Patients with Pacemaker or Implantable Cardioverter-Defibrillator

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KEYWORDS

- Pacemaker • Cardioverter-Defibrillator • Preoperative • Perioperative
- Management

KEY POINTS

- Providers charged with preoperative management frequently encounter patients with a cardiac implantable electronic device (CIED). Safe and efficient perioperative management of this complex patient population requires specific knowledge and the development of a comprehensive system-based approach to care.
- Before surgery, the CIED physician should be contacted for records and a perioperative prescription. Documentation of CIED interrogation and appropriate function (maximum 6 months [implantable cardioverter-defibrillator (ICD)], 1 year [pacemaker]) should be confirmed before induction of anesthesia.
- Electromagnetic interference (EMI) remains the principal intraoperative issue. If EMI is likely, ICD antitachycardia therapy should be disabled and external defibrillation pads applied. Reprogramming to an asynchronous pacing mode should be considered for any pacing-dependent patient.
- Magnet behavior should be confirmed if magnet use is planned. Some rate enhancements might require disabling. Optimizing oxygen delivery for major surgery might require increasing the lower rate limit. Appropriate positioning of the electrosurgery unit dispersive electrode can minimize EMI from electrosurgery.
- Postoperatively, CIEDs often require reinterrogation to confirm appropriate function, restore rate enhancements, and optimize pacing parameters. The ICD patient must have continuous cardiac monitoring until antitachycardia therapy is restored.
- Any interrogation and reprogramming must be documented in the medical record.

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INTRODUCTION

Four years after invention of the transistor in 1954, C. W. Lillehei, a cardiothoracic surgeon, and Earl Bakken, an electrical technician, developed the first battery-operated system to pace the heart. The first completely implantable, battery-powered pacemaker (PM) followed just 2 years later, and by 1985 the US Food and Drug Administration (FDA) had approved the implantable cardioverter-defibrillator (ICD) for clinical use.[1] In 1997, ICDs were approved for permanent antibradycardia pacing functions in addition to antitachycardia therapies. Further technological innovations have resulted in sophisticated 3-chamber pacing (right atrium [RA], right ventricle [RV], and left ventricle [LV]) to provide cardiac resynchronization therapy (CRT, also called biventricular [BiV] pacing) from both PMs (CRT-P) and ICDs (CRT-D); available in the United States since 2001. In 2012, a subcutaneous leadless ICD (that uses a subcutaneous electrode instead of traditional transvenous or epicardial leads) received FDA approval.

In North America, at least 3 million patients have a cardiac implantable electronic device (CIED),[2] with more than 400,000 PMs and 120,000 ICDs implanted annually in the United States.[3] An aging population, new indications for device use, and continued technological enhancements will likely increase the number of patients with a CIED. Consequently, clinicians involved in perioperative care should expect to encounter and manage such patients.

Although modern CIEDs have excellent functionality, this functionality comes at the cost of complexity. The sophistication of these devices, the multitude of complex issues surrounding effective perioperative management of the CIED patient, and changing patient conditions can increase the difficulty of providing care for these patients, especially for clinicians (including family physicians, internists, hospitalists, anesthesiologists, and surgeons) who are not CIED experts. Particular challenges for clinicians include evolving technology, specialized function of the devices, manufacturer-specific proprietary features, lack of standardization among device manufacturers, and an array of published literature that is often outdated and sometimes incorrect. In addition, electrical equipment (especially monopolar electrosurgical devices) often used when caring for these patients can interfere with CIED function, because no testing of interference with CIEDs is required before bringing a medical device to market. Perioperative planning often requires consideration of intraoperative electromagnetic interference (EMI), because it can lead to pacing inhibition (and asystole in a pacing-dependent patient), an inappropriate shock from an ICD, or induce a pacing-system driven tachycardia. Sometimes, surgical plans can be altered to substitute equipment that creates minimal or no EMI (such as bipolar electrosurgery) to mitigate these issues.

Certain procedures that are not part of the surgical event, but become required as a result of the surgery, can affect a CIED patient or interfere with CIED operation. Nerve stimulators, which introduce electricity and are used during some regional anesthetic procedures, can result in EMI and pacing inhibition[4] as well as interfere with electrocardiographic (ECG) monitoring.[5] For certain patients and operations, central venous cannulation is necessary, but placement of a thoracic central venous cannula in a patient with fresh leads (less than 3 months since implant)[6] might cause lead dislodgement, and any metal guide wire inserted into the thorax of a patient with an ICD can create false ventricular signals, leading to an ICD high-voltage discharge and possible patient injury.[7]

In response to these challenges, the American Society of Anesthesiologists (ASA), the Heart Rhythm Society (HRS), the Canadian Society, and others have published

documents intended to guide clinicians in the perioperative management of CIED patients.[2,6,8]

Practitioners involved in the preparation of CIED patients for surgery or the perioperative management of these patients should be familiar with the recommendations put forth by these organizations. They should also understand the indications for implantation, as well as the basic functions, operations, and limitations of these devices. Furthermore, to maximize CIED patient safety, practitioners should be facile in understanding and detecting potential problems in order to avert iatrogenic complications at a stage before the surgical procedure, including the need to triage to an expert in perioperative management of CIEDs.

This review begins by addressing the basic function of CIEDs, indications for implantation, and modes of operation. It then outlines the main considerations and controversies involved in the preoperative preparation and perioperative management of these patients. At the conclusion of this review, the reader will understand the considerations involved in the safe and effective perioperative management of the patient with a CIED.

DEVICE FUNCTION

Traditional CIED systems consist of a pulse generator and 1 to 3 leads. The earliest systems contained a large pulse generator that required abdominal implantation. Over time, technology has allowed for miniaturization of the pulse generator, which is now almost always implanted underneath the clavicle in a subcutaneous pectoral pocket. Modern pulse generators contain complex circuitry capable of analyzing and responding to incoming information; memory, so that information can be stored and later analyzed; and a battery (typically the largest single element within the device).

Technological advancements in lead technology have mirrored those of pulse generators. Although the earliest leads had to be affixed to the outside of the heart (epicardial leads) via thoracotomy, modern transvenous leads are inserted directly into the cardiac chambers through the superior vena cava. Modern transvenous leads offer several advantages over epicardial leads, including less trauma, lower pacing threshold (which lengthens battery life), and lower defibrillation threshold (DFT) (which improves ICD efficacy). Because of the aforementioned advantages of transvenous leads as well as the fact that epicardial lead placement is more invasive, epicardial leads are used only when transvenous lead placement is either not possible or is contraindicated (ie, mechanical tricuspid valve or adverse venous anatomy). Transvenous leads may be inserted into the RA, RV, or coronary sinus (CS), and all leads are capable of sensing and pacing in their respective chambers. For transvenous ICDs, the RV lead includes electrodes to provide high-voltage defibrillation therapy. Therefore, in contradistinction to conventional PMs, transvenous ICDs have 1 or 2 shock coils on the RV lead, allowing these CIEDs to be easily distinguished from one another via chest radiograph (**Fig. 1**). In most CRT systems, a CS lead is used to pace the LV, and the position of the CS lead is best determined by lateral chest radiograph (**Fig. 2**). Whether the patient receives 1, 2, or all 3 of these leads depends on the indications for implantation and device type selected. Subcutaneous ICDs do not have traditional transvenous or epicardial leads (**Fig. 3**) and have more limited functionality.

