Perioperative Pacemaker and Defibrillator Management: Why the Controversy?

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Preoperative Key Points	**Intraoperative Key Points**
• Identify the manufacturer and model of the generator • Have the pacemaker or defibrillator interrogated by a competent authority shortly before the case. • 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. • For conventional pacemakers, 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. Although a magnet might work, magnet use has been associated with inappropriate ICD discharge.	• Monitor cardiac rhythm / peripheral pulse with pulse oximeter (plethysmography) or arterial waveform. • Disable the "artifact filter" on the ECG monitor. • Avoid use of monopolar electrosurgery (ESU). • Use bipolar ESU only; if not possible, then pure cut (monopolar ESU) is better than "blend" or "coag." • Place the ESU current return pad 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. • Consider avoiding sevoflurane, isoflurane or desflurane in the patient with long QT syndrome. **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. ICD patients must be monitored until the antitachycardia therapy is restored.

Introduction Battery operated pacemakers (PM) were developed in 1958, and implantable cardioverter-defibrillators (ICDs) followed in 1980. The complexity of these cardiac rhythm management devices (CRMD) limits generalizations that can be made about the perioperative care of these patients. Population aging, continued enhancements, and new indications for implantation of CRMD will lead to increased implantations. Initially, ICDs treated only sudden cardiac arrest (SCA), whether from ventricular tachycardia (VT) or ventricular fibrillation (VF). Now, any patient with an ejection fraction < 35%, regardless of the etiology and without induction testing for VT or VF, is considered a likely ICD recipient.

Many technical issues conspire to create confusion in this field. All ICDs have the ability to provide brady pacing, so a pectoral (vs abdominal) ICD might be mistaken for a (non-ICD) PM. If ECGs are routinely collected from patients with "pacemakers" using a magnet, then some ICDs from Boston Scientific/Guidant/CPI (BOS) might be permanently deactivated with magnet placement.[1] Second, no ICD provides asynchronous mode pacing with magnet placement. Third, ICDs respond to, and process, electromagnetic interference (EMI) differently than a PM.

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.[7,8] ALL ICDs perform cardiac pacing, so ICD issues related primarily to brady pacing should be reviewed in the Pacing section.

Notices regarding potential failures for PMs,[9-12] ICD leads,[13] and ICDs[14-16] get published often. Retrospective analysis suggests that outright failure occurs in 4.6 (PM) and 20.7 (ICD) per 1,000 implants.[17] Also, for about 46,000 ICDs, Guidant[1] 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.[18] Finally, devices resembling cardiac pulse generators are being implanted at increasing rates for pain control, thalamic stimulation to control Parkinson's

[1] Guidant Cardiac Rhythm Management was acquired by Boston Scientific Corporation (BOS) in 2006. References to "Guidant" have been retained where changing them to BOS would lead to confusion.

disease, phrenic nerve stimulation to stimulate the diaphragm in paralyzed patients, and vagus nerve stimulation to control epilepsy and possibly obesity.[19]

Pacemaker Overview More than 2,500 PM models have been produced by 26 companies, and more than 250,000 adults and children in the US undergo new PM placement yearly. Nearly 3 million US patients have PMs. Outdated literature, limited or inadequate training, and "conventional wisdom" lead to confusion in this field.

Pacing 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] PMs with unipolar leads produce larger "spikes" on an analogue-recorded ECG, and they are more sensitive to EMI. Most PM 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. But generators with bipolar leads can be independently 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 1).[21] Most PMs in the US are programmed either to the DDD (dual chamber) or VVI mode (single chamber). DDI is used for 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 (D-CMP).[23-25]

Table 1: 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)

Indications Permanent pacing indications (Table 2) are reviewed in detail elsewhere.[26] In order to be effective, BiV, HOCM, and D-CMP pacing must provide the stimulus for ventricular activation, and A-V synchrony must be preserved.[27] PM inhibition, loss of pacing (from native conduction, junctional rhythm, EMI), or AV dys-synchrony can lead to deteriorating hemodynamics. BiV pacing can lengthen the Q-T interval in some patients, producing torsade-de-pointes.[28] Thus access to rapid defibrillation is required for the patient with BiV pacing.

