Intrathoracic Gadgets In The New Millennium: Primer On Pacemakers And Cardioverter-defibrillators

M Rozner, A Nguyen

Citation

M Rozner, A Nguyen. *Intrathoracic Gadgets In The New Millennium: Primer On Pacemakers And Cardioverter-defibrillators*. The Internet Journal of Cardiology. 2000 Volume 1 Number 1.

Abstract

The invention of a simple, battery powered cardiac pacemaker by Earl Bakken and C W Lillehei in 1958 has prevented millions of untimely deaths. Major advances in pacemaker technology, including development of demand modes and rate responsiveness, have permitted these patients to lead relatively normal lives as well. Additionally, the creation of the implantable cardioverter-defibrillator by Michael Mirowski in 1985 has decreased the rate of sudden death in patients prone to tachydysrhythmias.

These technologic advancements, coupled with the electronically hostile environments of the operating and procedural rooms, have complicated the job of delivering anesthetics to these patients for a variety of procedures. Much of the information that has been published regarding the care of these patients has become outdated, and new indications for implantation of pacemakers, ICDs, or both have appeared. In this primer, we attempt to provide basic information about implantable pulse generators and the care of the patient with these intrathoracic gadgets.

PACEMAKER OVERVIEW

Battery operated, implantable pacing devices were first introduced in 1958, just four years after the invention of the transistor. Industry sources report that 26 companies have produced almost 1,500 models to date. Currently, more than 150,000 adults and children in the United States undergo new pacemaker placement each year, and nearly 2 million patients have pacemakers today. Population aging, along with enhancements in pacemaker technology and new indications for implantation, will lead to growing numbers of patients with permanently implanted pacing devices in the new millennium.

The patient with a pacemaker often has significant comorbid disease. Our ability to care for these patients requires attention to their medical and psychological problems, as well as an understanding of these pulse generators and their likely idiosyncrasies in the operating or procedure room. Further complicating this arena is the sale of product lines from one manufacturer to another as well as recent corporate acquisition activity.

Most readers have seen the generic pacemaker code (NBG) of the North American Society of Pacing and Electrophysiology (NASPE) and British Pacing and Electrophysiology Group (BPEG)[1] (Table 1). Also, a glossary of terms frequently encountered in the pacing world is included at the end of this article.

Figure 1

Table 1: NASPE / BPEG Generic Pacemaker Code (NBG)

Position I	Position II	Position III	Position IV	Position V
Pacing Chamber(s)	Sensing Chamber(s)	Response(s) to Sensing	Programmability	Antitachycardia Function(s)
O=None **A**=Atrium **V**=Ventricle **D**=Dual (A+V)	**O**=None **A**=Atrium **V**=Ventricle **D**=Dual (A+V)	**O**=None **I**=Inhibited **T**=Triggered **D**=Dual (T+I)	**O**=None **P**=Programmable **M**=Multiprogrammable **C**=Communicating **R**=Rate Modulation *	**O**=None **P**=Pacing **S**=Shock **D**=Dual (P+S)

* Rate Modulation takes precedence over the other Position IV modes.

PACEMAKER INDICATIONS

Table 2: Pacemaker Indications

- Diseases of Impulse Formation (Sinus Node Disease)
- Diseases of Impulse Conduction (A-V Blocks)
- Long Q-T Syndrome
- Hypertrophic Obstructive Cardiomyopathy*
- Dilated Cardiomyopathy*

* See text for special precautions

Indications for permanent pacing are shown in Table 2. Most readers are familiar with pacing for diseases of impulse formation (sinus node diseases) and problems with impulse conduction ("the blocks"). Dual chamber pacing can also be used to treat long Q-T syndrome.[2] Three-chamber pacing (right atrium, both ventricles) has been introduced to treat hypertrophic obstructive cardiomyopathy (HOCM) in both adults and children,[2,3] as well as dilated cardiomyopathy (DCM).[4] HOCM and DCM pacing require careful attention to pacer programming, since effective pacing in these patients requires a program rate greater than the patient's native sinus or junctional escape rate and an AV delay shorter than the native P-R interval so that the ventricle is paced 100% of the time.[5] Inhibition or loss of pacing (i.e.; from native depolarization, atrial irregularity, or electromagnetic interference) can lead to deteriorating hemodynamics in these patients.

