

Perioperative management of patients with cardiac implantable electronic devices

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Editor's key points

- The use and complexity of cardiac implantable electronic devices continues to increase.
- Recommendations for the perioperative management of patients with implantable pacemakers and defibrillators include a multidisciplinary individualized approach.
- The baseline function of these devices must be understood and adjusted if necessary based on patient- and procedure-specific needs.

Summary. Many anaesthesia practitioners caring for patients with a cardiac implantable electronic device (CIED) lack the knowledge, experience, and requisite programming devices to independently manage these patients perioperatively. A recently updated ASA task force Practice Advisory presents expert opinion regarding the perioperative management of patients with CIEDs, and the Heart Rhythm Society (HRS) recently published a consensus statement on this subject in collaboration with the ASA, American Heart Association (AHA), and Society of Thoracic Surgeons (STS). The main intent of these documents is to provide recommendations that promote safe management of patients with CIEDs throughout the perioperative period and reduce the likelihood of adverse outcomes. Reviews of this topic focusing on the actions of the anaesthesiologist have been published, but a multidisciplinary approach to the perioperative management is now advocated. In emergent situations, however, or when there is no time for the requisite consultations, and in practice settings where the suggested multidisciplinary approach is simply not feasible, the anaesthesia team must still provide effective, safe perioperative management. Thus, all anaesthesiologists should become familiar with the basics of the current CIED technology and the essential tenets of perioperative CIED management. This review discusses relevant advances in CIED technology and practical perioperative management as outlined in the 2011 ASA Practice Advisory and HRS consensus statement.

Keywords: CIED, perioperative management; equipment, implantable cardioverter defibrillator; equipment, pacemakers

The number of patients with cardiac implantable electronic devices (CIEDs; previously termed cardiac rhythm management devices) continues to grow at an astonishing rate worldwide, but the level of comfort most anaesthesiologists have in managing such patients in the perioperative period has not kept pace with that growth despite periodic review of the topic in the literature.^{1–4} In many centres, placement of a magnet on a CIED has become the standard approach to perioperative management. While magnet application to control CIED function is appropriate in some cases, in others, 'blind' magnet application alone as a management strategy might provide nothing more than a false sense of security because it might fail to address all necessary perioperative issues, accomplish the intended goals, or both.

The ASA published an updated task force Practice Advisory in conjunction with the Heart Rhythm Society (HRS) in 2011 that provides expert recommendations for perioperative management of patients with a CIED.⁵ This advisory was followed by an Expert Consensus Statement from the HRS in collaboration with the ASA, the American Heart Association (AHA), and the Society of Thoracic Surgeons.⁶ These documents provide recommendations that promote safe management of patients with CIEDs throughout the

perioperative period and reduce the likelihood of adverse outcomes.

There are no new management recommendations in the 2011 Advisory compared with the one published in 2005.⁷ But what is encouragingly 'new' (as outlined in the consensus statement) is the emphasis now being placed on an individualized approach to patient management, effective multidisciplinary communication before the procedure, a team approach throughout the perioperative period, and a reduced reliance on representatives from industry [Industry Employed Allied Health Professionals (IEAPs)] to independently manage CIED patients in the absence of physician direction.

Compared with a Practice Guideline (which generally mandates a specific course of action), a Practice Advisory is more of an educational intervention; it is a report developed by experts to aid in decision-making to ensure the safety of patients. A Practice Advisory does not constitute a standard of care, but it is believed that following the expert management recommendations in a Practice Advisory should help prevent complications. The use of a Practice Advisory obviously cannot guarantee a specific outcome, and practitioners can 'adopt, modify, or reject' the recommendations based on their medical judgement, their own experience, and the clinical

situation. In reality, many anaesthesia practitioners lack the knowledge, the experience, and the requisite technological devices to independently manage CIED patients perioperatively.

As outlined in the consensus statement, the ‘best’ perioperative care of a patient with a CIED usually comes from the recommendations of the physician (and their assistants) who usually monitor/manage the CIED (the CIED ‘team’). Such recommendations should routinely be sought in advance whenever feasible. Once the plan for CIED management in the perioperative period has been decided (based on specific information provided to the CIED team from the surgical or procedural team; Table 1), it is reasonable for an IEAP to assist with the implementation of that prescription as necessary, but it is inappropriate for an IEAP to independently recommend perioperative management. In the absence of time for such multidisciplinary communication, it is also reasonable for another CIED team (e.g. a cardiologist, or other knowledgeable colleague) to assist with developing and implementing a perioperative plan, but in many cases (e.g. off-hour emergencies and urgent cases when there has not been adequate time for preoperative consultations), it will fall to the anaesthesiologist to manage the device in the immediate preoperative period. Thus, as with all other life-saving equipment in the operating theatre, it behoves all anaesthesiologists to become familiar with the basics of the current technology and the essential tenets of perioperative CIED management as outlined in the Practice Advisory. In this review, we will discuss relevant advances in CIED technology in the context of practical perioperative management, and specific clinical scenarios.

Pacemakers

Basics

Pacemakers can be permanently implanted devices or temporary, and the indications for pacing continue to expand.

