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CHAPTER 13.1

Out-of-Operating Room Procedures—Adult

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[1]Electroconvulsive therapy

[2]TIPS

[3]Tracheobronchial stenting, RF ablation

[4]DC cardioversion, ICD

[5]Interventional neuroradiology

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Anesthesia for Out-of-Operating Room Procedures

General Comments

Advances in the fields of radiology, cardiology, and neurology have led to an increase in the number of anesthesia procedures performed away from the OR. In line with these changes, the ASA has provided guidelines for the safe delivery of anesthesia at locations remote from the OR environment.

Anesthetic considerations for out-of-OR locations (modified from ASA Guidelines[1]) include:

- Primary and backup O_2 sources (e.g., piped O_2 + 1 full E cylinder)
- Adequate and reliable suction
- Adequate and reliable scavenging system (for inhalational anesthesia)
- Self-inflating hand resuscitator bag with ability to deliver at least 90% O_2
- Adequate anesthetic drug supplies and equipment
- Adequate monitoring equipment to allow adherence to the "Standards of Basic Anesthetic Monitoring"[2]

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- Sufficient electrical outlets connected to an emergency power supply
- Wet locations (e.g., cysto, arthroscopy, labor, and delivery) should be equipped with either an isolated electrical source or circuits with ground-fault interrupters.
- Adequate illumination for patient observation and monitoring equipment (flashlight backup)
- Sufficient space for expeditious access to patient, machine, and support equipment
- Emergency cart with defibrillator immediately available
- Immediate access to skilled anesthesia support personnel

Suggested Readings

1. American Society of Anesthesiologists: *Guidelines for Non-Operating Room Locations*. American Society of Anesthesiologists, Park Ridge: 1997.

2. American Society of Anesthesiologists: *Standards for Basic Anesthesia Monitoring*. American Society of Anesthesiologists, Park Ridge: 1998.

3. Melloni C: Anesthesia and sedation outside the operating room: how to prevent risk and maintain good quality. *Curr Opin Anaesthesiol* 2007; 20(6):513–9.

4. Pino RM: The nature of anesthesia and procedural sedation outside the operating room. *Curr Opin Anaesthesiol* 2007; 20(4): 347–51.

Electroconvulsive Therapy (ECT)

Procedural Considerations

Description: Electroconvulsive therapy (ECT) is the transcutaneous application of small electrical stimuli to the brain to produce generalized seizures for the treatment of selected psychiatric disorders, such as severe depression. There are several important aspects of ECT that are of relevance to the anesthesiologist. The first is the uncontrolled motor activity associated with generalized seizures. Prior to introduction of GA, the most common injuries associated with ECT were compression fractures of the vertebral bodies and broken limbs from violent tonic clonic motor activity. Even with complete paralysis, the masseter muscles are directly stimulated to contract during seizure induction. As a result, the most common injury currently associated with ECT is broken teeth.

A second consequence of ECT induction is that the electrical stimulus can cause contraction of cranial musculature and a brief dilation of meningeal blood vessels, resulting in postictal headaches in up to 40% of patients. Patients < 50 yr and those with a Hx of migraine headaches appear most at risk for post ECT headaches that may occasionally require aggressive pain management. Finally, ECT may be a significant hemodynamic stressor. Initially, central parasympathetic centers are activated, resulting in bradydysrhythmias in 30% of patients. Brief sinus pauses are not uncommon. The initial parasympathetic effects are followed by sympathetically mediated increases in HR and *(Print pagebreak 1445)* BP up to 20–30% above baseline. Mean arterial blood pressure has been known to double in some instances. These cardiovascular responses can persist for minutes to an hour or more after the procedure is completed.

The optimal position for ECT is supine. Occasionally, the head is kept slightly raised to help maintain an adequate airway and decrease anxiety. Patients typically come to ECT quite anxious about the procedure. ECT is generally performed in a PACU, or specialized ECT suite. In many centers, outpatients make up the majority of patients seen for ECT. The electrical stimulus is applied through plastic adhesive leads prepared with a contact gel. These leads are usually applied to the forehead in a bitemporal or right unilateral placement. Monitoring typically includes a two-lead electroencephalogram (EEG) and frequently an electromyogram (EMG) to measure motor activity. A BP cuff is inflated to act as a tourniquet and prevent neuromuscular blockade in the distal limb. Thus, an arm or leg can be used to measure motor duration of the seizure. A special ECT device is used to generate the appropriate electrical stimulus. Seizures are typically 30–90 sec in duration, and the entire procedure—from the induction of anesthesia to patient awakening—is generally < 15 min. The recovery period averages 45–90 min and allows for monitoring of vital signs, as well

as the opportunity for the postictal confusion to clear. Patients can wake up mildly confused-to-frankly delirious and require close nursing supervision. Postictal agitation is also quite common and may require an intervention. Treatments are typically performed every other day, and the average number of treatments is 6–12 in the acute management of major depression. However, ECT treatments currently tend to be tapered rather than stopped abruptly. Thus, the frequency of treatments may go from 3/week for acute treatment, to 1/week, 2/month, and finally 1/month. Maintenance ECT with a frequency ranging from every few weeks to every few months is commonly prescribed for those patients who respond to ECT but fail to benefit from pharmacotherapy.

The most common morbidities associated with ECT include headaches and myalgias. Postictal confusion is the rule and some anterograde and retrograde memory loss occurs in most patients who have completed an acute course of ECT. Memory loss is typically confined to the period immediately before, during, and immediately after an acute series of ECT. There tends to be a cumulative memory loss with subsequent ECT treatments within a given series. In most patients, memory deficits largely subside in the first 1–3 months following an acute series of treatments. In rare instances, autobiographical memory loss has been reported for months or years after an ECT series has been completed. Long-term memory loss appears to be more common with bilateral lead placement. In addition, ECT-related mortality is estimated at approximately 4/10,000. Cardiac events account for 67% of all ECT-related deaths, with malignant arrhythmias and MIs accounting for most fatalities. Pulmonary events (obstruction, pulmonary edema, or emboli) account for most additional mortality. Cerebrovascular infarctions or hemorrhages have rarely been reported with ECT.

Usual preop diagnosis: Depression; mania; catatonia; refractory psychosis

Summary of Procedures

Position	Supine
Incision	None
Special instrumentation	Seizure generator & electrodes; EEG/EMG monitors
Unique considerations	Requires muscle relaxation to prevent injury. 50–80 mg of succinylcholine is usually sufficient. Using larger dose of succinylcholine can lead to patient waking up while paralyzed. Non-disposable bite blocks are required to prevent dental injury. Apply tourniquet (BP cuff) to one arm before administration of muscle relaxant. A slow heart rate preop may require atropine. A high BP preop may require aggressive hypotensive Rx with beta blockers, phentolamine, hydralazine etc. If the seizure duration is not > 25 sec, then another seizure may be ordered. Give more induction agents needed. Because one arm is not paralyzed, asking the patient to squeeze your fingers will tell you that she/he is awake.
Antibiotics	None
Procedure time	Setup: 5–10 min Treatment: < 10 min (seizure duration 25–280 sec)
Postop care	PACU → room or home
Mortality	4/10,000
Morbidity	HA/myalgias/nausea: Common Confusion/memory loss: Common. Be aware that postoperative hypoxia can present with confusion. Cardiac dysrhythmias: 10–40% (brief asystole common). Keep a close eye on the EKG. MI: Rare Pulmonary edema from excessive IV fluids: not uncommon. Pulmonary aspiration and/or negative pressure pulmonary edema: Rare CVA: Rare
Pain score	2–3 (HA)

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Patient Population Characteristics

Age range	≥ 18 yr. ECT is rarely performed in adolescent and preadolescents; however, patients in their 90s are sometimes candidates for ECT. There is a preponderance of geriatric patients on many ECT services.
Male:Female	1:2
Incidence	The lifetime prevalence of major depression (the primary indication for ECT) is 17%; 26% of women and 12% of men are affected. < 1% of patients with major depression undergo ECT; and approximately 400,000 ECT procedures are performed in North America annually.
Associated conditions	Substance abuse (30% of all depressed patients meet criteria for alcohol or drug abuse); panic attacks (30% of depressed patients); psychotic symptoms (14% of patients); HTN and sinus tachycardia; dehydration; self-inflicted trauma. Pregnancy.

Anesthetic Considerations

Preoperative

Patients presenting for ECT usually have failed to respond to antidepressants; however, most will continue to take psychotherapeutic agents. Many of the older patients will be taking other medications for coexisting medical conditions. Drug interactions are an important consideration for the anesthesiologist (see Drug Interactions, p. F-1). The most commonly used medications are listed in Table 13.1-1.

Anesthesia for ECT may seem to be a benign procedure; however, these cases—which seldom take > 20 minutes—can prove very challenging, especially in the geriatric population. ECT can place significant stress on the cardiovascular system; therefore, particular care should be taken to evaluate and optimize the patient's *(Print pagebreak 1447)* pretreatment cardiovascular status. ECT usually takes place in remote locations, so the anesthesiologist must ensure that the location is properly equipped and complies with ASA Guidelines for Out-of-OR Procedures (see p. 1444) and Standards for Basic Anesthesia Monitory.

Table 13. 1-1. Commonly Used Medications in the Treatment of Depression

Tricyclic	MAOI	SSRI	SNRI and other Antidepressants
amitriptyline (Elavil, others) amoxapine (Asendin) desipramine (Norpramin) doxepin (Sinequan) imipramine (Tofranil) maprotiline (Ludiomil) nortriptyline (Pamelor) Protriptyline (Vivactil) trimipramine (Surmontil)	isocarboxazid (Marplan) phenelzine (Nardil) tranylcypromine (Parnate) transdermal selegiline (Emsam) **Lithium** (Often used as an adjunctive agent/mood stabilizer in depression)	fluoxetine (Prozac) paroxetine (Paxil) sertraline (Zoloft) fluvoxamine (Luvox) citalopram (Celexa) escitavopram (Lexapro)	venlafaxine (Effexor) duloxetine (Cymbalta) nefazodone (Serzone) mirtazapine (Remeron) bupropion (Wellbutrin) trazodone (Desyrel) **Atypical Antipsychotics** (Used Adjunctively) olanzapine (Zyprexa) quetiapine (Seroquel) aripiprazole (Abilify) risperidone (Risperdal) ziprasidone (Geodon)

MAOI = monoamine oxidase inhibitor
SSRI = selective serotonin reuptake inhibitor
SNRI = selective norepinephrine/serotonin reuptake inhibitor

Respiratory	These patients will require airway management and PPV. Hence, preop assessment of the airway must focus on the ease of mask ventilation and the potential need for ET intubation (e.g., airway compromise or severe GERD).
Cardiovascular	A recent MI (< 3 mo) is a contraindication to ECT. Relative contraindications include aortic aneurysm, angina, CHF, and thrombophlebitis. The presence of dysrhythmias, a pacemaker, or ICD is not a contraindication for ECT. For the patient with a pacemaker, a means (e.g., a magnet) should be available to convert the pacemaker to an asynchronous mode. **Tests:** As indicated from H&P.
Gastrointestinal	Patient should be npo. Patients with Sx of GERD should be pretreated with Na citrate (30 mL po), ranitidine (50 mg iv) and metoclopramide (10 mg iv). ET intubation should be considered for all patients at risk for aspiration.
Neurological	ECT is relatively contraindicated in the presence of ↑ ICP, and recent CVA (< 3 mo), intracranial mass lesions or recent intracranial surgery (< 3 mo).
Endocrine	Presence of a pheochromocytoma (Sx of which may be confused with a psychiatric disorder) is a contraindication to ECT. < 1% of hypertensive patients will have a pheochromocytoma.
Genetic	for family Hx of pseudocholinesterase deficiency. Mivacurium (0.15 mg/kg) is a suitable alternative to succinylcholine. **Tests:** Dibucaine number (normal ≥ 80) and serum cholinesterase level, if indicated from H&P.
Hepatic	Hepatotoxicity has been associated with use of MAOI. **Tests:** Consider LFTs for patients on chronic MAOI therapy.
Orthopaedic	In patients susceptible to bone fracture (e.g., severe osteoporosis, osteoporosis imperfecta), an increased succinylcholine dosage (1.5 mg/kg) is given to ensure profound muscle relaxation. Patients with severe rheumatoid arthritis may have unstable C-spine, and extreme care should be taken during positioning of head and neck.
Ophthalmologic	Retinal detachment is a relative contraindication to ECT. Succinylcholine should be avoided in patients with glaucoma treated with cholinesterase-inhibitors (e.g., echothiophate). Mivacurium (0.15 mg/kg) is a suitable alternative.
Pregnancy	Pregnancy is not a contraindication for ECT (even in the third trimester). After the 4th mo, the need for full-stomach precautions requires rapid-sequence induction and ET intubation (see p. B-4). Left uterine displacement should be maintained during treatment. Monitor fetal heartbeat.
Psychiatric Drugs	Patients receiving tricyclic antidepressants (TCAs) may have an exaggerated pressor response to direct-acting sympathomimetic drugs, with the potential for tachycardia, dysrhythmias, and hyperthermia. The response to indirect-acting sympathomimetic drugs (e.g., ephedrine) may be attenuated in these patients. TCAs also will increase the effects of anticholinergic drugs (e.g., glycopyrrolate, atropine). Patients receiving MAOIs will exhibit exaggerated responses to indirect-acting sympathomimetic drugs (e.g., ephedrine). Additionally, in these patients succinylcholine metabolism is inhibited (↑ NMB), and meperidine is contraindicated (↑↑ BP, ↑ Sz, ↑↑ T). It is probably unnecessary to discontinue TCAs or MAOIs prior to ECT, as long as these interactions can be avoided. Lithium should be discontinued for at least 3 d prior to ECT to avoid delayed recovery and subsequent posttreatment agitation and confusion. Lithium also is associated with ↑ NMB (succinylcholine and pancuronium). SSRIs have

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	been associated with prolonged ECT-induced seizure duration, and adverse behavioral/neurological effects following haloperidol administration (use droperidol and metoclopramide with caution). No adverse interactions have been reported between anesthetic agents and SSRIs or SNRIs.
Laboratory	Tests as indicated from H&P.
Premedication	Although usually not required, some patients may benefit from an antisialagogue (glycopyrrolate 0.2 mg iv). Patients with Hx of postop N/V will benefit from a prophylactic antiemetic (e.g., ondansetron 4 mg iv). Patients with postseizure muscle pain and headache may benefit from ketorolac (30 mg iv). Some patients will require 500-1,000 mg caffeine iv to decrease seizure threshold. The caffeine effect should be manifest in 5 min. Verapamil (not adenosine, which is blocked by caffeine) should be available to control supraventricular tachycardia (0.07–0.25 mg/kg over 2 min). Esmolol and diltiazem are alternative drugs for control of HR.