Transvenous leads can be either unipolar or bipolar. With a bipolar lead, the cathode and anode are both present on the lead itself, whereas with a unipolar lead, only the cathode is present on the lead, and the pulse generator functions as the anode. Thus, the distance between the cathode and anode is smaller with a bipolar lead,
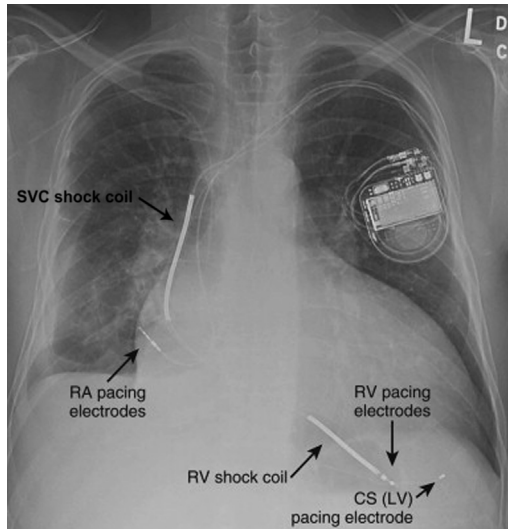
Fig. 1. A defibrillator system with biventricular antibradycardia pacemaker capability. This chest film was taken from a 50-year-old man with head and neck cancer, coronary artery disease, and ischemic cardiomyopathy with ejection fraction of 15%. The ICD generator is in the left pectoral position with 3 leads: a conventional, bipolar lead to the RA, a quadripolar lead to the RV, and a unipolar lead to the CS. (CS lead is in an unusual location: inferior and apical, close to RV lead). This system is designed to provide resynchronization (antibradycardia) therapy in the setting of a dilated cardiomyopathy with a prolonged QRS (and frequently with a prolonged P-R interval as well). The bipolar lead in the RA performs both sensing and pacing functions. The lead in this RV is a true bipolar lead with ring and tip electrodes for pacing and sensing. The presence of a shock conductor (termed a shock coil) on the RV lead in the RV distinguishes a defibrillation system from a conventional pacemaking system. The lead in the CS depolarizes the LV, and the typical current pathway includes the anode (ring electrode) in the RV. Because of the typically wide QRS complex in a left bundle branch pattern, failure to capture the LV can lead to ventricular oversensing (and inappropriate antitachycardia therapy) in an ICD system. Many defibrillation systems (including this one) also have a shock coil in the superior vena cava (*SVC*), which usually is electrically identical to the defibrillator case (called the can). When the defibrillation circuit includes the ICD case, it is called an active can configuration. (*From* Rozner MA, Schulman PM. How should we prepare the patient with a pacemaker/implantable cardioverter-defibrillator? In: Fleisher LA, ed. Evidence-based practice of anesthesiology, 3rd edition. Philadelphia: Elsevier, 2013; with permission.)

reducing susceptibility to EMI during sensing. PM systems (but not ICD systems) with bipolar leads can be programmed to the unipolar mode for pacing, sensing, or both. Sometimes, a PM automatically switches from bipolar to unipolar pacing and sensing if a lead fault is detected.

Differences between bipolar and unipolar pacing include: bipolar pacing usually produces lower amplitude spikes recorded during analogue-recorded ECG compared with unipolar pacing; digitally processed ECG systems often fail to show spikes if programmed to filter high-frequency signals (typical for any bedside ECG monitor); and unipolar spikes can be misinterpreted as QRS complexes by observers unfamiliar with pacing issues. In addition, ECG monitors can undercount or overcount the ECG pulse rate. Thus, both the ASA and HRS recommend monitoring every patient with some form of mechanical pulse display and rate counter whenever patient ECG monitoring is required, whether it is the pulse oximeter plethysmogram or an
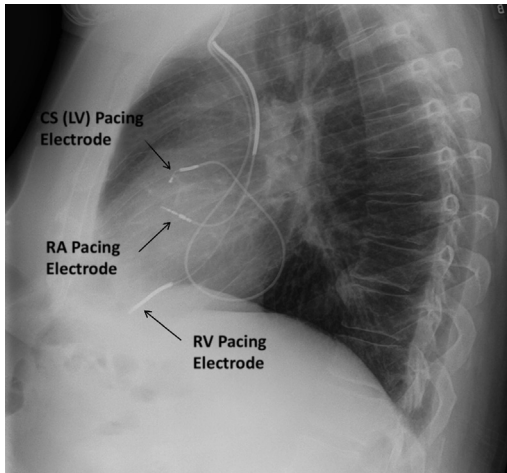
Fig. 2. Lateral chest radiograph showing position of CS lead.

invasive arterial line. An example of ECG rate overcounting is shown in **Fig. 4**, and a simulation showing rate undercounting is shown in **Fig. 5**. Many automated ECG analyzers report "pacing, no further analysis" even in the setting of clear pacing system malfunction (**Fig. 6**).

During implant (and at every follow-up visit), lead impedance values and thresholds for sensing and pacing are measured. Some CIEDs automatically perform daily threshold and impedence tests, which can be reviewed at the time of device interrogation. Values outside the acceptable range, or that wildly fluctuate, may suggest a faulty connection, dislodged lead tip, fractured coil, or insulation breach.[9] For ICDs, the DFT, which is the lowest amount of energy required to defibrillate the heart, may also be tested during the implant procedure. Some physicians use empirical energy
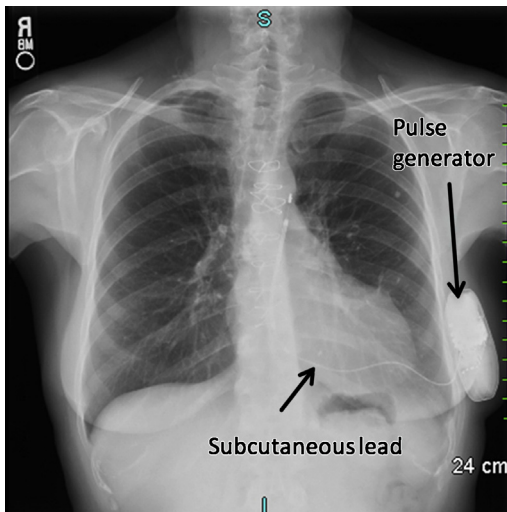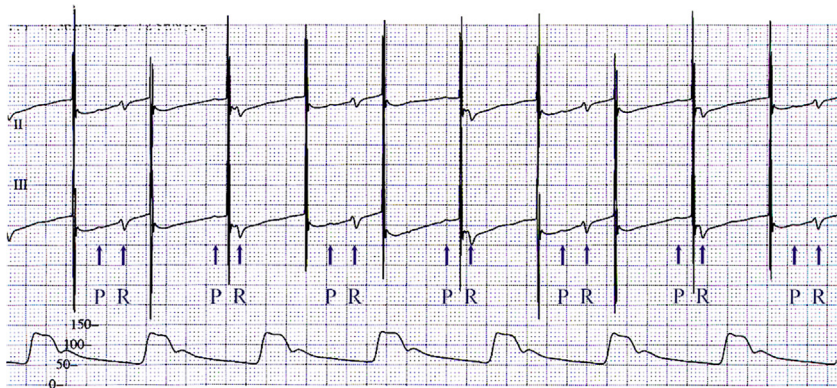

Fig. 3. Subcutaneous ICD.

Fig. 4. Improper placement of a transesophageal PM, resulting in pacing without capture. ECG lead II (*top*), the middle recording is ECG lead III (*middle*), and the bottom recording is the invasive arterial pressure waveform (*bottom*). This 72-year-old man developed sinus bradycardia with evidence of tissue underperfusion intraoperatively. A transesophageal PM was placed (fixed mode AOO), and the monitor reported an ECG heart rate of 75 bpm in the setting of noncapture and a sinus rate of 50 bpm. The patient's native atrial (*P*) and ventricular (*R*) depolarizations showing first-degree A-V block (P-R interval of 280 milliseconds) have been marked. The arterial pressure waveform confirms pacing noncapture. (*From* Rozner MA. Implantable cardiac pulse generators: pacemakers and cardioverter-defibrillators. In: Miller RD, Eriksson LI, Fleisher LA, et al, eds. Miller's Anesthesia, 7th edition. Philadelphia: Elsevier, 2009; with permission.)
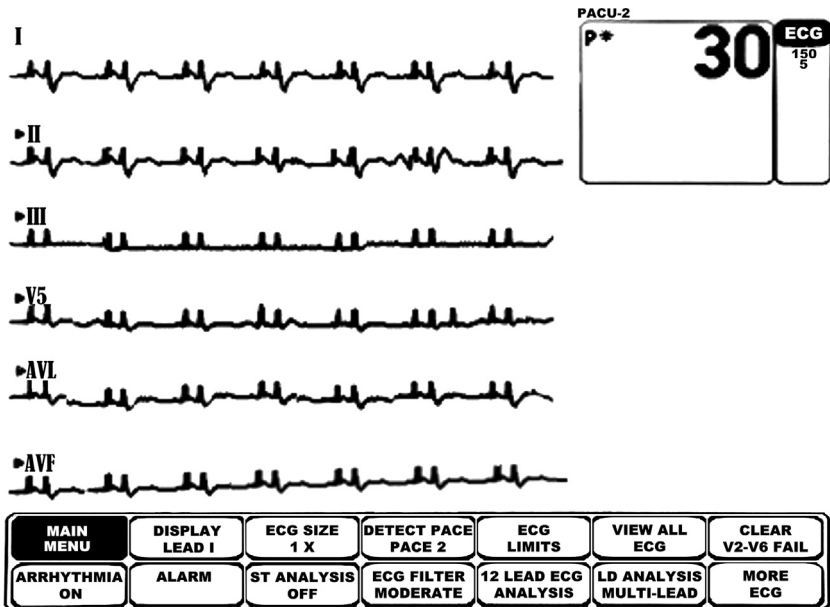