PACEMAKER MAGNETS

Placement of a magnet over a pacemaker might produce no change in pacing since NOT ALL PACEMAKERS SWITCH TO A CONTINUOUS, ASYNCHRONOUS MODE WHEN A MAGNET IS PLACED. Despite oft-repeated folklore, most pacemaker manufacturers warn that magnets were never intended to treat pacemaker emergencies or prevent electromagnetic interference effects. Rather, magnet-activated reed switches were incorporated to produce pacing behavior that demonstrated remaining battery life and, sometimes, pacing threshold safety factors.

Also, not all models from a given company behave the same way. Only about 60% of pacemakers have "high rate (80-100 bpm)" asynchronous pacing with magnet. About 25% switch to asynchronous pacing at program rate, and 15% respond with a brief (60-100 beat) asynchronous pacing event. Possible effect(s) of magnet placement are shown in Table 3.[6,7,8] In some devices, magnet behavior can be altered via programming.

Table 3: Pacemaker Magnet Behavior

- No apparent rhythm or rate change
- No magnet sensor (some pre-1985 Cordis, Tele models)
- Magnet mode disabled (some post-1990 CPI, Pacesetter, Vitatron)
- EGM mode enabled (some CPI, others)
- Program rate pacing in already paced patient (many CPI, Intermedics, Telectronics, Vitatron, others)
- Improper monitor settings (e.g.; pace filter on)
- Brief (60-100 beats) asynchronous pacing, then return to program values (most Intermedics models)
- Continuous or transient loss of pacing
- Discharged battery (some pre-1990 devices)
- Pacer enters diagnostic "Threshold Test Mode" (some Medtronic, Siemans, Intermedics, others)
- Asynchronous pacing without rate responsiveness using fixed parameters (possibly not in patient's best interest)

For all generators, calling the manufacturer remains the most reliable method for determining magnet response and using this response to predict remaining battery life. A list of telephone numbers is shown in Table 10. For generators with programmable magnet behavior [CPI, Medtronic, Pacesetter, Telectronics, others], only an interrogation with a programmer can reveal current settings. Most manufacturers publish a reference guide, although not all of these guides list all magnet idiosyncrasies.

PREANESTHETIC EVALUATION AND PACEMAKER REPROGRAMMING

Primary management of the patient with a pacemaker includes evaluation and optimization of coexisting disease(s). No special laboratory tests or radiographs (chest films are remarkably insensitive for determination of lead problems) are needed for the patient with a pacemaker. Such testing should be dictated by the patient's underlying disease(s), medication(s), and planned intervention. For programmable devices, interrogation with a programmer remains the most reliable method for evaluating lead performance and obtaining current program information. Current NASPE and Medicare guidelines include telephonic interrogation every 4-12 weeks (depending upon device type and age) and a direct evaluation with a programmer every six months (Medicare) or once per year (NASPE).[9] The prudent anesthesiologist should ensure that a timely evaluation has taken place.

Important features of the preanesthetic device evaluation are shown in Table 4. Special attention should be paid to patients from countries where pacemakers might be reused,[10,11] since battery performance might not be related to length of implantation in the current patient.

Table 4: Preanesthetic Pulse Generator (Pacemaker, ICD) Evaluation

- Determining the indication for and date of initial device placement
- Determining the last generator test date and battery status
- Obtaining a history of generator events (if any)
- Obtaining the current program information (device interrogation)
- For pacing devices, palpation of the patient's cardiac rhythm while observing the electrocardiogram on a properly configured monitor to ensure that generator discharges become mechanical systoles
- Ensuring that magnet detection is enabled
- Determining whether the pacing mode should be reprogrammed

Appropriate reprogramming (Table 5) is the safest way to avoid intraoperative problems, especially if monopolar "Bovie" electrosurgery will be used. Reprogramming a pacemaker to asynchronous pacing at a rate greater than the patient's underlying rate ensures that no over- or undersensing will take place, thus protecting the patient. Reprogramming a device will not protect it from internal damage caused by electromagnetic interference.