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Intraoperative

Anesthetic technique: A review of previous anesthetic records is very helpful in formulating the anesthetic plan and in anticipating physiological changes unique to each patient. Usually brief iv anesthesia (mask oxygenation and ventilation) with profound muscle relaxation is required to prevent patient injury during seizures. Prior to induction, a tourniquet (BP cuff) is applied to the non-iv arm and inflated to a pressure above systolic. This prevents neuromuscular blockade distal to the cuff and permits direct monitoring of seizure activity. Preop BP control (e.g., labetalol 5–20 mg, diltiazem 10–20 mg iv, or esmolol 0.5–1 mg/kg iv in increments) is often necessary.

Induction	Preoxygenation should be attempted in all patients. In some patients who are intolerant of a mask, a less intrusive blow-by technique may be tried. Anesthesia is induced with either STP (1.5–3 mg/kg), sodium methohexital (0.5–1 mg/kg), or etomidate (0.1–0.2 mg/kg). An induction close of etomidate will block stress-induced cortisol production for up to 24 h. Propofol (1–1.5 mg/kg) may be used, but may shorten seizure duration. TCAs and MAOIs can increase sleep time. After tourniquet inflation, succinylcholine (1 mg/kg) is injected to induce paralysis. Hyperventilation is carried out to enhance seizure activity. A bite block is placed and then the patient is ready for ECT. In barbiturate-tolerant patients, remifentanil (1–3 mcg/kg) has been used as a means of reducing the barbiturate dose, thereby permitting adequate seizure duration. Patients receiving remifentanil need minimal postseizure BP control.
Maintenance	Given the brevity of this procedure, maintenance of anesthesia is rarely a concern; however, occasionally a second or third treatment may be necessary if the seizures are of inadequate duration (< 25 sec) and quality. In this case, a subsequent dose (10–30 mg) of succinylcholine may be needed. Assisted ventilation is necessary until spontaneous ventilation resumes. Of major concern during the seizure period is the hypertensive response. Some patients may need to be treated prior to induction of anesthesia with either labetalol (5–20 mg iv) or esmolol (10 mg q 1 min) to control HR/BP. SNP (5–50 mcg/bolus iv) is useful to control BP in refractory cases.
Emergence	Patients should be awake within 5–10 min postseizure and often are disoriented. Small doses of midazolam (e.g., 0.25–0.5 mg iv) may help to control agitation. ASA guidelines for postanesthesia care should be followed (see p. 1444).
Blood and fluid requirements	No blood loss IV: 20 ga × 1 NS/LR @ TKO
Monitoring	Standard monitors (see p. B-1) Tourniquet EEG Seizure activity is usually monitored by a psychiatrist observing the tourniqueted limb and by measuring EMG and EEG

	EMG	activity. (These monitors are usually an integral part of the ECT seizure generator.)
Positioning	Supine	
	Dysrhythmias	Brief periods of asystole and profound bradycardia are not uncommon (usually related to parasympathetic overactivity). Treatment is rarely necessary.
	Tachydysrhythmias	Responds well to esmolol (10–15 mg iv) or lidocaine (1 mg/kg iv), although treatment is usually unnecessary.
Complications		
	↑ BP	↑ BP readily responds to esmolol (10–30 mg), or labetalol (5–20 mg). In refractory cases, 10–50 mcg of SNP may be necessary.
	Dental damage Pulmonary edema Aspiration	Use of bite block is essential. Dental damage is not prevented by muscle relaxation (direct electrical stimulation of facial and jaw muscles).

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Postoperative

	HA, myalgias N/V Disorientation	
Complications	Memory impairment	Rx: ketorolac 30 mg iv Rx: ondansetron 4 mg iv Rx: midazolam 0.25–0.5 mg iv
	MI/ischemia Dysrhythmias Pulmonary edema/aspiration	
	↑ BP	Prolonged ↑ BP is unusual and may suggest the need for further workup.

Suggested Readings

1. Cohran M, DeBattista C, Schmiesing C, et al: Negative pressure pulmonary edema. A potential hazard in patients undergoing ECT. *J ECT* 1999; 15:168–70.

2. DeBattista C, Cohran M, Barry JJ, et al: Fetal heart decelertation during ECT induced seizures: is it important? *Acta Anaesth Scand* 2003;47:101–3.

3. Ding Z, White PF: Anesthesia for electroconvulsive therapy. *Anesth Analg* 2002;94:1351–64.

4. Saito S: Anesthesia management for electroconvulsive therapy: hemodynamic and respiratory management. *J Anesth* 2005;19 (2):142–9.

5. Smith D, Angst M, Brock-Utne JG, et al: Seizure duration with remifentanil/methohexital vs. methohexital in middle aged patients undergoing ECT. *Acta Anaesth Scand* 2003;47:1064–6.

6. Wagner KJ, Mollenberg O, Rentrop M, et al: Guide to anesthetic selection for electroconvulsive therapy. *CNS Drugs* 2005; 19 (9):745–58.

Interventional Neuroradiology

Procedural Considerations

The indications for endovascular therapy for the brain and spine have continued to grow with the technical strides made in both devices and imaging during the past decade. Endovascular therapy is now widely used in the treatment of intracranial aneurysms, arteriovenous malformations (AVMs), arteriovenous fistulas (AVFs), and tumors. It also is extensively used in revascularization of the cerebral circulation in the setting of acute stroke or for the treatment of stenoses with angioplasty and/or stent. Many of these procedures can be performed with the patient awake; however, GA or deep sedation often is used to minimize patient movement during procedures that require careful catheter and device control for safe operation. These procedures can be divided into three broad categories: (a) embolization, (b) aneurysm therapy, and (c) cerebral revascularization.

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Embolization

This therapy may be used for a variety of lesions, including AVMs in the brain; dural AVFs; Vein of Galen malformations; vascular neoplasms, such as meningiomas, hemangiomas, glomus tumors, and juvenile nasal angiofibromas; and for treatment of epistaxis.

AVM embolization usually is performed as an adjunct to radiosurgery or microsurgery, although in selected cases, embolization may be the definitive treatment. Brain AVMs are generally parenchymal lesions with multiple feeding pial arteries and draining veins. The goal of embolization is to reduce the size and shunt burden presented by the AVM before either radiosurgery or microsurgical resection. Liquid embolic agents are preferred, with n-butyl cyanoacrylate (NBCA) and ethylene vinyl alcohol copolymer (EVOH) being the two materials currently used for the procedure. Embolization often is preceded by neurophysiologic testing, which may include the superselective injection of amobarbital into the portion of the intracranial circulation being considered for embolization. Some centers perform the procedure with the patient awake to allow for more thorough clinical testing prior to embolization, while others prefer the patient to have general anesthesia to minimize patient motion.

Dural arteriovenous fistulas involve the dural sinuses, most commonly in the area of the cavernous, transverse, and sigmoid sinuses. Because of their location, these malformations usually are supplied from meningeal vessels. A cavernous sinus fistula also may develop as a direct large-hole fistula between the internal carotid artery and the cavernous sinus. Patients may have a variety of symptoms depending upon the location, size and drainage pattern of the dural fistula. The embolization process for these dural-based lesions differs somewhat from the technique used for pial-based brain AVMs. Arterial embolization may be used, but venous embolization is often used to definitively occlude the fistula. Embolization of meningeal arteries may be preceded by clinical testing for cranial nerve deficits. This usually is accomplished with the superselective injection of lidocaine before embolization and it often preferred to have the patient awake for this procedure. If arterial embolization is utilized, a liquid embolic (NBCA or EVOH) is often utilized; however a particulate embolic may also be used. Particle embolization is often done with polyvinyl alcohol particles (PVA). The venous embolization is usually done with platinum coil occlusion.

Vein of Galen malformations are congenital lesions that may present in infants or children. Presenting symptoms include CHF, hydrocephalus, and neurodevelopmental delay. These lesions often require a staged approach, and present a special challenge in the neonate or infant. In general, arterial embolization is performed as the initial endovascular approach, and a liquid embolic agent is used. In some cases, this may be augmented by a venous approach, with embolization using platinum coils.

Tumor embolization usually is performed as an adjunct to the surgical resection of highly vascular tumors (e.g., meningiomas, hemangiomas, hemangioblastomas, glomus tumors, and juvenile nasal angiofibromas). Generally, arterial embolization of meningeal supply vessels is done before surgery, using PVA or trisacryl gelatin microspheres. Physiologic testing with super-selective injection of lidocaine often precedes embolization. When there is tumor encasement of a major artery the patient may also undergo balloon test occlusion followed by permanent occlusion to reduce the risk of intraoperative bleeding.

Aneurysm therapy

Endovascular therapy is the treatment of choice for many intracranial aneurysms, and it consists of either direct intra-aneurysmal obliteration with detachable platinum coils or occlusion of the parent artery to produce thrombosis of the aneurysm. A randomized, controlled trial has shown better clinical outcome for patients treated with aneurysm coiling than surgical clipping in the setting of subarachnoid hemorrhage. Narrow-necked aneurysms may be treated using a microcatheter to introduce coils directly into the aneurysm. Wide-necked aneurysms are more difficult to treat using this technique. Balloon remodeling often is used for treatment of wide-necked aneurysms. This technique involves placing a balloon over the ostium of the aneurysm. The balloon is intermittently inflated with each coil insertion to prevent coil prolapse into the parent vessel. Fenestrated stents have also become available to treat wide-necked aneurysms. These are introduced into the parent artery over the ostium of the aneurysm, which is then coiled through

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the fenestrations. Parent artery occlusion is still used for some giant or fusiform aneurysms. It generally is done in a two-step process. Test occlusion is initially performed with a balloon-tipped catheter and the patient is evaluated using clinical testing and neurophysiological monitoring. The testing may be done with controlled hypotension to improve the test sensitivity. If the patient tolerates test occlusion, a permanent occlusion is usually done using detachable balloons and/or coils.

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Cerebral Revascularization

Acute stroke thrombolysis or thrombectomy is performed up to 8 h after the onset of symptoms in the middle and anterior cerebral artery circulations (carotid territory) and at some centers up to 24 h after the onset of symptoms in the vertebrobasilar territory. The FDA has recently approved a device for mechanical embolectomy in the setting of stroke. In addition, many endovascular therapists employ intra-arterial thrombolytics either alone or combined with a mechanical thrombectomy device. Other devices including baskets, ultrasound, suction thrombectomy catheters, and intracranial stents have been proposed or are in development.

Angioplasty and stent placement for symptomatic atherosclerotic stenosis in the cerebrovascular circulation is becoming more widely performed in lieu of medical or direct surgical therapy. Stents with distal protection devices have now been approved for the treatment of cervical carotid artery stenosis. Distal protection devices (e.g., balloon or basket devices) have been shown to reduce the thromboembolic complication rate and are now required for treatment in most cases. Vascular lesions located more distally and intracranial lesions are treated either with angioplasty alone or are stented following angioplasty.

Vasospasm often accompanies subarachnoid hemorrhage and results in ischemic complications, which are a common cause of morbidity and mortality following aneurysmal rupture. The endovascular therapist is often asked to treat this problem with either drugs or balloons. Direct administration of intra-arterial vasodilators, such as verapamil, nimodipine and nicardipine, has been used particularly for treatment of more distal spasm. More proximal spasm involving the arteries of the circle of Willis is often treated using high-compliance angioplasty balloons.

Summary of Procedures

	Embolization	Aneurysm Therapy	Cerebral Revascularization
Position	Supine		
Incision	Femoral artery, catheterization (may utilize brachial or radial artery)		
Unique considerations	BP control; AVM; anticoagulation; EP monitoring	BP control; ± EP monitoring; anticoagulation	
Antibiotics	Usually none; occasionally used with closure device		
Procedure time	2–5 h	2–4 h	
Closing considerations	Femoral artery compression or closure device		
EBL	Minimal		
Postop care	Ward or ICU × 24–48 h	ICU	Ward or ICU
Mortality	1–2% (vascular lesions)		
Morbidity	Overall: 5% Thromboembolic stroke Hemorrhage (AVM, AVF)	SAH	Vessel rupture/dissection
Pain score	1–2	1–2	1–2

Patient Population Characteristics

Age range	Neonatal-elderly

Male:Female	1:1
Etiology	Congenital; acquired (traumatic, infectious, degenerative, etc.)
Associated conditions	SAH ± vasospasm; ↑ ICP; HTN/CAD/PVD; blood dyscrasia

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Anesthetic Considerations

Preoperative

Patients presenting for diagnostic neuroradiologic procedures frequently may require only local anesthesia and sedation. The newer nontoxic and low osmolality contrast agents have improved patient comfort and tolerance of these procedures while minimizing adverse reactions. Patients presenting for interventional neuroradiological procedures (e.g., embolization or stenting) are likely to experience more discomfort and, therefore, may require GA in order to tolerate the often lengthy procedures. The advantages of GA, however, must be balanced against the potential need for intraop neurological monitoring (e.g., speech, vision, and mental status) that requires the patient to be awake and cooperative. In this set of circumstances, close consultation between the neuroradiologist and anesthesiologist is required in formulating the anesthesia plan.

Respiratory	Access to the airway may be limited; therefore, examination should focus on the need for elective ET intubation. Patients with chronic cough may require GA to ensure immobility. **Tests:** As indicated from H&P.
Cardiovascular	Patients with recent intracranial hemorrhage may demonstrate ECG abnormalities (PVCs in 30–80%; ST-T wave changes in >50%), which need to be differentiated from new ischemic heart disease (ECHO, cardiac enzymes). **Tests:** ECG; other tests as indicated from H&P.
Neurological	Symptoms vary with the location, size, and type of lesion. Aneurysms seldom produce neurological symptoms unless they leak or rupture, whereas tumors are commonly associated with symptoms of ↑ ICP (HA, N/V, altered mental status, papilledema). Patients with recent cerebral hemorrhages are likely to be medicated with calcium-channel blockers (e.g., nimodipine, nicardipine) to ↓ arterial vasospasm. Patients with ↑ ICP or cranial trauma usually will need GA with intubation and mechanical ventilation.
Premedication	Preop sedation may mask the Sx of ↑ ICP or intracranial hemorrhage. Patients at high risk for contrast-media reactions (e.g., patients with previous contrast reaction, allergy to iodine or seafood) should receive prophylactic treatment consisting of prednisone, 50 mg po q 6 h × 3, starting 18 h before the study, and diphenhydramine, 50 mg po/im, 1 h before the procedure.

