

Anaesthetic consideration in patients with cardiac implantable electronic devices scheduled for surgery

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ABSTRACT

With advances in cardiology and cardiothoracic surgery, several newer implantable cardiac devices have become common in the surgical population. Multichamber pacemakers, implanted cardiac defibrillators and ventricular assist devices are frequent in current day practice. Many of the newer implantable cardiac electronic devices are targeted at managing heart failure. While managing such patients for non-cardiac surgeries, specific issues related to equipment characteristics and troubleshooting should be a priority for the anaesthesiologists. There is a possibility of malfunction of the devices resulting in catastrophic outcomes. Therefore, it is imperative to understand the pathophysiology, device characteristics and troubleshooting before embarking on anaesthetising patients with implantable cardiac electronic devices.

Key words: Cardiac resynchronisation, haemodynamic monitoring, implantable intracardiac electronic devices, pacing, troubleshooting

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INTRODUCTION

Cardiac implantable electronic devices (CIEDs) are used to treat problems with rhythm and heart failure. Table 1 shows the types of implantable electronic devices (IEDs) commonly used. Implantable haemodynamic monitoring devices have been recently approved by the Food and Drug Administration in the United States of America in order to assist in heart failure management. It is vital for the anaesthesiologists to know the equipment characteristics, troubleshooting and their interaction with anaesthetic manoeuvres and agents to safely anaesthetise the patients with any of these implanted devices. The implanted devices treat near-fatal conditions (such as extreme bradycardia, ventricular fibrillation and pulseless ventricular tachycardia). Anaesthesiologists who are alien to the management of these CIEDs could be situationally challenged, which may result in deleterious effects to the patient and cause permanent device damage. In the United States of America alone, more than 3 million people have PPMs implanted and about 300,000 people have artificial implantable cardioverter defibrillators (AICDs) with pacing capabilities.^[1,2] The number of people with these CIEDs are increasing world over and present more frequently for non-cardiac

surgery. In a recent survey from India, Shenthar *et al.* reported that about 37,000 cardiac device implantations take place in India annually.^[3] About 80% of these procedures consisted of bradycardia-related permanent pacemaker (PM) insertions, 10% were ICDs and the remaining were cardiac resynchronization therapy devices (CRTDs). Hence, it is reasonable to expect anaesthesiologists to encounter patients with either one of the CIEDs scheduled for surgery in their day-to-day practice. Discussion about PPM [Figure 1a], AICD [Figure 1b], CRT [Figure 1c], CRTD [Figure 1d] and haemodynamic monitoring implants^[4] is relevant.

TECHNOLOGY OVERVIEW

Permanent pacemakers

A single-chamber pacemaker has a pulse generator with a single lead implanted in the right ventricle (RV)

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Table 1: Type of devices	
Issue	Device
Problem with conduction system	PPM
Treatment of life-threatening arrhythmias	AICD
Treating heart failure	CRT and CRTD
Adjunct to heart failure management	Implantable pulmonary artery pressure monitoring (heart failure monitoring system)

PPM – Permanent pacemaker; AICD – Artificial implantable cardioverter defibrillator; CRT – Cardiac resynchronisation therapy; CRTD – Cardiac resynchronisation therapy, with or without defibrillator