In general, rate responsiveness should be disabled by programming.[12,13] A number of reports of inappropriate pacemaker behavior owing to rate responsive problems have appeared.[14,15] Unfortunately, some problems have been misinterpreted, and patients have been inappropriately treated (i.e.; inappropriate deepening of anesthetic depth in response to a pacemaker mediated tachycardia). 6,13,[16]

Table 5: Reprogramming Probably Needed

Any rate responsive device – see text (problems are well known, problems have been misinterpreted with potential for patient injury, and the FDA has issued an alert calling for reprogramming in devices with minute ventilation sensors – see Table 6)
Special pacing indication
HOCM, DCM, or pediatric patient
Pacemaker-dependent patient
Major procedure in chest or abdomen
Special Procedures (See Table 7)

Special attention must be given to any device with a minute ventilation (bioimpedance) sensor (Table 6), since inappropriate tachycardia has been observed secondary to mechanical ventilation17, monopolar "Bovie" electrosurgery18, and connection to an electrocardiographic monitor with respiratory rate monitoring.[19,20] All of the manufacturers stand ready to assist with evaluation and reprogramming (company telephone numbers are shown in Table 10). Note that Guidant-CPI recommends increasing the pacing amplitude to 5 volts or greater in any patient expected to experience "Bovie" electrosurgery.

Table 6: Pacemakers with Minute Ventilation (Bio Impedance) Sensing

- ELA Medical
- Brio Series 212, 220, 222
- Talent Series 130, 213, 223
- Opus RM Series 4534
- Chorus RM Series 7034, 7134
- Guidant / CPI
- Pulsar and Pulsar_Max Families 1170, 1171, 1172, 1270, 1272
- Medtronic
- Kappa 400 (but not Kappa 600, 700 series)
- Legend Plus series 8446, 8448
- Pacesetter / St Jude
- Tempo Series 1102, 1902, 2102, 2902
- Telectronics / St Jude
- Meta Series 1202, 1204, 1206, 1230, 1250, 1254, 1256

INTRAOPERATIVE (OR PROCEDURE) MANAGEMENT

No special monitoring or anesthetic technique is required for the patient with a pacemaker. However, electrocardiographic monitoring of the patient must include the ability to detect pacemaker discharges (some electrocardiographic monitors permit filtering of pacemaker spikes, and such filtering should be disabled). Also, patient monitoring must include the ability to ensure that myocardial electrical activity is converted to mechanical systoles. Mechanical systoles can be evaluated by palpation of pulse, auscultation, pulse oximetry plethysmogram, or the arterial waveform. Some patients might need to have their pacing rate increased to meet an increased oxygen demand.

Monopolar "Bovie" electrosurgery (diathermy) 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 electrocautery, and a "significant number" of device failures.[21] Monopolar electrosurgery is more likely to cause problems than bipolar electrosurgery, and patients with unipolar electrode configuration are more sensitive to electromagnetic interference than those with bipolar configurations.

Magnet placement during electrocautery might allow spurious reprogramming of an older (pre-1990) generator; however, newer generators are relatively immune to such effects. Battery depletion, leading to pacemaker shutdown, has been reported after use of monopolar electrosurgery.[22] Battery depletion can cause the pacemaker to switch to an energy conserving mode (e.g.; VVI in place of DDD), which will appear to the clinician as "reprogramming."

Some procedures require the use of monopolar electrosurgery or other precautionary measures. These procedures with special pacing ramifications are shown in Table 7.