Intraoperative

Anesthetic technique: MAC (see p. B-3) may be adequate for patients undergoing diagnostic procedures and necessary for patients requiring neurological assessment during more invasive procedures; otherwise, use GETA.

Induction	Standard induction (see p. B-2). Patients with ↑ ICP should be hyperventilated to an $ETCO_2$ of 30 mmHg. In patients with vascular lesions that may leak or rupture, BP responses to laryngoscopy and intubation should be blunted (e.g., remifentanil: 3–5 mcg/kg iv 1–2 min in advance).
Maintenance	Standard maintenance (see p. B-2). Muscle relaxation is usually mandatory to control ventilation and minimize the chance of movement. Hyperventilation may be necessary to ↓ ICP and may also enhance the quality of the angiogram. Prompt awakening is important to permit neurologic evaluation. Ondansetron (4 mg iv)

Emergence	is useful to ↓ postop N/V. Extubate when airway reflexes have returned. Continuous control of BP may be necessary during emergence phase. Patients typically are transported to ICU immediately following the procedure.	
Blood and fluid requirements	IV: 18 ga × 1–2 NS @ 3–5 mL/kg/h	
Monitoring	Standard monitors (see p. B-1). Arterial line Urinary catheter	BP can be monitored from femoral line placed by radiologist. However, another arterial line often will be necessary for postop monitoring in the ICU. Place urinary catheter if procedure is lengthy (> 3 h).
	± EPs	Keep isoflurane or sevoflurane < 0.5 MAC and N_2O <50% to minimize interference with EP monitoring. Supplement with remifentanil infusion, if necessary. TIVA may be requested in the erroneous belief that EP's cannot be obtained while using inhalational agents.
Control of BP	SNP (0.2–2 mcg/kg/min) Maintain normovolemia. Esmolol (50–200 mcg/kg/min)	BP control may be necessary during intracranial catheter manipulation, embolization, and postembolization. Close communication with the radiologist is important. SNP/esmolol may be infused through a second peripheral iv.
Positioning	and pad pressure points. eyes.	X-ray table may not be well padded → nerve damage.
Complications, contrast- related	Common reactions: N/V Itching Urticaria Sensation of warmth Pain Anxiety Rash	These reactions occur in > 5% of patients, and may require no treatment apart from reassurance or a mild anxiolytic. Mild allergic reactions may be treated with diphenhy dramine 25–50 mg iv. Monitor patients for progression of Sx → need for more aggressive therapy.
	Neurotoxic Sx: Hemiplegia Blindness Aphasia ↓ consciousness	These reactions may be related to the hyperosmolarity of the agent. If persistent, procedure should be terminated. Rx may require steroids and vasopressors to improve perfusion. In the anesthetized patient, these Sx will be masked.
	Major allergic reactions: Bronchospasm ↓ BP Cardiac arrest Pulmonary edema Laryngeal edema Dysrhythmias	Epinephrine (0.25–0.5 mg iv) should be given immediately. **Rx of anaphylaxis** includes: eliminate antigens (e.g., contrast agent, latex, etc.); secure airway; administer 100% O_2 iv fluids, epinephrine, and diphenhydramine + ranitidine. Supplemental Rx may include steroids (e.g., hydrocortisone 5 mg/kg), atropine, $NaHCO_3$ arginine vasopressin, and epinephrine infusion.
Complications, other	Hemorrhage	Aneurysmal rupture or AVM bleeding may require immediate transport to OR for surgical repair.
	Vasospasm	Rx: vasodilators (e.g., NTG) or papaverine delivered by catheter, or balloon angioplasty.
	Occlusion of vessel	2° catheter injury of vessel wall. Rx: angioplasty. (Recanalization and stenting may be used for thrombotic occlusions.)

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Postoperative

Complications	Neurologic deficits	CT scan for evaluation, as prompt neurosurgical intervention may be required.
	Vasospasm	May require Ca^{+}channel blocker (e.g., nimodipine). Consult with neurosurgeon.

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Direct Current (DC) Cardioversion

Procedural Considerations

Description: Direct current (DC) cardioversion is a treatment for cardiac arrhythmias that uses a brief, dosed discharge of electricity across the heart. This biphasic waveform energy is more efficient, requiring 20–170 J, than monophasic waveform, which requires 50–360 J. Effective depolarization of a critical mass of the heart terminates the arrhythmia, allowing NSR to resume. The electrical shock is delivered across the chest wall, using two external paddles placed in one of the standard positions (i.e., the anterior-posterior (A-P), basilar-apical, or apical-posterior). The pulse is delivered synchronous to the QRS, thus avoiding the vulnerable period for inducing malignant tachyarrhythmias. Shock to treat ventricular fibrillation is applied emergently and asynchronously (thus, the term ‘defibrillation’). To avoid discomfort, cardioversion should always be performed with the patient under deep sedation or brief GA. It is unacceptable to deliver this therapy to an awake patient.

Usual preop diagnosis: Atrial fibrillation (AF); atrial flutter; other supraventricular tachyarrhythmias; ventricular tachyarrhythmias

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Summary of Procedures

Position	Supine with defibrillator pads positioned A-P, basilar-apical, or apical-posterior
Unique considerations	Adequate anticoagulation (INR = 2–3) in patients with AF
Antibiotics	None
Procedure time	≥ 30 min
Postop care	Monitoring of cardiac rhythm in treatment room
Mortality	0.1%
Morbidity	Skin burns: < 15% (1st degree); 2% (2nd degree); lesser incidence with biphasic waveform Embolic event: 2% (↑ risk with mitral valve disease) Acute pulmonary edema: 1%

	More serious arrhythmia: 1% Myocardial damage: Incidence unknown, but estimated to be very low—proportional to delivered energy.
Pain score	2–3

Patient Population Characteristics

Age range	All ages
Male:Female	3:1
Incidence	100,000/yr in the United States
Etiology	Reentry substrates (e.g., atrial flutter and fibrillation, ventricular tachycardia) from hypertensive heart disease, remote MI, cardiomyopathy; idiopathic
Associated conditions	LV dysfunction; CAD; cardiomyopathy; HTN; valvular disease; COPD; obesity; CVA; acute MI; pulmonary edema

Anesthetic Considerations

Preoperative

In general, patients presenting for cardioversion fall into one of two categories: elective or emergent. The presence or absence of hemodynamic instability will define the category. In the emergency patient, full-stomach precautions may be necessary (see p. B-5). Elective cardioversions usually are carried out on patients who have failed drug therapy.

Respiratory	Preop evaluation of the airway should focus on the need for elective ET intubation (patients with GERD, difficult mask fit, or airway compromise).
Cardiovascular	Relative contraindications to elective cardioversion include digitalis toxicity (toxic = > 3 ng/mL), ↓ K⁺, inadequate anticoagulation, presence of β-blockade, AV block. The presence of significant CHF, CAD, or valvular disease may predispose this patient population to ↓ ↓ BP in response to anesthetic agents. Consider use of etomidate (0.1–0.2 mg/kg). Patients at ↑ risk for embolization include those with Hx of embolization within 2 yr, mitral stenosis, intraarterial thrombus, CHF, or hyperthyroidism. In these patients, ensure adequate anticoagulation (PT 1.5–2 × baseline, INR 2.0–3.0). It has been suggested that NTG patches near the electrodes be removed prior to cardioversion to avoid risk of explosion. **Tests:** ECG; TEE (for thrombus and size of atrium); digitalis level (toxic = > 3 ng/mL → refractory VF following cardioversion); electrolytes; INR.
Endocrine	Hyperthyroidism → AF
Gastrointestinal	Full-stomach precautions (see p. B-4) may be necessary in the emergency patient.
Neurological	Hx for TIAs or CVAs →↑ risk of embolic event. Pre- and postprocedure neurologic exams should be done.
Hematologic	need for anticoagulation (see above).
Laboratory	Other tests as indicated from H&P.
Premedication	Usually not needed. For the emergency patient, take full-stomach precautions (see p. B-4).

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Intraoperative

Anesthetic technique: Brief GA with mask oxygenation and ventilation

Induction	Preoxygenate patient. For hemodynamically fragile patients, etomidate (0.1–0.2 mL/kg iv) is perhaps the agent of choice (**NB:** etomidate-induced clonus → ECG artifact). For the hemodynamically stable patient, use propofol (1.0-1.5 mg/kg iv slowly) until loss of lid reflex. Additional analgesia may be provided by remifentanil (1–2 mcg/kg iv), thereby reducing anesthetic requirements.	
Maintenance	Occasionally necessary to repeat cardioversion. Additional small doses of propofol, etomidate, or remifentanil may be required.	
Emergence	Patients should awaken rapidly with full recovery of airway reflexes. Outpatients are usually discharged to home within 1–2 h.	
Blood and fluid requirements	No blood loss IV: 20 ga × 1 NS/LR @ TKO	
Monitoring	Standard monitors (see p. B-1).	Avoid placement of ECG electrodes in precordial area.
Positioning	Hospital bed, supine	Procedure takes place at patient's bedside.
Complications	Loss of airway	Use airway manipulation ± artificial airways; be prepared to intubate. Use ACLS protocols.
	VF ↑ ↑ BP/myocardial ischemia	Cardioversion → catecholamine surge → acute MI in susceptible patient population. Rx: Atropine (e.g., 0.4 mg iv)
	Severe bradycardia	Ensure good electrode/skin contact.
	Thermal injury ↓ CO	2° anesthetic drugs or myocardial stunning from cardioversion. Rx: inotropic support (e.g., ephedrine)

Postoperative

Complications	Recall	Especially in hemodynamically fragile patients. Discuss possibility with patient in advance.
	Systemic embolization	Neurological exam should be repeated post-cardioversion.
	↓ BP/↓ CO/CHF New dysrhythmia	Atrial contraction may not be effective following cardioversion →↓ CO/↓ BP.
Pain management	Minimal	Myalgias not uncommon; consider ketorolac.
Tests	ECG	Verify NSR.

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Implantation Of Cardioverter-Defibrillator (ICD)

Procedural Considerations

Description: The implantable cardioverter-defibrillator (ICD) is an effective device for the prevention of premature death from ventricular tachycardia (VT) or ventricular fibrillation (VF). The results of randomized trials involving survivors of cardiac arrest and those considered at risk for sudden death showed the superiority of ICD therapy over conventional medical therapy in lowering the incidence of sudden death and overall mortality. The most recent trial—MADIT II—showed the device therapy to be advantageous over standard medical therapy in patients with low LVEF (< 30%). Over the past decade, significant advances have occurred in ICD technology. The devices have decreased dramatically in size (now at 30–40 mL), along with substantial increases in functionality. Newer devices can incorporate the full capabilities of a permanent pacemaker for bradycardia support and resynchronization therapy, as well as hemodynamic monitoring. Therapies for atrial tachyarrhythmias (atrial tachycardia and fibrillation) are also available in select devices (e.g., Medtronic GEM AT). The more efficient biphasic waveform, which results in a much lower defibrillation threshold (DFT) and, hence, lowers required energy delivery and storage, is now standard for all ICDs, allowing for further miniaturization. Implantation of these small ICDs results in mortality and morbidity rates very similar to those associated with standard pacemaker implantation.

The device system consists of a small pulse generator and transvenous leads that are designed to record ventricular depolarizations and deliver a shock via coils or patches. ICD terminates VT/VF by sensing these rhythms and responding with an appropriate countershock. The most common ICD implantation uses endocardial leads inserted percutaneously (transvenous approach) via pectoral (or, rarely, abdominal) subcutaneous/submuscular pulse generator placement. In the unusual circumstances of difficult endocardial access or high DFT (> 25 J), additional leads can be placed either in the coronary sinus or subcutaneously. Very rarely would the leads (in the form of patches) be applied epicardially via a thoracotomy approach.

In the **transvenous approach,** the insertion of leads and pulse generator requires minimal anesthesia; however, during testing of defibrillation efficacy, VF is induced once or twice, and sometimes more frequently. Thus, in addition to continuous monitoring of VS and cardiac rhythm, the anesthesiologist should pay special attention to the patient's hemodynamic stability prior to VF induction and after the defibrillation. In the event of failed defibrillation by the programmed first shock, a somewhat prolonged VF may occur. In the case of repeated DFT testing, it is customary to give at least 5-min intervals between VF inductions to allow for sufficient hemodynamic recovery. In patients with significant LV dysfunction, ↓ BP is not uncommon, but caution should be taken with fluid administration. If recovery from ↓ BP is slow, complications such as pneumo/hemothorax or pericardial effusion/tamponade should be considered. In the absence of a PA catheter (which would interfere with ICD lead positioning), accurate assessment of hemodynamic status is limited. Thus, meticulous attention should be directed at arterial pressure, HR, and oxygenation status. Finally, it is not uncommon to encounter acute atrial fibrillation (AF) from induction and conversion of VF. Fortunately, a cardioversion can be applied easily, using the ICD itself or relying on the external rescue system (external cardioversion).

Usual preop diagnosis: Documented, induced, or high-risk ventricular fibrillation

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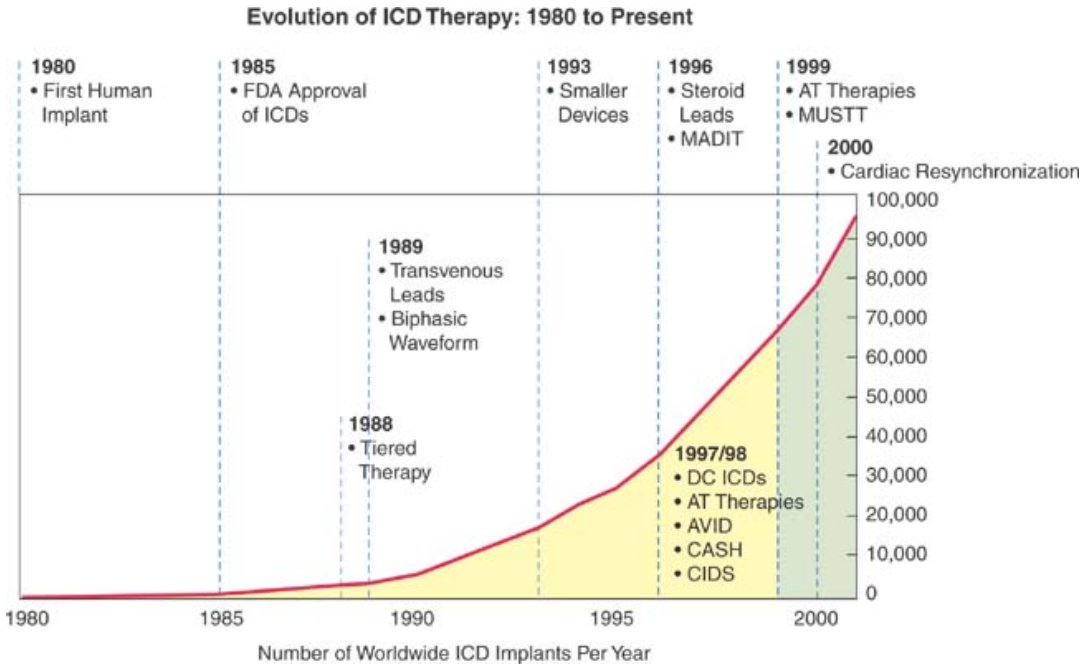

Figure 13.1-1. 1. The annual implantation rate of ICDs is rising as the units become easier to implant and the indications for their use broadens. (Reproduced with permission from Medtronic, Inc. Minneapolis MN.)