Fig. 5. A PM simulator set to AV pacing, rate 75 bpm, PR 200 milliseconds was connected to a Dash monitor (GE Healthcare, Milwaukee, WI), which had been appropriately configured to display pacing artifacts (Detect Pace = Pace 2) and lead analysis set to lead I. However, the monitor is reporting an ECG heart rate of 30 bpm, likely because of the low-voltage signals sensed on leads 3, V5, aVL, and aVF. This phenomenon can frequently be observed clinically but has not been investigated to any great extent.
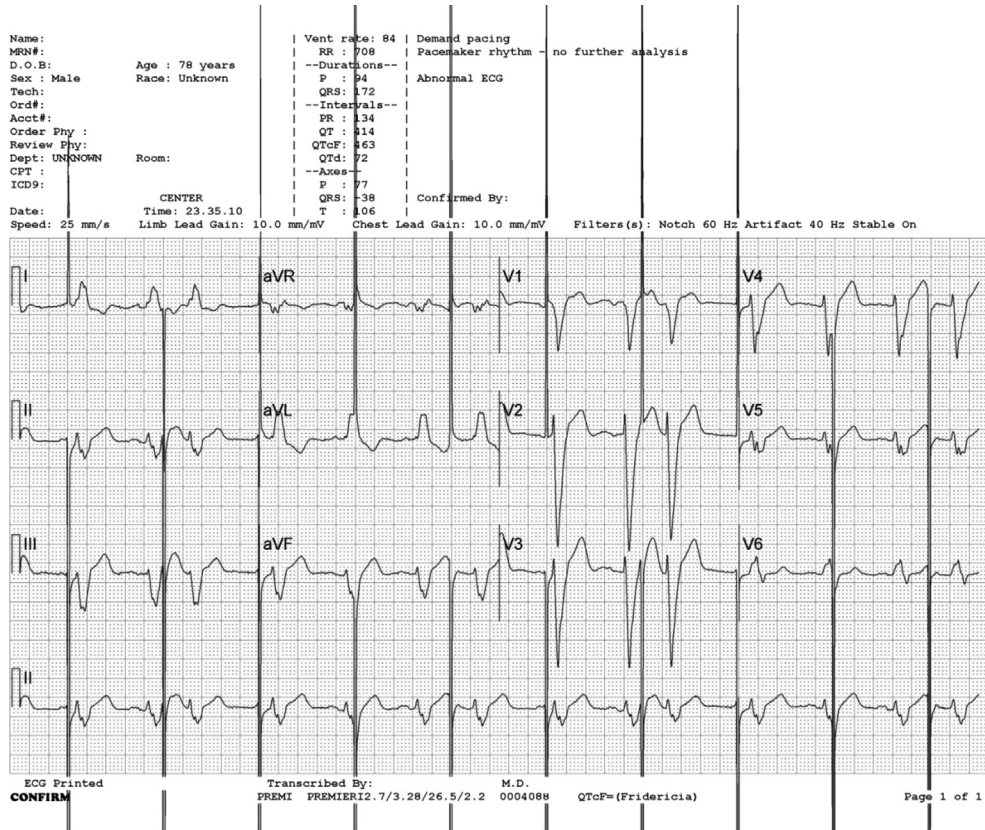
Fig. 6. A critically ill 78-year-old man (with presumed transfusion-related lung injury) with a single-chamber ICD (tachytherapy disabled, pacing VVI 50 bpm) underwent transesophageal PM placement for sinus bradycardia at 52 bpm with frequent PVCs, resulting in frequent ventricular-only pacing with the creation of retrograde P waves and poor perfusion. (The cycle length of the underlying sinus rhythm was 1154 milliseconds. With a PVC at 450 milliseconds from the QRS [see 3rd and 10th QRS above], along with the 134-millisecond PR interval, the next P wave following the compensatory pause would occur at 1724 milliseconds after the PVC. As a result, the ICD would issue a pace at 1200 milliseconds from the PVC, resulting in continued AV dyssynchrony.) The transesophageal pacing device was initially set to 80 bpm, but it was reduced to 60 bpm. This 12-lead ECG clearly shows inappropriate atrial pacing at the second, fourth, fifth, seventh, and ninth pace, but the automated interpretation (and the ECG reader) reported no analysis because of the pacing.

settings and forgo DFT testing to avoid the need for induction of ventricular fibrillation (VF), which has been associated with patient injury.

All PMs and transvenous ICDs have sophisticated pacing, sensing, and electrical storage capabilities. Subcutaneous ICDs have no permanent pacing capability. ICDs use R-R intervals (heart rate) to detect tachyarrhythmias. Each cardiac R-R interval is measured and the rate categorized as normal, too fast (short R-R interval), or too slow (long R-R interval). When enough short R-R intervals are detected, an antitachycardia event begins. ICDs then attempt to distinguish between malignant (ventricular tachycardia [VT] or VF) and nonmalignant (SVT, atrial fibrillation with rapid ventricular response) tachyarrhythmia based on programmable discriminators (such as QRS morphology, R-R interval variability, P-R relationship [when available]). When therapy becomes indicated, transvenous ICDs can deliver antitachycardia pacing (ATP) (less painful, so better tolerated; less battery consumption) or shock, depending on the presentation and device programming.[1] Most newer transvenous ICDs deliver ATP while charging the capacitor for shock if no previous ATP had been delivered. ATP has about an 85% success rate at terminating episodes of hemodynamically stable VT[10]; it is often programmed as the first therapy option for VT because it is painless and requires less energy than defibrillation.[9] However, the use of ATP can delay the time to first shock, because each ATP cycle requires 8 to 15 seconds. ATP can also accelerate stable VT into unstable VT or VF. Other reasons for prolonged time to defibrillation include low battery voltage, frequent ICD discharges, EMI (which can increase the capacitor charge time), or cold temperature.[1] ICD shocks terminate VF in more than 98% of episodes.[11] Subcutaneous ICDs cannot deliver ATP, and DFTs for subcutaneous ICDs are about twice those for transvenous ICDs.

Although ATP can be used as a first-line therapy for VT in lieu of shock, it still might be associated with myocardial injury. The recently published MADIT-RIT (Multicenter Automatic Defibrillator Implantation Trial-Reduce Inappropriate Therapy) trial reported that any inappropriate therapy (for rhythm other than VT or VF), whether ATP or shock, is associated with higher mortality.[12] Despite improvements in detection of ventricular tachyarrhythmias, on average more than 10% of shocks are inappropriate.[1]

To prevent an inappropriate shock, most ICDs are programmed to reconfirm VT or VF after charging. Once a shock has been delivered, no further ATP can take place. Like PMs, transvenous ICDs begin antibradycardia pacing when the R-R interval is too long. The extent of pacing dependency in ICD patients remains unknown.[13] Subcutaneous ICDs provide ventricular-only pacing support for a brief period after therapy.

Arguably, the most profound advances in CIED technology have been in the area of CRT. Heart failure from impaired LV systolic function accounts for roughly 1 million hospitalizations and more than 58,000 deaths annually.[14] Despite maximum medical therapy, many patients continue to be symptomatic. Advanced heart failure is well known to be accompanied by conduction defects and arrhythmias caused by sinus or atrioventricular (AV) node dysfunction and intraventricular conduction delays or bundle branch block (QRS>120 milliseconds).[11] In turn, slowed transmission of LV depolarization delays activation of the LV lateral and inferolateral walls, leading to dyssynchronous ventricular contraction and decreased stroke volume. This intraventricular and interventricular dyssynchrony has been shown to increase the risk of death in this population.