Table 7: Special Procedures in Patients with Implantable Generators

- Lithotripsy
- acceptable with precautions to protect the generator from the shock wave
- atrial pacing must be disabled to prevent false "r" wave sensing by the lithotriptor
- TUR and Uterine Hysteroscopy
- procedures using monopolar electrosurgery
- easily accomplished after device reprogramming to asynchronous mode
- Magnetic Resonance Imaging
- Absolutely contraindicated by most generator manufacturers
- deaths have been reported23
- Electroconvulsive Therapy
- requires non-sensing (asynchronous) mode24
- Nerve Stimulator Testing / Therapy
- inappropriate detection of TENS, neuromuscular, and chiropractic electrical muscle stimulation as VT or VF has been reported 25,26

PACEMAKER FAILURE

Pacemaker failure has three etiologies: 1) generator failure; 2) lead failure; or 3) failure of capture. Failure of capture owing to a defect at the level of the myocardium (i.e.; the generator continues to fire but no myocardial depolarization takes place) remains the most difficult problem to treat. Myocardial changes that alter the refractory period or increase the energy requirement for depolarization can result from myocardial ischemia / infarction, acid-base disturbance, electrolyte abnormalities, or abnormal levels of antiarrhythmic drug(s). Sympathomimetic drugs generally lower pacing threshold. For a complete review of pacemaker malfunction, see Hayes and Vlietstra.[27]

POST ANESTHESIA PACEMAKER EVALUATION

A pacemaker that was reprogrammed for the perioperative period should be reset appropriately. If a patient was subjected to monopolar "Bovie" electrosurgery, then the device should be interrogated to ensure proper functioning and remaining battery life.[28]

IMPLANTABLE CARDIOVERTER-DEFIBRILLATOR (ICD) OVERVIEW

The development of an implantable, battery powered device able to deliver sufficient energy to terminate ventricular tachycardia (VT) or fibrillation (VF) has represented a major

medical breakthrough for patients with a history of ventricular tachydysrhythmias. These devices prevent death in the setting of malignant ventricular tachydysrhythmias,[29,30] and they clearly remain superior to antiarrhythmic drug therapy.[31] Initially approved by the US FDA in 1985, more than 40,000 devices will be placed this year, and industry sources report that more than 200,000 patients have these devices today.

A significant number of technologic advances have been applied since the first ICD was placed, including considerable miniaturization (pectoral pocket placement with transvenous leads is the norm) as well as battery improvements that now permit permanent pacing with these devices. Thus, one could easily confuse the patient with a pectoral ICD for a patient with a pacemaker.

Like pacemakers, ICDs have a generic code to indicate lead placement and function32 (Table 8). The most robust form of identification, called the "label form," expands the fourth character into its component generic pacemaker code (NBG).

Figure 2

Table 8: NASPE / BPEG Generic Defibrillator Code (NBD)			
Position I	Position II	Position III	Position IV
Shock Chamber(s)	Antitachycardia Pacing Chamber(s)	Tachycardia Detection	Antibradycardia Pacing Chamber(s)
O=None A=Atrium V=Ventricle D=Dual (A+V)	O=None A=Atrium V=Ventricle D=Dual (A+V)	E=Electrogram H=Hemodynamic (not yet available)	O=None A=Atrium V=Ventricle D=Dual (A +V)

Newer ICDs (since 1993) have many programmable features, but essentially they 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 the device detects a sufficient number of short R-R intervals within a period of time (all programmable), it will begin an antitachycardia event. The internal computer will decide between antitachycardia pacing (less energy use, better tolerated by patient) or shock. If shock is chosen, an internal capacitor is charged.

Most newer devices are programmed to reconfirm VT or VF after charging in order to prevent inappropriate shock therapy. Typically, ICDs deliver no more than 6 shocks per event, although some can deliver as many as 18. Once a shock is delivered, no further antitachycardia pacing can take place. Approximately 20-40% of shocks are for rhythm other than VT or VF33 despite reconfirmation.[34] Supraventricular tachycardia remains the most common etiology of inappropriate shock therapy,[35,36] and causes of inappropriate shock have been reviewed elsewhere.[37]

An ICD with antibradycardia pacing capability will begin pacing when the R-R interval is too long. In July, 1997, the US FDA approved devices with sophisticated dual chamber pacing modes and rate responsive behavior for ICD patients who need permanent, dual chamber pacing (about 20% of ICD patients).