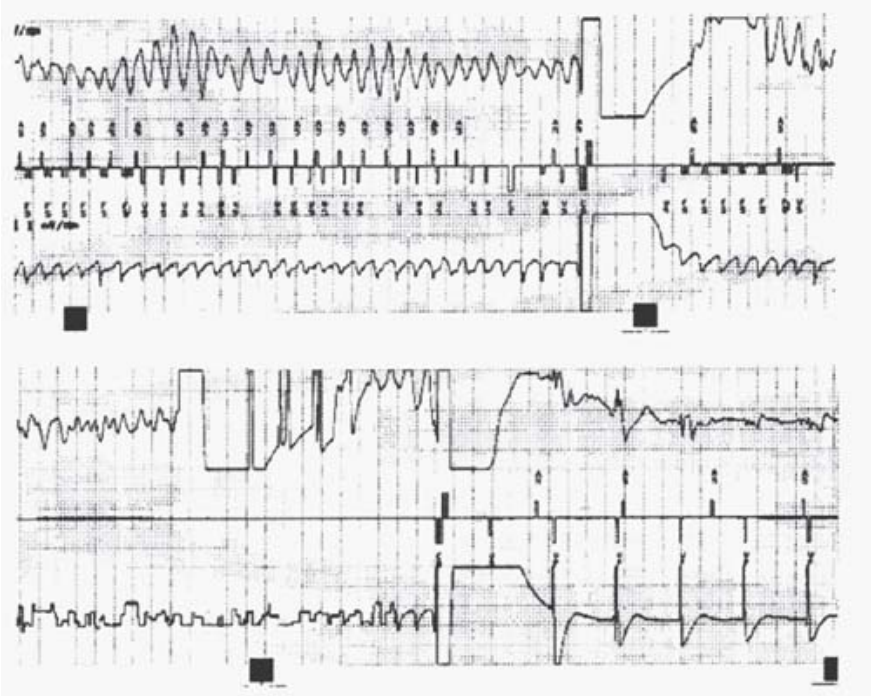

Figure 13.1-2. 2. Induced VF (with underlying AF) is shown on top panel, whereby the first (24-J) shock failed to terminate VF but terminated AF (as indicated by the ICD annotation). The second shock (34-J) terminated VF, resulting in V-paced rhythm with underlying sinus and AV block. Total down-time during VF was 16 sec. Down-time is dependent on the detection time and charge time, which, in turn, depend on the energy programmed.

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Summary of Procedures

Position	Supine with defibrillator pads positioned A-P or basilar-apical
Incision	Left pectoral or abdominal
Special instrumentation	ICD pulse generator, lead(s), and testing system (manufacturer-specific)

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Unique considerations	Multiple inductions of VT/VF with associated ↓ CO, ↓ BP
Antibiotics	Standard iv antimicrobial for staphylococcus/streptococcus organism
Surgical time	1–2 h (more for ICD with cardiac resynchronization [CRT])
Closing considerations	Routine subcutaneous/submuscular pocket closure
EBL	5–20 mL
Postop care	Monitoring of arrhythmia, pocket bleeding/hematoma, pneumothorax
Mortality	0.1% (transvenous); ≥ 5% (thoracotomy)
Morbidity	New-onset arrhythmias: ≥ 5% Pneumothorax: ≥ 5% (transvenous) Pericardial effusion/tamponade: ≥ 1% (transvenous)
Pain score	3 (6–9, thoracotomy)

Patient Population Characteristics

Age range	5–90 yr
Male:Female	4:1
Incidence	50,000/yr in the United States
Etiology	Reentry substrates from remote MI and cardiomyopathy; congenital anomalies (e.g., Long-QT and Brugada syndromes)
Associated conditions	LV dysfunction; CAD; cardiomyopathy; HTN; valvular disease; COPD; obesity; AF; CVA; anoxic encephalopathy

Anesthetic Considerations for ICD and Pacemaker Placement

Preoperative

Patients presenting for **ICD placement** may be divided into three populations, based on symptomatology, associated pathology, and probable outcome: (a) **Supraventricular dysrhythmias** (e.g., Wolff-Parkinson-White [WPW] syndrome): usually young and otherwise healthy patients. May be associated with Ebstein's anomaly (tricuspid valve defect → RV failure), mitral valve disease, or CAD. Low periop mortality (1%); (b) **Ventricular dysrhythmias:** usually older patients with significant ventricular dysfunction (EF = 10–35%) and other pathologies, such as CAD or cardiac failure. These patients have either survived an episode of VT/VF or are otherwise at risk for sudden death; and (c) **Congestive heart failure (CHF)** without significant dysrhythmias, usually 2° dilated cardiomyopathy. These patients have very low EFs (10–25%), left bundle branch block, and Hx of failed conventional means of CHF treatment. The ICD device is implanted in these patients to provide paced ‘resynchronization’ of the contractions of the LV and RV. This requires a third-pacer lead placed into the coronary sinus to pace the LV independently of the RV. In this case, the device is not placed primarily for its defibrillator function, but for its ability to pace both ventricles synchronously (biventricular pacing). Patients presenting for **permanent pacemaker insertion** may have a variety of dysrhythmias, including sick sinus syndrome (SSS), heart blocks (2nd- and 3rd-degree), and tachycardias refractory to medication.

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Respiratory	May have associated pulmonary disease 2° smoking. **Tests:** CXR; consider PFT, as indicated from H&P.
	ICD: ICD patients are left on full medication, since it usually is impossible to wean them from antidysrhythmic medications before surgery. In most studies, patients have a mean LV EF of 35% and a New York Heart Association functional class of II or III.
	Supraventricular dysrhythmias: Look for precipitating factors in the dysrhythmia, and any methods that have been used to terminate the dysrhythmia. Usually, drug therapy is terminated

Cardiovascular	before surgery to make a dysrhythmia inducible. Note type of drugs used to terminate a dysrhythmia. **Ventricular dysrhythmias:** Ask about any methods that have been used to terminate dysrhythmia. Look for associated conditions, including CAD, CHF, cardiomyopathy, LV aneurysm, HTN, mitral insufficiency, diabetes. Generally, these patients have poor LV function with ↑ sensitivity to myocardial depressants. It is important to note that they may be on combinations of antidysrhythmics. Many of these drugs have significant negative inotropic effects. Of special note is amiodarone, which has been associated with intractable bradydysrhythmias, refractory vasodilation, and difficulty in weaning from CPB. **Pacemaker:** The anesthesiologist should be aware that there is an NASPE code (North American Society of Pacing and Electrophysiology) that describes pacemaker function with a three- to five-letter code. The first letter refers to the heart chamber that is paced and the second to the chamber that is sensed. These first two letters can be A (atrial), V (ventricular), or D (dual). The third letter indicates whether there is a triggering (T) or inhibiting (I) function, or both (D). For example, a VVI notation indicates that the ventricle is paced and sensed and there is inhibition by native beats. A fourth and fifth letter may be used to describe programmability and dysrhythmia control, respectively. **Tests:** ECG: dysrhythmia, ischemia, electrophysiologic report. ECHO: ventricular function, wall motion abnormalities, valvular problems. Cardiac angiography: ventricular function, CAD, valvular disease, LV aneurysm.
Renal	Patients with poor ventricular function may have associated renal compromise. Electrolyte abnormalities (K^+, Mg^{++}) may be associated with ↑ cardiac irritability and should be corrected preop. **Tests:** BUN; Cr; electrolytes
Hematologic	Hb/Hct; coag tests (PT, PTT, Plt)
Laboratory	Other tests as indicated from H&P.
Premedication	For adults: midazolam 0.5–2.0 mg iv, with careful observation and supplemental O_2

Intraoperative

Anesthetic technique: Local anesthesia with sedation, GA with LMA, or GETA, as indicated. Placement of most ICDs and pacemakers is done in the cardiac catheterization suite. ICDs are very small and are implanted in the same position as a pacemaker. If patients are orthopneic due to their CHF, or if the procedure is projected to be long, GA is often preferable. Also, elderly patients may become disoriented with sedation and, thus, may require GA.

Induction	Exact type of induction depends on the patient's medical condition. Sedation can be provided with small doses of midazolam (1–2 mg) ± fentanyl (25–50 mcg) titrated to effect. An alternative technique is to use a propofol infusion (e.g., 25–75 mcg/kg/min). Since local anesthesia is provided by the surgeon, the procedure usually is not painful and does not require postop pain control. It is important to avoid oversedating these patients, since they will tend to become disoriented and uncooperative. Even if local anesthesia with sedation is provided for the placement of leads and the device, a brief period of GA is always required for device testing. This can

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	be provided easily with mask ventilation and induction with propofol (e.g., 1 mg/kg iv) or etomidate (e.g., 0.1 mg/kg iv), similar to anesthesia for cardioversion procedures. For those patients requiring GA for the entire procedure, induction with STP (2–4 mg/kg), propofol (1–2 mg/kg), or etomidate (0.1–0.3 mg/kg) is often used. Muscle relaxants are not required unless intubation is planned. Narcotics usually are not required since local anesthesia is used.	
Maintenance	As previously discussed, verification of correct lead placement involves the induction of ventricular fibrillation or tachycardia and the testing of the device's capability to restore NSR. External defibrillation should be available at all times, as should antidysrhythmics (e.g., lidocaine and amiodarone). While the device is tested, the patient should be breathing 100% O_2 Multiple testing cycles can result in depressed LV function, and inotropes may be needed.	
Emergence	These patients are extubated (if GETA or LMA used). Recovery is in the PACU. If, however, multiple test shocks are needed or the heart displays evidence of injury (need for inotropes, ST segment abnormalities), then extubation may need to be deferred to ICU.	
Blood and fluid requirements	IV: 16–18 ga × 1 NS/LR @ 6–8 mL/kg/min	Care should be taken to minimize iv fluids in CHF patients.
Monitoring	Standard monitors (see p. B-1)	
	± Arterial line	
	± CVP/PA	A CVP or PA catheter may be placed according to LV function. ICD patients generally require only an arterial line.
	External defibrillation	Because antidysrhythmics may affect the testing procedure, they should be avoided when possible. Defibrillation or cardioversion are treatments of choice.
	Temperature	Normothermia should be maintained.
Positioning	Supine and pad pressure points. eyes.	
Complications	Pneumohemothorax Pericardial effusion/tamponade HTN/CHF	
	Coronary sinus rupture	Rarely, cardiac rupture may occur during lead extraction. Coronary sinus rupture has been reported during biventricular lead placement.

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Postoperative

Complications	Recurrent dysrhythmias Hemorrhage Ischemia	
Pain management	Usually managed with oral analgesics.	
Tests	CXR ECG Electrophysiologic testing Electrolytes	line/lead placement, r/o pneumohemothorax. for ischemia, dysrhythmias.

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Transjugular Intrahepatic Portosystemic Shunt (TIPS)

Procedural Considerations

Description: Hepatic cirrhosis is a progressive disease which eventually results in portal HTN and the development of varices at a variety of sites. Bleeding from esophageal varices is a serious complication of portal HTN, occurring in 25% of patients within 1 year of diagnosis (50% mortality). Prior to 1989, surgically placed shunts were used to direct high-pressure portal blood into the systemic venous circulation in patients with recurrent bleeding after endoscopic sclerotherapy or banding. The **transjugular intrahepatic portosystemic shunt (TIPS)** procedure has almost completely replaced surgical shunts.

TIPS is, as the name suggests, a percutaneous shunt between the portal and systemic circulations. The shunt is created between the hepatic vein and portal vein within the liver parenchyma, maintained by placement of a stent graft. This creates a low-resistance conduit to decompress the portal circulation, thereby decreasing variceal blood flow and ascites formation. Although it can be performed with conscious sedation, balloon dilation of the tract is extremely painful, typically requiring GA.

TIPS was developed initially by Rosch in dog studies in 1969. The first percutaneous portosystemic shunts were performed in humans using an angioplasty balloon in 1982, but the tract closed due to elastic recoil of the cirrhotic liver tissue. Palmaz and Richter performed the first successful TIPS in humans in 1989, using metallic stents to maintain the patency of the tract. Since then, TIPS has become the procedure of choice for patients who fail sclerotherapy and banding. In addition, it addresses another common problem associated with cirrhosis: refractory ascites.

Through the right IJ, a 10 Fr sheath is placed in the upper IVC. A catheter/guidewire combination is used to select the right hepatic vein. A wedged hepatic venogram using CO_2 is performed. Injection of iodinated contrast can result in rupture of the liver capsule and exsanguination. The wedged venogram refluxes contrast through the sinusoids and into the portal vein, thereby providing a map. The catheter is exchanged over a stiff wire for a metallic introducer/needle. A variety of needle kits are available including the Colapinto (Cook Inc., Bloomington, IN), Rosch-Uchida (Cook Inc, Bloomington, IN), and Hawkins set designed for CO_2 injections (Angiodynamics, Queensbury, NY). All include a long introducer sheath and coaxially inserted curved-tip needle or metal cannula, with directional indicator, to help steer the needle toward the right portal vein.

