anesthesia and sedation during the diagnostic part of the study facilitates acquisition of data in as near normal state as is possible. It is important to recognize and limit effects on intracardiac and intrapulmonary pressures and systemic and pulmonary resistances when the procedure is done under GA with IPPV. At a minimum, and when tolerated, baseline hemodynamic measurements should be performed with an FiO_2 as close to 0.21 as possible. In some cases, additional diagnostic information may be collected to study the effects of O_2, NO, vasodilators or inotropes, exercise and balloon occlusion of intracardiac or extracardiac shunts on the CO, pulmonary flow, and PVR and SVR.

From O_2 sat, dissolved O_2 (PO_2), and Hb measurements, the O_2 content (mL/dL) of the mixed venous blood and systemic arterial blood is used to calculate systemic AV O_2 content difference. Pulmonary AV O_2 content difference is similarly estimated by calculating the O_2 content of pulmonary venous and arterial blood. Systemic (Q_S) and pulmonary flow (Q_P) can then be derived using the **Fick principle:**

$$\text{Flow (Q)(L/min)} = \frac{O_2 \text{ consumption (mL/min)}}{\text{AV } O_2 \text{ difference (mL of } O_2\text{/L of blood)}}$$

When the partial pressure of dissolved O_2 is < 100, the PO_2 portion of the equation can be negated and the flow can be calculated using the O_2 consumption and sat measurements alone.

$$\text{Pulmonary Flow } (Q_p) = \frac{O_2 \text{ Consumption}}{\text{Pulmonary vein sat} - \text{Pulmonary artery sat}}$$

$$\text{Systemic Flow } (Q_s) = \frac{O_2 \text{ Consumption}}{\text{Systemic artery } SaO_2 - \text{Mixed venous } SaO_2}$$

Based on Ohm's law, which states V = IR, where V = voltage (or pressure drop) across a circuit, I = the current (or flow) through the circuit and R = the resistance in the circuit. SVR and PVR can be calculated as follows:

$PVR = (PA_p - LA_p)/Q_p$

$SVR = (Ao_p - RA_p)/Q_s$

Where PA_p = pulmonary artery pressure; LA_p = left atrial pressure; Ao_p = aortic pressure; and RA_p = right atrial pressure; pulmonary vascular resistance = PVR; systemic vascular resistance = SVR.

Angiography

Biplane cineangiography is performed to delineate intracardiac or vascular anatomy and to evaluate ventricular function. Images are obtained by injection of radiographic contrast agents through angiographic catheters positioned in appropriate locations. The angiograms may be performed in postero-anterior and lateral projections or by angling the cameras to obtain cranial, caudal, left anterior, or right anterior oblique projections. Based on the site of injection and the information required, the injection may be performed with a power injector, delivering large amounts of contrast quickly, or by hand.

Interventional Procedures

Valvuloplasty

Aortic valvuloplasty: A retrograde approach from the femoral artery generally is used, although an antegrade and transseptal approach from the femoral vein is preferred by some. In either approach, following hemodynamic evaluation and *(Print pagebreak 1490)* angiographic estimate of the aortic valve annulus, a wire is positioned across the valve and a balloon catheter is advanced over the wire and positioned across the aortic valve. The balloon is then inflated and deflated quickly. The inflation of the balloon leads to a transient loss of CO, ↓ SBP, and occasionally may be accompanied by ↓ HR. These hemodynamic changes recover quickly on balloon deflation. While complications of aortic valvuloplasty are rare, the anesthesiologist must be ‘prepared for the worst,’ which includes annular rupture and the creation of significant aortic regurgitation.

Pulmonic valvuloplasty: After femoral venous or IJ access is obtained, the technique for balloon dilation of the pulmonary valve is nearly identical to that outlined above for the aortic valve. Loss of CO and ↓ HR are seen during the time of balloon inflation with this intervention as well. While annular rupture also is a potential complication of this procedure, the creation of pulmonary insufficiency is of less concern and better tolerated than aortic insufficiency.

Angioplasty

A number of transcatheter treatment options are available for management of **pulmonary artery stenoses,** including **balloon angioplasty** and **endovascular stent implantation.** Angioplasty has been shown to be highly effective in anatomically appropriate cases with a low complication rate. Hemodynamic and angiographic assessment of the lesion is obtained, followed by selection of an optimal balloon catheter, based on both the size of the stenosis and surrounding ‘normal’ tissue. Using the same “over-the-wire technique,” a balloon is advanced and centered over the stenosis. Hemodynamic and angiographic data are assessed following each intervention. A high index of suspicion for complications—including dissection or pulmonary artery tear, obstructive intimal flaps, thrombi, and reperfusion pulmonary edema—is justified, as management may require ventilatory manipulations and/or emergent cardiovascular resuscitation.

Balloon angioplasty of coarctation of the aorta may be performed for treatment of native or recurrent coarctation. Angiography of the aorta is performed to delineate the coarctation and estimate the dimension of the coarctated segment and the adjacent aorta. As with other angioplasty techniques, the balloon size is based on the dimensions of the stenotic area and surrounding vessel. Transient loss of lower body perfusion and ↓ HR are to be expected, as with balloon valvuloplasty, on inflation of the balloon. Pressure and angiographic data are obtained to determine adequacy of results and absence of complications. There is a 4–5% incidence of intimal tear and dissection that, in most cases, are nonprogressive. Rarely, aortic disruption may require emergent surgical repair.

Endovascular Stent Placement

Stent implantation in the pulmonary arteries or for aortic coarctation is used to maintain vessel diameter and decreased gradients in patients unresponsive to balloon dilation. Stents are mounted on balloon catheters and the balloon/stent combination is advanced over a previously placed wire. A long sheath (originating in the groin or neck) is placed across the area of narrowing to prevent the

stent from slipping off the balloon catheter as it makes its way through the heart or vessels. After the stent has been properly positioned, the long sheath is withdrawn to expose the balloon/stent combination. The balloon is inflated to expand the stent and appose it to the vessel wall. Placement of long sheaths, particularly through the right ventricular outflow tract (RVOT), can be difficult and may result in transient bradyarrhythmias and loss of CO.

Closure of Congenital Defects

Atrial septal defects (ASDs): As many as 80–85% of secundum ASDs may be amenable to device closure in the cath lab. Most devices currently used include a left atrial disc with an occlusive membrane, a central spool or connecting pin, and a right atrial disc with an occlusive membrane. The membrane occludes flow through the defect and, within months, the device becomes incorporated into the septum due to endothelialization. A sizing balloon inflated across the defect permits estimation of the stretched diameter. A long sheath is then placed across the defect over a wire. The device attached to the delivery cable is loaded in the long sheath and advanced to the left atrium. The left atrial disc is opened, the device is withdrawn until the left atrial disk is in contact with the atrial septum; then the right atrial disc is opened, effectively "sandwiching" the atrial septum between the two disks. TEE is used to guide placement of the device. Intracardiac ECHO has been introduced recently and offers ECHO guidance without the requirement of GA.

