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Perioperative care of the patient with a cardiac pacemaker or ICD

Marc A. Rozner, PhD, MD*

* Professor of Anesthesiology and Perioperative Medicine. Professor of Cardiology.
The University of Texas MD Anderson Cancer Center

Preoperative key points

- Have the pacemaker or defibrillator interrogated by a competent authority shortly before the anesthetic.
- Obtain a copy of this interrogation. Ensure that the device will pace the heart.
- 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.
- Determine the patient's underlying rhythm/rate to determine the need for backup pacing support.
- Identify the magnet rate and rhythm, if a magnet mode is present and magnet use is planned.
- Program minute ventilation rate responsiveness off, if present.
- Program all rate enhancements off.
- Consider increasing the pacing rate to optimize oxygen delivery to tissues for major cases.
- Disable antitachycardia therapy if a defibrillator.

Intraoperative key points

- Monitor cardiac rhythm / peripheral pulse with pulse oximeter or arterial waveform.
- Disable the «artifact filter» on the EKG monitor.
- Avoid use of monopolar electrosurgery (ESU).
- Use bipolar ESU if possible; if not possible, then pure cut (monopolar ESU) is better than «blend» or «coag».
- Place the ESU current return pad in such a way to prevent electricity from crossing 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 and pacer quiescence, limit the period(s) of asystole.

Postoperative key points

- Have the device interrogated by a competent authority postop. Some rate enhancements can be re-initiated, and optimum heart rate and pacing parameters should be determined. Any ICD patient must be monitored until the antitachycardia therapy is restored.

INTRODUCTION

Battery operated pacemakers were developed in 1958, and implantable cardioverterdefibrillators (ICDs) followed in 1980. ICD advancements have three important results. First, due to pacing spikes on an ECG, a pectoral (rather than abdominal) ICD might be mistaken for a (non-ICD) pacemaker. If ECGs are routinely collected from patients with «pacemakers» using a magnet, then some ICDs from Boston Scientific (BOS)/Guidant/CPI might be permanently deactivated with magnet placement[1]. Second, ICD brady-pacing is NEVER converted to asynchronous mode with magnet placement. Third, ICDs respond to, and process, electromagnetic interference (EMI) differently than a pacemaker.

The complexity of cardiac generators limits generalizations that can be made about the perioperative care of these patients. Population aging, continued enhancements and new indications for implantation of cardiac devices will lead to increased implantations. These issues led the American Society of Anesthesiologists (ASA) to publish a Practice Advisory for these patients[2]. Other guidelines have been published as well[3-6], although not all authors recommend ICD disablement in the perioperative period[7]. ICDs also perform permanent cardiac pacing, so ICD issues related primarily to antibrady pacing should be reviewed in the Pacing section.

Recently, some generator manufacturers have issued a variety of notices regarding potential failures in both pacemakers[8-10] and ICDs[11-13]. Also, for some ICDs, Guidant has found that the device improperly enters the «magnet mode», which prevents any detection (and, therefore, treatment) of tachyarrhythmias. As a «work-around», Guidant has recommended the permanent disabling of the magnet mode through programming[14]. Retrospective analysis suggests that outright failure occurs in 1.4 (pacemaker) and 36.4 (ICD) per 1,000 implants in 2001-2002[15].

Finally, devices resembling cardiac pulse generators are being implanted at increasing rates for pain control, thalamic stimulation to control Parkinson's disease, phrenic nerve stimulation to stimulate the diaphragm in paralyzed patients, and vagus nerve stimulation to control epilepsy and possibly obesity[16].

Interestingly, a new report states that monopolar electrosurgery (the «Bovie») is unlikely to interfere with either pacemaker or ICD generators[17]. Other reports might not agree[18,19].

PACEMAKER OVERVIEW

More than 2,000 pacemaker models have been produced by 27 companies, and more than 250,000 adults and children in the US undergo new pacemaker placement yearly. Nearly 3 million US patients have pacemakers. Outdated literature and limited training often lead to confusion regarding pacemakers and perioperative care.