Portal venous pressures are measured and the pressure gradient between the portal vein and right atrium determined. Following a portal venogram, the catheter is exchanged for an angioplasty balloon, and the tract dilated (Fig. 13.1-3C). The use of covered stents for TIPS creation have led to significantly improved patency rates and for this reason, the Viatorr (Gore, Flagstaff, AZ) self-expanding covered stent has largely replaced the bare metal stents. The Viatorr is positioned across the tract and the uncovered portion is first deployed within the portal venous system (Fig. 13.1-3D). The covered portion is then pulled into the tract and deployed in a separate step. The stent may be dilated to a diameter of 8–10 mm using an angioplasty balloon, depending on the stent diameter and desired porto-systemic gradient. If necessary, a second stent is deployed to cover any remaining unstented portions of the hepatic tract. Following TIPS creating, portal venogram and pressure gradients are remeasured. Ideally, the pressure gradient following shunting should be between 6–12 mmHg. If the gradient is too high, there is a risk of *(Print pagebreak 1463)* rebleeding; if too low, there is overshunting of blood, thus bypassing the entire portal venous system and increasing the risk of encephalopathy and liver failure. After successful creation of the shunt, all devices, including the right jugular sheath, are removed, and hemostasis is achieved. Patients are closely monitored in an ICU or step-down unit for 24–48 h.

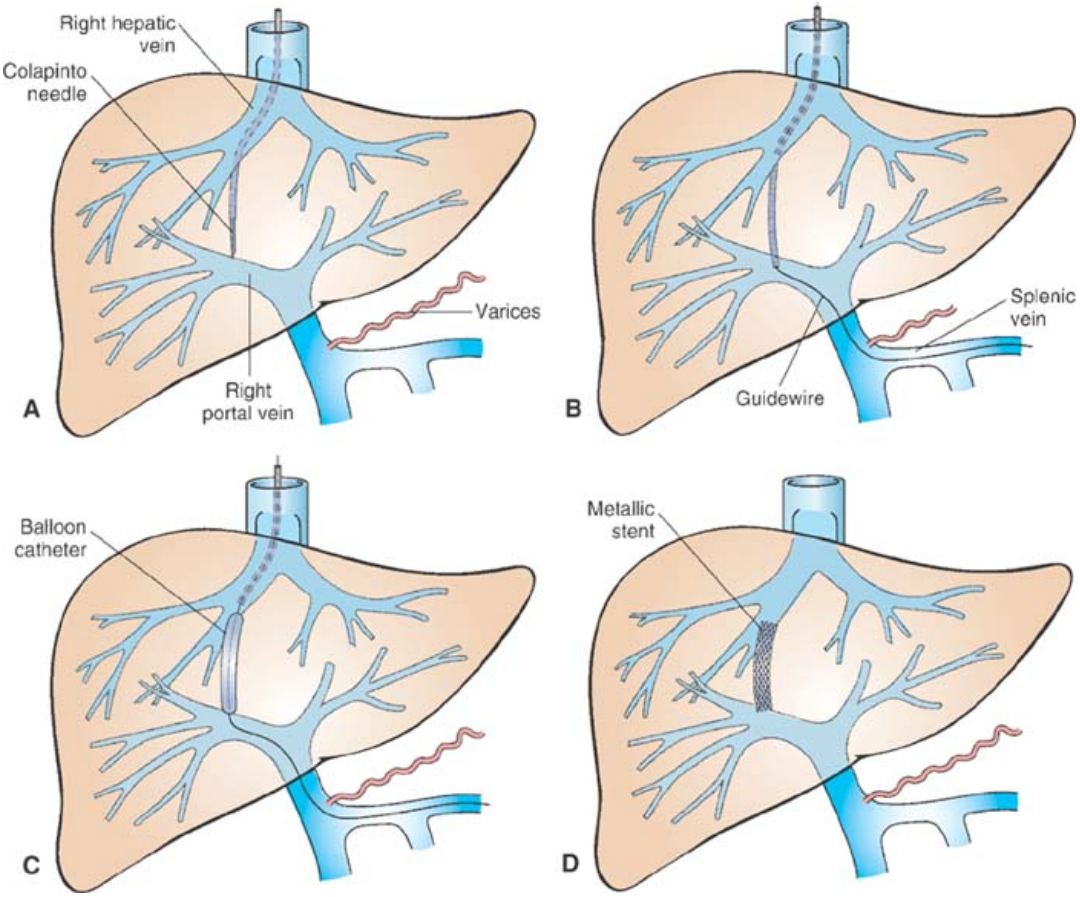

Figure 13.1-3. 3. TIPS placement: **(A)** Sheathed Colapinto needle is advanced out of hepatic vein into portal vein branch. Varices are present. **(B)** Guide wire is advanced through the needle sheath into splenic vein. **(C)** Parenchymal liver tract is dilated using a balloon angioplasty catheter. **(D)** The metallic stent is deployed within the shunt tract. (Redrawn with permission from Haskal ZJ, Ring F: *Current Techniques in Interventional Radiology.* Current Science, Philadelphia: 1994.)

DIPS (Direct IVC-to-portal shunt) is a newer alternative to TIPS. Simultaneous venous access is required from both the internal jugular vein and common femoral vein. For DIPS, an intravascular ultrasound probe is used to guide needle puncture from the IVC, through the caudate lobe, and into the main portal vein. Since the tract traverses extrahepatic regions, placement of a covered stent is mandatory. A theoretically fewer number of passes is needed to access the portal vein because the puncture is ultrasound guided; however, there is likely a greater risk of intraperitoneal hemorrhage with each puncture attempt.

If TIPS/DIPS is performed for the treatment of bleeding varices, it may be necessary to embolize and sclerose the varices if they persistently fill following shunt creation. This may be accomplished using sclerosing agents (e.g., ethanolamine) with an occlusion balloon and embolic agents (e.g., metallic coils, Gelfoam), depending on operator preference.

Usual preop diagnosis: Bleeding esophageal varices (as a result of portal HTN); ascites; Budd-Chiari and hepatorenal syndromes

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Summary of Procedures

Position	Supine
Incision	Right IJ access
Special instrumentation	Rosch-Uchida, Colapinto, or Hawkins needle set; angioplasty balloons; endovascular stent grafts, marker pigtail, CO_2 injection apparatus, intravascular ultrasound (IVUS) for DIPS, embolic agents (e.g., coils, gelfoam, ethanolamine) for variceal embolization/sclerosis if necessary.
Unique considerations	May need FFP.
Antibiotics	Cefazolin 1 g iv
Procedure time	2–6 h
EBL	0–3,000 mL
Postop care	ICU or step-down unit; careful fluid management
Mortality	Emergency: 50–100% Postprocedure: See Tables 13.1-2, 13.1-3, 13.1-4, 13.1-5
Morbidity	Encephalopathy: 18–30% Late liver failure: 10–25% Shunt occlusion: 10%/yr Liver capsule puncture → intraperitoneal hemorrhage (continue procedure to decompress portal venous system →↓ bleeding). Hepatic artery puncture: may require embolization. Allergic reactions (see Contrast-related complications, p. 1453). MI (related to ↑ CVP) Renal failure (usually transient)
Pain score	7–8 (first few h only)

Table 13. 1-2. MELD Score Calculation

The MELD (Model for End-stage Liver Disease) score is calculated using three objective indicators—serum bilirubin, serum creatinine level (Cr), and international normalized ratio (INR)—according to the United Network for Organ Sharing modification of the original formula:

MELD = 9.6 × log e (Cr) + 3.8 × log e (Bilirubin) + 11.2 × log e (INR) + 6.4

The MELD Score can easily be calculated by accessing the following website:
http://www.mayoclinic.org/meld/mayomodel7.html

Table 13. 1-3. Overall Mortality Based on MELD Score

MELD Score	No. of Patients	Mortality Rate (%)		
		30 days	3 months	6 months
≥ 10%	28	0 (0, 0)	0 (0, 0)	0 (0, 0)
11–17	83	7.3 (1.7, 12.9)	16.0 (8.0, 24.0)	24.9 (15.1, 34.7)
18–24	40	17.9 (5.9, 29.9)	34.8 (19.4, 50.2)	38.6 (22.4, 54.9)
≥ 25	15	42.6 (16.7, 68.4)	65.5 (39.9, 91.2)	74.2 (50.0, 98.3)

Patients undergoing elective TIPS creation with a MELD score of 18 or more had a significantly lower 3-month survival rate than those with a MELD score of 17 or less. Numbers in parentheses are 95% confidence intervals. Mortality tables reprinted with permission from Ferral H, Gamboa P, Postoak DW, et al: Survival after elective transjugular intrahepatic portosystemic shunt creation: prediction with Model for End-Stage Liver Disease Score. *Radiology* 2004;231(1):231–6.

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Table 13. 1-4. Mortality Based on MELD Score and Cause of Cirrhosis

MELD Score	Group*	No. of Patients	Mortality Rate (%)		
			30 days	3 months	6 months
≥ 17	A	39	5.1 (0, 12.1)	7.7 (0, 16.1)	13.9 (2.5, 25.2
	B	72	5.6 (0.3, 11.0)	14.4 (6.1, 22.7)	21.4 (11.3, 31.4)
≥ 18	A	14	42.9 (16.9, 68.8)	57.1 (31.2, 83.1)	57.1 (31.2, 83.1)
	B	41	17.9 (5.9, 29.9)	37.9 (22.0, 53.7)	45.9 (28.1, 63.2)

A = Alcohol-induced disease, B = Non-alcohol-induced disease
Patients undergoing elective TIPS creation with a MELD score of 18 or more had a significantly lower 3-month survival rate than those with a MELD score of 17 or less. Numbers in parentheses are 95% confidence intervals. Mortality tables reprinted with permission from Ferral H, Gamboa P, Postoak DW, et al: Survival after elective transjugular intrahepatic portosystemic shunt creation: prediction with Model for End-Stage Liver Disease Score. Radiology 2004; 231(1): 231–6.

Table 13. 1-5. Mortality Based on MELD Score and Ascites

MELD Score	Ascites	No. of Patients	Mortality (%)		
			30 days	3 Months	6 Months
≥ 17	No	48	4.2 (0, 9.8)	4.2 (0, 9.8)	4.2 (0, 9.8)
	Yes	63	6.4 (0.3, 12.5)	18.4 (8.6, 28.3)	31.3 (18.6, 43.9)
≥ 18	No	18	22.2 (3.0, 41.4)	39.8 (16.8, 62.8)	46.5 (22.6, 70.4)
	Yes	37	25.4 (11.0, 39.8)	44.4 (27.4, 61.4)	48.7 (31.1, 66.3)

Patients undergoing elective TIPS creation with a MELD score of 18 or more had a significantly lower 3-month survival rate than those with a MELD score of 17 or less. Numbers in parentheses are 95% confidence intervals. Mortality tables reprinted with permission from Ferral H, Gamboa P, Postoak DW, et al: Survival after elective transjugular intrahepatic portosystemic shunt creation: prediction with Model for End-Stage Liver Disease Score. *Radiology* 2004; 231(1):231–6.

Anesthetic Considerations

Preoperative

Patients presenting for TIPS procedures have portal HTN usually 2° end-stage liver disease (ESLD), which will affect the function of a variety of organ systems, as described below.

Respiratory

Abdominal distension → atelectasis →↑ pulmonary shunting → hypoxemia (hepatopulmonary syndrome in ESLD).
Encephalopathy → hyperventilation →↓ $PaCO_2$(respiratory alkalosis with chronic acidosis as compensation). Pulmonary effusion may be present in 5–10% of patients.
Tests: CXR (for Sx of atelectasis); ABG and PFT, if indicated.

Cardiovascular	Cardiomyopathy (ETOH) and CAD (tobacco) occur at higher incidence in this patient population. Diuretic therapy → hypovolemia + ↓ K^+(furosemide) or → K^+(spironolactone). Hyperdynamic circulation 2° to ↓ peripheral resistance + ↓ cardiac reserve are common findings, and correlate with poor postop outcome. **Tests:** ECG; electrolytes; cardiac ECHO, if indicated from H&P.
Neurological	Symptoms of hepatic encephalopathy range from mild confusion to coma. These patients may be very sensitive to narcotics and sedatives. A characteristic finding in liver failure is asterixis (liver flap). Hyponatremia and hypoglycemia may mimic hepatic encephalopathy. **Tests:** As indicated from H&P.
Hepatic	Drug metabolism may be markedly reduced; anticipate prolonged effect with sedative and narcotic drugs. Drugs with particularly prolonged action include midazolam, meperidine, ranitidine and lidocaine. Apparent resistance to pancuronium and all muscle relaxants is most likely due to an increased volume of distribution. Succinylcholine effects may be prolonged in patients with severe ESLD (2° ↓ plasma cholinesterase). **Tests:** Bilirubin; PT; albumin; LFTs
Gastrointestinal	Ascites →↑ intraabdominal pressure →↑ risk of aspiration. Full-stomach precautions and rapid-sequence induction are recommended (see p. B-4). Portal HTN → variceal bleeding. If possible, avoid esophageal instrumentation (e.g., TEE, esophageal stethoscope, etc.). Gastritis and peptic ulceration may be present.
Renal	Oliguric renal failure may complicate ESLD (hepatorenal syndrome). This may be reversible if liver failure improves. Differential Dx includes prerenal azotemia and acute tubular necrosis. ***NB:** Bilirubin metabolites interfere with creatinine measurement and may mask ↑ creatinine levels. **Tests:** BUN; Cr; electrolytes
Endocrine	Hypoglycemia may be present in cases of severe cirrhosis. ESLD patients may have ↓ response to catecholamines. **Tests:** Glucose
Hematologic	Patients may be anemic 2° GI bleeding. The majority of patients will exhibit coagulopathy 2° ↓ hepatic synthetic function (all factors except VIII and fibrinogen) and ↓ Plt. Patients may require vitamin K (if coagulopathy is present and time permits), FFP (if PT > 2 sec above baseline), or Plt transfusion (if Plt < 100 K) before procedure; these products should be readily available. **Tests:** CBC; Plt; PT; others as indicated from H&P.
Premedication	Patients with significant ascites will require full-stomach precautions (see p. B-4). ***NB:** Benzodiazepines should be used with caution in liver failure patients.

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Intraoperative

Anesthetic technique: In some patients (and at some centers), sedation with local anesthesia may be satisfactory; however, balloon dilation of the intrahepatic tract can be exceedingly painful. Remember, these patients may be very sensitive to narcotics → respiratory arrest. GETA is often necessary to provide adequate analgesia and airway protection.