The goal of CRT is to restore synchronous LV activation by pacing both ventricles in order to approximate more normal ventricular conduction. As opposed to AV sequential dual-chamber (RA and RV only) pacing, CRT devices pace both the LV and RV to coordinate, or resynchronize LV contraction and RV/LV ejection. Atrial-synchronized

BiV pacing can improve myocardial mechanics and energy utilization, resulting in improved cardiac output, hemodynamics, heart failure symptoms, and quality of life and mortality in patients with heart failure.[15]

IMPLANT INDICATIONS

The American College of Cardiology (ACC) and the American Heart Association (AHA) in conjunction with the HRS have issued guidelines on indications for CIED placement.[16] A summary of indications for implantation is shown in **Table 1**. Most patients with a need for a PM have sinus or AV nodal disease. In addition, an increasing percentage of patients with dilated cardiomyopathy now undergo BiV pacing. BiV pacing from a conventional pacemaker (CRT-P) is discussed in more detail later.

Indications for implantation of a transvenous ICD are summarized in **Table 1**. Transvenous ICDs significantly reduce all-cause mortality and mortality caused by arrhythmias when compared with antiarrhythmic drugs alone.[17,18] Initially, transvenous ICDs were indicated only for secondary prevention of sudden cardiac death after VF arrest or sustained VT. Studies suggesting prophylactic placement in patients without history of tachyarrhythmia have significantly increased the number of patients for whom ICD therapy is indicated. MADIT, completed in 1996, proved benefit in primary prevention of sudden cardiac arrest in patients with heart failure, impaired left ventricular function (LV ejection fraction [LVEF] <35%) caused by previous myocardial infarction, clinical nonsustained VT, and VT inducible by electrophysiology study.[18]

Two additional seminal trials have confirmed the benefit of implanting ICDs for primary prevention. (1) MADIT-II (ischemic cardiomyopathy, LVEF <30%, and heart failure functional class I, II, or III),[19] and (2) SCD-HeFT (Sudden Cardiac Death–Heart Failure Trial) (LVEF <35% regardless of the cause and heart failure class II or III)[20] significantly increased the number of patients eligible for ICD implantation without showing previous ventricular tachyarrhythmia.

Table 1
Indications for PM or ICD implantation

	Left Ventricular Ejection Fraction at Time of Implant (%)[a]	QRS Duration	Heart Failure Functional Class[b]	Coronary Artery Disease	Bradycardia and Possible Pacer Dependence
Conventional PM	>35	Any	Any	+/–	+
Transvenous ICD	<35	Any	I, II, III	+/–	+/–
Subcutaneous ICD	<35	Any	I, II, III	+/–	– (no permanent pacing)
CRT-D	<35	>120 ms	III, IV (recently some I and II)	+/–	+/–
CRT-P	<35 preferring no ICD	>120 ms	III, IV (recently some I and II)	+/–	+/–

[a] Left ventricular ejection fraction (LVEF) often changes after implant, particularly in setting of CRT. Most patients requiring pacing who have LVEF <35% receive an ICD, although patient preference or other circumstances could affect this decision.
[b] Patients with class IV heart failure generally receive only ICD in the setting of CRT. CRT was initially restricted to patients with class III or IV heart failure, but recently indications have expanded to class I and II in certain clinical scenarios.

Additional ACC/AHA indications for ICD placement regardless of LVEF include previous cardiac arrest from a nonreversible cause, hypertrophic cardiomyopathy, long QT or Brugada syndrome with syncope, arrhythmogenic RV dysplasia, or infiltrative cardiomyopathy (sarcoidosis, amyloidosis).[9]

For patients with symptomatic heart failure despite optimal medical therapy, the 2008 ACC/AHA/HRS Guidelines for CRT include LVEF less than 35%, QRS duration greater than 120 milliseconds, sinus rhythm, and New York Heart Association (NYHA) class III or ambulatory class IV symptoms (**Table 1**).[16] As most CRT patients also meet criteria for ICD implantation, a CRT-D rather than CRT-P is more frequently selected. In 2012, the ACC/AHA/HRS issued a focused update in this area; class I indications were expanded to include patients with NYHA class II, extending the message that CRT is now indicated for patients with milder symptoms. However, the 2012 update restricted the class I recommendation to patients with left bundle branch block (LBBB) morphology and QRS duration greater than 150 milliseconds (LBBB with QRS 120–149 milliseconds or non-LBBB pattern with QRS >150 milliseconds has been downgraded to a class IIa recommendation).[21]

Up to 30% of patients meeting standard criteria for CRT do not show improvement (CRT nonresponders).[9,22] These most recent guideline revisions represent an effort to better define patients who are likely to benefit from CRT pacing.

PACING MODES

The Pacemaking Code of the North American Society of Pacing and Electrophysiology and the British Pacing and Electrophysiology Group (NBG) was first published in 1983 and last revised in 2002 (**Table 2**).[23] This code provides a generic understanding of the antibradycardia programming of any CIED. The code has 5 positions: position I describes the chamber(s) paced; position II describes the chamber(s) sensed; position III describes how the CIED responds to a sensed event; position IV adds an R for rate modulation; and position V describes the presence or absence of multisite pacing (such as for BiV pacing or CRT).

As described by the code, and depending on the number of leads and device programming and features, pacing may be delivered to and sensing may occur from a single chamber, 2 chambers, or multiple chambers. The most common single-chamber and dual-chamber pacing modes in the United States are VVI and DDD, respectively.[24] In the VVI mode, pacing and sensing take place only in the ventricle. Ventricular pacing occurs at the programmed lower rate limit; the I in the third position indicates that pacing output is inhibited by a sensed ventricular event. Chronic atrial fibrillation with a slow ventricular response reflects a common reason to select VVI pacing.

Table 2
NASPE/BPEG Generic PM Code (NBG) (revised 2002)

Position I	Position II	Position III	Position IV	Position V
Chambers paced	Chambers sensed	Response to sensing	Programmability	Multisite pacing
O = none	O = none	O = none	O = none	O = none
A = atrium	A = atrium	I = inhibited	R = rate modulation	A = atrium
V = ventricle	V = ventricle	T = triggered		V = ventricle
D = dual (A+V)	D = dual (A+V)	D = dual (T+I)		D = dual (A+V)

In the DDD mode, sensing and pacing take place in both the RA and RV. The D in the third position indicates that atrial events are either sensed or paced, and the CIED then ensures that ventricular events are synchronized to this atrial activity. In the absence of rate modulation (discussed later) and several advanced programmable features, atrial pacing in the DDD mode should occur at the programmed lower rate limit.

Because of its ability to maintain AV synchrony, multiple studies have shown the DDD mode to be superior to VVI for preventing PM syndrome (symptoms from AV dissociation) for patients requiring significant ventricular pacing.[24–26] Other pacing modes that can preserve AV synchrony include atrial pacing in patients with intact AV nodal function (eg, AAI, DDI) and those modes in which sensed atrial activity triggers ventricular pacing (eg, VDD) in patients with AV nodal block. Preserving AV synchrony usually optimizes LV filling and cardiac output and minimizes AV valvular insufficiency and retrograde atrial depolarization, which can occur with isolated RV pacing.[24]

Although preserving AV synchrony can be important when RV pacing is required, unnecessary RV pacing has been associated with detrimental effects such as atrial fibrillation, LV dysfunction, and congestive heart failure.[27] In the late 1990s, the DAVID (Dual Chamber and VVI Implantable Defibrillator) trial compared DDD pacing with VVI pacing in ICD patients without proven need of pacing.[28] Patients were randomized to 1 of 2 groups: 1 group had the pacing component of the ICD programmed to VVI at 40 beats per minute (bpm) (backup pacing only), whereas the other group had the pacing component programmed to DDD at 70 bpm. The study was stopped prematurely because of an increase in the primary composite end point of death or worsened heart failure in the DDD group. As a consequence of this and other studies,[27] pacing algorithms to minimize ventricular pacing have been developed and widely implemented for patients who require pacing (discussed later). Patients not requiring regular pacing, such as those undergoing primary ICD implant for protection against VT or VF or those undergoing CIED implant in the setting of infrequent sinus pauses, often receive single-chamber devices programmed to VVI pacing at a rate of 40 to 50 bpm.