Table 2: Permanent Pacemaker Indications
Sinus Node Disease
Atrioventricular (AV) Node Disease
Long Q-T Syndrome
Hypertrophic Obstructive Cardiomyopathy (HOCM)[29,30]
Dilated Cardiomyopathy (D-CMP)[30]

Pacemaker Magnets Despite oft-repeated folklore, magnets were never intended to treat PM 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 models from a given company behave the same way. Common effect(s) of magnet placement on conventional PMs are shown in Table 3.[31-33] Magnet behavior can be altered or disabled via programming in many devices. For generators with programmable magnet behavior [Biotronik, BOS, CPI, Guidant Medical, Pacesetter, St Jude Medical], only a magnet test or interrogation with a programmer can reveal current settings.

Preanesthetic Evaluation and Pacemaker Reprogramming Preoperative management of the patient with a PM includes evaluation and optimization of coexisting disease(s). No special laboratory tests or x-rays are needed for the patient with a conventional PM. A patient with a BiV PM 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.[34,35]

Important features of the preanesthetic device evaluation are shown in **Preoperative Key Points**. 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.[36]

Direct interrogation with a programmer remains the only reliable method for evaluating battery status, lead performance, and adequacy of current settings. Some devices retain pacing histograms and information about tachydysrhythmia(s). Appropriate reprogramming (Table 4) is the safest way to avoid intraoperative problems, especially if monopolar "Bovie" electrosurgery will be used. Some PM manufacturers stand ready to 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.[46]

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.[47] Reprogramming a device **will not** protect it from internal damage or reset caused by EMI. In general, rate responsiveness and "enhancements" (dynamic atrial overdrive, hysteresis, sleep rate, A-V search, etc.) should be disabled by programming.[41,48,49] Note that for many older Guidant and/or CPI devices, Guidant Medical recommended increasing the pacing voltage to "5 volts or higher" when monopolar electrosurgery will be used. Few cardiologists know or follow this recommendation, but there are reports of threshold changes during both intrathoracic[50] and non-chest surgery.[51,52]

Table 3: Pacemaker Magnet Behavior
Most common responses - Asynchronous "high rate" pacing, not always in the best interest of the patient.
Medtronic (most models) 85 bpm, 65 if battery depleted
BOS/Guidant Medical / CPI (current models since 1990, magnet mode enabled) > 85 bpm (max 100), 85 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, BOC, CPI, Guidant, Pacesetter, St Jude models)
EGM mode enabled (BOS, 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)

Table 4: Pacemaker Reprogramming Likely Needed
Any rate responsive device – see text (problems are well known,[37,38] and have been misinterpreted with potential for patient injury,[39-42] and the FDA has issued an alert regarding devices with minute ventilation sensors (Table 5)[43]
Special pacing indication (HOCM, D-CMP, 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 Succinylcholine use (although no convincing evidence) MRI (usually contraindicated by device manufacturers), possible in some patients[44,45]

Recently, pacing threshold was shown to be increased by disease states.[53] Special attention must be given to any device with a minute ventilation (bioimpedance) sensor (Table 5), since inappropriate tachycardia has been observed secondary to mechanical ventilation,[42,54] monopolar ("Bovie") electrosurgery,[42,55,56] and connection to an ECG monitor with respiratory rate monitoring.[39,40,43,57-59] Sometimes, inappropriate <anesthetic> therapy has been delivered in these settings with bad results.[54,60]

Table 5: Devices with Minute Ventilation Sensors
ELA Medical Symphony, Brio (212, 220, 222), Opus RM (4534), Chorus RM (7034, 7134), Talent (130, 213, 223)
BOS, Guidant Medical and/or CPI Altrua (S401-404, S601-606), Insignia Plus (1194, 1297, 1298), Pulsar (1172, 1272), Pulsar Max (1170, 1171, 1270), Pulsar Max II (1180, 1181, 1280)
Medtronic Kappa 400 series (401, 403)
Telectronics / St Jude Meta (1202, 1204, 1206, 1230, 1250, 1254, 1256), Tempo (1102, 1902, 2102, 2902)

Intraoperative (or Procedure) Management of Pacemakers No special technique or monitoring is needed for the PM patient, but attention must be given to a number of concerns (Table 6). Monopolar "Bovie" electrosurgery (ESU) use remains the principal intraoperative issue for the patient with a PM. 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.[61] Monopolar ESU is more likely to cause problems than bipolar ESU.[62] Magnet placement during electrosurgery might prevent aberrant PM 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.[62,63]

Table 6: Essentials of Device Monitoring
ECG monitoring of the patient must include the ability to detect PM discharges ("artifact filter" disabled)
Perfused (peripheral) pulse must be monitored with a waveform display
The pacing 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

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 PM dependent. Also, some potent inhalational agents (isoflurane, sevoflurane, and desflurane) might exacerbate the long Q-T syndrome.[64-67]

Pacemaker Failure PM 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 PM output at pacing energies that will not produce myocardial capture.[68,69] Sympathomimetic drugs generally lower pacing threshold. Outright generator and/or lead failure is rare.