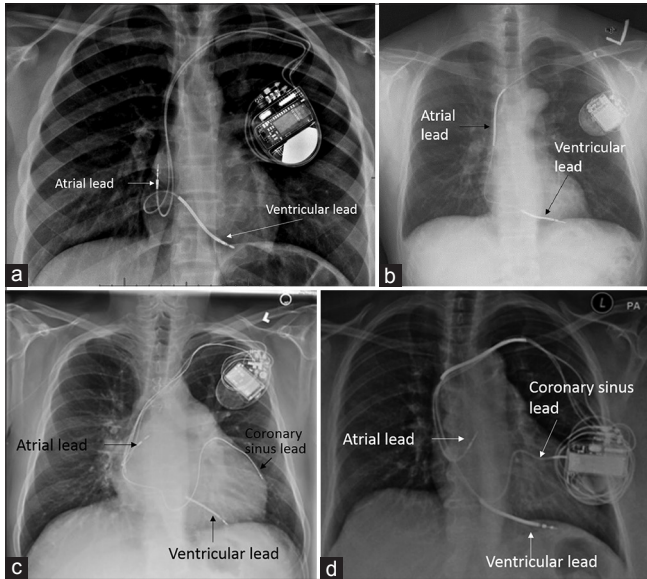


Figure 1: (a) Lead disposition of dual chamber pacemaker. A: atrial lead; V: ventricular lead. (b) Automatic implantable cardioverter defibrillator. (c) Leads in right atrium, right ventricle and coronary sinus to aid in cardiac resynchronization therapy. (d) Cardiac resynchronization with defibrillation device *in situ*

Dual-chamber pacemakers have a pulse generator with two leads, one implanted in the right atrium and the other in the RV [Figure 1a] Biventricular pacemakers have a pulse generator with three leads implanted in the right atrium, RV and coronary sinus which allows pacing of the left ventricle.

All cardiac pacemakers consist of a pulse generator, which provides the electrical impulse from a battery power source implanted commonly in the infraclavicular region of the anterior chest wall, and one or more electrodes (referred to as leads), which deliver the electrical impulse from the pulse generator to the myocardium. The leads are placed either percutaneously or via venous cutdown.

Epicardial cardiac pacemaker systems utilise a pulse generator with leads that are surgically attached

directly to the epicardial surface of the heart. These systems have largely been replaced by transvenous systems. The major role for epicardial pacing systems in current practice is for temporary pacing following cardiac surgery;^[5] such systems, however, are designed as temporary systems that must be removed within the 1st day to weeks following cardiac surgery.

Leadless systems have a self-contained system which includes both the pulse generator and the electrode within a single unit that is placed into the RV via a transvenous approach.^[6-8]

A pacemaker with additional features to treat ventricular tachyarrhythmias by way of defibrillation and anti-tachycardia pacing is an AICD [Figure 1c]. AICDs may be implanted for primary or secondary prevention of sudden cardiac death from ventricular tachyarrhythmias.

The AICD system comprises three elements:^[9-11]

1. Pacing/sensing electrodes: The lead with the pace/sense electrodes is placed transvenously, with the distal electrode positioned on the right ventricular apical endocardium. Dual-chamber AICDs have an additional lead with another pair of pace/sense electrodes in the right atrium for atrial sensing and pacing.
2. Defibrillation electrodes: Most contemporary AICD systems have two or three defibrillation electrodes. Along with the distal coil in the RV on the transvenous lead, some ICD leads have a second defibrillation coil proximal to the right ventricular coil. In addition, with ‘active can’ technology, the metal housing of the ICD serves as one of the shocking electrodes.
3. Pulse generator: The pulse generator contains the sensing circuitry as well as the high-voltage capacitors and battery. The development of small pulse generators (thickness ≤15 mm) has permitted pectoral implantation in nearly all patients.

The current ICD lead systems utilising between one and three leads are typically placed transvenously via the axillary, subclavian or cephalic vein. Modern devices are small enough to be implanted in the pectoral region, either subcutaneously or submuscularly, similar to a pacemaker implantation.

PACEMAKER NOMENCLATURE

A standard classification has been developed to help understand and use PPMs [Table 2]. A ‘three’-letter NBG code was first proposed in 1974 and was universally accepted.^[12] Subsequently, a five-letter code was proposed and is the mode currently used and accepted. However, most clinicians in their day-to-day communication continue to use the three-letter model.