Table 1 Important information to be given to the CIED team so they can provide specific recommendations to the surgical/procedural team regarding the preoperative preparation of the patient’s CIED for the planned procedure. Modified from ref.⁶

Intended surgical procedure
Location of pulse generator
Patient position during the procedure
Type of electrocautery to be used
Other sources of EMI likely to be present
Whether cardioversion or defibrillation will be necessary
Availability of Industry Employed Allied Health Professional or knowledgeable personnel with manufacturer-specific programmer
Anticipated post-procedural disposition (e.g. anticipated discharge to home <23 h, inpatient admission to critical care bed, telemetry bed)
Other circumstances: cardiothoracic or chest wall surgical procedure that could impair/damage or encroach upon the CIED leads, anticipated large blood loss, operation in close proximity to CIED

The most common indications for pacing currently include: symptomatic bradycardia (including that resulting from sinus node dysfunction), atrioventricular (AV) conduction block after catheter ablation of the AV node or junction.⁸ Pacing can be provided in several ways, including application of external pacing pads, urgent insertion of a transvenous pacing lead via central venous access, and implantation of permanent intracardiac leads along with a pulse generator. Regardless of how it is provided, pacemaker programming (and therefore pacemaker function) must always be individualized to the needs of the individual patient.

Pacing can be delivered to a single chamber (atrium or ventricle only), dual chambers (atrium and ventricle), or multiple chambers (in biventricular pacing) and can use either unipolar or bipolar leads. Over the last 15 yr, bipolar leads have been predominantly used. With a bipolar lead, both the cathode and anode are present on the lead itself and thus the distance between them is much smaller than with a unipolar lead (where the pulse generator functions as the anode). The advantage of the bipolar configuration is reduced susceptibility to electromagnetic interference (EMI).

Pacemaker leads are generally placed in the right atrial (RA) appendage, right ventricle (RV), or, in a dual-chamber device, both (Fig. 1). Depending on device programming, in a single-chamber mode, the device can sense intrinsic electrical activity in the chamber where the lead is placed to either inhibit or trigger pacing in that chamber. The lower rate or escape interval is programmed based on the desired heart rate and underlying condition of the patient. If no spontaneous depolarization of the chamber is sensed within the programmed limits, the device will deliver a pacing stimulus. If a spontaneous chamber depolarization occurs and is sensed, the device will inhibit the delivery of a pacing stimulus and wait for a subsequent depolarization during the next pre-set time interval.

A dual-chamber pacing mode allows for both sensing and subsequent triggering or inhibition of pacing in one or both chambers. This ‘physiological’ mode of pacing maintains AV synchrony because atrial systole immediately precedes ventricular systole, and the atrial rate is the same as the ventricular rate. These factors optimize left ventricular (LV) filling, AV valve function, and ultimately cardiac output. Physiological pacing modes also minimize the AV valvular insufficiency that occurs with isolated ventricular pacing and retrograde atrial depolarization. More than doubling of cardiac output has been demonstrated with atrial pacing for the treatment of AV junctional rhythm in patients with ischaemic cardiomyopathy.⁹

Pacemaker mode coding

Table 2 shows the current North American Society of Pacing and Electrophysiology (NASPE)/British Pacing and Electrophysiology Group (BPEG) generic code for antibradycardia, adaptive rate, and multisite pacing.¹⁰ This code has been universally accepted to describe pacemaker programming

since October 2001. Familiarity with the programming designations allows for an understanding of the behaviour exhibited by a given device. The first letter describes the chamber(s) being paced, the second letter describes the chamber(s) where sensing takes place, and the third letter describes the response to sensed events, resulting in programming designations such as AAI, VOO, VVI, or DDD. The following examples illustrate how the code is used.

The AAI mode can be programmed for a patient with normal AV conduction with symptomatic sinus bradycardia to ensure adequate heart rate. In the AAI mode, a sensed spontaneous atrial depolarization inhibits pacing of the atrium. If no depolarization occurs within a pre-set time interval, the device provides pacing at a pre-set rate.

The VVI mode can be programmed for a patient with atrial fibrillation and a slow ventricular response to ensure adequate ventricular rate. The behaviour of the pacemaker is similar to that explained above for the AAI mode, but applied to the ventricle.

The DDD mode is able to sense and subsequently trigger or inhibit pacing of the atrium, ventricle, or both and is

thus versatile for use in a variety of clinical scenarios. For example, the DDD mode can be programmed for patients with complete AV block and normal sinus node function to ensure that each spontaneous atrial depolarization is followed by a ventricular depolarization. This mode will provide AV sequential or 'physiological pacing' because the paced ventricular rate tracks the spontaneous atrial rate.

Pacing modes that preserve AV synchrony include those that pace the atria in patients with AV node competency (e.g. AOO, AAI, DOO, DVI, DDI, and DDD) and those that sense atrial activity to trigger ventricular pacing (e.g. VAT, VDD, and DDD) in patients with slow ventricular rates or AV nodal block. Asynchronous modes (e.g. AOO, VOO, and DOO) do not provide sensing and simply pace the designated heart chambers without regard to underlying electrical activity. They are most often used for temporary pacing applications (e.g. emergency situations) or in an environment (such as an operating theatre) where electromechanical interference (e.g. from electrocautery) can cause inhibition of pacing based on sensed intrinsic electrical activity. Asynchronous atrial pacing is helpful when intact AV conduction is present, but asynchronous ventricular pacing is often used in emergency situations (e.g. acute high-degree AV conduction block or asystole).

The fourth and fifth positions of the NBG code

Position IV specifies the presence or absence of rate modulation (discussed in detail below), and Position V specifies the location or absence of multisite pacing (also discussed below). While the full five-digit programming code is not always used, it can provide relevant information contributing to the decision-making of the perioperative practitioner.