ICD INDICATIONS

Table 9. ICD Indications

- Ventricular Tachycardia
- Ventricular Fibrillation
- Brugada Syndrome
- Arrhythmogenic Right Ventricular Dysplasia
- Long Q-T Syndrome
- Hypertrophic cardiomyopathy

Initially, ICDs were placed for hemodynamically significant VT or VF. Newer indications associated with sudden death include: long Q-T syndrome, Brugada syndrome (right bundle branch block, S-T segment elevation in leads V1-V3), and arrhythmogenic right ventricular dysplasia.[38] A recent study suggests that ICDs can be used as primary prevention of sudden death in young patients with hypertrophic cardiomyopathy.[39] One should also expect new, multichamber ICD placement in patients with HOCM and dilated cardiomyopathy who have experienced VT or VF.

ICD MAGNETS

Like pacemakers, magnet behavior in ICDs depends upon the manufacturer. Most devices will suspend tachydysrhythmia detection (and therefore therapy) when a magnet is appropriately placed to activate the reed switch. Some devices from Angeion, CPI, or Ventritex can be programmed to ignore magnet placement. Antitachycardia therapy in some CPI devices can be permanently disabled by magnet placement for 30 seconds. In general, magnets will not affect antibradycardia pacing mode or rate (except ELA Defender [rate change] and Telectronics Guardian 4202/4203 [disabled]*). Interrogating the device and calling the manufacturer remain the most reliable method for determining magnet response.

- The Telectronics Guardian models 4202 and 4203 were used only in clinical trials and never marketed to the general public. Nevertheless, these devices could be encountered in patients who underwent implantation as part of a clinical trial.

PREANESTHETIC EVALUATION AND ICD REPROGRAMMING

Like the patient with the pacemaker, primary management of the patient with an ICD includes evaluation and optimization of coexisting disease(s). Again, no special laboratory tests or radiographs (chest films are remarkably insensitive for determination of lead problems) are needed for these patients. Rather, such testing should be dictated by the patient's underlying disease(s), medication(s), and planned intervention. There are no current NASPE or Medicare guidelines for followup, although the American College of Cardiologists recommends a maximum of 3 months between evaluations.[40]

ALL ICDs should be disabled prior to the induction of anesthetic and commencement of the procedure. The comments in the pacing section (and Tables 4-7) apply here for the newer devices with antibradycardia pacing.

INTRAOPERATIVE (OR PROCEDURE) MANAGEMENT

No special monitoring or anesthetic technique (owing to the ICD) is required for the patient with an ICD. However, electrocardiographic monitoring and the ability to treat a tachydysrythmia must be present during the time of ICD disablement. Therapy can be delivered by the ICD at the direction of a programmer, or the patient can be cardioverted / defibrillated with an external device. Although many recommendations exist for defibrillator pad placement to protect the ICD, one should remember that the patient, not the ICD, is being treated.

POST ANESTHESIA ICD EVALUATION

The ICD must be reinterrogated and re-enabled. Any detected events should be reviewed and counters should be cleared. If external cardioversion or defibrillation was applied, the device should be carefully tested.

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. Both 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.

GLOSSARY

Atrioventricular Delay - The time that a dual chamber system waits after detecting (or initiating) an atrial event before pacing the ventricle. Some generators shorten this time as heart rate increases (termed "rate adaptive AV delay" or "dynamic AV delay"). In a patient with a conducting AV node, the sensed A-V delay will be slightly longer than the "P-R" interval on the surface electrocardiogram (see "Fusion Beat"), since the ventricular sensing element is attached to the apex of the right ventricle.