Although DDD is the most common pacing mode, it is not appropriate for all circumstances. For the patient with paroxysmal atrial arrhythmia, this mode requires enabling of the mode switch feature to prevent forced ventricular pacing in the setting of high atrial rates. DDD pacing without a functioning atrial lead can result in R-on-T pacing and VF.[29]

The AAI mode requires intact AV nodal function, because sensing and pacing take place only in the atrium. Because patients with SA node disease have a 0.6% to 5% annual risk of developing AV block[24,30] AAI pacing is rarely used in the United States. However, because of the desire to minimize RV pacing, special hybrid pacing modes now exist that incorporate the use of AAI, allowing a device to switch back and forth between AAI and DDD depending on the presence or absence of intrinsic AV conduction.[31] Sometimes, these algorithms allow significantly prolonged AV delays or a dropped QRS, which can mimic pacing system malfunction.

The modes VDD and DDI warrant mentioning. VDD allows for dual-chamber sensing but ventricular-only pacing. It can be used in the case of AV nodal dysfunction but intact and appropriate sinus node behavior. This pacing strategy requires only a single lead incorporating atrial sensing electrodes as well as ventricular conductors that can both sense and pace, which reduces the overall diameter and blood flow obstruction of the lead (**Fig. 7**). However, this mode lacks the ability to provide atrial pacing. DDI pacing is used for the patient with a dual-chamber device suffering from paroxysmal rapid atrial arrhythmias such as atrial fibrillation. This mode prevents high ventricular pacing rates, which could result from attempted ventricular tracking of an atrial
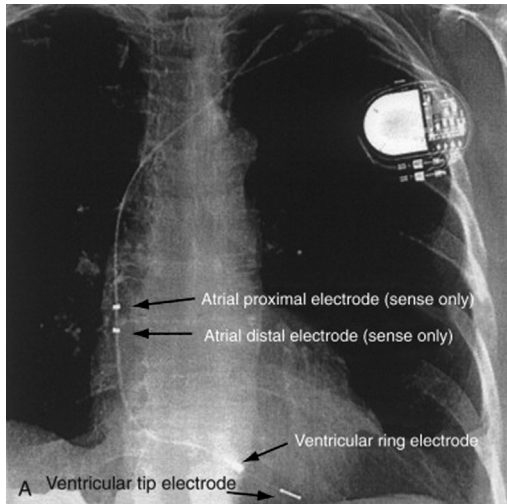
Fig. 7. A VDD pacing system. This configuration is placed into patients with abnormal AV conduction but normal sinus node function, as it cannot be used to depolarize the atrium. This device has 2 electrodes positioned within the RA that can provide sensing to detect intrinsic atrial activity. The ventricular portion of the lead shows the classic bipolar pattern with a ring electrode just proximal to the tip electrode, and these electrodes can be used for sensing intrinsic ventricular activity, as well as depolarizing the ventricle. Because the surface ECG often shows ventricular pacing that tracks the atrial activity, inspection of the surface ECG often produces an erroneous diagnosis of a dual-chamber (DDD) PM. (*From* Rozner MA. Implantable cardiac pulse generators: pacemakers and cardioverter-defibrillators. In: Miller RD, Eriksson LI, Fleisher LA, et al, eds. Miller's Anesthesia, 7th edition. Philadelphia: Elsevier, 2009; with permission.)

arrhythmia, but offers AV synchrony only in the setting of atrial pacing. Most DDD devices have a programmable feature allowing for automatic switching to DDI on detection of a high atrial rate. Depending on the manufacturer, this feature is called mode switch, automatic mode switch, or atrial tachy response.

Asynchronous modes (e.g. AOO, VOO, and DOO) pace their respective chambers without regard to underlying electrical activity. Asynchronous ventricular pacing can result in R-on-T phenomena, so asynchronous pacing modes are used primarily for temporary pacing applications (eg. emergency situations) or during procedures in which EMI might cause pacing inhibition. Asynchronous pacing is often used in the operating room, particularly in the pacing-dependent patient when EMI from monopolar electrocautery is deemed likely.[6]

In the fourth position, the NBG code uses an R to denote the presence of rate modulation. Because some patients cannot increase their heart rate in response to increased oxygen demand (termed chronotropic incompetence), CIED manufacturers have devised several mechanisms to detect patient exercise, such as sensors that detect vibration, respiration, or changes in RV pressure. However, activation of rate response sensors from vigorous chest wall skin preparation, pressure on the generator, vibration from a bone saw, or EMI from a minute ventilation device, resulting in an increased paced rate, has led to inappropriate in-hospital treatment and patient harm.[32–35]

The fifth position of the NBG code denotes multisite pacing, meaning the presence of more than 1 lead in a single cardiac chamber, biatrial, or BiV pacing. Although classically, CRT pacing takes place with discrete leads for each ventricle, multisite atrial and biatrial pacing to prevent atrial fibrillation[36] as well as multisite ventricular pacing

to achieve CRT without access to the LV[37] have been reported. Some implanters have used a standard dual-chamber pacing device in an off-label setting for multisite ventricular pacing, in which 1 RV lead (typically in the outflow tract) is connected to the atrial port and the other RV lead (typically in the apex) is connected to the ventricular port.

Like PMs, transvenous ICDs have a 4-place generic NBD code (see **Table 3**) to indicate lead placement and device function, although this code is rarely used outside the research application. Position I indicates the chamber(s) shocked, position II indicates the chamber(s) in which ATP is administered, position III identifies the detection method, and position IV indicates the chamber(s) delivering antibradycardia pacing.[24] Because all transvenous ICDs can perform pacing for bradycardia, the most comprehensive description includes the first 3 characters of the NBD, followed by a dash (-), then the 5-character PM NBG.[38] Many PMs and ICDs now have antiatrial tachycardia, which includes ATP and low-energy cardioversion. Most devices providing antiatrial tachycardia therapy require at least 1 minute of atrial arrhythmia before delivering any therapy.

CIEDS AND PERIOPERATIVE RISK

Although CIEDs are reliable, system malfunction or failure can result from several factors: (1) generator issues; (2) lead issues; or (3) external issues such as EMI. Although the scope of perioperative problems directly related to the CIED is limited, the presence of a CIED may be a general marker for patients at higher risk of cardiovascular or general medical complications in the operative and postoperative period.

An FDA database analysis provides information on the general failure rate of these devices. Maisel and colleagues[39] evaluated the database over a 12-year period and found that, per 1000 implants, 4.6 PMs and 20.7 ICDs had been explanted for issues other than battery depletion. Between 1990 and 2002 (the study period), 2.25 million PMs and 415,780 ICDs were implanted, and 30 PM and 31 ICD patients died as a direct result of device malfunction. Subsequently, Laskey and colleagues[40] analyzed FDA records for transvenous ICD explantations for 2003 to 2007 (459,000 transvenous ICDs and 256,000 CRT-D implanted) and found 10,593 (2.3%) transvenous-ICD and 1925 (0.8%) CRT-D failures. Death might be the first indication of a failed ICD system.[41]

Alerts exist for premature ICD lead failure, which can result in inappropriate shock or failure of shock delivery.[42,43] In addition, several PMs and ICDs remain on alert for silent premature battery depletion,[44,45] and an entire line of Boston Scientific devices have their magnetic mode permanently disabled because of a switch malfunction.[46]

Although it is not known whether the presence of a CIED portends increased perioperative morbidity and mortality, scenarios frequently associated with device failure

Table 3			
North American Society of Pacing and Electrophysiology (now the Heart Rhythm Society)/ British Pacing and Electrophysiology Group generic defibrillator code (NBD)			
Position I	Position II	Position III	Position IV (or Use PM Code)
Shock chambers	ATP chambers	Tachycardia detection	Antibradycardia pacing chambers
O = none	O = none	E = electrogram	O = none
A = atrium	A = atrium	H = hemodynamic	A = atrium
V = ventricle	V = ventricle		V = ventricle
D = dual (A+V)	D = dual (A+V)		D = dual (A+V)

occur with some regularity in the operating room. For example, failure to capture can result from myocardial ischemia/infarction, acid-base disturbance, electrolyte abnormalities, or abnormal antiarrhythmic drug level(s).[47] Although outright generator or lead failure is rare under routine circumstances, the exposure to EMI that frequently occurs in the operating room presumably places these patients at significantly higher risk for both of these adverse events.