Rate-responsive pacing

Optimal systemic perfusion requires modulation of heart rate to meet metabolic demands. Rate modulation (also called rate adaptation) allows a pacemaker to automatically increase the paced heart rate in response to certain monitored physiological conditions such as exercise. Rate modulation can be utilized in atrial- and ventricular-based pacing modes (AAIR, VVIR, DDDR, and DDIR). The most commonly utilized sensor to effect rate modulation uses an accelerometer that detects acceleration due to motion, and in response delivers rate-adaptive pacing. Sensors capable of detecting changes in thoracic impedance are also in use in some devices (e.g. Boston Scientific devices). Some of these devices use a



Fig 1 Typical appearance of a dual-chamber pacemaker.

Table 2 The NASPE/BPEG generic code for antibradycardia, adaptive rate, and multisite pacers¹⁰

Pacing	Sensing	Response	Rate modulation	Multisite pacing
A=atrium	A=atrium	I=inhibited	R=rate modulating	V=ventricle
V=ventricle	V=ventricle	T=triggered	O=none	A=atrium
D=dual (A & V)	D=dual (A and V)	D=dual (I and/or T)		D=dual (A and V)
	O=none	O=none		O=none

blended sensor that both detects acceleration and determines minute ventilation to deliver rate-responsive pacing.

Multisite pacing

Position V in the code provides information about the presence or absence of multisite pacing (e.g. there is more than one lead in a single cardiac chamber or there is biventricular pacing). The former refers essentially to there being more than one lead in the atrium in attempts to suppress atrial fibrillation, but this is not currently clinically relevant. The latter, however, refers to biventricular pacing as cardiac resynchronization therapy (CRT), which is extremely clinically relevant.

Advanced cardiac failure is well known to be accompanied by conduction defects and dysrhythmias due to sinus- or AV node dysfunction and intraventricular conduction delays that delay the onset and completeness of RV or LV systole in at least 30% of patients.¹¹ The dyssynchrony between and within LV and RV contractions has been demonstrated to increase the risk of death in this population.^{12–15} In addition to AV timing, CRT utilizes atrial synchronous biventricular pacing to optimize the timing of RV and LV contraction. As opposed to AV sequential dual-chamber pacing, in CRT, the LV and RV are paced and the activation sequence of the ventricles is timed to ‘resynchronize’ RV and LV ejection. Atrial-synchronized biventricular pacing can improve cardiac output, haemodynamics, heart failure symptoms, and quality of life in patients with progressive heart failure symptoms.¹⁶ CRT through biventricular pacing is currently indicated for reduction in symptoms of moderate-to-severe heart failure (NYHA Functional Class III or IV) in those patients who remain symptomatic, despite stable, optimal medical therapy with an LV ejection fraction (LVEF) of <35% and QRS duration on surface ECG of >130 ms.

Implantable cardioverter defibrillators

Ventricular tachycardia (VT) and ventricular fibrillation (VF) account for the majority of the reported 300 000–350 000 sudden cardiac deaths (SCDs) in the USA each year.^{17–19} SCD accounts for about 40% of all deaths in patients with heart failure;²⁰ such deaths are six to nine times more likely to occur in patients with congestive heart failure, ischaemic heart disease, or dilated cardiomyopathy than in the general population.²¹

Implantable cardioverter defibrillators (ICDs) are devices capable of detecting a ventricular arrhythmia and delivering a defibrillatory shock. The first human implant in 1980 used epicardial leads surgically implanted through a thoracotomy with a large pulse generator implanted in the abdominal cavity. Early ICD recipients had spontaneous life-threatening ventricular arrhythmias and had failed numerous anti-arrhythmic medications, such that these devices were truly life-saving. Over time, technology has allowed miniaturization of the ICD pulse generator. Devices are now implanted in a subcutaneous pectoral pocket with transvenous leads. The current-generation ICDs can terminate VF in >98% of

episodes,⁸ and all such devices now incorporate sophisticated pacemaker technology in case defibrillation results in bradycardia or asystole and to deliver antitachycardia pacing to terminate VT.

In patients with cardiomyopathy and decreased LV function (LVEF ≤35%), numerous large clinical trials have demonstrated a survival benefit of prophylactic ICD implantation compared with conventional medical therapy.^{22–24} The mortality benefit is seen in both ischaemic cardiomyopathy and non-ischaemic cardiomyopathy patients due to prevention of sudden death.^{25 26} Thus, ICDs have become a definitive therapy for patients at high risk for malignant ventricular arrhythmias (primary prophylaxis) and are also implanted in patients who have survived a malignant arrhythmia (secondary prophylaxis).

ICDs use a lead in the RV to sense electrical activity and to deliver a defibrillatory shock when indicated (Fig. 2). These devices can be single chamber (RV lead only), dual chamber (atrial and ventricular leads), and triple chamber (atrial, RV, and LV leads—a CRT device). Programming of pre-defined ‘zones’ allows the ICD to distinguish different types of malignant tachyarrhythmias and provide different therapies to interrupt them. These zones are individually determined ranges of heart rates based on specific pathology and risks in a given patient. When a fast ventricular rhythm is sensed and the duration of the arrhythmia is sufficient to meet programmed criteria, a tachyarrhythmia is declared. Based on the rate, programming, and duration of the arrhythmia, the device begins a sequence of therapies. Generally, slower rates of tachycardia are considered to be VT and treatment often begins with overdrive pacing.