These systems consist of an impulse generator and lead(s). Leads can have one (unipolar), two (bipolar), or multiple (multipolar) electrodes with connections in multiple chambers. In unipolar pacing, the generator case serves as an electrode, and tissue contact can be disrupted by pocket gas[20]. Pacemakers with unipolar leads produce larger «spikes» on an analogue-recorded ECG, and they are more sensitive to EMI. Most pacemaking systems use bipolar pacing/sensing configuration, since bipolar pacing usually requires less energy and bipolar sensing is more resistant to interference from muscle artifacts or stray electromagnetic fields. Often, bipolar electrodes can be identified on the chest film since they will have a ring electrode 1 to 3 cm proximal to the lead tip. Generators with bipolar leads can be programmed to the unipolar mode for pacing, sensing, or both.

The Pacemaking Code of the North American Society of Pacing and Electrophysiology (NASPE) and the British Pacing and Electrophysiology Group (BPEG) describes basic pacing behavior (Table I)[21]. Most pacemakers in the US are programmed either to the DDD (dual chamber) or VVI mode (single chamber). DDI is used for patients with atrial dysrhythmias, and VDD pacing (single wire device providing AV synchrony) can be found in patients with AV nodal disease but normal sinus node function. Atrial-only pacing (AAI) is uncommon in the US. Biatrial pacing is being investigated as a means to prevent atrial fibrillation[22], and biventricular (BiV) pacing (also called Cardiac Resynchronization Therapy [CRT]) is used to treat dilated cardiomyopathy (DCM)[23-25].

INDICATIONS

Permanent pacing indications (Table II) are reviewed in detail elsewhere[26]. In order to be effective, BiV, HOCM, and DCM pacing must provide the stimulus for ventricular activation, and A-V synchrony must be preserved[27]. Pacemaker inhibition, loss of pacing (i.e.; from native conduction, junctional rhythm, EMI), or AV dys-synchrony can lead to deteriorating hemodynamics in these patients. BiV pacing can lengthen the Q-T interval in some patients, producing torsade-depointes[28]. Thus access to rapid defibrillation is required for the patient with BiV pacing.

PACEMAKER MAGNETS

Despite oft-repeated folklore, magnets were never intended to treat pacemaker emergencies or prevent EMI effects. Rather, magnet-activated switches were incorporated to produce pacing behavior that demonstrates remaining battery life and, sometimes, pacing threshold safety factors. Placement of a magnet over a generator might produce no change in pacing since *not all pacemakers switch to a continuous asynchronous mode when a magnet is placed*. Also, not all

Table I. NASPE/BPEG Generic Pacemaker 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)

Table II. Permanent pacemaker indications.

Sinus node disease
Atrioventricular (AV) node disease
Long Q-T syndrome
Hypertrophic obstructive cardiomyopathy (HOCM)
Dilated cardiomyopathy (DCM)

models from a given company behave the same way. Some effect(s) of magnet placement are shown in table III[29-31]. Magnet behavior can be altered or disabled via programming in some devices. For all generators, calling the manufacturer remains the most reliable method for determining magnet response and using this response to predict remaining battery life. For generators with programmable magnet behavior [Biotronik, BOS, CPI, Guidant Medical, Pacesetter, St Jude Medical], only an interrogation with a programmer can reveal current settings.

Table III. Pacemaker magnet behavior.

Most common responses (except Biotronik, Intermedics) - Asynchronous «high rate» pacing, not always in the best interest of the patient
Boston Scientific/Guidant Medical/CPI (current models since 1990, magnet mode enabled) > 85 bpm (max 100), 85 if battery depleted
Medtronic (most models) 85 bpm, 65 if battery depleted
Pacesetter/St Jude Medical (current models since 1990, magnet mode enabled) > 87 bpm (max 98.6 bpm), 86.3 if battery depleted
ELA Medical (current models since 1989) > 80 bpm (max 96 bpm), 80 if battery depleted. ELA devices take 8 additional asynchronous cycles (six at magnet rate, then two at programmed rate) upon magnet removal. Magnet placement increases the pacing voltage to 5v
Biotronik (ONLY when programmed to asynchronous mode, [not the default state]) 90 bpm, 80 if battery depleted
No apparent rhythm or rate change
No magnet sensor (some pre-1985 Cordis, Tele models)
Magnet mode disabled (possible with Biotronik, CPI, Guidant, Pacesetter, St Jude models)
EGM mode enabled (CPI, Guidant, Pacesetter, St Jude)
Program rate pacing in already paced patient (many CPI, Intermedics, Pacesetter, St Jude, Tele)
Brief (10-100 beats) asynchronous pacing, then return to program values (all Intermedics; most Biotronik models when programmed to their default state)
Continuous or transient loss of pacing
Pacing threshold problems
Discharged battery (some pre-1990 devices)
Diagnostic «Threshold Test Mode» (Siemens)