General anesthesia:

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Induction	Rapid-sequence induction (see p. B-4) is necessary in patients with encephalopathy, abdominal distention and recent variceal bleeds (blood in the stomach).	
Maintenance	Standard maintenance (see p. B-2). If muscle relaxation is to be maintained, low-dose vecuronium (1–1.5 mcg/kg/min), cisatracurium (3 mcg/kg/min infusion) or rocuronium (5–15 mcg/kg/min) may be used to maintain muscle relaxation.	
Emergence	Extubate when the patient is awake and protective laryngeal reflexes are present. Patient should be transferred to PACU accompanied by anesthesiologist.	
Blood and fluid requirements	Potential for large blood loss IV: 14–16 ga × 1–2 FFP available Plt available 2–4 U PRBC available NS/LR (as appropriate)	Glucose-containing solutions may be required for patients with hepatic failure ± CHF. blood glucose levels frequently. Vasopressor response may be impaired.
Monitoring	Standard monitors (see p. B-1)	Ventricular arrhythmias can be provoked by hepatic vein catheterization.
Positioning	and pad pressure points. eyes.	Radiology tables usually are not well-padded → nerve damage.
Complications	Portal vein rupture Liver capsule perforation	Intraabdominal hemorrhage may be massive and require emergency surgery.
	Complete heart block	Patients with pre-existing LBBB may require a pacemaker pre-TIPS (2° risk of RBBB during procedure).
	CHF	Shunt →↑↑ venous return → CHF

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Postoperative

Complications	Portal vein thrombus ↑ encephalopathy Sepsis Bleeding	May mimic symptoms of PE or MI. 2° ↓ hepatic portal blood flow May require hemodynamic support (e.g., dopamine)
	Fluid/electrolyte disturbance	Stent insertion →↑ venous return →↑ diuresis → electrolyte/fluid imbalance.
Pain Management	IV opiates	

Suggested Readings

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15. Semba CP, Saperstein L, Nyman U, et al: Hepatic laceration from wedged venography performed before transjugular intrahepatic portosystemic shunt placement. *J Vasc Interv Radiol* 1996;7(l):143–6.

Imaging and Image-Guided Procedures

Procedural Considerations

Description: Projectional imaging includes x-ray fluoroscopy, and cross-sectional imaging includes computed tomography (CT), ultrasound (US), and magnetic resonance imaging (MRI). These techniques have become indispensable in modern diagnosis. In addition, a growing number of invasive procedures are being performed using cross-sectional imaging for guidance, not only for diagnostic purposes but also for therapeutic purposes. Indications include Dx of primary or metastatic tumors; tumor staging; Dx of benign processes, such as *(Print pagebreak 1468)* infections; drainage of fluid collections; local regional treatment of tumors and vascular malformations, endovascular treatment of hemorrhage, aneurysms, and dissections; percutaneous treatment of urinary and biliary obstructions; and placement of venous access devices. Selection of imaging modality depends on ease of identification of the target lesion and resolution of surrounding and intervening structures. Patient compliance is crucial to success, because image resolution and spatial accuracy require the patient to be immobile during image acquisition and the procedure itself. In compliant adults, most of these procedures may be done using conscious sedation. For procedures in the pediatric population, as well as for more invasive procedures in adults, GA is frequently necessary.

Diagnostic imaging: Pediatric: CT scans are performed in a large, ring-shaped gantry, through which the patient is passed on an automated table. US is performed with a hand-held transducer attached to a console. Diagnostic MRI scans are performed primarily in a large, circumferential magnet with a cylindrical center bore, also incorporating an automated table. In general, conscious sedation is sufficient to ensure pediatric patient compliance for diagnostic CT, US, or MRI, but occasionally GA is necessary. **Adults:** Almost all CT, US, and MRI studies are performed without anesthesia. Approximately 5% of adult patients are too

claustrophobic to complete an MRI study. Some of these may benefit from sedation, but use of GA is rare.

Image-guided procedures: Pediatric: Procedures performed on the pediatric patient routinely require GA. X-ray fluoroscopy-guided procedures—including angiography, angioplasty, stent placement, arterial embolization, vascular malformation sclerosis, thrombolysis, venography, renal and adrenal vein sampling, transvenous biopsy, gastrostomy and gastrojejunal tube placement, renal drainage, ureteral stent placement, biliary drainage, bronchial dilation, and placement of venous access devices (Broviacs, ports, and PICCs)—are performed in a cath-angio lab, which frequently is OR-certified. Procedures usually entail real-time x-ray imaging, requiring all personnel in the room to wear protective lead garments. For CT- and US-guided biopsies and fluid drainage, initial lesion localization images are obtained after initiation of anesthesia and immobilization of the patient. A skin entry site is then selected and marked, based on coordinates determined from the initial images. Biopsies may require multiple needle passes, either coaxially through a large-bore guiding needle, or separately without such a guide. With CT, confirmation of needle position requires interruption of the procedure to acquire images, while with US, real-time images are obtained. Ideally, adequacy of biopsy sample is determined by an on-site cytopathologist. Manipulation of a hormonally-active tumor can cause acute release of hormones. Fluid drainage may be simple aspiration or, more frequently, will result in placement of an indwelling drainage catheter. Instrumentation of infected beds (abscess, obstructed urinary or biliary system) can cause acute bacteremia and sepsis. **Adults:** X-ray fluoroscopy, CT- and US-guided procedures, such as biopsies, fluid drainage, and tissue ablation, are routinely performed under conscious sedation. More invasive and painful procedures, such as stent-graft repair of aneurysms and dissections and radiofrequency (RF) ablation of unresectable tumors (see p. 1477), frequently require GA, spinal, or epidural anesthesia. The required site of access and the positioning of the operators should be considered before the procedure. Position of the ETT and central lines can be immediately confirmed using fluoroscopy. Occasionally, iv injection of iodinated contrast medium is necessary, and adverse reactions—such as urticaria, airway edema, hormone release (e.g., from pheochromocytoma, etc.), or anaphylaxis—may occur.

The developing field of MRI-guided procedures—sometimes referred to as interventional MRI (iMRI) or magnetic resonance-guided therapy (MRT)—reflects the emergence of new magnet geometries, allowing physician access to the patient during imaging. These geometries may be C-arm configurations, parallel discs above and below the patient, or dual rings where the patient is placed either through the apertures of the rings or perpendicularly between the rings. Faster image-acquisition pulse sequences are allowing near-real-time feedback. In addition to guiding biopsies and drainage, this technology enables more aggressive procedures, such as craniotomies or percutaneous tumor ablations, to be performed with immediate feedback showing the progress of excision or ablation. Clearly, many of these procedures require GA and, accordingly, require MRI-compatible monitoring and anesthetic equipment. For safety, the anesthesiologist also is subject to the same restrictions that apply to patients, so having a pacemaker, ICD, ferromagnetic aneurysm clips, or a metallic foreign body in the orbit precludes that person's suitability to perform these cases. Hybrid systems also are being marketed, combining MRI and x-ray fluoroscopy, CT and x-ray fluoroscopy, or CT and positron emission tomography (PET). These may involve overlapping precautions and risks.

Usual preop diagnosis: Tumor, primary or metastatic; lymphadenopathy; abscess, effusion, empyema, pseudocyst, or other fluid collection; arterial occlusive disease; aneurysm or pseudoaneurysm; trauma; DVT; cirrhosis

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Summary of Procedures

	CT/X-ray Fluoroscopy	US	MRI/MRT
Position	Supine, prone or lateral decubitus		+ sitting
Unique considerations	Metallic objects should be kept out of the CT imaging field. Exit the procedure room during scanning to avoid radiation exposure, or use protective lead garment. Contrast reaction possible.	No ionizing radiation. Room lights are frequently dimmed for better viewing of the screen.	All equipment, including monitors, valves, anesthesia machine, O_2 tanks, laryngoscopes, etc., must be nonferromagnetic. Other metals should be removed from the imaging field to avoid artifact.
Antibiotics	Indicated for open procedures or when draining infected fluid collections, including abscesses, empyemas, and obstructed biliary or urinary systems.		

Procedure time	≥ 1 h		
EBL	Procedure-dependent; may be internal hemorrhage, may be preexisting hemorrhage		
Postop care	PACU → room		
Mortality	Rare		
Morbidity	Hemorrhage Infection/sepsis Organ injury/perforation Pneumothorax Pulmonary embolus Arrhythmia Hemodynamic Collapse		
Pain score	1	1	Procedure-dependent

Patient Population Characteristics

Age range	All
Male:Female	1:1
Incidence	Common
Associated conditions	**Fluid collections:** Patients may present with fever, sepsis, pain, or ileus. Mass effect, such as with empyema or pericardial effusion, may also affect respiratory or cardiovascular function. Instrumentation or relief of mass effect may induce a vasovagal response or acute bacteremia and sepsis. Some infections (echinococcus, entamoeba, methicillin-resistant staphylococcus aureus [MRSA], vancomycin-resistant enterococci [VRE]) may require special precautions, such as respiratory isolation, gown/glove standards, and pre- and post-procedure equipment sterilization. **Solid tumors:** Mass effect may result in obstruction of airways, blood vessels, GI/biliary tract, or urinary tract, or neural impingement. HTN may be seen with significant renal compression and, occasionally, with neuroendocrine tumors. Hematopoietic, hepatic, or renal compromise may result in coagulopathy or Plt dysfunction. **Vascular pathologies:** Aggressive anticoagulation and/or antiplatelet therapy may be used intraop. Restoration of arterial flow to kidneys may → rapid ↓ of renin production and BP. Thrombolysis of venous occlusions can → PE. Placement of central vascular access catheters can cause air embolism or cardiac arrhythmias from right atrial irritation. Sclerosis of vascular malformations may result in chemical pulmonary embolism, acute pulmonary vasospasm and hypertension.

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Anesthetic Considerations

Preoperative

The adult patient population requiring anesthesia services for cross-sectioned imaging is medically quite diverse; however, many have in common the inability or unwillingness to lie still during the scanning procedure. Some of these patients are very ill,

requiring the services of an anesthesiologist to maintain cardiorespiratory stability. Adult patients should be npo for 6 h preprocedure (elective). In general, US and CT scans present fewer problems for the anesthesiologist than MRI. Regardless of the method of anesthesia chosen, these patients must lie perfectly still, the airway must be protected, and IPPV may be required. Thus, children, the mentally retarded, and claustrophobic, uncooperative, or critically ill patients may all require GA.

Respiratory	As a result of limited access to the patient's airway, the preop examination should focus on the need for elective ET intubation to protect the airway. ET intubation and mechanical ventilation also may be required in trauma patients, the critically ill, or patients with GERD or sleep apnea. An LMA may be suitable for patients not at risk of aspiration.
Cardiovascular	Presence of a cardiac pacemaker or ICD is a contraindication to MRI, as are PA catheter thermistors or pacing wires.
Neurological	Patients with ↑ ICP or cranial trauma usually need GA with mechanical ventilation and intubation. The presence of aneurysm clips and/or coils may be a contraindication to MRI (with surgeon or radiologist). Some of the newer aneurysm clips are nonferromagnetic and are, therefore, MRI-compatible.
Musculoskeletal	The presence of spinal instrumentation, metal plates, pins, screws, joint replacements, or other prostheses is usually not a contraindication to MRI.
Premedication	Midazolam 1–5 mg iv (titrated to effect) may be appropriate in the very anxious adult patient; alternatively, lorazepam 1–2 mg po/sl 1 h before procedure.

Considerations for MRI/MRT

The MRI/MRT suite poses many challenges to the anesthesiologist. Because of the high magnetic fields involved in MRI, any equipment containing ferromagnetic components—such as ECG monitors, anesthesia machines, etc.—cannot go near the magnet. Thus, MRI-compatible equipment is mandatory in the area of the MRI scanner. The magnetic field will destroy information on credit card/access card magnetic strips, and may damage pagers as well as mechanical devices, including wrist watches and infusion pump motors. (A microdrip infusion set is a suitable replacement for an infusion pump.)

Noise	May be very distressing for some patients and may average 95 dB in a 1.5–T scanner. Exposure to noise levels of this magnitude should not exceed 2 h/d. Ear plugs or earphones with music can be helpful.
Thermal injury	Thermal injury is caused by induced currents in metal implants or in looped conductors in contact with the skin.
Projectile effect	The magnet has a strong attraction for ferromagnetic objects that can become lethal missiles; therefore, all objects, such as pens, scissors, iv poles, O_2cylinders, keys, stethoscopes, etc., must be removed prior to entering the scanning room.
Implanted/foreign material	There are several reports describing problems that may occur with cardiac pacemakers (failure to pace), aneurysm clips (hemorrhage) and intravascular wires (induced currents). Metal workers may be at special risk for ocular damage 2° imbedded particles.
Contrast agent	Currently, gadolinum chelates are the only agents in use and have a higher safety margin than iodinated contrast agents. Adverse reactions, however, occur in 2% of patients, and include HA, nausea, dizziness, hemodynamic instability, and dysrhythmias.

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Intraoperative

Anesthetic technique: Typically, iv/po sedation, often without the services of an anesthesiologist. Patients unwilling or unable to cooperate will require GA.

IV sedation	In patients with a normal airway and no Hx of GERD, sedation can be carried out most easily using a propofol infusion (25–100 mcg/kg/min), ± midazolam (0.025–0.10 mg/kg) titrated to effect. ***NB:** Infusion pumps may be damaged by the magnet. (A microdrip infusion is a useful alternative.)