Ventricular septal defect (VSD): Closure with a device can be performed in the cath lab for isolated or multiple muscular VSDs, as well as perimembranous defects. The technique requires establishment of a continuous AV guide wire loop across the defect. Most often, the wire course is from the femoral vein, through the right atrium, into the RV, across the VSD, out the aortic valve, around the aorta, and out the femoral artery. The device is then deployed via a long sheath placed across the VSD through the RV aspect. Hemodynamic compromise may be seen with tension on the wire if aortic or tricuspid insufficiency is induced. Transient arrhythmias are routine while crossing the VSD and deploying the device. Great care must be taken to avoid entrapment in the mitral, aortic, and tricuspid valves during device deployment. In addition to fluoroscopy, TEE is used to guide placement of the device. Improvements in the devices developed more recently have significantly reduced the cath lab morbidity of this procedure.

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Coil occlusion: Aortopulmonary collaterals, AVMs, Blalock-Taussig (B-T) shunts, venous collaterals, coronary artery fistulae, and patent ductus arteriosi (PDA) have all been successfully occluded using the technique of coil embolization. The embolization coils consist of a metal wire, either stainless steel or platinum, ± Dacron strands, and are available in multiple sizes, lengths, and shapes. While PDA or coronary artery fistula embolization may obviate the need for surgery, most embolizations serve to either reduce the cardiac workload by decreasing the amount of shunting or simplify a planned surgical procedure.

The technique for coil closure of collaterals or other communications is straightforward. A catheter is placed in the vessel to be occluded and a selective angiogram is done to delineate the anatomy and diameter of the vessel to be closed. Coils that are slightly larger than the diameter of the vessel are used, since the vessel will distend when the coil is deployed. Using a long 'pusher' wire, the coil is advanced through the catheter and deployed in the vessel. Repeat angiography is performed to confirm complete closure. If residual flow remains, additional coils are placed. Coil dislodgement and embolization to a distal blood vessel is the most common complication. In general, the errant coil can be retrieved in the cath lab without much difficulty and a new coil of a larger size placed to occlude the vessel.

Other Procedures

Endomyocardial biopsy is commonly performed for rejection surveillance in patients following cardiac transplantation. It also may be performed in patients presenting with acute onset of cardiomyopathy for histopathological Dx of myocarditis. The preferred site for obtaining cardiac biopsy is the RV aspect of the intraventricular septum. The specimen is obtained with a biopsy forceps advanced to the RV through a long sheath. It is usual to obtain four to five specimens to improve the diagnostic gain, as the histopathological changes can be patchy. Complications of endomyocardial biopsy include cardiac perforation and tricuspid valve damage. GA is required in patients with compromised airway and/or cardiopulmonary status from lymphoproliferative disease or obesity 2° to steroid therapy.

A variety of other transcatheter therapeutic procedures may be performed in the cardiac cath suite. **Rashkind balloon atrial septostomy, static balloon septoplasty, Brockenbrough transseptal needle puncture,** and **radiofrequency-assisted perforation** of the pulmonary valve or the atrial septum are all less commonly used than the procedures described above, but routinely are undertaken in high-volume cath labs.

Electrophysiology Study (EPS)

Patients with atrial or ventricular arrhythmias may require either diagnostic or therapeutic interventions in the cath lab. EP studies

are catheterization procedures in which intracardiac electrical signals are recorded via specialized catheters that can both record electrical activity and stimulate the heart. These studies often are used to make a Dx of the mechanism of arrhythmia, assess the hemodynamic impact of the arrhythmia, assess efficacy of pharmacologic therapy, and map the location of abnormal conduction pathways or automatic foci. Although routine studies usually take 2–3 h, some may be quite lengthy.

Radiofrequency ablation (RFA) is a procedure in which abnormal electrical conducting pathways or automatic electrical foci (identified by EPS) are destroyed, using the application of RF energy delivered through a deflectable electrode catheter. This procedure was first described in pediatric surgery in 1991, but has rapidly become a preferred therapeutic option for supraventricular tachycardia in this population. On some occasions, RF lesions must be placed close to other critical structures in the heart (e.g., AV node).

With advances in technology and an increased understanding of high-risk pediatric patient populations, **transvenous pacemaker** and **implantable cardioverter defibrillator (ICD)** placements are becoming more common in the pediatric population. Pacemaker placement has become more common as data have accumulated regarding the risk of sudden death in patients with congenital complete heart block, as well as increased survival with postop heart block. New indications for ICD placement in patients with long QT syndrome, congenital heart disease, and hypertrophic cardiomyopathy have increased the number of ICD implantations in the last 5 yr. These procedures are commonly performed in the cath lab under GA.

Anesthetic Considerations

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Preprocedure

Cardiac catheterization and interventional procedures in children range from those requiring simple diagnostic procedures to those requiring complex interventional procedures such as balloon angioplasties or stent placement. These *(Print pagebreak 1492)* patients can present a challenge, given their abnormal cardiac anatomy and physiology. Many of them have undergone repeated catheterizations and will have had multiple anesthetics. All patients require a thorough preanesthetic H&P, emphasizing cardiorespiratory function and associated comorbidities. Most children will follow the same npo protocol as they would for surgery (see NPO Guidelines, see D-1). Be cautious in single ventricle patients who are prone to clotting of shunt or are dependent on their venous return for hemodynamic stability and oxygenation. In such patients either an IV can be started for hydration or clear liquids can be given up to two hours before surgery

Previous Anesthesia	Surgical and cardiological interventions; h/o difficult access; endotracheal tube size and anesthetic techniques; problems with previous anesthetics.
Family History	Family history for anesthetic related problems; h/o malignant hyperthermia.
Prematurity	Will affect the decision to intubate, apnea monitoring if <55 wks, need for pre-op admission; associated clinical problems.
Neurological	Head US in neonates; note preop neurological status as there is risk of embolism; for h/o seizures; h/o developmental delay. Patients are heparinized during procedure.
Craniofacial and Airway	H/o difficult airway; any surgery to the airway; h/o tracheal stenosis due to multiple intubations in the past; stridor due to laryngo- or bronchomalacia; h/o loose teeth.
Respiratory	H/o cyanosis, chronic cough and other chronic respiratory problems; ensure that they are under optimum control. H/o steroid use for RAD. H/o recent URI →↑ risk of adverse periop events. Patients with pulmonary HTN may have OSA. Cardiac transplant patients can develop lymphoproliferative disease, which results in redundant lymphoid tissue in the pharynx and epiglottis-possible airway obstruction. Requirement for CPAP, BiPAP, NO. Meds for pulmonary HTN should be continued. **Tests:** Assess perfusion scan for distribution of PBF. CXR to r/o infiltrates, CHF and cardiomegaly. Compare with baseline. Review current problem, hx of all surgeries; pacemaker, ICD etc.

