Anesthesiology 2005; 103:186–98

Practice Advisory for the Perioperative Management of Patients with Cardiac Rhythm Management Devices: Pacemakers and Implantable Cardioverter–Defibrillators

A Report by the American Society of Anesthesiologists Task Force on Perioperative Management of Patients with Cardiac Rhythm Management Devices

PRACTICE advisories are systematically developed reports that are intended to assist decision making in areas of patient care. Advisories provide a synthesis and analysis of expert opinion, clinical feasibility data, open forum commentary, and consensus surveys. Advisories are not intended as standards, guidelines, or absolute requirements. They may be adopted, modified, or rejected according to clinical needs and constraints.

The use of practice advisories cannot guarantee any specific outcome. Practice advisories summarize the state of the literature and report opinions derived from a synthesis of task force members, expert consultants, open forums, and public commentary. Practice advisories are not supported by scientific literature to the same degree as standards or guidelines because of the lack of sufficient numbers of adequately controlled studies. Practice advisories are subject to periodic revision as warranted by the evolution of medical knowledge, technology, and practice.

Additional material related to this article can be found on the ANESTHESIOLOGY Web site. Go to http://www.anesthesiology.org, click on Enhancements Index, and then scroll down to find the appropriate article and link. Supplementary material can also be accessed on the Web by clicking on the "ArticlePlus" link either in the Table of Contents or in the HTML version of the article.

Developed by the American Society of Anesthesiologists Task Force on Perioperative Management of Patients with Cardiac Rhythm Management Devices: James R. Zaidan, M.D., M.B.A. (Chair), Atlanta, Georgia; John L. Atlee, M.D., Milwaukee, Wisconsin; Peter Belott, M.D., El Cajon, California; Kurt S. Briesacher, M.D., Atlanta, Georgia; Richard T. Connis, Ph.D., Woodinville, Washington; John D. Gallagher, M.D., Lebanon, New Hampshire; David Hayes, M.D., Rochester, Minnesota; Jane E. Hershey, M.D., Highland, Maryland; Neal Kay, M.D., Birmingham, Alabama; David G. Nickinovich, Ph.D., Bellevue, Washington; Marc A. Rozner, Ph.D., M.D., Houston, Texas; Mark F. Trankina, M.D., Birmingham, Alabama. Submitted for publication December 28, 2004. Accepted for publication December 28, 2004. Supported by the American Society of Anesthesiologists under the direction of James F. Arens, M.D., Chair, Committee on Practice Parameters. Approved by the House of Delegates on October 27, 2004. A list of the references used to develop this Advisory is available by writing to the American Society of Anesthesiologists. This Advisory is endorsed by the American Heart Association, the Heart Rhythm Society, and the Society of Cardiovascular Anesthesiologists.

Address reprint requests to the American Society of Anesthesiologists: 520 N. Northwest Highway, Park Ridge, Illinois 60068-2573. This Practice Advisory, as well as all published ASA Practice Parameters, may be obtained at no cost through the Journal Web site, www.anesthesiology.org.

* *Inappropriate ICD therapy* refers to the delivery of antitachycardia therapy (paced or shock) in the absence of a clinically indicated tachyarrhythmia. Inappropriate ICD therapy can harm a patient by inducing ischemia, worsening the arrhythmia, or causing the patient to move during a delicate procedure.

Methodology

A. Definition of Cardiac Rhythm Management Devices

For this Advisory, a *cardiac rhythm management device* (CRMD) refers to any permanently implanted cardiac pacemaker or any implantable cardioverter–defibrillator (ICD). The term *CRMD* also refers to any cardiac resynchronization device. The term *CRT* refers to a CRMD that provides cardiac resynchronization therapy using biventricular pacing techniques. Generic pacemaker and defibrillator codes are provided in appendix 1. Note that every ICD includes both pacing and shock therapies for the management of bradyarrhythmias and tachyarrhythmias.