General anesthesia:

Induction	Standard induction (see p. B-2) on an MRI gantry (typically in the magnet anteroom). The anesthetized patient is then transported into the magnet.
Maintenance	Standard maintenance (see p. B-2). Most commonly, a propofol infusion provides satisfactory sedation for the procedure (see pump considerations, above). Since continuous muscle relaxation is usually not required, spontaneous ventilation may be safest.
Emergence	Emergence and extubation are often accomplished after the patient has been moved to the adjacent anteroom, where additional airway and other support equipment are readily available. The patient should be recovered in the PACU, which may be some distance from the MRI suite. Appropriate monitoring and personnel should accompany the patient.
Blood and fluid requirements	No blood loss IV: 20 ga × 1 NS/LR @ TKO

Monitoring	Standard monitors (see p. B-1)	Monitoring in the MRI/MRT suite presents special problems, discussed below.
Monitoring, MRI	ECG	ECG may be distorted by magnetic fields. Use MRI-compatible electrodes. Twist leads together to avoid creating loops (↓ artifacts, ↓ burns). V5 and V6 are least likely to develop artifacts.
	Pulse oximetry	MRI-compatible oximeters are available. Locate probe outside bore of the magnet (e.g., toe). Avoid burn injury 2° induced current in looped leads.
	BP (NIBP)	Replace all ferrous connections on cuff and tubing with nylon connectors. Use tubing extensions to keep apparatus away from the field.
	± Arterial Line	If an arterial line is medically indicated, keep the transducer close to the patient to avoid recording artifacts. Use MRI-compatible transducers and connectors. Recording equipment should have radiofrequency filters.
	Precordial/esophageal stethoscope	Often unsatisfactory because of magnet noise. An MRI-compatible, infrared, wireless stethoscope is available.
	Temperature	MRI-compatible T monitors are available, although usually not necessary for adults (short procedure).
	Capnography	MRI-compatible capnographs are available. Long sample lines will distort waveforms, and $ETCO_2$ concentration may not be accurate; however, this is still useful for measuring RR and relative changes in $ETCO_2$

	PA catheter	PA catheters with thermistors or pacing wires are an absolute contraindication to MRI.
	Urinary catheter	Catheters with T probes must be removed to avoid electrical or burn hazards.
	Verbal/visual	The patient and the monitors may be viewed directly (in procedure room) or through a screened window. Contact should be maintained throughout the procedure.
Positioning	and pad pressure points. eyes.	CT and MRI gantries may be poorly padded → potential nerve injury.
	Contrast-related	Gadolinium → local and systemic reactions (see Contrast-related complications, p. 1453).
	Loss of airway	Patient must be promptly extracted from the magnet bore and moved beyond the range of the magnet to permit use of emergency intubation and resuscitation equipment.
Complications	Psychological	Panic attacks and claustrophobia occur in 5–10% of patients. Use of a blindfold may be helpful in selected patients. Heavy sedation or even GA may be necessary.
	Hearing loss	Temporary hearing loss and tinnitus may be expected in 43% of patients. Prevent by using ear plugs. GA ↑ risk of hearing damage 2° stapedius muscle relaxation.
	Thermal injury	Results from induced current, heating of oximeter probe, and looping cables.

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Postoperative

Complications	Hearing loss	See discussion above.
	Thermal injury	See discussion above.

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Tracheobronchial Stenting

Surgical Considerations

Description: Tracheobronchial stenting may be performed for benign or malignant strictures of upper and lower airways that are either unsuitable for surgical reconstruction or as a temporizing measure. Patients may not be considered surgical candidates due to poor medical condition (e.g., comorbidity, recent thoracic surgery, or limited life span) or certain characteristics of the stricture (e.g., active disease, airway inflammation, extensive length, or multifocality). The most common cause of tracheobronchial obstruction is

bronchogenic carcinoma, with the leading benign cause being stricture secondary to prolonged intubation. Less common causes include radiation stenosis, polychondritis, tracheomalacia, and, in children, extrinsic strictures 2° vascular malformations.

Since the first lung transplant in 1963, postsurgical bronchial stenosis has joined the list of indications for tracheobronchial stenting. Bronchial stenosis is a relatively common complication of lung transplantation, occurring in single-lung, double-lung, and heart/lung transplant recipients. It is believed that this complication is 2° the lack of bronchial arterial supply, with resulting airway ischemia. These ischemic stenoses occur at the bronchial suture line and in the more distal airway, and have been reported to occur in 10% of patients undergoing transplantation.

Stent types: There are two primary types of airway stents: silicone-based and metallic, with both bare and covered metallic prostheses available.

Silicone stents: Silicone-based stents (Silastic) are available both as straight, short tubes and as bifurcated Y-shaped devices. Straight stents are flanged on both ends to prevent dislodgement, and can remain in place in patients for extended periods. The selection of the correct size and length is critical. The stent must be long enough to enable its flanges to anchor the stent within the stricture; short enough to avoid compromise of a lobar bronchus distally or the trachea proximally; and of satisfactory diameter to maintain the caliber of the airway. The main advantage of silicone stents is that they are easily removed, either when the patient's ventilatory status has recovered sufficiently, or when reconstructive surgery is possible. In addition, the stent can be easily repositioned to obtain optimal placement. Bifurcated silicone stents are also available to accommodate the Y-shaped configuration of the carina with extension into the distal trachea and both mainstream bronchi.

Silicone-based stents do have disadvantages. Stenotic airways need to be predilated before stent insertion, whereas metallic stents can be placed within a narrow airway lumen and subsequently dilated. Silicone stents frequently become occluded with mucus plugs and granulation tissue or tumor overgrowth; therefore, regular bronchoscopic examination and treatment are necessary to keep the airway clear. Silicone stents and covered metallic stents are more likely to migrate than bare stents due to lack of incorporation into the bronchial wall. In general, silicone stents must be placed under GA because of the need for rigid bronchoscopy.

Metallic stents: The main advantages of metallic stents (e.g., Gianturco Z, Wallstent, Palmaz) are the ease of insertion, an extremely thin wall that rapidly becomes embedded in the airway, and the large gaps in the wall that allow normal ciliary function and reduced mucus impaction. The procedure can be performed using flexible bronchoscopy in the interventional room, under deep sedation. The main disadvantage of metallic stents is the inability to remove or reposition these devices once deployed. Stents become firmly embedded in the wall of the airway and incorporated into the epithelium in < 6 weeks. Removal can be accomplished by using pincers to grip the wall of the stent and applying a twisting motion to pull the stent away from the wall. Potential complications from this maneuver are catastrophic and, in our experience, once these devices are placed, they should be considered permanent. Another problem associated with metallic stents is the development of granulation tissue either at the ends of the stents or *(Print pagebreak 1474)* through the interstices. This requires careful follow-up by repeat bronchoscopy and may require subsequent procedures, such as bronchoplasty, restenting, and laser tissue ablation.

Because of the flexibility and low profile of the deployment systems used for metal stents, it is feasible to place them under conscious sedation; however, our practice is to utilize GA for tracheal stent placement to reduce patient movement due to the coughing that occurs with tracheal irritation. Most bronchial interventions can be performed without full GA.

Insertion Techniques: Silicone stents have low inherent radial force, and strictures need to be dilated before stenting. Rigid bronchoscopy is necessary to allow dilation and subsequent stent placement. Dilation can be performed with the Holinger bronchoscope, which is abutted to the stricture and advanced with a corkscrew motion. Gum-tipped Jackson dilators and various angioplasty balloons also can be used. In patients with tracheal stomas, a T-tube stent can be inserted either via the stoma or the mouth. This extends up to the vocal cords and down as far as the carina. In patients without tracheal stomas, either Y-tubes or straight stents are inserted in a similar fashion. The stent is mounted on the rigid scope, which is advanced across the stricture and then withdrawn, leaving the stent in place. A biopsy forcep is used to advance a limb of the Y-tube into the other bronchus. Placement of stents above the carina in this fashion is relatively straightforward, and the stents can be removed and repositioned until a satisfactory result is achieved. With more distal bronchial stents, the operator's vision is somewhat obscured and deployment is more difficult.

For insertion of **metallic stents,** cross-sectional and fluoroscopic imaging is used to determine the optimal length and diameter of the stent. During the procedure, selective tracheobronchography may be performed by injecting water-soluble nonionic contrast through a catheter at the level of stricture. Flexible bronchoscopy helps guide the stent placement with a soft-tipped guidewire being advanced through either the scope or the ETT into the distal airway. In the rare case where the stricture is too narrow and tight to allow passage of a small, flexible bronchoscope, the guidewire is passed, and the lesion is stented based on fluoroscopy, reconstructed CT images or bronchography. Using fluoroscopy, the stent is positioned across the stricture and visually confirmed with bronchoscopy after deployment. For tracheal stenosis, care must be taken during intubation, as the stricture often is close to the vocal cord.

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Usual preop diagnosis: Bronchial compression 2° carcinoma; post-transplantation; relapsing polychondritis; sarcoidosis

Summary of Procedures

Position	Supine
Incision	None
Special instrumentation	Bronchoscope (flexible or rigid); self-expanding metallic stent (covered and uncovered); balloon-expandable, short metallic stent
Unique considerations	May have to pull the end of the tracheal tube back to the level of the vocal cords to adequately treat the entire trachea. Alternatively can stent through LMA.
Antibiotics	Not usually administered.
Procedure time	1–2 h
EBL	0
Postop care	ICU or step-down unit
Mortality	1–5%
Morbidity	Tracheobronchial irritation (usually temporary) Stent malposition → bronchial occlusion or vocal-cord paralysis
Pain score	2–4 (first few h only)

Anesthetic Considerations

Preoperative

Respiratory compromise due to airway obstruction may pose a significant management challenge. It is therefore somewhat controversial, and highly institution-dependent, whether these procedures should be performed outside of the OR. A thorough preoperative workup is necessary before anesthesia. The majority of patients present for *(Print pagebreak 1475)* palliation of an obstructing pulmonary malignancy or treatment of granulation tissue obstruction of lung transplant anastomosis. Some may present emergently with impending airway obstruction that precludes a complete preoperative workup. The choice of anesthesia is primarily a function of the type of stent, surgeon preference, and the comorbid conditions of the patient. In general, silicone stent placement, which requires airway dilation with rigid bronchoscopy, will necessitate GA. Metallic stents can be placed without the need for preceding airway dilatation; therefore, either topical anesthesia, with or without conscious sedation, or GA can be used. Immediate improvements in FEV_1, FVC, and PEF can be expected after stenting of an obstructed tracheobronchial segment.

Respiratory	Patients with upper or lower airway stricture may present with cough, stridor, dyspnea, and fatigue. Airway obstruction can be classified as dynamic or fixed, depending on whether the obstruction varies with the respiratory cycle. Stridor that worsens during inspiration suggests an extrathoracic dynamic obstruction, while expiratory stridor is associated with intrathoracic dynamic obstruction. Other physical findings may include bronchospasm (in COPD patients), clubbing, or cyanosis. Preop fiber optic bronchoscopic examination and/or high-resolution, thin-section CT scans will help to define the location, size, and extent of the obstruction. In patients suspected of having tracheomalacia, scans are performed at maximal inspiration and maximal expiration to unmask subtle areas of narrowing exacerbated by ↑ intrathoracic pressure on inspiration. Using this information, the appropriate size for an ETT can be estimated and potential problems with tracheal intubation can be anticipated. **Tests:** CXR; PFTs with flow/volume loops (see Fig. 5-14,

	Anesthetic Considerations for Mediastinoscopy, p. 322); CT scans preferably with three-dimensional reconstructions.
Cardiovascular	Directed at any underlying disease process. Restoration of intravascular volume before induction of GA is important in patients with hypovolemia 2° chronic malnutrition from malignancy. **Tests:** As indicated from H&P.
Musculoskeletal	Patients with lung cancer may have myasthenic syndrome (Eaton-Lambert) with ↑ resistance to depolarizing muscle relaxants and ↑ sensitivity to NDMRs. Post-lung transplant patients on certain immunosuppressive therapies (e.g., cyclosporine) may have prolonged muscle blockade from NDMRs.
Hematologic	Blood cross-match not necessary unless high risk of hemorrhage from injury (e.g., rigid bronchoscopy used in patients with friable tumors). Maintaining adequate O_2carrying capacity is important in patients with poor pulmonary reserve. **Tests:** CBC; others as indicated from H&P.
Laboratory	Other tests as indicated from H&P.
Premedication	Patients in respiratory distress are extremely anxious; however, anxiolysis has to be balanced against the risk of impending respiratory arrest in some patients. Careful titration of anxiolytic medications is necessary to avoid oversedation. An antisialagogue (e.g., glycopyrrolate 0.2 mg iv) will help minimize secretions and improve visualization through the bronchoscope. Post-lung transplant patients may be steroid-dependent and stress-dose steroid supplement may be required.

Intraoperative

Anesthetic technique: Be prepared for an airway emergency. Preparations should be made for emergency rigid bronchoscopy and/or tracheostomy below the lesion. A variety of laryngoscope blades and ETTs of all sizes, including small, uncuffed (5–6 mm) tubes, should be readily available. Endoscopic evaluation of the airway must be performed in a spontaneously breathing patient, if the airway lesion has not been defined. Muscle relaxation must be avoided until a detailed examination is completed and the operator is certain an airway can be maintained subsequently. Vocal-cord paralysis, which can mimic tracheal stenosis, can be obscured by muscle relaxation.

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Topical anesthesia	Anesthetize palate, pharynx, larynx, vocal cords, and trachea with lidocaine (2–4%), using nebulizer or having the patient gargle viscous lidocaine (4%). Avoid local anesthetic overdose.
Conscious sedation	Midazolam will increase the seizure threshold in the setting of relative local anesthetic overdose. Other options include propofol (10–100 mcg/kg/min), with or without a short acting-opioid (e.g., fentanyl 25–50 mcg; remifentanil 0.05–0.1 mcg/kg/min). Caution should be exercised when mixing opioids and sedatives to avoid respiratory depression.
Induction	Patients should be well preoxygenated. Patients may be unable to lie flat 2° respiratory distress. Low-density helium-oxygen mixtures (Heliox) reduce airflow resistance past the obstruction, which may be beneficial in optimizing the patient. Ideally spontaneous ventilation should be maintained until the airway is secured. Inhaled sevoflurane, intravenous ketamine, judicious propofol (without opioid), or awake FOB with topical anesthesia is appropriate. Optimally, the ETT is positioned 1 cm above the lesion. Flexible bronchoscopy of the distal airways is then performed through the stricture, and the distal extent of the stricture relative to the carina is identified. In patients with a stricture near the vocal cords, the use of an LMA is a viable option, as it avoids passing an airway through the lesion and offers the ability to bronchoscopically examine the entire lesion. Avoid muscle relaxation if possible; if necessary, consider small dose of succinylcholine (in the future: rocuronium-sugammadex). Distal or mild airway stenoses may be appropriately managed with a RSI.