Cardiovascular	If the patient has a pacemaker, note the settings and the reason for placing the pacemaker and when last interrogated. Identify existing shunts - will affect anesthetic plan and FiO_2 Assess cardiopulmonary reserve, (e.g., exercise tolerance, diaphoresis, and feeding difficulties). hx of syncope, hypoxic spells; note current SaO_2 Transplant patients may develop CAD. arrhythmias, palpitations, murmurs. **Tests:** ECG; recent ECHO and cardiac catheterization reports.
Gastrointestinal	Risk of reflux due to chronic use of steroids. May have G-tube/Nissen. Some single ventricle patients may have hepatic dysfunction.
Renal	Transplant recipients may develop renal dysfunction due to antirejection medication or HTN. Patients with CHF are on diuretics and could be hypovolemic. Patients may have had renal insult during previous surgery. **Tests:** BUN and Cr as these patients are also at risk for renal injury due to contrast, and also to guide hydration therapy.
Endocrine/Steroid	Transplant patients are on steroids. for other endocrine concerns.
Hematology/ Immunology	History of previous transfusions and reactions. Immunological deficiency that may affect the type of blood transfusion e.g., neonates require CMV negative blood and products.
Syndromes	for coexisting syndromes and associated anomalies.
Ob/Gyn	Last menstrual period.
Vascular	H/o vascular occlusion.
Current Medications	Stop warfarin at least three doses before cardiac cath. Heparin can be continued. Hold diuretics and ACE inhibitor starting the night before; continue all cardiac meds.
Laboratory	HCT: baseline to make decision regarding transfusion; ↑HCT suggests chronic hypoxia; Severe anemia should be corrected prior to cath if possible. Type and crossmatch blood if the patient needs transfusion for anemia or any interventional procedure; blood should be available in the cath lab. Electrolytes, especially if the patient is on diuretics and or digitalis. WBC: if the child has a h/o fever and recent URI. Drug levels - e.g., digitalis, antiseizure meds to make sure they are not outside the therapeutic range. Pregnancy test: must be done the morning of surgery if patient has attained menarche.
Premedication	Midazolam 0.5–0.75 mg/kg oral. Be cautious in patients with OSA. Cyanotic kids should have O_2sat monitored before and continuously after premedication. Antibiotics are given to patients as required for SBE prophylaxis or for those undergoing interventional procedures.
NPO	Most patients should follow the ASA guidelines for NPO. Avoid prolonged NPO in single ventricle and other shunt-dependent lesions, as the shunt flow might decrease with dehydration →↑ viscosity.
Equipment	Transport patients to and from the cath lab with a pulse oximeter and other monitors as appropriate. Equipment to manage difficult airways and hemodynamically unstable patients should be readily available, e.g., difficult airway cart, I-stat, arterial line, blood pump, pumps to infuse vasopressors, pacemaker, defibrillator, NIRS monitor.

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Intraprocedure

Anesthetic technique: The object of anesthesia and sedation in the cath lab is to maintain the patient's physiological state at rest with minimal anesthetic-related disturbance. Not all procedures require ETT placement, but all require an immobile patient. This can be achieved by varying degrees of sedation, from conscious to general anesthesia. Some interventional procedures (e.g., stenting, coiling) require a motionless field for prolonged periods of time, and are, therefore, unsuitable for sedation. Patients who require venous access via the IJ vein may not tolerate lying still for long periods of time. Critically ill neonates require intubation and controlled ventilation. Patients with moderate to severe pulmonary HTN can be managed with sedation since the physiological changes associated with intubation, and more likely extubation, might result in a pulmonary hypertensive crisis. Some older children with procedures of shorter duration where groin access is being used may tolerate incremental iv sedation with local anesthesia.

Anesthesia and sedation can be managed with propofol/ketamine (100 mg propofol + 1 mg of ketamine mixed together and infused at 150–200 mcg/kg/min) or a propofol/remifentanil infusion, as long as the patient remains normocarbic and normoxic. Hypercarbia will affect hemodynamic catheterization values.

IPPV decreases systemic venous return, particularly in the setting of depleted intravascular volume. This is particularly noteworthy in those patients with single ventricle physiology, where pulmonary blood flow is mostly passive and depends on adequate preload. When possible, patients with Fontan physiology should be allowed to breathe spontaneously. This improves pulmonary blood flow and hence systemic blood flow and cardiac output.

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Induction

Standard inhalation or iv induction (see p. D-1). The choice of anesthetic drugs must include careful consideration of their effects on myocardial contractility, preload and afterload, pulmonary and systemic vascular resistance and respiration.

Maintenance

GETA with volatile agents (e.g., sevoflurane) or iv infusion (e.g., propofol with remifentanil or ketamine). Most catheterizations require the patient to be maintained on room air for accurate O_2sat and pressure measurements. Keep $FiO_2 < 0.3$, otherwise dissolved plasma oxygen may cause an overestimate of the pulmonary blood flow, and $Q_p:Q_s$ratio will be correspondingly exaggerated. More importantly any FiO_2changes should be communicated with the interventionalist so that $Q_p:Q_s$calculations can be corrected.

Patients with pulmonary HTN presenting for cardiac catheterization are at high risk for adverse events. Avoid the routine use of anti-sialogogues so that the heart rate remains at baseline. Our institutional practice for these patients is to maintain spontaneous ventilation (uninstrumented airway) under propofol-ketamine anesthesia.

Patients requiring ASD device closure require TEE placement to guide the correct placement of the device; endotracheal intubation is necessary. TEE is not needed for PDA device closure, unless patient condition dictates it.

EP studies are best managed with iv propofol 50–150 mcg/kg/min, because this agent has the least ability to induce dysrhythmias. Recent studies demonstrate that sevoflurane or isoflurane (1 MAC or lower) may be acceptable. In patients with a history of prolonged QT interval, TIVA is recommended. Overall, a slow heart rate obtained by the use of remifentanil works well with prolonged QT. Dexmedetomidine should be avoided as it prolongs the QT interval. Reversal agents can also prolong the QT interval.