Although well-controlled studies are lacking, specific evidence in the literature suggests that CIED patients may be at increased perioperative risk. Badrinath and colleagues[48] retrospectively reviewed ophthalmic surgery cases at a single center in India from 1979 to 1988 (14,787 cases) and found that the presence of a PM was associated with a significantly increased mortality within 6 weeks postoperatively. The causes of death in this study were predominantly caused by cardiorespiratory failure or cardiac arrest. Pili-Floury and colleagues[49] reported that 2 of 65 PM (3.1%) patients undergoing significant noncardiac surgery died postoperatively of cardiac causes over a 30-month study period. CIED-specific perioperative issues may adversely affect outcomes. Pili-Floury and colleagues[49] reported that 12% of patients required preoperative modification of PM programming and 7.8% required postoperative modification. Levine and colleagues[50] reported increases in pacing thresholds (the amount of energy required to sustain myocardial depolarization) in some thoracic operations. In abstract form, Rozner and colleagues[51] reported a 2-year retrospective review of 172 PM patients evaluated at a preoperative anesthesia clinic, showing that 27 of 172 (16%) needed a preoperative intervention (9 of 27 were generator replacement for newly discovered battery depletion). In addition, follow-up of 149 of these patients who went on to have a surgical procedure showed 5 ventricular pacing threshold increases, 1 atrial pacing threshold increase, and 1 PM electrical reset (all of which occurred during nonthoracic surgery in which monopolar electrocautery was used). Cheng and colleagues[52] prospectively evaluated 92 patients with PMs or ICDs undergoing noncardiac surgery or endoscopic procedures. There was no change in pacing or sensing thresholds but significantly decreased lead impedance in all chambers. One ICD reported an elective reset caused by battery depletion during the case, and several devices reported EMI but no therapy was delivered.

Multiple factors have been reported to cause confusion regarding effective perioperative care of this patient group. First, all ICDs have bradycardia pacing capabilities, so the presence of pacing artifacts on an ECG might lead a clinician to mistake a transvenous ICD for a PM. Second, magnet application to an ICD never produces asynchronous pacing. Instead, magnet application to an ICD usually, but not always, suspends antitachycardia therapies, because some ICDs can be programmed to ignore magnet placement.[47] Third, although some ICDs emit a tone on magnet application to confirm that antitachycardia therapies have been suspended, most ICDs do not emit tones or have any other mechanism to allow for confirmation of appropriate magnet placement. Fourth, ICDs process and respond to EMI differently than a PM. Electronic devices that may be mistaken for cardiac pulse generators are being implanted with increasing frequency for various reasons such as pain control, management of Parkinson disease, phrenic nerve stimulation of the diaphragm, or vagus nerve stimulation (as part of epilepsy therapy).

PRACTICE RECOMMENDATIONS AND EXPERT CONSENSUS STATEMENTS

Based on the information presented earlier, as well as additional case reports describing perioperative CIED-related complications,[47,53,54] many experts consider CIED patients to be at higher perioperative risk and strongly advocate treating them accordingly.

To promote safe perioperative management and mitigate risk in these patients, the ASA published an updated Practice Advisory in 2011 providing expert recommendations for perioperative management of patients with a CIED.[8] This advisory was followed by an Expert Consensus Statement from the HRS in collaboration with the ASA and other organizations.[6] The HRS document in particular emphasizes an individualized approach to patient management, effective multidisciplinary communication before the procedure, a team approach throughout the perioperative period, and reduced reliance on industry representatives to independently manage CIED patients. These documents acknowledge that many providers, including anesthesiologists, surgeons, and internists lack the knowledge, experience and requisite technological devices to independently manage CIED patients. The HRS document further states that the best perioperative care of a patient with a CIED generally comes from the recommendations of a physician or designated CIED team member with specific expertise and experience in monitoring and managing these devices.

Although the importance of these recommendations cannot be overstated, the reality is that not every surgical patient with a CIED is triaged to a CIED expert; especially in the case of a surgical urgency or emergency, in which engaging a CIED expert may not be feasible. Furthermore, because the frequency of patients with CIEDs presenting for surgery seems to be increasing, clinicians who are not CIED experts are being increasingly asked to contribute to the effective preoperative preparation or perioperative management of these patients. Therefore, it is incumbent on clinicians to develop an understanding of how these devices function, as well as the relevant perioperative management considerations as described in this document.

PREOPERATIVE CONSIDERATIONS

Important features of the preoperative CIED evaluation are summarized under preoperative key points in **Box 1**. For the non-CIED expert involved in preoperative preparation of a CIED patient, identifying the generator manufacturer and model provides the first step in perioperative risk reduction and care of these patients. The next step is to establish proper device function, which can be accomplished by determining the most recent device interrogation and analyzing a copy of the interrogation report. A CIED report should provide detailed information regarding the type of device, the indication for its implantation, battery status, current settings (including whether magnet response has been deactivated), pacing dependency, and an overall indication of whether the device was functioning properly at the time of the assessment. Typically, CIEDs should be evaluated every 3 to 12 months, with shorter intervals recommended for patients with more complicated devices or medical conditions and devices under alert notification.[55] However, as mentioned earlier, considerable evidence indicates that PM failure rates are estimated at 5 per 1000 per year and ICD failure rates approach 2.5%.[39,40] Thus, review of the patient's CIED performance, or a de novo interrogation if the device has not been recently interrogated, seems prudent, especially for hemodynamically challenging surgery or cases in which EMI (ie, the need for monopolar electrosurgery) is likely to occur. Although there are no data conclusively showing the need to perform a comprehensive preoperative evaluation of a CIED, anecdotal evidence and case series suggest that incomplete evaluation can result in intraoperative problems and patient harm.[47] In any situation wherein a preoperative device evaluation cannot take place, one should be prepared for perioperative device malfunction or failure.

Although the presence of a CIED generally does not indicate the need for specific preoperative laboratory tests (including chest radiograph, cardiac stress test, or

Box 1
Perioperative recommendations for the patient with a cardiac generator

Preoperative Key Points

The clinician involved in preparing patients for surgery should:

1. Identify the presence of a CIED

2. Identify the generator manufacturer and model (PM, transvenous ICD, subcutaneous ICD) of the CIED

3. Establish contact with the patient's CIED physician/clinic to establish appropriate device function, obtain records, and a specific perioperative prescription (HRS)

4. Have the CIED interrogated by a competent authority shortly before the anesthetic (ASA). HRS recommends an interrogation within 6 months for an ICD and within 1 year for a PM

5. Obtain a copy of this interrogation. Ensure that ICD detection and treatment settings are appropriate and that the CIED paces the heart with an adequate safety margin

In collaboration with a CIED expert:

1. Consider replacing any device near its elective replacement period in a patient scheduled to undergo either a major surgery or surgery within 25 cm of the generator

2. Determine the patient's underlying rate and rhythm to determine the need for backup (external) pacing support

3. Identify the magnet rate and rhythm for a PM, if a magnet mode is present and magnet use is planned

4. Program minute ventilation rate responsiveness off, if present

5. Consider programming all rate enhancements off to prevent rhythm misinterpretation

6. Consider increasing the pacing rate to optimize oxygen delivery to tissues for major cases

7. If EMI is likely: (a) disable antitachycardia therapy if an ICD; (b) consider asynchronous pacing for some pacing-dependent patients. Magnet application might be acceptable for some PMs (provide asynchronous pacing) or ICDs (disable antitachycardia therapy). Asynchronous pacing from an ICD requires reprogramming

Intraoperative Key Points

- Monitor cardiac rhythm/peripheral pulse with pulse oximeter plethysmogram or arterial waveform

- Consider disabling the artifact filter on the ECG monitor

- Whenever possible, avoid use of monopolar electrosurgery (ESU)

- Use bipolar ESU if possible; if not possible, pure cut (monopolar ESU) is better than blend or coag

- Position the ESU dispersive electrode to divert electricity away from the generator-heart circuit, even if the pad must be placed on the distal forearm and the wire covered with sterile drape

- If the ESU causes ventricular oversensing, pacing quiescence, or inappropriate tachycardia, limit the effect by suspending the use of monopolar electrocautery, reprogramming the cardiac generator, or placing a magnet over the PM (not indicated for ICD)

Postoperative Key Points

- Many patients require postoperative interrogation or reprogramming. In particular, any CIED that underwent preoperative or intraoperative reprogramming should be reinterrogated and restored to appropriate parameters. Postoperative CIED interrogation should always be prompted by intraoperative hemodynamic instability or any concern for inappropriate CIED function. In many cases, rate enhancements may need to be reinitiated, and optimum heart rate and pacing parameters should be determined and programmed. The ICD patient must remain in a fully monitored setting (postanesthesia care unit or intensive care unit) until antitachycardia therapy is restored.