PREANESTHETIC EVALUATION AND PACEMAKER REPROGRAMMING

Preoperative management of the patient with a pacemaker includes evaluation and optimization of coexisting disease(s). No special laboratory tests or x-rays are needed for the patient with a conventional pacemaker. A patient with a BiV pacer (or ICD) might need a chest film to document the position of the coronary sinus (CS) lead, especially if central line placement is planned, since spontaneous CS lead dislodgement can occur[32,33].

Important features of the preanesthetic device evaluation are shown in *Preoperative Key Points* (above). Current NASPE and Medicare guidelines include telephonic (magnet) evaluation every 4-12 weeks (depending upon device type and age) and a comprehensive device interrogation with a programmer at least once per year[34].

Direct interrogation with a programmer remains the only reliable method for evaluating battery status, lead performance, and adequacy of current settings. Some devices collect pacing histograms and information about tachydysrhythmia(s). Appropriate reprogramming (Table IV) is the safest way to avoid intraoperative problems, especially if monopolar «Bovie» electrosurgery will be used. The pacemaker manufacturers might assist with this task (see Appendix for company telephone numbers); however, any industry-employed allied professional (i.e., the «rep») should be supervised by an appropriately trained physician[35].

Reprogramming the pacing mode to asynchronous, at a rate greater than the patient's underlying rate, usually ensures that no over- or undersensing from EMI will take place. However, setting a device to asynchronous mode has the potential to create a malignant rhythm in the patient with structurally compromised myocardium[36]. Reprogramming a device *will not* protect it from internal damage or reset

Table IV. Pacemaker reprogramming likely needed.

Any rate responsive device – see text (problems are well known, have been misinterpreted with potential for patient injury, and the FDA has issued an alert regarding devices with minute ventilation sensors (Table V)
Special pacing indication (HOCM, DCM, pediatrics)
Pacemaker-dependent patient
Major procedure in the chest or abdomen
Rate enhancements are present that should be disabled
Special procedures
Lithotripsy
Transurethral or hysteroscopic resection
Electroconvulsive therapy
MRI (usually contraindicated by device manufacturers), possible in some patients

caused by EMI. In general, rate responsiveness and «enhancements» (dynamic atrial overdrive, hysteresis, sleep rate, A-V search, etc.) should be disabled by programming[37,38]. Note that for many BOS/Guidant and/or CPI devices, BOS recommends increasing the pacing voltage to «5 volts or higher» when monopolar electrosurgery will be used. Few cardiologists follow this recommendation, but there are reports of threshold changes during both intrathoracic[39] and non-chest surgery[40].

Recently, pacing threshold was shown to be increased by disease states[41]. Special attention must be given to any device with a minute ventilation (bioimpedance) sensor (Table V), since inappropriate tachycardia has been observed secondary to mechanical ventilation[42,43], monopolar («Bovie») electrosurgery[42,44,45], and connection to an ECG monitor with respiratory rate monitoring[46-51]. Sometimes, inappropriate <anesthetic> therapy has been delivered in these settings[43,52].

Table V. Devices with minute ventilation sensors

ELA Medical Symphony, Brio (212, 220, 222), Opus RM (4534), Chorus RM (7034, 7134), Talent (130, 213, 223)
Boston Scientific/Guidant Medical and/or CPI Pulsar (1172, 1272), Pulsar Max (1,170, 1,171, 1,270), Pulsar Max II (1,180, 1,181, 1,280), Insignia Plus (1,194, 1,297, 1,298), Altrua (S401, S402, S403, S404, S601, S602, S603, S605, S606)
Medtronic Kappa 400 series (401, 403)
Telectronics / St Jude Meta (1,202, 1,204, 1,206, 1,230, 1,250, 1,254, 1,256), Tempo (1,102, 1,902, 2,102, 2,902)

INTRAOPERATIVE (OR PROCEDURE) MANAGEMENT OF PACEMAKERS

No special technique or monitoring is needed for the pacemaker patient, but attention must be given to a number of concerns (Table VI). Monopolar «Bovie» electrosurgery (ESU) use remains the principal intraoperative issue for the patient with a pacemaker. Between 1984 and 1997, the US FDA was notified of 456 adverse events with pulse generators, 255 from electrosurgery, and a «significant number» of device failures[53].