Position I – Reflects the chamber(s) paced; Position II – Reflects the chamber(s) sensed. Programmed in the ‘O’ mode, a device will pace automatically at a specified rate, ignoring any intrinsic rhythm; Position III – Position III refers to how the pacemaker responds to a sensed event; ‘I’ indicates that a sensed event inhibits the output pulse and causes the pacemaker to recycle for one or more timing cycles. ‘T’ indicates that an output pulse is triggered in response to a sensed event. ‘D’ indicates dual modes of response and is restricted to dual chamber systems. An event sensed in the atrium inhibits the atrial output but triggers a ventricular output. There is a programmable delay between the sensed atrial event and the triggered ventricular output to mimic the normal PR interval. If the ventricular lead senses a native ventricular signal during the programmed delay, it will inhibit the ventricular output. ‘O’ indicates no response to sensed input; it is most commonly used in conjunction with an ‘O’ in the second position; Position IV – The fourth position reflects rate modulation, also referred to as rate responsive or rate adaptive pacing. ‘R’ indicates that the pacemaker has rate modulation and incorporates a sensor to adjust its programmed paced heart rate in response to patient activity. ‘O’ indicates that rate modulation is either unavailable or disabled; Position V – Rarely used fifth position. Specifies only the location or absence of multisite pacing, defined as stimulation sites in both atria, both ventricles, more than one stimulation site in any single chamber or a combination of these. The most common application of multisite pacing is biventricular pacing for the management of heart failure.

Commonly used modes of pacing are shown in Table 3. VVI pacing with a transvenous catheter inserted into the RV is a common clinical scenario. It implies that demand ventricular pacing is initiated; the output is inhibited by sensed ventricular activity. Anaesthesiologists must be familiar with this mode and ECG showing ‘pacing spikes’ [Figure 2].

ELECTROMAGNETIC INTERFERENCE

Electromagnetic interference (EMI) is the potential disruption of the operation of an electronic device when it is in the vicinity of an electromagnetic field generated by an external source. During surgical procedures, the function of CIEDs may be affected by EMI, most commonly due to use of an electrocautery unit (ECU). Cardiac IEDs with unipolar sensing configuration are more susceptible to EMI than those with bipolar sensing. ECU uses radiofrequency current to transect tissues and achieve haemostasis. The effects of ECU on CIEDs differ depending on whether the ECU used is monopolar or bipolar. Current flow is localised between the two poles of the bipolar cautery instrument and usually not associated with problems. When monopolar cautery is used, the current flow is not restricted and spreads throughout the body. It is important for anaesthesiologists to realise that many electrical interferences such as electrocautery may be perceived by the pacemaker as intrinsic rhythm and the pulse generation may be inhibited. With ongoing electrical interference monitoring, ECG alone may not alert the

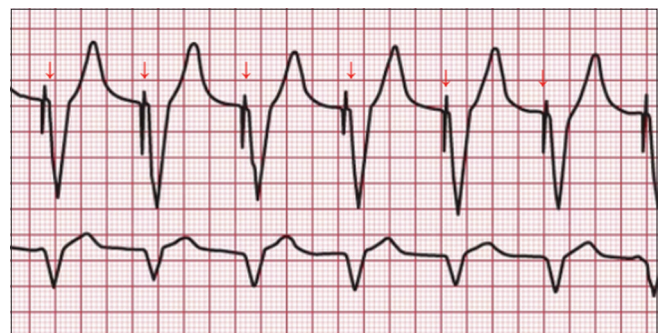


Figure 2: VVI pacing. Arrows show pacing ‘spikes’

Table 2: Pacemaker codes

Position I Pacing chamber(s)	Position II Sensing chamber(s)	Position III Response(s) to sensing	Position IV Programmability	Position V Multisite pacing
O	O	O	O	O
A	A	I	R	A
V	V	T		V
D (A + V)	D (A + V)	D (T + I)		D (A + V)

O – None; A – Atrium; V – Ventricle; D – Dual; I – Inhibited; T – Triggered; R – Rate modulation

anaesthesiologists involved in patient care about the absence of heart rhythm. In such cases, it may be wise to monitor the pulse plethysmography from pulse oximeter waveform or arterial waveform.^[13-19]

PRE-OPERATIVE ASSESSMENT

In addition to a thorough history and physical examination, a focused interview on the CIED is essential. In most patients, a detailed patient information card will be present detailing the type of device and model number, the indication for insertion and current settings.