echocardiogram), preoperative management of the patient with a CIED must include evaluation and optimization of coexisting disease(s). Special attention to underlying medical issues should be given to the patient with an ICD (which often indicates the presence of cardiomyopathy or other coexisting cardiac disease) as well as the patient with CRT. Patients with heart failure should be evaluated with respect to heart failure guidelines.[56]

Although, as a general principle, tests should be ordered based on usual non-CIED factors such as the history of the patient and the stability of underlying disease, some situations specifically related to the presence of a CIED might necessitate certain testing. For instance, a chest radiograph might be useful for the patient with an LV lead expected to undergo central line placement, because the CS lead dislodges in at least 4.7% of patients at a rate of 2.3% per year.[57] In addition, for cases in which previous records are not available or it is not possible to obtain a de novo interrogation or consultation with a CIED expert, a chest radiograph can provide device type identification, including PM versus ICD versus CRT as well as device manufacturer (**Fig. 8**). The chest film can also provide information about lead configuration and possibly a lead fracture. Additional steps that might provide information about the device include (1) reviewing the implant card that CIED patients are instructed to carry with them at all times and (2) calling the device manufacturer. **Table 4** contains a list of device manufacturers and their phone numbers.

After confirming appropriate device function, the next step in safely preparing a CIED patient for surgery should be identifying the patient's underlying rate and rhythm, which can identify pacing dependence. In general, pacing dependence implies the lack of spontaneous ventricular activity when the CIED is programmed to the VVI mode (AAI for single-chamber atrial devices) at the lowest programmable rate. In the absence of an interrogation, pacing dependency might be established through history or by examining the ECG. A history of AV nodal ablation or a previous placement of a temporary pacing wire confirms likely pacing dependence, and implantation for symptomatic bradyarrhythmia or syncope suggests possible pacing dependence. On the surface ECG, pacing dependence might be present if every complex is paced, except in the case of QRS complexes for CRT, because the goal of CRT programming is to achieve 100% BiV pacing. Pacing dependency represents a key consideration for intraoperative management, as discussed in more detail later.

Other considerations include: ensuring that magnet behavior is appropriate (asynchronous pacing, proper rate and acceptable AV delay for PM, suspension of antitachycardia therapies for ICD) if magnet use is planned (discussed in detail later); programming minute ventilation rate response (and possibly other pacing features that can mimic pacing system malfunction) to off when present; and increasing the lower pacing rate to optimize oxygen delivery for major surgery.

INTRAOPERATIVE CONSIDERATIONS

Although recommendations for intraoperative management usually remain beyond the scope of the preoperative consultant, some key points deserve mention, because consultants may be asked to advise perioperative care team members, especially in urgent or emergent situations. Important intraoperative key points are summarized in **Box 1**).

Patient monitoring (discussed earlier) and protection of the patient and the pulse generator against the effects of EMI (most commonly from monopolar electrosurgery) remain the principal intraoperative issues. For ICDs, the ASA and HRS differ in their specific recommendations. The ASA states that all ICDs should have antitachycardia therapy disabled whenever monopolar electrosurgical unit (ESU) use is planned,
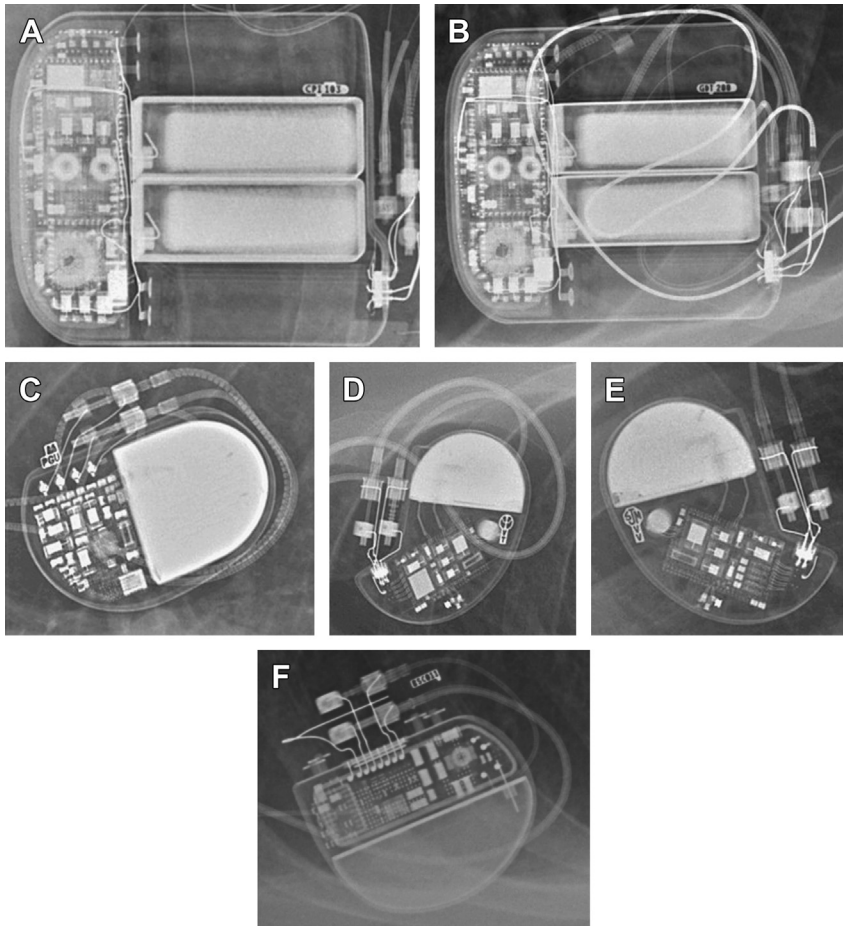
Fig. 8. Radiographic identifiers for some generator manufacturers. PM and ICD generators can be identified from operative dictations, patient cards, or some chest radiographs. Using digital radiograph equipment with postprocessing zoom capability, corporate radiograph logo identifiers from CPI (*A*), Guidant (*B*), Medtronic (*C*), Pacesetter (*D*), St Jude Medical (*E*), and Boston Scientific (*F*) are shown. (*From* Rozner MA. Implantable cardiac pulse generators: pacemakers and cardioverter-defibrillators. In: Miller RD, Eriksson LI, Fleisher LA, et al, eds. Miller's Anesthesia, 7th edition. Philadelphia: Elsevier, 2009; with permission.)

whereas the HRS states that ICD deactivation might not be needed for monopolar ESU application inferior to the umbilicus. Both the ASA and HRS documents agree that consideration should be given to reprogramming the CIED to an asynchronous pacing mode for a pacing-dependent patient undergoing a procedure likely to cause EMI, and both statements caution that magnet application to an ICD does not accomplish this goal.

Further, significant controversy exists regarding the use of a magnet to achieve asynchronous pacing (in the case of a PM) or temporarily suspend antitachycardia therapy (in the case of an ICD). Although many centers routinely place a magnet on a CIED to contend with the issue of EMI, this approach may be unreliable, and several investigators have warned against substituting magnet application for individualized

Table 4 Device manufacturers and phone numbers	
AM Pacemaker (Guidant Medical)	800-227-3422
Angeion	800-264-2466
Arco Medical (Boston Scientific)	800-227-3422
Biotronik	800-547-0394
Boston Scientific	800-227-3422
Cardiac Control Systems	Unavailable
Cardiac Pacemakers–CPI (Boston Scientific)	800-227-3422
Cardio Pace Medical (Novacon)	Unavailable
Cook Pacemaker	800-245-4715
Coratomic (Biocontrol Technology)	Unavailable
Cordis (St Jude Medical)	800-722-3774
Diag/Medcor (St Jude Medical)	800-722-3774
Edwards Pacemaker Systems (Medtronic)	800-325-2518
ELA Medical (Sorin)	877-669-7674
Intermedics (Boston Scientific)	800-227-3422
Medtronic	800-505-4636
Pacesetter (St Jude Medical)	800-722-3774
Siemans-Elema (St Jude Medical)	800-722-3774
Sorin	877-669-7674
Telectronics Pacing (St Jude Medical)	800-722-3774
Ventritex (St Jude Medical)	800-722-3774
Vitatron (Medtronic)	800-328-2518

Note: In general, manufacturer telephone support is available from a technician/specialist 24 hours per day, 365 days per year. Information that can be obtained includes device type, model and serial number, and data available at the time of implant. More specific information about CIED function (such as programmed parameters, battery, and lead status) may or may not be available from the manufacturer depending in part on whether the patient has remote (home) monitoring.

treatment. In a recently published series describing cases from 3 institutions, inadequate preoperative assessment of CIED function coupled with erroneous assumptions about the effects of magnet application contributed to or caused inappropriate ICD therapy, premature CIED battery depletion, and patient injury.[47] The investigators concluded that practitioners should exercise caution when applying magnets to PMs or defibrillators for surgery. Although magnet application to control CIED function might represent an appropriate management strategy in some cases, the practice of blindly placing a magnet over an ICD is discouraged by both the ASA and HRS. In lieu of blind magnet application, both the ASA and HRS advise practitioners to either obtain knowledge of device functionality and magnet effects before surgery or obtain a timely preoperative CIED interrogation.