Monopolar ESU is more likely to cause problems than bipolar ESU.54 Magnet placement during electrosurgery might prevent aberrant pacemaker behavior. Spurious reprogramming with magnet placement is unlikely. If monopolar electrosurgery is to be used, then the ESU current-return pad must be placed to ensure that ESU current path does not cross the pacemaking system. Some authors recommend placement of this pad on the shoulder for head and neck procedures or the distal arm (with sterile draping of the wire) for breast and axillary procedures[54,55].

Choice of anesthetic agents should be dictated by the patient's underlying physiology as well as the procedure. However, the use of drugs that suppress the AV or SA node (such as potent opiates or dexmedetomidine) can abolish any underlying rhythm that might be present and render the patient truly pacemaker dependent. Also, some potent inhalational agents (isoflurane, sevoflurane, and desflurane) might exacerbate the long Q-T syndrome[56-59].

PACEMAKER FAILURE

Pacemaker failure has three etiologies: 1) failure to capture; 2) lead failure; or 3) generator failure. Failure to capture can result from myocardial ischemia/infarction, acid-base disturbance, electrolyte abnormalities, or abnormal antiarrhythmic drug level(s). External pacing might further inhibit pacemaker output at pacing energies that will not produce myocardial capture[60,61]. Sympathomimetic drugs generally lower pacing threshold. Outright generator and/or lead failure is rare.

POST ANESTHESIA PACEMAKER EVALUATION

Any pacemaker that was reprogrammed for the operating room should be reset appropriately. For non-reprogrammed devices, most manufacturers recommend interrogation to ensure proper functioning and remaining battery life if any electrosurgery was used.

IMPLANTABLE CARDIOVERTER-DEFIBRILLATOR (ICD) OVERVIEW

For the patient with ventricular tachycardia (VT) or fibrillation (VF), ICDs clearly reduce deaths[62,63], and they remain superior to antiarrhythmic drug therapy[64]. Initially approved by the US FDA in 1985, at least 100,000 devices

Table VI. Essentials of pacemaker monitoring.

ECG monitoring of the patient must include the ability to detect pacemaker discharges («artifact filter» disabled)
Perfused (peripheral) pulse must be monitored with a waveform display
The pacemaker rate might need to be increased due to an increased oxygen demand
BiV and HOCM patients probably need beat-to-beat cardiac output monitoring
Appropriate equipment must be on hand to provide backup pacing and/or defibrillation

will be placed this year, and more than 250,000 patients have these devices today. Further, studies suggesting prophylactic placement in patients *without* evidence of tachyarrhythmias (Multicenter Automatic Defibrillator Implantation Trial –II [MADIT-II] - ischemic cardiomyopathy, ejection fraction less than 0.30[65] and Sudden Cardiac Death – Heart Failure Trial [SCD-HeFT] – any cardiomyopathy, ejection fraction less than 0.35[66]) has significantly increased the number of patients for whom ICD therapy is indicated.

Like pacemakers, ICDs have a four-place code (Table VII)[67]. The Pacemaker Code can be used instead of Position IV.

ICDs measure each cardiac R-R interval and categorize the rate as normal, too fast (short RR interval), or too slow (long R-R interval). When enough short R-R intervals are detected, an antitachycardia event is begun. The internal computer chooses antitachycardia pacing (ATP - less energy use, better tolerated by patient) or shock, depending upon the presentation and device programming. Most ICDs are programmed to «reconfirm» VT or VF after charging to prevent inappropriate therapy. Typically, ICDs deliver 6–18 shocks per event. Once a shock is delivered, no further ATP can take place. Despite improvements in detection of ventricular dysrhythmias (Table VIII)[68], more than 10% of shocks are for rhythm other than VT or VF[69].

Supraventricular tachycardia remains the most common etiology of inappropriate shock therapy[70,71], and causes of inappropriate shock have been reviewed elsewhere[72]. Most ICDs will begin pacing when the R-R interval is too long. ICDs with sophisticated, dual and three chamber pacing modes (including rate responsiveness) are approved for patients who need permanent pacing (about 20% of ICD patients). Note that the use of dual chamber (DDD) pacing in an ICD patient might decrease survival when compared to single chamber (VVI) pacing[73].