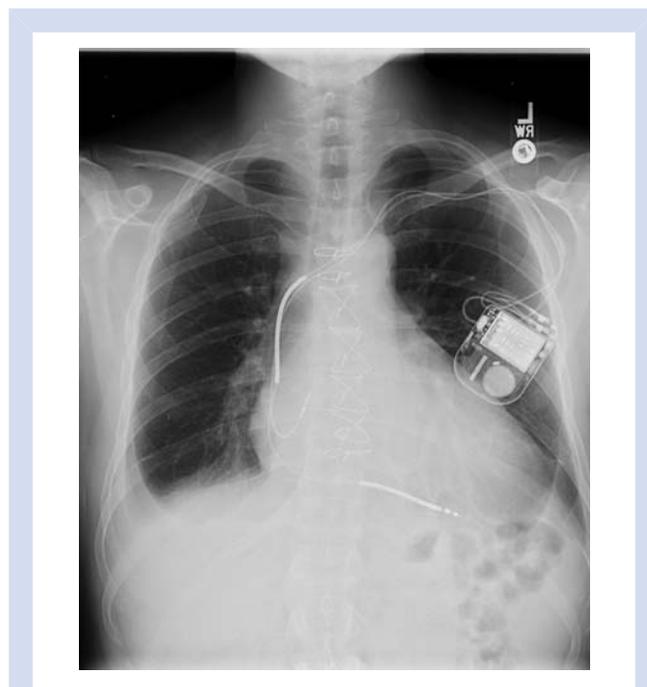


Fig 2 Typical appearance of an implanted ICD. Note the thick radio-opaque coils of the RV lead.

Should this fail to terminate the arrhythmia, the device follows by delivering a defibrillatory shock.

An additional sensing electrode in the RA can help distinguish true VT from conducted supraventricular tachycardia and thus avoid unnecessary, uncomfortable, and potentially deleterious ICD discharges. If the rate sensed falls into the higher zone, the rhythm is most likely perceived as VF and a high-energy shock is delivered.²⁷ ICDs store a log of arrhythmias detected within the programmed zones, which allows for a review of the stored data to characterize the arrhythmia and treatments delivered by the device.

Perioperative management of patients with CIEDs

The HRS consensus statement emphasizes that best practice results from predetermination of appropriate perioperative management by the team who usually manages and monitors the CIED. It is clear that availability of complete information about a patient's CIED and precise recommendations from the CIED team for the day of surgery can be very helpful. It is desirable in general that a pacemaker has been checked within the last 12 months and an ICD within the last 6 months, but this cannot guarantee that nothing has changed in the interim. As discussed in the HRS consensus statement, the procedural/operative team should ideally be seeking the recommendations of the patient's CIED team in advance whenever feasible for elective procedures since all necessary information should reside with them. Failing this, the availability of an IEAP or a knowledgeable colleague with a programming device will be helpful to ensure device function. Unfortunately, these conditions are rarely met in real practice and certainly cannot be expected to be met off-hours and during urgent or emergent unscheduled cases. Thus, regardless of the circumstances (e.g. elective case without the recommendations of the CIED team or emergent case), the anaesthesiologist needs to be able to obtain certain key information and understand what can cause problems with a CIED if they are to take the specific recommended steps to avoid them, as outlined in the ASA Practice Advisory. A discussion of the perioperative considerations is followed by a delineation of specific actions to be taken.

Considerations

Electromagnetic interference

The most common issue arising in the perioperative period is interference with device function from EMI. Any apparatus that emits radiofrequency waves between 0 and 10^9 Hz can generate EMI and therefore interfere with proper device function. Table 3 provides a list of commonly encountered sources of EMI in the perioperative setting. Higher frequency waves (e.g. X-rays, γ -rays, infrared, and ultraviolet light) are unlikely to cause interference with CIED function, though repeated and/or prolonged exposure to certain types of radiation can cause deterioration of insulation

Table 3 A list of factors associated with the generation of EMI commonly encountered in the perioperative setting. Reporting the anticipated presence of any/all such factors to the CIED team may help them devise appropriate recommendations

Electrocautery (monopolar >>>> bipolar)
Evoked potential monitors
Nerve stimulators (twitch monitors)
Fasciculations
Shivering
Large tidal volumes
External defibrillation
Magnetic resonance imaging
Radio frequency ablation or lesioning
Extracorporeal shock wave lithotripsy
Electroconvulsive therapy

within the device with resultant short-circuiting or other electrical problems.

For pacemakers in general, inhibition of pacing due to oversensing is the most common result of exposure to EMI, though in some cases, sudden asynchronous pacing, reversion to a programmed backup mode (often VVI or VOO mode), or both can be seen. Prolonged exposure to EMI can cause a pacemaker to initiate a noise reversion mode or noise suppression protocol which triggers asynchronous pacing until the noise stops.

With an ICD, EMI can result in inappropriate delivery of a defibrillatory shock. Thus, if pacing modes appear to be changing abruptly or intermittently on ECG monitors, unrecognized EMI should be considered. This being said, the potential for EMI to affect the behaviour of modern pacemakers has decreased significantly compared with prior generations of devices, with the nearly routine use of bipolar leads being a major factor.

The vast majority of devices now use bipolar leads; however, unipolar leads are still sometimes used when epicardial leads are placed (often in the paediatric population) and in adults with older devices. Bipolar leads minimize the physical distance over which the circuit is completed because both the anode and cathode are located very close to each other on the lead itself. In contrast, with unipolar leads, the lead tip acts as the cathode and the pulse generator acts as the anode to complete the circuit. There is a greater potential for interference from EMI with unipolar leads because in effect, the entire circuit acts as a large antenna. Additional reasons why modern devices are less susceptible to EMI noise protection algorithms, which disregard noise outside of the expected cardiac range of frequencies, and include the incorporation of filters and circuit shields that insulate the circuitry and internal components from the metal device casing.