Bipolar Lead - An electrode with two conductors. Bipolar sensing is more resistant to oversensing from muscle artifact or stray electromagnetic fields. Some pacing generators can be programmed to unipolar mode even in the presence of bipolar electrodes.

EGM Mode – Passive acquisition and internal storage of electrocardiographic data for diagnostic purposes while pacing (or monitoring) with programmed parameters.

Generator - The device with a power source and circuitry to produce an electrical impulse designed to be conducted to the heart. Typically, pacing generators are placed in a pectoral pocket, and leads are inserted into the right atrium, right ventricle, or both. Since 1995, though, Implantable Cardioverter-Defibrillators (ICDs) have also been approved for pectoral pocket placement.

Hysteresis - If present, the amount by which the patient's intrinsic rate must fall below the programmed rate before the generator begins pacing. Some pacers regularly decrease the pacing rate in order to search for resumption of intrinsic activity. These functions, when present, mimic pacemaker malfunction.

ICD Mode - The designation of chamber(s) shocked, chamber(s) paced for antitachycardia pacing, method of tachycardia detection, and chambers paced for antitachycardia therapy. Table 7 shows the NASPE/BPEG generic ICD code.

Oversensing - Detection of undesired signals that are

interpreted as cardiac activity. Oversensing can lead to pacemaker driven tachycardia (pacing device, DDD mode with atrial oversensing and ventricular tracking); ventricular pause (pacing device with electrocautery-induced ventricular oversensing, leading the pacer to “detect” ventricular activity), or inappropriate shock (defibrillator, event oversensing).

Pacing Mode - The designation of chamber(s) paced, chamber(s) sensed, sensing response, rate responsiveness, and antitachyarrhythmia function for a pacemaker system. Table 1 shows the NASPE/BPEG generic pacemaker code.

Programmed Rate (also Automatic Rate) - The lowest sustained regular rate at which the generator will pace. Typically, the device begins pacing when the patient’s intrinsic rate falls below this value.

Pseudofusion Beat (FB) - A pacemaker spike delivered shortly after a native depolarization, often misdiagnosed as undersensing, owing to the position of the sensing electrode relative to the depolarizing wavefront. Confirmation of appropriate sensing behavior can be made by lengthening the sensing interval (i.e.; decreasing the program rate [atrial FB] or lengthening the AV delay [ventricular FB]).

Rate Modulation - The ability of the generator to sense the need to increase heart rate. Mechanisms include: 1) a mechanical sensor in the generator to detect motion or vibration; 2) electronic detection of Q-T interval (shortens during exercise) or transthoracic impedance to measure changes in respiration or; or 3) sensor(s) for central venous blood temperature or oxygen saturation. Some generators now incorporate multiple sensors.

Sleep Rate (also Circadian Rate) - The rate (lower than the Programmed Rate) at which the pacing generator will pace during programmed “nighttime” hours.

Undersensing - Failure to detect a desired event.

Unipolar Lead - An electrode with only one conductor, present only in older pacemaker systems. They produce larger spikes on the electrocardiogram than bipolar leads. Systems with unipolar leads utilize the generator case as the second conductor.

Upper Sensor Rate (USR, also Upper Activity Rate or UAR) - The maximum rate to which a rate modulated pacemaker can drive the heart. USR is not affected by UTR.

Upper Tracking Rate (UTR, also called Upper Rate Limit) - Pacemakers programmed to DDDxx mode cause the ventricles to track atrial activity. Should a patient develop an atrial tachyarrhythmia, such as atrial fibrillation or flutter, the generator acts to limit ventricular pacing. When the atrial rate exceeds the UTR, the generator can change mode (i.e.; switch to DDI) or introduce second degree A-V Wenkebach block.