Heparin 50–100 U/kg is given for patients with arterial sheaths. The activated clotting time (ACT) should be in the range of >300 sec during the procedure and <175 sec when the catheters are removed. When the sheath is removed, a considerable amount of time is necessary waiting for hemostasis. NO may be required for the Rx of pulmonary HTN.

Emergence

Do not allow child to emerge before hemostasis has been achieved at the access site. If the patient's clinical status allows deep extubation, it can be done to prevent coughing. Use of remifentanil infusion may provide analgesia during the procedure, yet allow for a rapid emergence. Consider remifentanil for patients with pulmonary HTN and controlled ventilation, where a smooth emergence is essential to prevent a hypertensive crisis. Interventional procedures and EP/ablation require overnight ICU admission for observation. Most other patients can recover in PACU.

A second volume iv may be desirable for interventional cases. The cardiologist also

Blood and fluid requirements	IV: 20–22 ga × 1 NS/LR PRBCs Fluid warmer	will have a venous access line that can be used if necessary. Interventional procedures may cause tearing of vessels and/or myocardium and can cause abrupt hemorrhage; therefore blood must be available in the room. Neonates can lose significant blood during the access and sampling and also may require transfusion. Follow serial Hcts.
Monitoring	Standard monitors, including Bair-Hugger ± Arterial line ± Foley catheter	If A-line access is required, discuss with the cardiologist. Frequently, the femoral artery is cannulated for the catheterization and may be available for use; however, access may be limited at crucial times (e.g., stenting or coiling), and therefore a peripheral arterial line may be desirable. For cases of long duration, consider Foley catheter placement. Monitor temperature. NIRS monitor (e.g. Somanetics Invos) is recommended in single ventricle and in other cyanotic lesions since pulse oximetry is a poor predictor of changes in cerebral saturation.
Positioning	and pad pressure points. eyes.	Supine, arms flexed above head to allow fluoroscopy of chest. Adolescent patients are at risk of brachial plexus injury. Keep extension within 90°. All ECG leads and monitoring wires must be cleared from axilla and chest to allow fluoroscopy.
Complications	Airway obstruction	Rx: Airway support, oral/nasal airway, LMA. Intubate if necessary.
	Aspiration	Rx: Suction, secure airway if needed. Bronchodilators, H1, H2 blockers if needed. CXR. O_2 monitoring. Admit if post-op oxygen requirement persists.
	Arrhythmias	Determine etiology, whether hemodynamically stable or not. Cardiovert if necessary. Check electrolytes, ABG, Consult EP.
	Hemorrhage	Rx: Fluid resuscitation with crystalloid, 5% albumin and/or blood; vasopressors as needed.
	Hypoxemia	Try to determine the cause. Check HCT in single ventricle patients. Rx: Airway support; increase FiO_2 Intubate and ventilate as needed.
	Pulmonary hypertensive crisis	Avoid hypoxia, hypercarbia, and acidosis, maintain the depth of anesthetic, and give additional anesthetic if tolerated. Consider NO, systemic vasopressors.
	Contrast reaction/anaphylaxis	Rx: Support airway, 100% FiO_2 intubate if needed: phenylephrine, volume resuscitation, steroid, antihistamine, H_2 blocker.
	Hypothermia	Especially neonates. Rx: Forced-air warming device, heat lamp. Increase environmental temperature.

	Air embolism	Rx: 100% FiO_2; identify and occlude source; Trendelenburg; fluid resuscitation; vasopressor support. Aspirate air from central access if possible.

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Postprocedure

Complications	Hematoma at access site Ischemic limb Emergence delirium
Pain management	Infiltrate access sites with local anesthetic. Postop analgesia usually not required.
Tests	CXR, if indicated.

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Pediatric Oncologic Procedures

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Most patients undergoing evaluation to rule out malignancy undergo staging procedures to determine the extent of disease at diagnosis. The staging procedures include computed tomography of the chest to evaluate the possibility of lung metastases; as well as bone scintigraphy or positron emission tomography (PET scan) to determine whether there is metastatic spread to bone. Pediatric patients with neuroblastoma also undergo staging with ^{131}I-metaiodobenzylguanine since this study appears to complement bone scintigraphy and can be useful as a therapeutic tool. Besides these studies, patients must also undergo bone marrow aspirates and biopsies to evaluate for bone marrow involvement. Patients < 5 years of age undergoing oncologic evaluation typically need sedation or GA for imaging procedures. Most bone marrow aspirates and biopsies for these patients are also performed using GA although these can also be performed using conscious sedation. In addition to these staging studies, patients with leukemia or lymphoma undergo serial spinal taps with concurrent administration of intrathecal therapy. These procedures are for both diagnostic purposes and for central nervous system (CNS) prophylaxis since about 50% of leukemia patients develop CNS disease in the absence of such prophylaxis. With current treatment protocols the incidence of CNS relapse has been drastically reduced with the use of CNS prophylaxis. Cranial irradiation is required for patients with CNS disease at diagnosis and for certain high-risk subsets. As part of the workup patients also undergo diagnostic biopsies to establish a diagnosis. If a complete resection cannot be performed the diagnostic biopsy should be performed at the most accessible site to minimize complications. However, it is essential to obtain enough tissue for diagnostic and most recently for biologic studies, because the latter can help target therapy. After a diagnosis of cancer is established, patients are given the option of inserting a central venous catheter since most pediatric cancers are systemic diseases requiring multimodality therapy to maximize outcome. Patients also require serial bone marrow aspirates *(Print pagebreak 1497)* and lumbar punctures. Because these procedures are painful, they are usually performed under general anesthesia unless circumstances such as the presence of upper respiratory infections (URI) complicate the clinical course. In that case, the procedure might need to be performed under conscious sedation, especially if it is a critical part of treatment (i.e., patients with relapsed disease). The diagnostic biopsies and central line placements are generally performed in the operating room under general anesthesia. The only exception occurs in patients with mediastinal masses where the patient's respiratory status is tenuous. In this circumstance, the diagnosis should be established using the least invasive procedure to minimize the complications resulting from anesthesia. This is especially true in patients with a differential diagnosis of leukemia and lymphoma where the use of steroids could jeopardize establishing a diagnosis. Line removals on the other hand, can be performed in a procedure room with sedation or GA. Pediatric oncology patients are followed very closely during their treatment, undergoing at least monthly physical exams to evaluate for side effects of therapy and determine whether proceeding with the prescribed therapy is indicated. When these patients require invasive procedures, it is essential to work with the primary oncology team to evaluate whether the requested procedure is elective or required.