EMI–CIED interactions

There are several adverse outcomes potentially related to exposure of a CIED to EMI in the perioperative period that

Table 4 Adverse outcomes to be avoided in patients with CIEDs

Damage to the device, the leads, or site of lead implantation
Failure to deliver pacing, defibrillation, or both
Changes in pacing behaviour
Inappropriate delivery of a defibrillatory shock (if an ICD is present)
Inadvertent electrical reset to backup pacing modes

the anaesthesiologist should take steps to avoid. Table 4 defines the adverse outcomes to be avoided in patients with CIEDs, as any of these can result in significant morbidity or mortality due to hypotension, dysrhythmias, myocardial tissue damage, myocardial ischaemia, and/or potential secondary damage to other organ systems. In addition to potential harm to the patient, from the systems-based perspective, EMI exposure can cause delay or cancellation of scheduled surgery by necessitating additional surgical procedures to manage device malfunctions and can potentially extend hospital stays incurring increased medical costs.

As outlined in the consensus statement, there are experience and data suggesting that the likelihood of adverse EMI–CIED interactions decreases with the distance from the EMI source to the pulse generator (a critical distance of 6 in. is mentioned). With modern subpectoral devices and electro-surgical cautery units, it is currently believed that the potential for interactions is markedly reduced when the surgery is below the umbilicus and the cautery dispersal pad is placed so as to direct the current away from the pulse generator.²⁸ Nevertheless, it remains the recommendation to take specific actions to minimize EMI exposure to the CIED and to protect the patient from the potential result of altered CIED behaviour as a result of exposure to EMI. Aside from the potential effects of EMI, one should also take care to avoid dislodging recently implanted leads (<6 weeks old; e.g. by placement of a pulmonary artery catheter).

Decisions and actions

As outlined in the Practice Advisory, key principles in the perioperative management of the patient with a CIED are as follows.

Before operation

- Determining that a CIED is present and defining the functionality of the device (e.g. pacemaker or ICD).
- Determining whether significant EMI will be present during the planned procedure that might affect the programmed behaviour of the CIED.
- Determining whether the patient is dependent on antibradycardia pacing and whether or not reprogramming of the pacemaker mode is required.
- If an ICD is present, deciding the manner in which the antitachycardia therapies shall be suspended (e.g. by a programming device or by temporarily applying a magnet to the device).
- Determining that the device is functioning as intended.

Preoperative decision-making regarding the issues listed above is detailed in Figure 3.

Intraoperatively

- Ensuring the availability of a backup source of pacing, defibrillation, or both.
- Maintaining vigilance and monitoring in accordance with ASA standards so as to rapidly detect any haemodynamic compromise as a result of interference with CIED function.
- Management of EMI.
- Rapid implementation of the backup source of pacing, defibrillation, or both as required.

After operation

- Maintenance of appropriate vigilance and monitoring with the immediate availability of backup pacing, defibrillation, or both until all CIED settings are restored.
- Formal interrogation of the CIED as appropriate (Table 4 and discussion below).

Preoperative considerations

While there are no data conclusively demonstrating the need to perform a comprehensive preoperative evaluation of a CIED, there is a large anecdotal experience, as well as published case reports in which incomplete evaluation has resulted in intraoperative problems. In addition to a thorough patient interview and relevant physical exam, the preoperative assessment should include a focused interview regarding the CIED and a review of all available medical records, ECGs, and chest X-rays. Occasionally, detailed information regarding the type of device, the indication for its implantation, and current settings will be in the patient's chart. However, this information is usually not available, and few patients (or their families) can verbally and accurately provide all of the necessary information, so it is up to the practitioner to use all available information to determine what is present, how it is programmed, if the patient is dependent on the device, if it is functioning as intended, and determine what needs to be done with it to prepare the patient for surgery.

The chest radiograph (CXR) is particularly helpful to determine what is present (Figs 1 and 2). Examination of the CXR can immediately provide information about lead configuration, and thus whether the device is a single- or dual-chamber pacemaker, a biventricular device, or an ICD. Practitioners will be able to recognize the number and location of the leads (RA, RV, or both). Generally, the RV lead of an ICD has two thick radio-opaque sections representing the high-voltage coils for delivery of a defibrillatory shock and terminates in the RV. A biventricular system has three leads (one in the RA, one that enters the coronary sinus and travels towards the left side of the heart, and one in the RV that often has the radio-opaque coils indicating the presence of an ICD). Careful examination of the CXR can also help determine whether the device will function as intended. For