Maintenance	Inhalational anesthesia is unreliable in most cases due to the limited ventilation with a bronchoscope in situ (resistance and leak). TIVA is preferable: use propofol (50–100 mcg/kg/min) and remifentanil (0.05–0.2 mcg/kg/min) infusions. Once the airway is secured, muscle relaxation can be given to avoid movement or coughing during the procedure. Succinylcholine drip (0.25–1 g/250 mL NS, titrated to twitch suppression; avoid phase II block by keeping dose < 5–6 mg/kg), or intermediate-acting (cisatracurium 0.1 mg iv, vecuronium 0.1 mg/kg iv, Rocuronium 0.15–0.3 mg/kg IV) muscle relaxant may be used. Manual IPPV through side-arm of rigid bronchoscope or via the swivel connector if fiber optic bronchoscope is used. High-flow (up to 20 L/min) O_2or O_2flush (barotrauma risk) may be required to compensate for leak if rigid bronchoscope is used. Hyperventilate patient in preparation for periods of apnea. Low-frequency jet ventilation (50 psi at 10/min with I:E 1:2–4) via a Sander's injector is an alternative. Barotrauma and dynamic lung hyperinflation are potential problems with this approach.
Emergence	Patient must be fully awake before extubation with no residual neuromuscular blockade. Emergence can be ‘stormy.’ Patient may cough violently to clear secretions and blood. Wake-up from remifentanil infusion tends to be smoother; consider airway suctioning and lidocaine (1 mg/kg iv) to decrease airway reactivity. Postop O_2supplementation (preferably humidified).
Blood and fluid requirements	IV: 18 ga × 1 NS/LR @ 1–2 mL/kg/h Transfusion unnecessary except to optimize O_2carrying capacity or to treat hemorrhage.
Monitoring	Standard monitors (see p. B-1) ± Arterial line $ETCO_2$not accurate during rigid bronchoscopy Depending on patient's comorbidities.
Positioning	Supine and pad pressure points. eyes.
Complications	Hypoxemia: Suction secretions/blood; airway instrumentation may have to be interrupted and bronchoscope removed to improve oxygenation and ventilation. Hypercarbia: Commonly 2° inadequate ventilation. May cause increased sympathetic drive with 2° hypertension/ tachycardia/ dysrhythmias. Simply↑ TV and RR. Hypertension: Ensure adequate ventilation and sedative/anesthesia. Bronchospasm: Rx: bronchodilator (e.g., albuterol puff) Stent dislodgement: From coughing or movement. Ensure adequate anesthesia and muscle relaxation. Bleeding: More likely with rigid bronchoscope. Tracheobronchial injury: Requires frequent suctioning. Major hemorrhage may require thoracotomy using DLT or BB to isolate and/or tamponade bleeding site. Transfusion. Aspiration of debris: Patient may need to be kept intubated after the procedure.

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Postoperative

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Complications	Airway edema	Rx with corticosteroids (dexamethasone 10 mg IV) and/or racemic epinephrine nebulizer. Impending airway obstruction will require reintubation.
	Airway obstruction	May be catastrophic. Secretion retention or stent dislodgement. Rigorous suction. Reintubation or restenting.
	Stent fracture/migration	May be catastrophic. May require emergent reintubation or restenting.
	Pneumothorax	Obtain CXR. May require chest tube placement if > 20%.
	Secretion retention	humidified O_2
Pain management	None	

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Radiofrequency Ablation

Surgical Considerations

Description: Radiofrequency ablation (RFA) was pioneered in 1920 by Harvey Cushing for the creation of small lesions within the CNS. Since then, the technique has been refined so that precise control of lesion size can be achieved by measuring the temperature and electrical resistance within the tissues being treated. Ablating neural tissue with RF is successful in treating pain from trigeminal neuralgia, facet osteoarthritis, and failed-back syndrome. RFA has expanded treatment options for certain solid organ tumors such as hepatocellular carcinomas, colorectal metastasis to the liver, primary and secondary lung cancers, renal cell carcinoma, and painful bone lesions. Since RFA is most often done percutaneously, it is well suited for the treatment of primary and secondary malignancies in the liver, as well as other sites in patients who are not suitable for open surgery.

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Mechanism of tissue destruction: In RFA, an alternating current operating in the frequency of radio waves (460–480 kHz) is emitted from the tip of an electrode or needle placed directly into tissues. This alternating current causes the local ions to vibrate, producing heat and inducing cell death by coagulative necrosis. The cytotoxic T threshold is 50°C; however, with RFA, temperatures can exceed this, and actually reach the boiling point of water (100°C). A limitation of RFA is the small lesion size it creates. Recent technical advances in RF systems have improved such that lesions > 5 cm in diameter can be created.

Techniques of radiofrequency ablation: Grounding pads are placed on the patient's thighs; if a single RF treatment probe is used, at least two and, preferably, four pads (96-cm^2 surface area each) or the equivalent (minimum total surface area = 200 cm^2) must be used. If a three-probe cluster is used, at least four RF grounding pads or their equivalent (400 cm^2 surface area) must be used. Presently available commercial generators usually require four grounding pads. The grounding pads and the treatment probes are connected to the RF generator. When the generator is activated, current flows between the conductive electrode tip and the grounding pads (or 'dispersive electrode'). The increase in the tissue T is proportional to the current density. Since the density is highest near the conductive electrode tip, coagulation is induced in the tissue surrounding the treatment probe. The linear extent (depth) of the resulting coagulation is determined by the length of the uninsulated probe tip, while the diameter of coagulation necrosis produced around the probe tip depends on the duration of treatment. Based on our experience using perfusion probes and pulsed current technique, areas of the tissue up to 4.5 cm diameter may be induced with a single probe and up to 7.3 cm diameter with clustered probes.

The lesion to be treated is identified and characterized by ultrasound or CT, which is used to guide the RF probe to the distal margin of the lesion. The generator is activated and output is gradually increased to a predetermined maximum, based on tip exposure and probe configuration (single vs clustered probes). Maximum power (90–120 Watts) is applied to the treatment probe cluster until tissue impedance rises. At this point, the power is turned off for 60 sec, then increased to maximum until once again impedance is seen to rise. Ultrasound monitoring of the RF site may be carried out throughout the ablation; however, it usually is limited due to the production of tissue water vapor that interferes with the transmission of the sound waves. CT can be used occasionally to check the stable position of the needle. Final tissue temperatures usually range from 60°–90°C.

Lesion size varies according to the size of the electrode, the current, duration of the treatment, and local blood flow. Tumor cells adjacent to large blood vessels may not be treated thoroughly due to the heat-sink effect of flowing blood, which carries away the RF energy as fast as it is deposited. Alternatively, cirrhotic livers with extensive fibrosis and ↓ blood flow may need fewer treatments because of increased conduction through the tumor compared to surrounding tissue, a phenomenon termed as the "oven effect" that helps achieve larger coagulation diameters.

Liver RF: The most well-known and best-studied application of RF is in the treatment of primary and metastatic liver tumors. RF has been used widely to treat HCC as well as metastases. Prospective and retrospective studies have demonstrated that complete necrosis can be achieved in 90% of tumors measuring < 3 cm in fewer than two sessions. However, the success rate drops markedly in tumors measuring > 3.5cm with complete necrosis achieved in < 50% at two sessions.

Lung RF: Recently, RF energy has been used to attempt ablation of certain primary and secondary lung tumors. The work that has been done to date has been performed in patients whose disease extent offers few therapeutic options. The results, therefore, have been understandably mixed; however, there has been a satisfying lack of major complications reported. Pneumothorax is seen in 30% of cases (similar to rates reported during lung biopsy); and, while transcranial Doppler has demonstrated microbubbles in the brain during ablation, there have been no reported sequelae. The same basic technique is used, although lower energies are applied, since there is less solid tissue in the lung, and high levels of impedance are reached sooner.

Bone RF: RF has been applied to both benign and malignant bone tumors. The first use was for the thermocoagulation of small, painful, osteoid osteomas. The pain in an osteoid osteoma is related to prostaglandin production within the cells of the small, central, vascularized tumor nidus. Pain relief is obtained only after complete removal of the nidus, surgically or percutaneously. Surgical removal requires cortical osteotomy and a hospital stay. Recently, RF has emerged as the method of choice for treating osteoid osteoma. The ablation is done percutaneously, usually under CT guidance as an outpatient procedure. The nidus is located and a single tip RF electrode is placed in the nidus. Because the area of treatment is almost always < 1 cm, larger, multi-tined electrodes are not required. Energy required to destroy the nidus is minimal. Patients typically have 1–2 days of postprocedure pain that differs from the pain of osteoid osteoma. Relief of the osteoid osteoma pain almost always occurs within the first 24–48 hours. Cure with one session can be as high as 90% and re-treatment can be performed if the first treatment is not immediately successful or if the patient's pain returns in the future.

Preliminary studies in **malignant bone tumor treatment** with RF show promise. Previously irradiated foci of tumor, whether primary or metastatic, that are still biologically active can be treated locally with internally cooled RF *(Print pagebreak 1479)* electrodes. Local pain control in painful bone metastases and control of hemorrhage in both the axial and appendicular skeletons have responded well to RF ablation. In areas where tumor abuts vital structures, such as the spinal cord, RF may not be effective, since local thermal injury may not be desirable. However, spinal RF can be performed in the vertebral body when the cortex

between the electrode and the spinal canal is intact.

Usual preop diagnosis: Primary or metastatic hepatic malignancy; primary or metastatic pulmonary malignancy; osteoid osteoma.

Summary of Procedures

Position	Supine or prone
Incision	Over the site to be accessed
Special instrumentation	RFA probes and generator
Unique considerations	Mild ↑ T during procedure; ↑ pain as ablation continues.
Antibiotics	None usually; occasionally, ciprofloxacin 500 mg iv
Procedure time	2–4 h
EBL	None
Postop care	Step-down unit
Mortality	< 5%
Morbidity	Postprocedure pain at site Hepatic hemorrhage: Rare, due to cauterizing nature of procedure Pneumothorax (during hepatic dome lesion ablation, pulmonary ablation) Hepatic abscess (↑ incidence in patients with previous biliary manipulation)
Pain Score	5–8 (first few h only)

Patient Population Characteristics

Age range	Adults
Male:Female	M > F
Incidence	Uncommon
Etiology	Pain (trigeminal neuralgia; facet osteoarthritis; metastatic cancer); primary malignancies
Associated conditions	Lung cancer; cancers of the neck; polychondritis; prolonged ICU stay; lung transplantation

Anesthetic Considerations

Patients presenting for RF ablation range from those with end-stage lung cancer to otherwise healthy chronic-pain patients. In addition, analgesic/anesthetic requirements are highly variable, depending on the size and location of the target lesions. Close communication between the various care providers is essential to achieving a positive outcome.

Respiratory	Access to the airway may be limited in the typical interventional radiology suite; thus, a patient with a potentially difficult airway may require elective intubation. Appropriate airway adjuncts (LMAs, light wand, fiber optic cart, etc.) should be readily available. Intraop risks include the possibility of pneumothorax, so needle decompression supplies also should be available. Lung cancer patients presenting for tumor ablation may have compromised pulmonary function and require objective assessment of pathophysiology with PFTs and/or ABG analysis. **Tests:** PFTs, ABG, as indicated from H&P. HTN and CHF are seen frequently in elderly patients presenting

Cardiovascular	for RF procedures. These patients often have a severe disease process, which may be complicated by other significant comorbidities. The potential for cardiac ischemia should be evaluated carefully. Preop beta blockade and antihypertensive therapy may be required. **Tests:** ECG, ECHO, noninvasive stress testing as indicated from H&P.
Neurological	A thorough neurological exam is important to document neurological deficits that are present before the procedure.
Hepatic	Patients may have coagulation defects and mental status changes 2° systemic liver disease. The potential for severe hemorrhage from vascular injury, the risk of aspiration, and the lack of cooperation (encephalopathy) should all be taken into account when planning the anesthesia. Patients with severe liver disease also may exhibit hepatopulmonary or hepatorenal syndrome manifested as hypoxemia or renal failure. Consider the need for preop correction of coagulation and fluid status. **Tests:** LFTs; ammonia; INR
Endocrine	The possibility of endocrine and metabolic derangements should be assessed. Lung cancer patients may have electrolyte problems 2° SIADH, while patients with liver disease are prone to developing hypoglycemia. **Tests:** As indicated from H&P.
Hematologic	Consider the possibility of chronic anemia or hypercoagulability 2° neoplastic disease. Chemotherapy or systemic disease may have depressed bone marrow function and altered the activity of WBCs and Plts. **Tests:** Hct, Plt count, or CBC, as indicated by H&P.
Premedication	Sedation must be adjusted according to patient requirements. Small doses of midazolam, titrated to minimal sedation, are most reasonable (0.5–1 mg increments). Patients with end-stage disease often require very little premedication.

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Intraoperative

Anesthetic technique: Sedation or GA, depending on the size and location of lesions. Most ablations are well tolerated with MAC; however, large lesions may require GA. The out-of-OR site often involves working in cramped quarters with poor access to anesthesia equipment. Nevertheless, the ASA standards of monitoring should be followed.

MAC: MAC cases are performed with fentanyl (25–150 mcg) and midazolam (0.5–2 mg) boluses, combined with a propofol infusion (25–100 mcg/kg/min). The substitution of remifentanil (0.02–0.1 mcg/kg/min) for fentanyl allows rapid titration of analgesia for the brief periods of intense stimulation.

Induction	Standard induction (see p. B-2), preceding placement of an ETT or LMA.	
Maintenance	Standard maintenance (see p. B-2). Since procedures are of an unpredictable duration, short-acting muscle relaxants (e.g., mivacurium 0.2 mg/kg, rocuronium 0.6 mg/kg) are advised. Propofol (25–100 mcg/kg/min) and remifentanil (0.02–0.1 mcg/kg/min) are an appropriate combination that easily can be titrated to effect. Persistent intraop HTN may be treated with labetalol (5–25 mg) or hydralazine (5–20 mg).	
Emergence	Standard emergence (see p. B-3). Short-acting analgesics (e.g., fentanyl 25–150 mcg) should be used in outpatients. Prophylactic treatment with antiemetics (metoclopramide 10 mg and granisetron 100 mcg iv) may be beneficial, since there is a high incidence of PONV.	
Blood and fluid requirements	IV: 20–14 ga × 1–2 NS/LR: 3–5 mL/kg/h	Larger access needed for hepatic lesions.

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Monitoring	Standard monitors (see p. B-1) ± Arterial line ± Urinary catheter	Foley for longer procedures (> 2 h)
Positioning	& pad pressure points eyes.	Radiology tables often poorly padded.
	Hemorrhage	Blood or colloid should be readily available, if the need is anticipated. Large retroperitoneal hemorrhage can develop, yet not be appreciated until blood loss is extensive.
Complications	Pneumothorax Hemothorax	Needle decompression and/or thoracostomy tube placement may be necessary during thoracic or high hepatic procedures.
	Electrical shock Thermal injury Hyperthermia	Electrocautery devices can produce serious injury if not properly grounded. Patients may develop rapid T increases 2° direct heating of large lesions.

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Postoperative

Complications	PONV Hemorrhage	Common. Occult blood loss may continue for several h after the procedure is terminated.
Pain management	Standard pain management (see p. C-2)	Postprocedure pain is usually well-tolerated.
Tests	Postprocedure HCT, as indicated.	

Suggested Readings

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