Preprocedure

Patients are first evaluated to determine whether the prescribed chemotherapy has produced any side effects requiring alteration of treatment or precluding continuing with the scheduled procedure. In addition, all patients undergo laboratory evaluation within 24–48 h of their scheduled procedure to make certain their blood counts are adequate for treatment administration.

A thorough preanesthetic H&P should be performed in all cases and the usual npo protocol applied (see p. D-1).

Major surgical procedures for patients with Sx of URI (e.g., cough, fever) are postponed unless there are circumstances (CNS disease, bone marrow relapse), which require the treatment to proceed. In those circumstances, the spinal taps and bone marrows can be performed with either light sedation or with the use of local anesthesia. Although the latter circumstance is rare there are definite situations where proceeding with therapy is definitely in the best interest of the patient. A number of chemotherapeutic agents have been associated with pulmonary

Respiratory	toxicity: bleomycin (2–5%), BNCU (20–50%), busulfan (2.5–11.5%), cyclophosphamide (rare), methotrexate (rare). The use of these agents might require closer evaluation to make certain the patient is able to proceed with his/her procedure. **Tests:** All pediatric oncology patients undergo weekly complete blood counts to evaluate the toxicity from therapy. In addition, patients who have received any of the agents associated with pulmonary toxicity undergo pulmonary function tests at regular intervals. Although some chemotherapy agents are associated with pulmonary toxicity the cumulative doses of those agents are such that most patients are asymptomatic.
Cardiovascular	Anti-cancer treatment can produce a wider range of cardiac toxicity. Anthracycline-induced cardiomyopathy is one of the most feared conditions for pediatric oncology patients. This complication is associated with the use of cumulative doses > 300 mg/m and fortunately is rare. It is insidious in origin and most commonly presents many years following treatment with doxorubicin, daunorubicin, or amsacrine. The use of high-doses of radiotherapy is also associated with cardiac complications including: constrictive pericarditis, atherosclerosis and early myocardiac infarction. Signs of CV toxicity may include SOB, ECG changes, rhythm disturbances, pericarditis or CHF. **Tests:** Patients receiving any agents associated with cardiac toxicity are monitored at yearly interval with echocardiograms and electrocardiograms. Therefore, these tests do not need to be performed prior to a procedure requiring general anesthesia unless the preprocedure history and physical exam suggest a change in the patient's clinical condition.
Hematologic	Bone marrow suppression with all cytotoxic drugs. **Tests:** Complete blood counts are performed once to twice a week in all pediatric oncology patients. These tests help determine whether continuing with the prescribed therapy is indicated.
Neurologic	Peripheral neuropathies due to vincristine, vinblastine, cisplatin, and procarbazine may be present. Patient should be carefully positioned and padded.
Laboratory	Most patients will have their labs checked as part of their anticancer therapy and do not generally require any additional labs.
Premedication	Usually not required because a parent can accompany child into procedure room; however, most children will have venous access and can be given small doses of midazolam if necessary. Consider midazolam syrup 0.5–0.75 mg/kg orally for the particularly anxious child without iv access in place. For children without venous access, a peripheral iv may be placed. Prior to this, application of EMLA or ELA Max cream (1 h or 20 min, respectively) provides topical anesthesia of the skin at the lumbar puncture or bone-marrow aspiration site, as well as the peripheral iv site. Midazolam (0.5–0.75 mg/kg po) can be administered to the anxious child without iv access.

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Intraprocedure

Anesthetic technique: GA (mask or LMA) or MAC in the appropriate patient. Procedures are usually short, 10–20 min. The oncologist should infiltrate the area with lidocaine after induction.

Induction	Most children have a central venous access line in place for their oncology treatment protocol; thus, induction can proceed with iv propofol 2–3 mg/kg. Infrequently, mask induction is performed.	
Maintenance	The provider performing the procedures infiltrates the area with lidocaine. For Broviac catheter removals, heparin must be removed from the catheter and discarded before use for induction. A sufficient bolus of propofol (e.g., 0.5–1 mg/kg) must be given just prior to pulling the catheter. Additional iv usually is not warranted, because the procedure is normally ≥ 10 min. Occasionally, the catheter may break during attempted removal, and the surgeon will have to make a skin incision to allow for removal of the internal fragment. In such cases, a peripheral iv may be inserted quickly to facilitate administration of additional propofol, or mask anesthesia may be given. If the SpO_2 decreases, blow-by $O_2$with gentle head and neck positioning are generally sufficient.	
Emergence	Allow child to awaken in procedure room. Ondansetron 0.15 mg/kg for patients receiving intrathecal chemotherapy during their lumbar puncture. Avoid dexamethasone, as steroids may be part of the patient's chemotherapy protocol, or may precipitate tumor lysis syndrome.	
Blood and fluid requirements	No blood loss.	Patients may require blood or factor supplementation prior to or during procedure based on preoperative laboratory values.
Monitoring	Standard monitors.	
Positioning	Lateral decubitus (lumbar puncture) Supine, seated or prone (Bone marrow aspiration, biopsy) Supine (Broviac)	
Complications	Airway obstruction Retained central venous catheter	Head and neck, reposition, jaw thrust. Rxmay require open surgical procedure.
Post-procedure Pain Management	Acetaminophen (po)	Lumbar punctures are not generally painful, whereas bone marrow aspirations and biopsies can be. Acetaminophen po is usually sufficient for analgesia. Rectal route should be avoided unless adequate Plt and WBC counts are confirmed.

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Upper/Lower GI Endoscopy

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Diagnostic indications for gastrointestinal endoscopy include: dysphagia, odynophagia, persistent vomiting, abdominal pain with weight loss/anorexia, abdominal pain despite therapy for GERD, gastrointestinal bleeding, evaluation of inflammatory bowel disease, and significant diarrhea of unexplained origin. Therapeutic indications for gastrointestinal endoscopy include: esophageal dilation, foreign body removal, sclerotherapy or banding of esophageal varices, and polypectomy. Children presenting for endoscopy may have congenital and acquired abnormalities of the GI tract. Examples include repaired tracheoesophageal fistula (TEF) with esophageal dysmotility or strictures, ingestion of a caustic material, and presence of a foreign body.

Many endoscopy procedures are done with sedation only. Requests for anesthesia are dependent on the gastroenterologist's preference, as well as the severity of the patient's underlying illnesses. All patients must receive a complete preanesthesia H&P and follow the same NPO protocol used for surgery (see p. D-1).