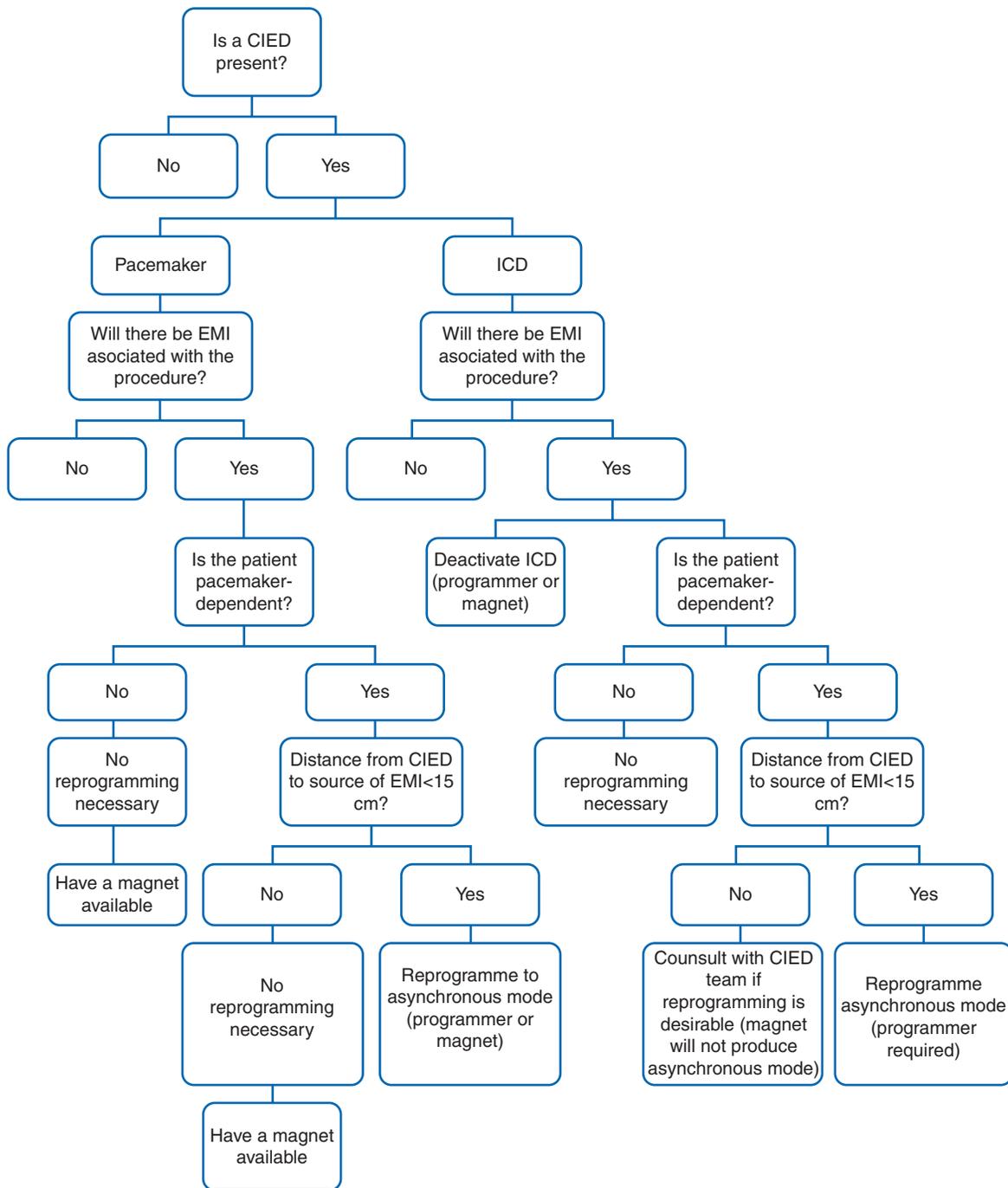


Fig 3 Suggested algorithm for preoperative decision-making regarding a modern CIED with bipolar leads. Suggested actions involving magnet application assume that the magnet response for the device is enabled, and cautery dispersal pads are appropriately located. Additional considerations may involve suspending rate-adaptive functionality, increasing outputs for cases involving transfusions or large volume shifts, and increasing the backup rate of a demand pacemaker.

example, one can usually identify a fractured lead (e.g. from subclavian ‘crush’).

Additional steps one can take to obtain necessary information include a review of the information card patients with implanted devices are supposed to keep on hand (though this is rarely available in the preoperative holding

area) and attempted phone calls to the patient’s cardiologist or pacemaker clinic. If one can identify the device manufacturer (either by asking the patient or by markings on the device visible on CXR), then one can also attempt to get the requisite information directly from the manufacturer by calling their toll-free number.

Next, it is essential to determine the dependence on the pacing function of the CIED. If a knowledgeable consultant with a programmer is involved, they will be able to recognize pacemaker dependency if there is a lack of spontaneous ventricular activity when the pacemaker is programmed to the VVI mode at a low rate. If no consultant is available, one should obtain a specific history and examine the ECG. A history that the indication for device implantation involved symptomatic bradyarrhythmia or syncope suggests pacemaker dependence, as does a history of AV nodal ablation. One should examine the ECG for P-waves and pacing spikes. If every P-wave and/or QRS complex on the ECG is preceded by a pacemaker spike, the likelihood is high that the patient is pacemaker-dependent and dependency should be the assumption.

Provocative manoeuvres to elicit bradycardia (e.g. prolonged Valsalva manoeuvre, or giving a small dose of edrophonium, esmolol, or adenosine) can be helpful to ensure effective sensing, pacing, and mechanical capture, but are not recommended and certainly should only be performed with extreme caution after assuring that a backup plan for pacing is already in place. Again, dependency should be the assumption if there is doubt, and there will rarely be the need for provocative manoeuvres.

Once pacemaker dependency has been established, one needs to determine whether reprogramming is necessary. Formal reprogramming of a pacemaker to an asynchronous mode is only done for pacemaker-dependent patients who will be exposed to significant EMI. In prior years, it was considered preferable by many to have all pacemaker reprogramming done by a knowledgeable consultant using the manufacturer's programmer. However, experience has shown that a magnet can easily be placed and secured over the device to reliably and conveniently create an asynchronous pacing mode when needed with modern devices implanted since 2000.

Furthermore, it is now appreciated that the use of a magnet might represent a safer and more convenient strategy due to the rapid reversion of the pacemaker to previous settings when the magnet is removed. Patients who are not pacemaker-dependent do not require reprogramming. If no reprogramming is deemed necessary, it is recommended that rate modulation be suspended in the perioperative period (it should be understood that rate adaptive functionality is suspended when a pacemaker is programmed to an asynchronous mode).