Pre-operative chest radiograph^[20] can give the following information: difference between a PPM and AICD; the number and position of lead (s) and the presence of a fractured lead. The RV lead in an AICD has two thick opaque sections representing high-voltage coils for defibrillatory shock delivery and terminates in the RV.

DEVICE INTERROGATION

The rhythm and functioning of the CIED must be reconfirmed in the pre-operative period.^[21-30] In most patients, this can be accomplished by accessing the results of a recent interrogation of the CIED. This is performed by trained technicians, whose contact details are available with the patient or the cardiologist. Recommendations of the Heart Rhythm Society for CIED interrogation before surgery are as follows: within 6 months for an AICD, within 12 months for a conventional PPM and within 3–6 months for any CRT device.

Patients who have a pacing burden of $\geq 40\%$ are deemed to be pacing dependent. An electrocardiogram that reveals a predominately paced rhythm also implies pacing dependence. The ECG should be examined for P-waves and pacing spikes. A pacing spike before every P-wave and/or QRS complex suggests that the patient is pacemaker dependent.

During pre-operative evaluation, the following should be addressed: If the patient is pacing dependent and there is a potential for interaction with EMI, then the mode of the PPM must be changed to asynchronous mode of pacing using a programming machine and in some cases a magnet.

When the patient has an AICD and there is potential for generation of EMI, the anti-tachycardia function of the AICD must be suspended.

REPROGRAMMING WITH A PROGRAMMING DEVICE

A reprogramming machine is used to suspend anti-tachyarrhythmia settings. It is essential to have transcutaneous pacing when the anti-tachyarrhythmia functions are disabled, as the AICD will not respond when there is VT. The advantages of using a reprogramming machine include changing an AICD to asynchronous mode and disabling a rate responsive sensor.^[24] However, the use of a reprogramming machine must be done by trained personnel and the changes are not quickly reversible like that of a magnet.

ROLE OF A MAGNET

A magnet is used to suspend anti-tachyarrhythmia functions of an AICD or to produce asynchronous pacing in a PPM. The use has been advocated by certain societies.^[21,25] However, the routine use of the magnet is not encouraged.^[22,23,30] When a magnet is applied on a PPM, asynchronous pacing will be initiated and when applied on an AICD anti-tachyarrhythmia detection is suspended but not pacing capabilities.

Since a magnet cannot initiate asynchronous pacing mode in an AICD, EMI can result in bradycardia or asystole. Other disadvantages include ability to maintain the position of the magnet in lateral or prone position, possible compromise to operative field sterility and presence of surgical drapes can hinder access to the magnet.

A word of caution while magnets are being used: the magnets have to be used by either technicians with knowledge of their effect or by doctors capable of handling the resultant asynchronous rhythm.

INTRAOPERATIVE MANAGEMENT

It is essential that the patient has continuous ECG and pulse oximetry monitoring and arterial pressure monitoring if indicated to give a beat-to-beat display and for correlation with artefacts and electrical interference.

The ECG monitor display should be selected such that the presence of pacing spikes is displayed. The filter in the ECG monitor should be set at 'diagnostic' so that the pacing spikes can be appreciated.

Use of a bipolar cautery is preferred. The electrosurgical receiving plate must be positioned so that the current pathway does not pass through or near the pacemaker. Electrocautery bursts should be limited to one second every 10 second interval. Artefacts may be picked up as QRS complexes and thus a false heart rate could be displayed. The presence of either a pulse oximeter or an arterial line will display the true heart rate, and determine whether the electrical pacing signal results in a mechanical ventricular contraction and can help detect the presence of an adequate arterial pulse or asystole.^[21,24]

It is essential to have equipment for urgent transcutaneous pacing, defibrillation or cardioversion. Transcutaneous pacing or defibrillator pads are best placed when the device has been reprogrammed. For an emergency, an external defibrillator with pacing capabilities must be available. The transcutaneous pacing or defibrillator pads must not be placed directly over the CIED. In a majority of the patients, the CIED is left sided, and the transcutaneous pacing or defibrillator pads can be positioned in an anteroposterior fashion.