For an ICD patient whose antitachycardia therapies are disabled (whether by programming or magnet placement), ECG monitoring and the ability to deliver external cardioversion or defibrillation must always be present; an approach often recommended includes application of external defibrillation pads before surgery until antitachycardia therapies have been restored. When applying external pads, an effort should be made to exclude the pulse generator from the current path to the extent possible. However, one should always remember that the patient, and not the ICD, is being
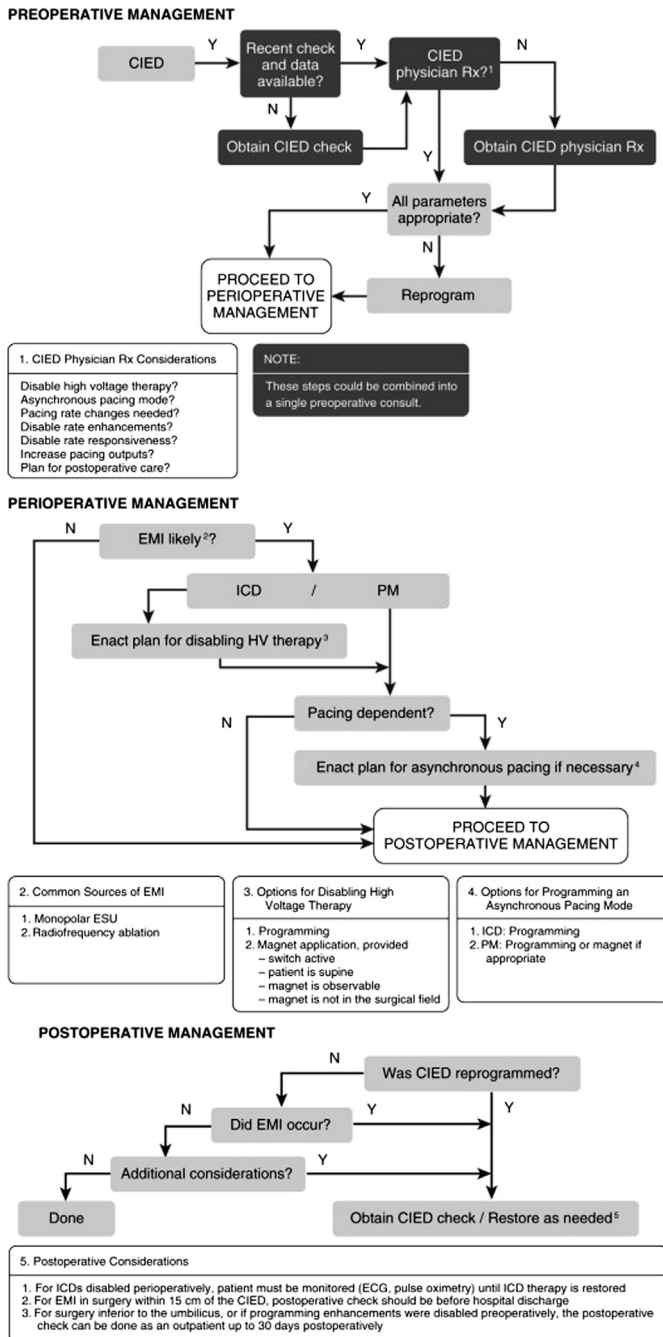
Fig. 9. Operative management considerations of a patient with a PM/ICD. HV, high voltage. (*From* Rozner MA, Schulman PM. How should we prepare the patient with a pacemaker/ implantable cardioverter-defibrillator? In: Fleisher LA, ed. Evidence-based practice of anesthesiology, 3rd edition. Philadelphia: Elsevier, 2013; with permission.)

treated. After any cardioversion/defibrillation, the CIED should be reinterrogated to ensure that normal function is maintained.

To mitigate the risk of EMI from monopolar electrosurgery, both the ASA and HRS concur that the ESU dispersive electrode should be placed so that the presumed ESU current path is directed away from the pulse generator and leads and does not cross the chest.

POSTOPERATIVE CONSIDERATIONS

Key postoperative considerations are summarized under postoperative key points in **Box 1**. Any CIED that underwent preoperative or intraoperative reprogramming should be reinterrogated and restored to appropriate parameters. Patients who have undergone hemodynamically significant surgery, encountered significant EMI issues, or whose ICD high-voltage therapies were disabled by programming must be monitored until the device is interrogated and proper function is confirmed or restored. For nonreprogrammed devices, consideration should be given to ensuring appropriate programming for the patient's postoperative course, which might entail the need to increase the pacing rate or disable features that allow prolonged AV times. The HRS states that stable patients who did not require perioperative reprogramming can be checked after patient discharge within a month of the surgery, rather than the immediate postoperative period. The ASA states that postoperative interrogation might be unnecessary if no monopolar ESU was used, no blood was transfused, there was limited fluid administered, and there were no untoward issues. The postoperative CIED plan, as well as any interrogation or reprogramming, should be recorded into the patient's chart.

Specific recommendations regarding preoperative, intraoperative, and postoperative considerations have been summarized as an algorithm (**Fig. 9**).

SUMMARY

The growing number of patients who present for surgery with a PM or ICD in place necessitates development of a knowledge base on the part of clinicians involved in perioperative care who are not CIED experts. This knowledge base, which should include understanding indications for CIED implantation, basic CIED function, and differences between conventional PMs and ICDs, allows the creation of a management plan tailored to each patient and their surgery. Both the ASA and HRS have published advisory statements, and although the methodology differs, both documents state that proper CIED function should be verified and a specific CIED prescription should be obtained before the surgery. In addition to acquiring general knowledge about CIED function, practitioners caring for patients in the preoperative environment should address the following specific issues in all patients presenting for surgery:

- Is a CIED in place?
- Has a CIED specialist been informed of the surgery and asked to provide recommendations about perioperative management?
- Is the CIED a PM or ICD, and which company manufactured it (so that the appropriate programming machine can be used)?
- Is EMI likely to occur during the surgery? In general, surgeries involving monopolar electrosurgery superior to the inguinal ligament are likely to cause EMI, and those involving monopolar electrosurgery inferior to the inguinal ligament, or only bipolar electrosurgery are unlikely to cause EMI.
- If EMI is likely and the patient has an ICD, antitachycardia therapies must be turned off immediately before surgery and then restored in the immediate

postoperative period. Continuous telemetry monitoring must be maintained and the capability for backup external cardioversion and defibrillation must be immediately available while antitachycardia therapies are suspended. If the plan for suspending antitachycardia therapies involves magnet application in lieu of formal device reprogramming, magnet function must be verified as enabled, easy access to the magnet must exist to allow for its observation and removal, and magnet placement must not interfere with the surgery.

- If EMI is likely and the patient is dependent on CIED pacing (with either a PM or ICD), the CIED should generally be programmed to an asynchronous pacing mode (AOO, VOO, or DOO) before surgery. For PMs, when appropriate, it is often possible to use a magnet for this purpose. In general, magnets do not affect the bradycardia pacing mode or rate of an ICD, meaning that formal device reprogramming is required when an asynchronous pacing mode is desired.

For clinicians involved in preoperative care of the patient with a CIED, acquiring a knowledge base and developing a systematic approach for these patients ensures safe and efficient perioperative care.

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