Figure 3

Table 10: Company Phone Numbers	
Am Pacemaker Corp (Guidant Medical)	800-227-3422
Angeion	**800-264-3466**
ARCO Medical (Guidant Medical)	800-227-3422
Biotronik, Inc	**800-547-0391**
Cardiac Control Systems	*unavailable*
CardioPace Medical, Inc (Novacon)	*unavailable*
Cardiac Pacemakers, Inc (Guidant)	**800-227-3422**
Cook Pacemaker Corp	800-245-4715
Coratomic (Biocontrol Technology)	*unavailable*
Cordis Corporation (St Jude Medical)	800-525-7042
Diag / Medcor	800-227-3422
Edwards Pacemaker Systems (Medtronic, Inc)	800-328-2518
ELA Medical	**800-352-6466**
Guidant Medical	**800-227-3422**
Intermedics, Inc (Guidant Medical)	**800-227-3422**
Medtronic, Inc	**800-328-2518**
Pacesetter, Inc (St Jude Medical)	**800-722-3774**
Siemans – Elema (St Jude Medical)	800-722-3774
Telectronics Pacing (St Jude Medical)	**800-722-3774**
Ventritex (St Jude Medical)	**800-722-3774**
Vitatron (Medtronic, Inc)	800-848-2876
Companies in **BOLD** market ICDs	

References

1. Bernstein AD et al. The NASPE/BPEG generic pacemaker code for antibradyarrhythmia and adaptive-rate pacing and antitachyarrhythmia devices. PACE 10:794-9, 1987.
2. Hayes DL. Evolving indications for permanent pacing. Am J Cardiology 83(5B):161D-165D, 1999.
3. Bevilacqua L, Hordof A. Cardiac pacing in children. Curr Opinion in Cardiol 13:48-55, 1998.
4. Auricchio A et al. The Pacing Therapies for Congestive Heart Failure (PATH-CHF) study: rationale, design, and endpoints of a prospective randomized multicenter study. Am J Cardiol 83(5B):130D-135D, 1999.
5. Gras D et al. Multisite pacing as a supplemental treatment of congestive heart failure: preliminary results of the Medtronic Inc. InSync Study. PACE 21:2249-55, 1998.
6. Rozner MA, R Nishman. Pacemaker tachycardia revisited. Anest Analg 88(4):965, 1999.
7. Purday JP, Towey RM. Apparent pacemaker failure caused by activation of ventricular threshold test by a magnetic instrument mat during general anaesthesia. Br J Anaest 69:645-6, 1992.
8. Bourke ME. The patient with a pacemaker or related device. Can J Anaest 43:R24-41, 1996.
9. Bernstein AD, Irwin ME, Parsonnet V et al. Report of the NASPE policy conference on anti-bradycardia pacemaker follow-up: Effectiveness, needs and resources. PACE 1994; 17 (Part I):1714-29
10. Sethi KK et al. Experience with recycled cardiac pacemakers. Indian Heart J 44:91-3, 1992.
11. Panja M et al. Reuse of pacemaker. Indian Heart J 48:677,-80 1996.
12. Anderson C, Masden GM. Rate responsive pacemakers and anaesthesia. A consideration of possible implications. Anaesthesia 45:472-6, 1990.
13. Levine PA. Response to rate-adaptive cardiac pacing: implications of environmental noise during craniotomy. Anesthesiology 87(5):1261, 1997.
14. Schwartzenburg CF et al. Rate-adaptive cardiac pacing: implications of environmental noise during craniotomy. Anesthesiology 87:1252-4, 1997.
15. Aldrete JA et al. Pacemaker malfunction due to microcurrent injection from a bioimpedance noninvasive cardiac output monitor. J Clin Monitoring 11:131-3, 1995.
16. von Knobelsdorff G et al. Interaction of frequency-adaptive pacemakers and anesthetic management. Discussion of current literature and two case reports. Anaesthesist 45(9):856, 1996.
17. Madsen GM, Anderson C. Pacemaker-induced tachycardia during general anaesthesia: a case report. Br J Anaes 1989; 63(3):360-1, 1989.
18. Van Hemel et al. Upper limit ventricular stimulation in respiratory rate responsive pacing due to electrocautery. PACE 12:1720-23, 1989.
19. Wallden J et al. Supraventricular tachycardia induced by Datex patient monitoring system. Anesth Analg 1998; 86(6):1339, 1998.
20. URL=http://www.fda.gov/cdrh/safety/minutevent.html; 1998 FDA User Facility Reporting #20. (URL=http://www.fda.gov/cdrh/fusenews.html) 1997.
21. Peters RW, Gold MR. Reversible prolonged pacemaker failure due to electrocautery. J Interventional Cardiac Electrophysiology. 2(4):343-4, 1998.
22. Gimbel JR et al. Survey of magnetic resonance imaging in pacemaker patients. URL=http://www.heartweb.org/heartweb/1096/963006p1.htm , 1996.
23. Alexopoulos GS, Frances RJ. ECT and cardiac patients with pacemakers. Am J Psychiatry 137:1111-12, 1980.
24. Philbin DM et al. Inappropriate shocks delivered by an ICD as a result of sensed potentials from a transcutaneous electronic nerve stimulation unit. PACE 21:2010-11, 1998.
25. Vlay S. Electromagnetic interference and ICD discharge