The cautery pad must be positioned such that the current from the ECU does not cross the CIED generator or leads.

During insertion of a central venous line, the anti-tachyarrhythmia function must be suspended and asynchronous mode must be initiated. An external defibrillator with pacing capabilities must be available. Continuous monitoring of the ECG and pulse oximetry is essential; waveform monitoring is advocated during insertion of central venous line whenever possible. The chance of dislodgment of a lead is maximum within 3 months of insertion of the CIED.^[21,31] A pre-central line radiograph will help us with the position of the leads and a post-central line X-ray will help diagnose possible lead dislodgment.

ANAESTHETIC AGENTS

Anaesthetic agents have no effect on the function of CIEDs in the perioperative period. However, in patients with bradycardia, avoiding high doses of fentanyl or dexmedetomidine may be prudent to prevent PPM dependence.^[32-34] In patients with long QT syndrome, drugs which cause QT prolongation such as methadone, haloperidol, ondansetron and high doses of inhalation agents are best avoided due to the theoretical risk of polymorphic ventricular tachycardia.^[35-39]

HAEMODYNAMIC MANAGEMENT

If the patient is pacemaker dependent, and the PPM has been programmed to a fixed rate, it is important to realise that tachycardia will not be seen in response to hypovolaemia. Careful attention to fluid replacement is essential.

INTRAOPERATIVE EMERGENCIES

In the event of an arrhythmia or bradycardia, before attempting defibrillation, the magnet if applied should be removed to permit reactivation of anti-tachyarrhythmia function. All sources of EMI should be discontinued to allow proper interpretation of the rhythm and appropriate therapy. Failure of the rhythm to revert after removal of the magnet will require either defibrillation or cardioversion depending on the rhythm. During the occurrence of such an event, bedside ECG recording with paper is helpful to determine the ventricular rate and rhythm. There may be a possibility that the recorded ventricular rate is lower than the set rate on the AICD, requiring reprogramming of the device in the post-operative period.

Total failure of a device is rare. Exposure of older devices to EMI rarely results in total failure. Problems with the device may manifest as inappropriate delivery of shocks or 'runaway' high rate (180–200 beats/min).^[22,39]

EMERGENCY SURGERY

In an emergency, time may be inadequate to evaluate the CIED. Patients who are undergoing supraumbilical surgeries are at a higher risk for EMI from the ECU if monopolar cautery use is needed.

Application of a magnet would be ideal if time permits. An ECG paper recording pre- and post-magnet application will allow us to know if the desired response is achieved.

Application of transcutaneous pacing/defibrillator pads is essential along with a standby external defibrillator with pacing capabilities. Continuous ECG, pulse oximetry monitoring and additionally an arterial line if indicated are essential.

POST-OPERATIVE MANAGEMENT

The rate and rhythm must be monitored continuously in the post-operative period.^[19,24,40] The CIED must be interrogated in the immediate post-operative period.

In the presence of haemodynamic instability, selection of a higher heart rate or a more optimal atrioventricular delay may be required. Following surgery till the device is reprogrammed to the original setting, the patient must be continuously monitored on an ECG and pulse oximetry. It is essential that both transcutaneous pacing/defibrillator pads and an external defibrillator are immediately available.

PACEMAKERS AND SPECIFIC CLINICAL CIRCUMSTANCES

Magnetic resonance imaging

The potential for magnetic field-induced lead heating of the CIED during magnetic resonance imaging (MRI) can result in myocardial thermal injury and changes in pacing properties.^[41-43]

The term 'magnetic resonance (MR) conditional' refers to any device for which a specified MRI environment with specified conditions of use does not pose a known hazard. The term 'MR safe' requires there be no hazard in any MR environment. For example, plastic objects are MR safe. No CIED has an MR safe designation. The designation MR unsafe refers to an object that is known to pose hazards in all MR environments. 'MR non-conditional' systems include all CIED systems other than those that meet MR conditional labelling.