Anesthetic Considerations

Gastrointestinal	Carefully evaluate for esophageal dysfunction and Sx of GERD. The stomach and bowel will be insufflated with air during the procedure, possibly increasing the likelihood of reflux.
Laboratory	As indicated from H&P. Usually none.
Premedication	If inhalation induction planned, midazolam 0.5–0.75 mg/kg po for anxious children. Parental presence may reduce the need for premedication. If iv induction is planned, EMLA cream (1 hr) or ELAMAX (20 min) should be applied for topical anesthesia. Consider midazolam for younger children requiring an iv induction.

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Intraprocedure

Anesthetic technique: Upper GI endoscopy for esophageal dilation, foreign body removal, severe GERD, gastrointestinal bleeding, and banding/sclerotherapy of esophageal varices requires GETA. For children ≥ 2, with no contraindications, supplemental O_2 via nasal cannula, spontaneous respiration, and propofol infusion can be considered. Children ≥ 2 have a higher incidence of complications when not intubated due to the relatively large endoscope. Complications include partial airway obstruction, tracheal compression, laryngospasm, bronchospasm, and desaturation. Placement of the endoscope in the mouth precludes the ability to use a mask or LMA. For lower GI endoscopy (e.g., colonoscopy), supplemental O_2 via nasal cannula or mask, spontaneous respiration, and propofol infusion may be preferable.

Induction	If rapid sequence indication present, iv catheter placed prior to induction. Proceed with preoxygenation, cricoid pressure, propofol (2–3 mg/kg) or STP (3–5 mg/kg), and succinylcholine (1–2 mg/kg) or rocuronium (1 mg/kg). ETT should be well secured to the side of the mouth. If risk of aspiration relatively low, a standard pediatric iv or mask induction is appropriate (see p. D-2).	
Maintenance	GETA with inhalational agents or iv infusion of propofol (100–250 mcg/kg/min), ± remifentanil (0.05–0.10 mcg/kg/min). Alternatively, GA/sedation may be continued with supplemental O_2via nasal cannula, spontaneous respiration, and infusion of propofol (100–250 mcg/kg/min), ± remifentanil (0.05–0.10 mcg/kg/min). Careful observation and/or holding the ETT prevents inadvertent extubation during removal of the endoscope.	
Emergence	If intubated, extubate awake. Emergence in procedure room. Patients usually transported to and recovered in PACU.	
Blood and fluid requirements	No blood loss. IV: 22 or 24 ga × 1 NS/LR @ maintenance	
Monitoring	Standard monitors (see p. D-1).	
Positioning	and pad pressure points. eyes.	Lateral decubitus for upper and lower endoscopy.
Complications	Airway obstruction Hypoxemia 2o gastric insufflation Inadvertant extubation Pulmonary aspiration GI perforation	2° endoscopist working in the mouth and pharynx

Postprocedure

Pain management	Acetaminophen (35–40 mg/kg pr or 10–15mg/kg po), hydromorphone (0.01–0.015 mg/kg) or morphine (0.05–0.1 mg/kg)

Suggested Readings

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Cross-Sectional Imaging (CT, MRI)

Rebecca E. Claure
Brenda Golianu

Preprocedure

A complete preanesthetic H&P should be performed in all cases and the usual NPO protocol followed (see p. D-1). For MRI, thorough questioning regarding potentially ferromagnetic implants (neurostimulators, cochlear implants, pacemakers, surgical clips, infusion pumps, etc.) is critical. Any questions regarding scanning limitations if certain implants are present should be directed to the radiologist.

Respiratory	Procedures for patients with Sx of URI (nasal congestion, cough, fever) are usually postponed for 3–4 wks unless the study is urgent. If Sx are minor, the study may proceed.
Cardiovascular	Pacemakers usually contraindicated. Prosthetic heart valves may be contraindicated (identify the type of valve present and consult with radiologist). Fresh surgical clips (e.g., recent PDA ligation) may also represent a contraindication for MRI.
Neurologic	Head CT or MRI may be performed in patients with seizure disorders or brain tumors. Review seizure meds and serum levels if appropriate. Recent drug levels may not be necessary in children with well controlled or stable seizure disorders. If ↑ ICP or ↓ intracranial compliance are present (e.g., 2° tumors or hydrocephalus), the anesthesia plan should include tracheal intubation with controlled ventilation. Metal surgical clips or coils are usually contraindications for MRI. Children with head trauma

	may have concurrent C-spine injuries.
Laboratory	As indicated from H&P. Usually none required.
Premedication	If inhalation induction planned, midazolam 0.5–0.75 mg/kg po for anxious children. Parental presence may reduce the need for premedication. If iv induction is planned, EMLA cream (1 hr) or ELAMAX (20 min) should be applied for topical anesthesia.

Intraprocedure

Unique considerations for MRI: See Adult Out-of-OR Procedures, p. 1470.

Anesthetic technique: CT scans—With current scanners, many studies can be completed in less than 15 minutes. Each set of data takes 2–3 minutes to collect, allowing many children to complete scans without any sedation. In some institutions, children undergo noninvasive CT scans with sedation by radiology personnel. For more complex cases, sedation/GA is provided by an anesthesiologist. Most commonly, noninvasive CT scans are performed with inhalation anesthesia via mask or under iv sedation with a continuous infusion of propofol (100–250 mcg/kg/min). For patients undergoing *(Print pagebreak 1502)* invasive CT-guided procedures (needle biopsy, placement of drainage tubes, such as thoracostomy tube, etc.), GETA is usually performed. Techniques include inhalational anesthesia and/or continuous infusion of propofol ± remifentanil.

MRI—MRI requires GA more often than noninvasive CT, since prolonged immobility is required for up to 1–2 hrs. Options include inhalational anesthesia with an MRI compatible anesthesia machine or continuous propofol infusion with an MRI compatible infusion pump. Hypothermia frequently occurs in small children. The cooling fan for the magnet can sometimes be turned off to decrease heat loss (discuss with MRI technician). One blanket over patient is usually permissible. The iv, airway circuit and monitors require extensions. Ferromagnetic objects in the MRI environment are a hazard. Objects can be propelled toward the magnet with sufficient speed and force to result in serious or fatal injury to the patient and/or health care provider.