B. Purposes of the Advisory

The purposes of this Advisory are to (1) facilitate safe and effective perioperative management of the patient with a CRMD and (2) reduce the incidence of adverse outcomes. *Perioperative management* refers to the preoperative, intraoperative, postoperative or recovery period in any setting where an anesthesia provider delivers anesthesia care. Adverse outcomes associated with a CRMD include (but are not limited to) damage to the device, inability of the device to deliver pacing or shocks, lead–tissue interface damage, changes in pacing behavior, electrical reset to the backup pacing mode, or inappropriate ICD therapies.* Adverse clinical outcomes include (but are not limited to) hypotension, tachyarrhythmia or bradyarrhythmia, myocardial tissue damage, and myocardial ischemia or infarction. Other related outcomes may include extended hospital stay, delay or cancellation of surgery, readmission to manage device malfunction, or additional hospital resource utilization and cost.

C. Focus

This Advisory focuses on the perioperative management of patients who have a preexisting, permanently implanted CRMD for treatment of bradyarrhythmia, tachyarrhythmia, or heart failure. Both inpatient and outpatient procedures are addressed by this Advisory. This Advisory does not address the perioperative management of any patient undergoing CRMD implantation or revision. It is not applicable to any patient (1) without

a permanently implanted pacemaker or ICD, (2) with a temporary CRMD, (3) with a noncardiac implantable device (*e.g.*, neurologic or spinal cord stimulator), or (4) with an implantable mechanical cardiac assist device (*e.g.*, ventricular assist device). This Advisory does not address any procedure where there are no known perioperative CRMD concerns, such as diagnostic radiation (*e.g.*, x-ray studies, fluoroscopy, or mammograms), computed tomography scans, or ultrasound.

D. Application

This Advisory is intended for use by anesthesiologists and all other individuals who deliver or who are responsible for anesthesia care. The Advisory may also serve as a resource for other physicians and healthcare professionals who treat patients with CRMDs.

E. Task Force Members and Consultants

The American Society of Anesthesiologists (ASA) appointed a Task Force of 12 members to (1) review and assess currently available scientific literature, (2) obtain expert consensus and public opinion, and (3) develop a practice advisory. The Task Force members consisted of anesthesiologists and cardiologists in private and academic practices from various geographic areas of the United States and two methodologists from the ASA Committee on Practice Parameters.

The Task Force used a six-step process. First, they reached consensus on the criteria for evidence of effective perioperative management of cardiac rhythm management devices. Second, original published articles from peer-reviewed journals relevant to these issues were evaluated. Third, consultants who had expertise or interest in CRMDs and who practiced or worked in various settings (*e.g.*, academic and private practice) were asked to (1) participate in opinion surveys on the effectiveness of various perioperative management strategies and (2) review and comment on a draft of the Advisory developed by the Task Force. Fourth, additional opinions were solicited from random samples of active members of both the ASA and the Heart Rhythm Society (HRS).† Fifth, the Task Force held an open forum at a national anesthesia meeting and at a major cardiology meeting to solicit input on the key concepts of this Advisory. Sixth, all available information was used to build consensus within the Task Force on the Advisory.

The draft document was made available for review on the ASA Web site, and input was invited *via* e-mail announcement to all ASA members. All submitted comments were considered by the Task Force in preparing the final draft.

F. Availability and Strength of Evidence

Practice advisories are developed by a protocol similar to that of an ASA evidence-based practice guideline, including a systematic search and evaluation of the literature. However, practice advisories lack the support of a sufficient number of adequately controlled studies to permit aggregate analyses of data with rigorous statistical techniques such as meta-analysis. Nonetheless, literature-based evidence from case reports and other descriptive studies is reported. This literature often permits the identification of recurring patterns of clinical practice.

As with a practice guideline, formal survey information was collected from Consultants and members of the ASA. For this Advisory, surveys were also sent to members of the HRS. Additional information was obtained from open forum presentations and other invited and public sources. The advisory statements contained in this document represent a consensus of the current spectrum of clinical opinion and literature-based findings.‡

Advisories

I. Preoperative Evaluation

Perioperative treatment of CRMD patients is a common occurrence. It has been reported that more than 500,000 individuals in the United States have permanently implanted pacemakers or ICDs with 115,000 new devices implanted each year.[1] Perioperative management of CRMD patients typically begins with a focused preoperative evaluation consisting of (1) establishing whether a patient has a CRMD, (2) defining the type of device, (3) determining whether a patient is CRMD dependent for antibradycardia pacing function, and (4) determining device function.