Despite recent data regarding the minimal EMI exposure to CIEDs distant from the site of surgery, in the interest of the highest level of safety for patients, without exception, the anti-tachyarrhythmia functions of an ICD should be suspended. This can be performed by reprogramming the device, although it is common nowadays to use a magnet for this purpose. While there are some caveats to this (discussed in detail below), the proper use of a magnet is a reliable and safe way to disable a modern ICD and can quickly restore the defibrillatory function of the device (should it be required perioperatively) without the need for additional reprogramming.

Equally important as having the pacemaker reprogrammed where needed and/or having the ICD deactivated is assuring that appropriate monitoring and vigilance are maintained, with the immediate availability of temporary pacing or external defibrillation if necessary until all CIED settings have been restored. The usual convention is to monitor the patient with external defibrillation/pacing pads connected to a bedside monitor/defibrillator on standby. An anterior-posterior configuration of the pads is recommended because it is perpendicular to the usual axis of the leads, and theoretically minimizes the induction of current down the leads if the pads need to be used.

Magnet use

Pacemakers

Application of a magnet to a modern pacemaker produces an asynchronous mode of pacing to protect a patient from the effects of EMI. The asynchronous rate obtained depends on the programming of the device, the remaining battery life, and defaults that vary by manufacturer. The specific mode of asynchronous pacing (e.g. AOO, VOO, and DOO) depends on the programming configuration of the device. Once the magnet is applied, asynchronous pacing persists for as long as the magnet remains in place over the pulse generator. Removal of the magnet results in reversion to baseline device programming.

Implantable cardioverter defibrillators

While there are no specific recommendations, a magnet can be secured over the pulse generator of an ICD to suspend the arrhythmia detection function of the ICD and prevent discharge. Subsequent removal of the magnet promptly reactivates the ICD. Compared with formal deactivation of detection by reprogramming, magnet use allows rapid re-initiation of the arrhythmia detection function of the device without the need for a programmer should a tachyarrhythmia occur and at the end of the procedure. The main caveat to the routine use of magnets to temporarily deactivate an ICD revolves around whether or not there is a possibility that the magnet response of the ICD is programmed to ignore magnet application.

Medtronic devices do not have such an option, and magnet application should reliably deactivate the device. Removal of the magnet should reliably reactivate the device. Some Boston Scientific and St Jude devices do have the option of programming the magnet response to off, which underscores the need to know how an implanted device is programmed (and illustrates why a false sense of security can result from the prevailing attitude of 'just stick a magnet on it'). If the patient has a Boston Scientific/Guidant Contak Renewal (a specific model of ICD that was subject to recall), a consultant should formally deactivate the device with a programmer.

Unlike Medtronic, St Jude, and devices from other manufacturers, Boston Scientific ICDs produce audible R-wave synchronous tones to let one know that the device has been

successfully deactivated. As long as one hears these tones, arrhythmia detection is suspended. Removal of the magnet reactivates detection and the tones will cease. If the position of the magnet shifts from the device (e.g. during positioning), the tones will cease, indicating reactivation of the device. The annunciation of a continuous tone indicates that the Boston Scientific device is programmed to off, and should prompt consultation with a knowledgeable colleague to interrogate the device. Failure to hear tones at all with magnet application suggests either that the magnet is not properly positioned, that the device is programmed to ignore magnet application, or that the device is not manufactured by Boston Scientific.

Medtronic devices also produce audible tones (similar to a European police siren) upon magnet application that indicate an alert is present, but which do not specifically indicate the status of antitachyarrhythmia detection or therapies. St Jude devices do not annunciate tones upon magnet application. One should always remember that all ICDs have backup pacing function.

Even when the ICD has been deactivated by a magnet, pacemaker function of an ICD is not affected. Thus, in a patient with an ICD, the magnet response will always be to deactivate the ICD and the pacing behaviour will not change to an asynchronous mode. If it is determined that an asynchronous mode is required for a pacemaker-dependent patient, this reprogramming should be performed by a knowledgeable consultant with a device programmer, or placement of a temporary transvenous pacemaker should be considered. If an asynchronous mode of pacing is manifest following application of a magnet, it is highly unlikely that an ICD is present.

Intraoperative considerations

Intraoperatively, vigilance must not be suspended, even if a device was reprogrammed. The patient with a CIED is at high risk of dysrhythmias and potentially interference from EMI. Thus, the cardiac rate and rhythm must be carefully monitored, and the peripheral pulse must be continuously assessed (by the pulse oximeter, by direct palpation, or by observation of an arterial waveform if invasive arterial pressure monitoring is in use) due to the risk of pulseless electrical activity in this high-risk population.

Any changes in electrical activity or sudden haemodynamic instability that seems temporally related to EMI should prompt one to ask the surgeon to temporarily stop using cautery until haemodynamic conditions are stabilized. If adverse pacing behaviour (or inhibition of pacing) is manifest, application of a magnet to the pulse generator should produce an asynchronous mode as long as an ICD is not present.

Precautionary measures that should also be used include: placing the cautery dispersal plate as distal as possible with respect to the site of device implantation, suggesting the limitation of cautery use to short, irregular bursts and using more 'cutting' than 'coagulating' current. One can also

recommend the use of a bipolar cautery unit, though this will rarely be surgically acceptable outside the setting of ophthalmological or neurosurgical cases. If the patient develops a malignant ventricular tachyarrhythmia, one should rapidly cardiovert or defibrillate the patient (in accordance with standard ACLS protocols) while attempting to minimize the current that might flow through the pulse generator and leads by positioning the external pads or hand-held paddles as far as possible from the pulse generator. Where feasible, an anterior–posterior position is preferred.