Induction	Standard pediatric mask or iv induction (see p. D-1) can be accomplished in the CT scanner room in a special induction area outside the MRI scanner. After induction and stabilization of the airway, the patient and all personnel entering the MRI scanner should undergo a second check for removal of metal objects and equipment. Once check completed, transport patient into scanner and resume monitoring.	
Maintenance	Sedation/GA continued with supplemental O_2via nasal cannula, spontaneous respiration, and infusion of propofol (100–250 mcg/kg/min). In children with an LMA or ETT, maintenance with inhalational agent or propofol infusion. Typically, these patients do not require muscle relaxants, and spontaneous breathing is appropriate unless controlled ventilation is required to treat ↑ ICP. Most infusion pumps need to remain a specific distance from the MRI scanner. The appropriate distance is dependent on the degree of shielding of each particular magnet. If breath holding for prolonged periods of time (e.g. several minutes for abdominal scans), intubation and/or paralysis may be required. Adequate ear protection should be routinely used during MRI.	
Emergence	Transport MRI patient back to induction area for emergence so that airway equipment is readily available. Patients usually transported to and recovered in PACU.	
Blood and fluid requirements	No blood loss. IV, if required: 22 or 24 ga × 1 NS/LR @ maintenance	
Monitoring	Standard MRI-compatible monitors (see p. D-1 for discussion of monitoring considerations).	For infants, use a child-size NIBP cuff on the leg. The length of tubing required significantly alters the values on infant-size cuffs.
Positioning	Ear protection necessary and pad pressure points. eyes.	
Complications	Airway obstruction	Repositioning, nasal or oral airway.
	Hypothermia	See adult MRI Unique Considerations and Complications, p. 1470.
	Burn injury	From inappropriate placement of pulse oximeter probe or EKG. Avoid coiling of wires and use only MRI compatible
	IV contrast reaction	

Hearing loss (MRI)	monitors.

Postprocedure

Pain management	Noninvasive procedures are painless. Acetaminophen (35–40 mg/kg pr or 10–15 mg/kg po), hydromorphone (0.01–0.015 mg/kg) or morphine (0.05–0.1 mg/kg) as appropriate for invasive procedures

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Surgical Considerations for ECMO

Procedural Considerations

Gary Hartman

Extracoporeal membrane oxygenation (ECMO) for prolonged periods (3–21 d) allows cardiopulmonary support for newborns and children with reversible respiratory failure. The most common indications are meconium aspiration and pulmonary HTN associated with congenital diaphragmatic hernia. The procedure is performed in the NICU with OR techniques. Patients are given anticoagulants prior to cannulation. Subsequently, repair of the diaphragmatic hernia also may be performed in the NICU on ECMO support before decannulation (Fig. 13.2-1 shows ECMO schematic).

The potential detrimental effects of the diaphragmatic repair on respiratory function can be managed with increased circuit flow. ECMO also has been helpful in some newborns with cardiopulmonary failure following correction of congenital cardiac defects. Vascular access is accomplished with one (venovenous) or two (venoarterial) cannulas. The IJ vein is cannulated in both methods with the tip of the cannula in the right atrium. In venoarterial ECMO, the common carotid artery is used with the tip of the cannula at the aortic arch. The wound is closed around the cannulas, which are secured to the infant's scalp.

Usual preop diagnosis: Meconium aspiration; diaphragmatic hernia; Bochdalek's hernia

Summary of Procedures

Position	Supine
Incision	Subcostal, right neck incision
Special instrumentation	ECMO circuit (Fig. 13.2-1)
Unique considerations	Anticoagulation
Antibiotics	Preop: ampicillin 25 mg/kg iv + gentamicin 2.5 mg/kg iv Intraop: cefazolin irrigation (1 g/500 mL NS)
Surgical time	1–2 h
Closing considerations	Assess for changes in ventilation (e.g., PIP, pre- and postductal ABG).
EBL	> 5–10 mL/kg
Postop care	Paralysis maintained; fentanyl infusion @ 2–4 mcg/kg/h
Mortality	25–30%
Morbidity	Respiratory failure sepsis
Pain score	6–7

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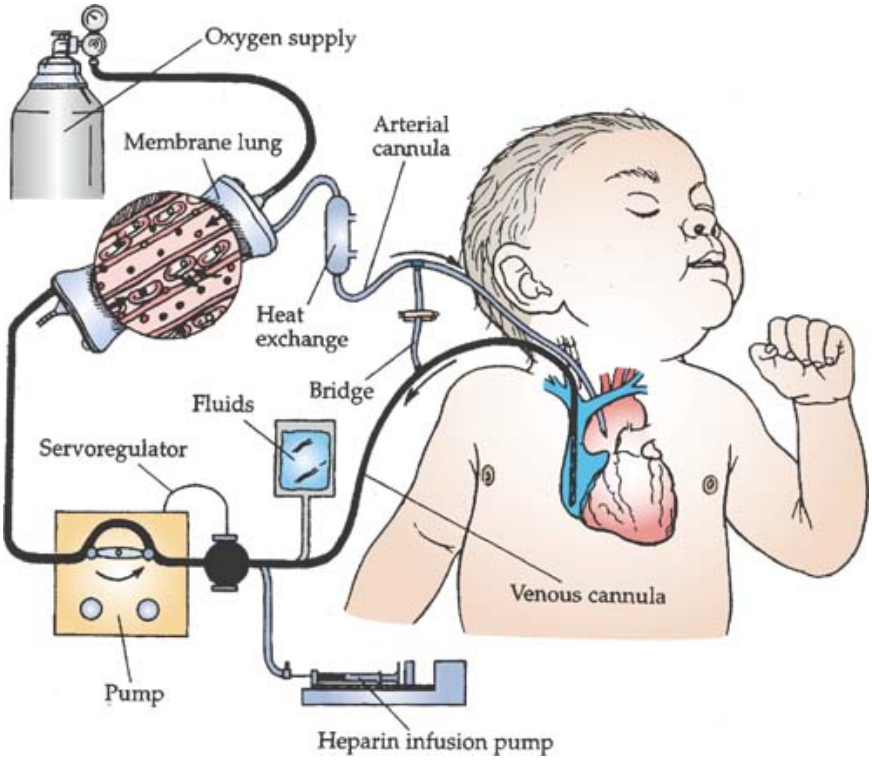

Figure 13.2-1. 1. ECMO circuit. Venous blood is withdrawn by gravity through a servoregulator to prevent pump from actively siphoning venous return. A pump delivers blood back to the arterial cannula after it passes through the membrane oxygenator and heat exchanger. Venous return is from the right atrium, while arterial infusion is into the aortic arch in double cannula (venoarterial) or right atrium (venovenous) techniques. (Reproduced with permission from Baker RJ, Fischer JE: *Mastery of Surgery*, Vol I, 4th edition. Lippincott Williams & Wilkins, Philadelphia: 2001.)