Although no controlled trials of the clinical impact of performing a focused preoperative evaluation for CRMD patients were found, case reports suggest that incomplete preoperative examination of patients with CRMDs may lead to adverse outcomes (*e.g.*, inhibited CRMD function, asystole).[2–4] The majority of Consultants and random samples from the ASA and HRS memberships agree that the above four preoperative evaluation activities should be conducted.§

Advisory. The consensus of the Task Force is that a focused preoperative evaluation should include establishing whether a patient has a CRMD, defining the type of device, determining whether a patient is CRMD dependent for pacemaking function, and determining CRMD function.

Determining whether a patient has a CRMD should be based on (1) a focused history including but not limited to the patient interview, medical records review, review of available chest x-ray films, electrocardiogram, or any available monitor or rhythm strip information and (2) a focused physical examination (checking for scars, palpating for device).

† Formerly North American Society of Pacing and Electrophysiology (NASPE).

‡ Refer to appendix 2 for a summary of the advisories.

§ Refer to appendix 3 for results of the Consultant, ASA membership, and HRS membership surveys.

Defining the type of device is accomplished by (1) obtaining the manufacturer's identification card from the patient or other source, (2) ordering chest x-ray studies if no other data are available,‖ or (3) referring to supplemental resources (*e.g.*, manufacturer's databases, pacemaker clinic records, consultation with a cardiologist).

Cardiac rhythm management device dependency for pacemaking function may be determined by one or more of the following: (1) a verbal history or an indication in the medical record that the patient has experienced a bradyarrhythmia that has caused syncope or other symptoms requiring CRMD implantation, (2) a history of successful atrioventricular nodal ablation that resulted in CRMD placement, or (3) a CRMD evaluation that shows no evidence of spontaneous ventricular activity when the pacemaking function of the CRMD is programmed to VVI pacing mode at the lowest programmable rate.

Cardiac rhythm management device function is ideally assessed by a comprehensive evaluation of the device.[5] If a comprehensive evaluation is not possible, then, *at a minimum*, confirm whether pacing impulses are present and create a paced beat. Consultation with a cardiologist or CRMD service may be necessary. Contacting the manufacturer for perioperative recommendations may be a consideration.

II. Preoperative Preparation

Preparation for patient safety and proper maintenance of the device during a procedure includes (1) determining whether electromagnetic interference (EMI) is likely to occur during the planned procedure; (2) determining whether reprogramming the CRMD pacemaking function to an asynchronous pacing mode or disabling any special algorithms, including rate adaptive functions, is needed; (3) suspending antitachyarrhythmia functions if present; (4) advising the individual performing the procedure to consider use of a bipolar electrocautery system or ultrasonic (harmonic) scalpel to minimize potential adverse effects of EMI on the pulse generator or leads; (5) assuring the availability of temporary pacing and defibrillation equipment; and (6) evaluating the possible effects of anesthetic techniques on CRMD function and patient–CRMD interactions.

Numerous descriptive studies and case reports suggest that the following procedures are likely to be associated with EMI: (1) electrocautery,[6–11] (2) radio frequency ablation,[12–20] (3) magnetic resonance imaging (MRI),[21–31] and (4) radiation therapy.[32–34] No studies were found that reported EMI during electroconvulsive therapy (ECT). Some descriptive studies report the occurrence of EMI during lithotripsy,[35,36] whereas other descriptive studies and case reports indicate no apparent EMI effects.[37–39] No controlled trials of the clinical impact of programming the pacemaking function to an asynchronous mode for a procedure were found. Although some case reports suggest that such reprogramming is beneficial during electrocautery,[40–42] other reports indicate that EMI may continue to affect reprogrammed pacemakers.[43,44] The literature lacks sufficient guidance regarding the potential perioperative impact of anesthetic techniques on CRMD function. The majority of Consultants as well as the samples of ASA and HRS members agree that it should be determined whether EMI is likely to occur before a planned procedure. The majority of Consultants agree that a CRMD's rate-adaptive therapy should be turned off before a procedure, whereas the ASA and HRS members are equivocal. The majority of Consultants and HRS members disagree that all patients' CRMDs should be programmed to an asynchronous mode before surgery, whereas the ASA members are equivocal. In addition, the majority of Consultants and HRS members agree that pacemaker-dependent patients' CRMDs should be programmed to an asynchronous mode before surgery, whereas the ASA members are again equivocal. The majority of Consultants and ASA and HRS members agree that (1) suspending antitachyarrhythmia functions if present, (2) advising the individual performing the procedure to consider use of a bipolar electrocautery system to minimize potential adverse effects of EMI on the pulse generator or leads, (3) assuring the availability of temporary pacing and defibrillation equipment, and (4) evaluating the possible effects of anesthetic techniques on CRMD function and patient–CRMD interactions are important steps in promoting patient safety and successfully treating patients with CRMDs. The Consultants and ASA members agree and the HRS members are equivocal regarding the consideration of using an ultrasonic scalpel.