ICD INDICATIONS

Initially, ICDs were placed for VT or VF. Currently, any patient with significant cardiomyopathy (EF ≤ 35%) will likely be a candidate for ICD placement (Table IX) shows current indications for ICD placement.

ICD MAGNETS

Like pacemakers, magnet behavior in many ICDs can be altered by programming. Most ICDs will suspend tachydysrhythmia detection (and therefore therapy) when a magnet is appropriately placed. Some ICDs from Angeion, CPI, Pacesetter (St Jude Medical) or Ventritex can be programmed to

Table VII. NASPE/BPG Generic defibrillator code (NBD).

Position I	Position II	Position III	Position IV (or use pacemaker code)
Shock chambers	Antitachycardia pacing 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)

Table VIII. ICD features to reduce undesired shock.

Onset criteria - usually, VT onset is abrupt, whereas SVT onset has sequentially shortening R-R intervals
Stability criteria - R-R intervals of VT is relatively constant, whereas R-R intervals of afib with rapid ventricular response is quite variable
QRS width criteria - usually, QRS width in SVT is narrow (< 110 msec), whereas QRS width in VT is wide (>120 msec)
«Intelligence» in dual chamber devices attempting to associate atrial activity to ventricular activity
Morphology waveform analysis with comparison to stored historical templates

Table IX. ICD Indications.

Ventricular tachycardia
Ventricular fibrillation
Post-MI patients with EF ≤ 30% (MADIT II)
Cardiomyopathy from any cause with EF ≤ 35% (SCD-HeFT)
Hypertrophic cardiomyopathy
Awaiting heart transplant
Long Q-T syndrome
Arrhythmogenic right ventricular dysplasia
Brugada syndrome (right bundle branch block, S-T segment elevation in leads V1-V3)

ignore magnet placement. Depending upon programming, *antitachycardia therapy in some BOS/Guidant/CPI devices can be permanently disabled by magnet placement for 30 seconds, and some patients have been discovered with their ICD antitachycardia therapy unintentionally disabled*[1]. In general, magnets will not affect the brady pacing mode or rate (except ELA [rate change]. The rare Telectronics Guardian 4202/4203 [pacing disabled]) and Intermedics devices (change pacing rate to VVI mode to reflect battery voltage) are unusual. Interrogating the device and calling the manufacturer remain the most reliable method for determining magnet response.

PREANESTHETIC EVALUATION AND ICD REPROGRAMMING

In addition to evaluating and optimizing comorbid disease(s), every ICD patient should undergo preoperative ICD interrogation. ALL ICD patients should have antitachycardia therapy disabled if monopolar Bovie use is planned[2,3]. For some surgery, appropriately tested ICDs can remain enabled unless a lead problem is present or if unanticipated patient movement from shock will be a problem[74]. See the pacing section apply here for antibradycardia pacing.

INTRAOPERATIVE (OR PROCEDURE) ICD MANAGEMENT

No special monitoring or anesthetic technique (due to the ICD) is required for the ICD patient. ECG monitoring and the ability to deliver external therapy must be present during the time of ICD disablement. Note that an inappropriate shock can be delivered without prior ECG changes if a lead is damaged or defective[75]. If emergency cardioversion or defibrillation is needed, the defibrillator pads should be placed to avoid the pulse generator to the extent possible. Nevertheless, one should remember that the patient, not the ICD, is being treated. The recommendations in the section «Intraoperative (or Procedure) Management of Pacemakers» apply here as well. ICDs should be disabled prior to insertion of a central line to prevent inappropriate shock and possible ICD failure[76].

POST ANESTHESIA ICD EVALUATION

The ICD must be reinterrogated and re-enabled, and pacing parameters should be checked and reset as necessary. All events should be reviewed and counters should be cleared.

SUMMARY

Electronic miniaturization has permitted the design and use of sophisticated electronics in patients who have need for artificial pacing and/or automated cardioversion/defibrillation of their heart. These devices are no longer confined to keeping the heart beating between a minimum rate (pacing function) and a maximum rate (ICD functions), as they are being used as therapy to improve the failing heart. The aging of the population and our ability to care for a patient with increasingly complex disease suggest that we will be caring for many more patients with these devices, and we must be prepared for this situation. Safe and efficient clinical management of these patients depends upon our understanding of implantable systems, indications for their use, and the perioperative needs that they create.

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