Patient Population Characteristics

Age range	Newborn–weeks or months
Male:Female	1–2:1
Incidence	1:4000 live births

Etiology	Unknown
Associated conditions	For diaphragmatic hernia: malrotation (40–100%); congenital heart disease (15%); renal anomalies; esophageal atresia; CNS abnormalities

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Anesthetic Management for Surgical Procedures Under ECMO

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ECMO therapy protects the pulmonary alveoli from ventilator associated barotrauma and oxygen toxicity, while maintaining tissue oxygenation. For surgical procedures that are done on ECMO, the anesthetic management can be either TIVA or a combination of intravenous and inhalation techniques. The plastic components of the bypass circuit can sequester varying amounts of the intravenous agents, especially fentanyl, altering the plasma levels and resulting in unpredictable hemodynamic changes. Volatile anesthetics are not routinely available on ECMO circuits due to difficulties with scavenging. If ECMO is performed for systemic hypoxemia, then the decreased pulmonary flow will not favor the uptake of inhalational anesthetics.

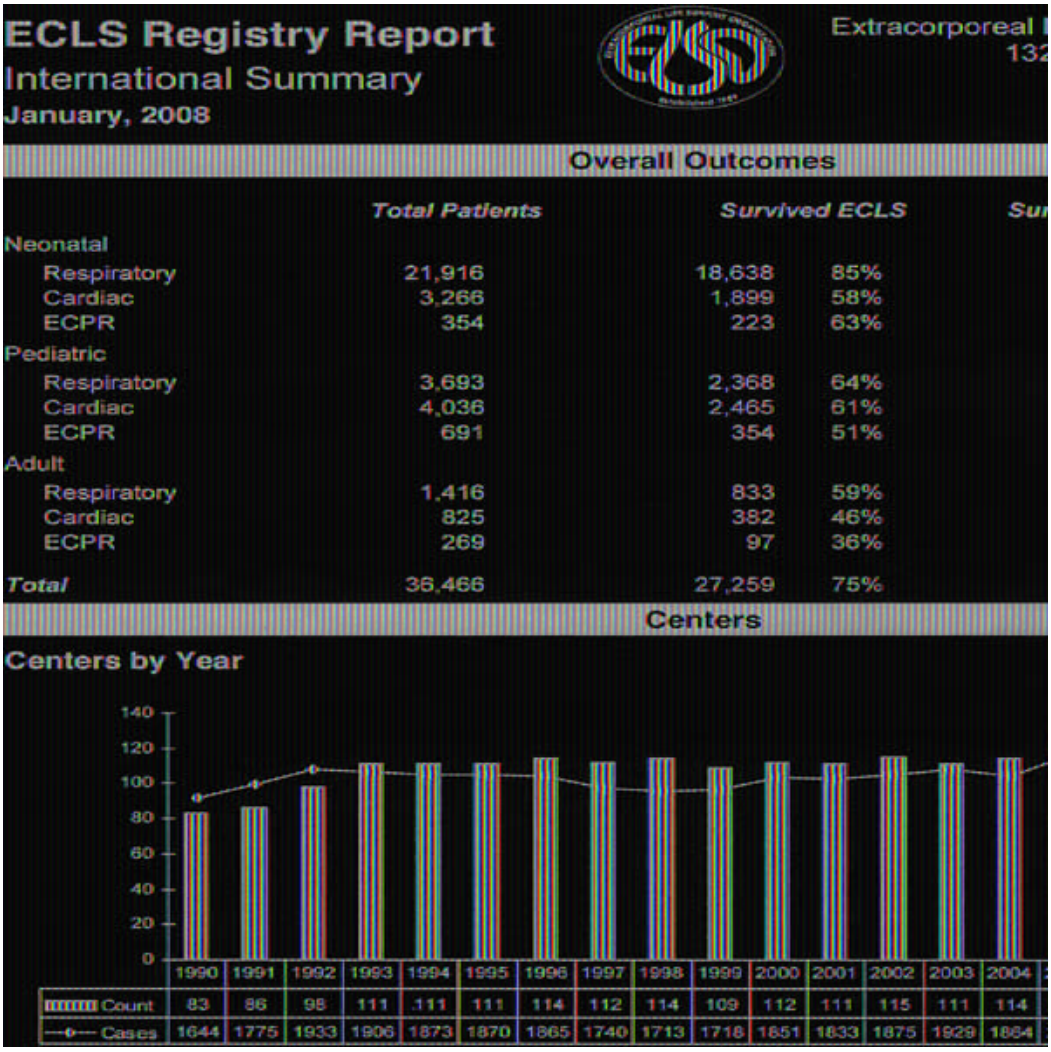

Figure 13.2-2. 2. ECLS Registry Report January 2008. Acknowledgment: ELSO, Extracoporeal Life Support Organization, Ann Arbor, Michigan, 2008.

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Figure 13.2-3. 3. Annual Respiratory Neonatal Runs (0–30 d), Annual Respiratory Pediatric Runs (> 30 d and <18 yr), and Annual Cardiac Runs (0–30 d old). Acknowledgment: ELSO, Extracoporeal Life Support Organization, Ann Arbor, Michigan, 2008.

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It is important to keep in mind that altering the surgical table height will have an impact on the venous return to the ECMO circuit (passive gravity assisted drainage), hence the perfusionist must be informed before undertaking this maneuver. Anesthetic agents also cause preload and afterload changes; additional volume should be readily available to maintain adequate venous volume. Blood and products, vasoactive agents must be available to overcome transient changes in filling and blood pressure.

Diaphragmatic hernia repair is the commonest procedure done on ECMO. On the morning of surgery a trial period off bypass is used to assess the adequacy of conventional ventilation independent of ECMO. If the surgery occurs on full ECMO support, ACT is maintained at 160–200 sec by addition of heparin to the ECMO circuit.

Monitoring includes: heart rate, arterial blood pressure, temperature, pump flow rate with frequent ABGs and VBGs.

The potential detrimental effects of diaphragmatic repair on respiratory function can be managed with increased circuit flow. ECMO also has been helpful in some newborns with cardiopulmonary failure following correction of congenital cardiac defects. Vascular access is accomplished with one (venovenous) or two (venoarterial) cannulas. The IJ vein is cannulated in both methods with the tip of the cannula in the right atrium. In venoarterial ECMO, the common carotid artery is used with the tip of the cannula at the aortic arch. The wound is closed around the cannulas, which are secured to the infant's scalp. The indications for the use of ECMO have shifted over the past decade. ECMO centers and total ECMO runs peaked in 2005 and 2006 and have since declined significantly. Neonatal respiratory runs peaked in the early 1990s and have declined since, presumably due to the use of other respiratory salvage strategies. Pediatric and cardiac indications have continued to increase, especially in the last 3–4 yr. These patients are frequently on support for longer durations and cannulation may be more complex. The majority of all ECMO runs still employ VA cannulation although some centers do a significant percentage of their runs on VV ECMO.

Suggested Readings

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