An ICD that has been deactivated by magnet application can be rapidly reactivated by magnet removal. Failure of the device to immediately sense the dysrhythmia, to charge, and to deliver a shock should prompt immediate external defibrillation.

Anaesthetic drugs and technique

Commonly used anesthetic agents are not believed to affect pacing thresholds, though the sequelae of anaesthetic management can, including hyperventilation (which can abruptly lower serum potassium concentration), significant acid–base, electrolyte, or both disturbances, significant volume loads, transfusion of blood, myocardial ischaemia, and high blood concentrations of local anaesthetics that can increase capture thresholds of the leads and alter lead impedance.

Postoperative considerations

After operation, the patient needs to remain appropriately monitored with the immediate availability of an external source of backup pacing and defibrillation until CIED settings are restored to baseline (particularly until the ICD is reactivated).

One of the more controversial aspects of the Practice Advisory is the recommendation that all devices be interrogated for the appropriateness of all settings before transfer from the recovery unit (or intensive care unit) to a non-monitored setting. The extent to which this recommendation is followed can depend on the manner in which the device behaviour was temporarily altered for the surgical procedure (magnet vs programmer) and a variety of intraoperative factors. As outlined in the HRS consensus statement,⁶ Table 5 defines those situations or intraoperative occurrences that should prompt a postoperative interrogation by knowledgeable personnel in the interest of the highest possible level of patient safety. Though it is not specifically discussed in that document, one should always consider requesting an evaluation of a CIED if there is a question of the appropriateness of device function. It might also be reasonable to have any device interrogated if a pulmonary artery catheter has been placed in the setting of recently implanted leads (<6 weeks), or when cannulae have been placed in the heart for cardiopulmonary bypass or mechanical circulatory support.

Table 5 Recommended indications for the interrogation of CIEDs before patient discharge or transfer from a cardiac telemetry environment⁶

Patients with CIEDs reprogrammed before the procedure that left the device non-functional such as disabling tachycardia detection in an ICD
Patients with CIEDs who underwent haemodynamically challenging surgeries such as cardiac surgery or significant vascular surgery (e.g. abdominal aortic aneurysmal repair)
Patients with CIEDs who experienced significant intraoperative events including cardiac arrest requiring temporary pacing or cardiopulmonary resuscitation and those who required external electrical cardioversion
Emergent surgery where the site of EMI exposure was above the umbilicus
Cardiothoracic surgery
Patients with CIEDs who underwent certain types of procedures that emit EMI with a greater probability of affecting device function
Patients with CIEDs who have logistical limitations that would prevent reliable device evaluation within 1 month from their procedure

Recommendations for specific procedures

The following summarizes the recommendations for specific non-operating theatre procedures associated with EMI.

For radiofrequency ablation, an ICD should be disabled, a pacemaker should be reprogrammed to an asynchronous mode in dependent patients, and ablation currents should be kept as far away as possible from the pulse generator and leads because current can be conducted down the leads to their point of contact with the myocardium.

Magnetic resonance imaging (MRI) has previously been contraindicated in patients with a CIED due to concerns surrounding the generation of heat, effects on pacing function, and the possibility that magnetic fields will induce current down the leads. Currently, there are several manufacturers that have MRI safe pacemakers. In the USA, Medtronic has recently released an FDA-approved device, but in Europe, in addition to Medtronic, St Jude Medical and Biotronik also have MRI safe pacemakers. The specific recommendations for scanning patients with these devices can be obtained from the manufacturer. It is critical to understand that it is not just the pulse generator that must be MRI safe, but the leads themselves have special designs and must be MRI safe as well. There are many centres, however, that perform limited MRI scanning using specific protocols in patients with current CIEDs. Despite this, having a CIED present is generally considered a contraindication to MRI scanning.

For extracorporeal shock wave lithotripsy, the ICD should be disabled, and atrial sensing/pacing disabled if the lithotripter triggers on the R-wave. Note that lithotripter shocks delivered in the proximity of a CIED can potentially loosen semiconductor components and lead connections.

For electroconvulsive therapy, disable the ICD and have the CIED interrogated following the therapy to assure the appropriateness of all settings.

Radiation therapy is not associated with EMI; however, as outlined in the HRS consensus statement, ionizing radiation is the most likely cause of electrical resets^{29 30} because ionizing radiation can cause cumulative damage to the insulation of the leads and the semiconductor circuitry within the pulse generator. Radiation therapy is not contraindicated in patients with CIEDs, assuming that appropriate shielding is used. The recommendation is to consider relocating the generator if it cannot be adequately shielded from the radiation field.

Conclusion

The ideal perioperative management of patients with a CIED derives from a multidisciplinary approach involving the procedural team, the patient's CIED team, and possibly IEAPs. Where such an approach is not feasible or has not occurred as envisioned, safe and effective perioperative care must still be rendered, and it is incumbent on anaesthesiologists to become familiar with the current recommendations and their implementation. While advances in modern CIED technology and in surgical equipment have decreased vulnerability to EMI in recent years, in the interest of the highest possible level of patient safety, the current practice recommendations continue to emphasize the need for an individualized and thoughtful approach to each patient, with specific actions taken to minimize CIED exposure to EMI and to protect patients from untoward haemodynamic effects as a result of such exposure in the perioperative period. The need to have every CIED interrogated before discharge of a patient from a monitored setting remains a controversial issue, but the recommendations set forth in the HRS consensus statement provide guidance in this decision-making process.

Conflict of interest

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