related to chiropractic treatment. PACE 21:2009, 1998.
26. Hayes DL, Vlietstra RE. Pacemaker malfunction. Ann Internal Med 119:828-835, 1993.
27. Levine PA et al. Electrocautery and pacemakers: management of the paced patient subject to electrocautery Annals of Thoracic Surgery 41:313-7, 1986.
28. Moss AJ et al. Improved survival with an implanted defibrillator in patients with coronary disease at high risk for ventricular arrhythmia. NEJM 335:1933-40, 1996.
29. Zipes DP et al. A comparison of antiarrhythmic drug therapy with implantable cardioverter defibrillators in patients resuscitated from near-fatal ventricular arrhythmias. NEJM 337:1576-83, 1997.
30. Buxton A et al. A randomized study of the prevention of sudden death in patients with coronary artery disease. NEJM 341:1882-1890, 1999.
31. Bernstein AD et al. North American Society of Pacing and Electrophysiology policy statement. The NASPE/BPEG defibrillator code. PACE 16:1776-80, 1993.
32. Grimm W et al. Electrocardiographically documented unnecessary, spontaneous shocks in 241 patients with implantable cardioverter defibrillators. PACE 15:1667-73, 1992.
33. Hurst TM et al. Inappropriate management of self-terminating ventricular arrhythmias by implantable cardioverter defibrillators despite a specific reconfirmation algorhythm: a report of two cases. PACE 20:1328-31, 1997.
34. Prasad K et al. Inappropriate shocks in patients receiving internal caredioverter-defibrillators for malignant ventricular arrhythmias. Indian Heart J 49:403-7, 1997.
35. Schumacher B et al. Radiofrequency catheter ablation of atrial flutter that elicits inappropriate implantable cardioverter discharge. PACE 20:125-7, 1997.
36. Rozner MA. The patient with an implantable cardioverter defibrillator. Prog in Anesthesiology 13:43-52, 1999.
37. Brugada P, Geelen P. Some electrocardiographic patterns predicting sudden cardiac death that every doctor should recognize. Acta Cardiologica 52:473-84, 1997.
38. Maron BJ et al. Efficacy of implantable cardioverter-defibrillators for the prevention of sudden death in patients with hypertrophic cardiomyopathy. NEJM 342:365-73, 2000.
39. Gregoratos G et al. ACC / AHA guidelines for implantation of cardiac pacemakers and antiarrhythmia devices. J Am Coll Cardiol 31:1175-1209, 1998.

Author Information

Marc A. Rozner, PhD, MD
Director, Preoperative Care Program, Division of Anesthesiology and Critical Care, The University of Texas M. D. Anderson Cancer Center

Anh-Duyen Nguyen, PA-C
Division of Anesthesiology and Critical Care, The University of Texas M. D. Anderson Cancer Center