Post Anesthesia Pacemaker Evaluation Any PM 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 VT or VF, ICDs clearly reduce deaths,[70,71] and they remain superior to antiarrhythmic drug therapy.[72] Initially approved by the US FDA in 1985, more than 100,000 devices will be placed this year, and more than 250,000 patients have these devices today. Further, data showing ICD placement in patients *without* evidence of tachyarrhythmias (Multicenter Automatic Defibrillator Implantation Trial – II [MADIT-II] - ischemic cardiomyopathy, ejection fraction less than 0.30[73] and Sudden Cardiac Death – Heart Failure Trial [SCD-HeFT] – any cardiomyopathy, ejection fraction less than 0.35[74]) has significantly increased the number of patients for whom ICD therapy is indicated. ICD placement reduces mortality from arrhythmia even in patients on optimal heart failure therapy.[75] Like PMs, ICDs have a four-place code (Table 7).[76] 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 R-R 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. Newer Medtronic ICDs begin a run of ATP while charging for shock. 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 8),[77] more than 10% of shocks are for rhythm other than VT or VF.[78]

Table 7: 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)

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Table 8: 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 a-fib 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

Supraventricular tachycardia remains the most common etiology of inappropriate shock therapy,[79,80] and causes of inappropriate shock have been reviewed elsewhere.[81] Lead degradation also has led to unexpected and inappropriate shock.[13,82] Most ICDs will begin <brady> 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.[83]

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 9 shows current ICD indications.

ICD Magnets Like PMs, 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 ignore magnet placement. Guidant now recommends permanently disabling the magnet mode on 45,000 ICDs under alert for magnet switch failure.[89] Depending upon programming, **antitachycardia therapy in some BOS, Guidant or 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] and Telectronics Guardian 4202/4203 [disabled]). Intermedics devices change pacing rate (VVI mode) to reflect battery voltage. Interrogating the device and calling the manufacturer remain the most reliable method for determining magnet response.

Table 9: ICD Indications
Ventricular tachycardia
Ventricular fibrillation
Post-MI patients with EF ≤ 30% (MADIT II)[84]
Cardiomyopathy from any cause with EF ≤ 35% (SCD-HeFT)[74]
Hypertrophic cardiomyopathy
Awaiting heart transplant[85]
Long Q-T syndrome[86]
Arrhythmogenic right ventricular dysplasia
Brugada syndrome (right bundle branch block, S-T segment elevation in leads V1-V3)[87,88]

Preanesthetic Evaluation and ICD Reprogramming The patient with an ICD likely has a significant cardiomyopathy (CMP). Guidelines from the ACC / AHA recommend beta blockade and afterload reduction for al most every CMP patient.[90] Since benefits of this therapy accrue quickly,[91] consideration might be given to delaying a case for 1-2 weeks after initiation of therapy.

Prior to any surgery, every ICD patient should undergo preoperative ICD interrogation. ALL ICDs should have antitachycardia therapy disabled if monopolar Bovie use is planned [2,48] or there are lead problems predisposing to inappropriate shock.[13,82] The comments in the P**acing 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 cardioversion or defibrillation 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.[82] 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, possible ICD failure, or patient injury.[92]

Post Anesthesia ICD Evaluation The ICD must be reinterrogated and re-enabled, and pacing parameters should be checked and reset as necessary. Until the ICD is checked and re-enabled for tachy therapy, the patient's ECG should be continuously monitored with immediate access to defibrillation equipment. All ICD 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.

Appendix: Company Phone Numbers			
Angeion	800-264-2466	Medtronic	800-505-4636
Biotronik	800-547-0394	Pacesetter (St Jude Medical)	800-722-3774
Cardiac Pacemakers, Inc - CPI (Guidant Medical)	800-227-3422	St Jude Medical	800-722-3774
ELA Medical	800-352-6466	Telectronics (St Jude Medical)	800-722-3774
Guidant Medical	800-227-3422	Ventritex (St Jude Medical)	800-722-3774
Intermedics (Guidant Medical)	800-227-3422	Vitatron (Medtronic)	800-505-4636

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