RADIATION THERAPY

High-energy ionising radiation used in radiation therapy can cause damage to pacemakers, even at very small doses.^[44] The possible damage^[45-47] can be divided into three types: (a) temporary change resulting in oversensing, (b) reset to factory settings and (c) complete device failure

Recommendations for management of a patient with CIED for radiation therapy^[48] include to assess if the patient is pacing dependent and use a non-neutron producing treatment rather than a neutron producing treatment to minimise the risk of device reset. In the event a neutron producing treatment is used, the CIED must be evaluated every week. The CIED must be relocated if the current location of the CIED will interfere with the treatment.

EXTRACORPOREAL SHOCK WAVE LITHOTRIPSY

Extracorporeal shock wave lithotripsy (ESWL) has been used to treat upper urinary tract calculi. In the

past, the presence of piezoelectric crystal for rate adaptive pacing could be damaged by the ESWL shock wave. However, modern devices do not incorporate piezoelectric crystals. For patients who have any significant degree of pacemaker dependence, pacing mode should be reprogrammed to VOO or DOO because of the potential for inhibition of the ventricular pacing circuit due to interference from the ESWL wave.

DIRECT CURRENT CARIOVERSION AND DEFIBRILLATION

Transthoracic direct current (DC) shock is used to treat life-threatening atrial and ventricular tachyarrhythmias. 'Zener' diode is incorporated into modern CIEDs to protect against damage from DC shocks.^[49] The diode directs a surge in current toward the electrode, protecting the pacemaker circuitry but delivering this energy to the endocardium. The cardioverter-defibrillator can also cause capacitive coupling with the endocardial lead, causing direct discharge at the electrode-endocardium interface.^[50] This leads to transient failure to capture by the CIED but in some instances due to the large discharge of focal energy permanent failure can ensue. Positioning of the paddles close on the chest wall can lead to the development of electrostatic discharges which can be interpreted as signals by AICDs.

Precautions for DC cardioversion and defibrillation in patients with AICDs include ascertaining that the paddles should be as far (>10 cm) from the pulse generator as possible without compromising the efficacy of the procedure and that the current path should be perpendicular to the plane of the pacing system, using anterior-posterior paddles.

RECENT ADVANCES: IMPLANTABLE HAEMODYNAMIC MONITORS/PRESSURE SENSORS

These devices are essentially toward haemodynamic management in patients with heart failure. These devices measure and upload the pulmonary artery blood pressure on a regular basis to assist the physician in controlling heart failure. They are new in the market and anaesthesia in patients having them is still a novelty. The first of these devices used is a diaphragm-tipped pressure catheter that would be passively placed in a vascular structure. In the case of the Medtronic Chronicle device, a generator was implanted subcutaneously and attached to a lead with

its electrode tip placed subcutaneously in the RV by passive fixation. This allows for remote measurement of RV systolic and diastolic pressure, imputed PA diastolic pressure, heart rate, activity, RV dp/dt and core body temperature. CardioMEMS is yet another heart failure management device that is placed in the distal pulmonary artery for monitoring PA pressure digitally, remotely. It is said that increasing PA pressure in heart failure situations heralds the onset of requirement of repeated hospital admissions. This instrument could permit the physician in viewing the trend of PA pressure over 90 days.

SUMMARY

Anaesthesiologists will encounter patients with CIEDs during their practice. Since after CIED implantation, the patients are reasonably well rehabilitated, they would be presenting for non-cardiac surgeries. Anaesthesiologists irrespective of the subspeciality of their practice may make an effort to understand equipment characteristics, troubleshooting and bail out of catastrophic complications. The number of CIED implants will increase with increasing number of patients having indications for placement of the same; thus, the need to understand them becomes all the more important.

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