Advisory. The Task Force agrees that planned procedures should include a determination as to whether EMI is likely to occur for either conventional pacemakers or ICDs.

If EMI is likely to occur, the conventional pacing function of a CRMD should be altered by changing to an asynchronous pacing mode# in pacemaker-dependent patients and suspending special algorithms, including rate-adaptive functions. These alterations may be accomplished by programming or applying a magnet when applicable.** However, the Task Force cautions against the use of the magnet over an ICD.†† In addition, an

‖ Most current CRMDs have an x-ray code that can be used to identify the manufacturer of the device.

The VVT mode (with attention to the upper rate limit) might also be considered for a patient with ventricular ectopy where concern exists regarding R-on-T pacing during an asynchronous pacing mode. However, the upper pacing rate during VVT mode is manufacturer- and possibly generator-specific and can approach 200 beats/min for many devices. Generally, VVT mode pacing would not be a consideration except in very rare circumstances. Before using the VVT mode, a cardiologist and the generator manufacturer should be consulted to determine the suitability of the upper pacing rate for any patient.

** A magnet correctly applied to a pacemaker often results in asynchronous pacemaker function at a predetermined rate without rate responsiveness. The magnet rate and response varies by manufacturer. Magnet response can be affected by programming and remaining battery life. The magnet rate may be excessive for some patients. Some pacemakers may have no magnet response.

†† Magnet application to an ICD rarely alters bradycardia pacing rate and function. A magnet correctly applied to an ICD often results in suspension of tachyarrhythmia therapy. For most ICDs, there is no reliable means to detect appropriate magnet placement. Some ICDs may have no magnet response. Some ICDs can be permanently disabled by magnet application.

ICD's antitachyarrhythmia functions should be suspended, if present. For ICD patients who depend on pacing function for control of bradyarrhythmia, these functions should be altered by programming as noted above. Consultation with a cardiologist or pacemaker–ICD service may be necessary.

For all CRMDs, consider advising the individual performing the procedure to use a bipolar electrocautery system or an ultrasonic scalpel when applicable. Temporary pacing and defibrillation equipment should be immediately available before, during, and after a procedure.

Finally, the Task Force believes that anesthetic techniques do not influence CRMD function. However, anesthetic-induced physiologic changes (*i.e.*, cardiac rate, rhythm, or ischemia) in the patient may induce unexpected CRMD responses or adversely affect the CRMD–patient interaction.

III. Intraoperative Management

The primary activities associated with intraoperative management of a CRMD include (1) monitoring the operation of the device; (2) preventing potential CRMD dysfunction; and (3) performing emergency defibrillation, cardioversion, or heart rate support.

1. Monitoring. Intraoperative monitoring includes continuous electrocardiography as well as monitoring of the peripheral pulse (*e.g.*, palpation of the pulse, auscultation of heart sounds, monitoring of a tracing of intraarterial pressure, ultrasound peripheral pulse monitoring, or pulse plethysmography or oximetry).[45] Although no controlled trials were found that examine the clinical impact of electrocardiography or peripheral pulse monitoring for CRMD patients, case reports note the importance of intraoperative electrocardiographic monitoring in the detection of pacemaker or cardiac dysfunction for these patients.[4,46–50] The majority of Consultants and ASA and HRS members agree that (1) continuous electrocardiographic monitoring should be done for all CRMD patients and (2) continuous peripheral pulse monitoring should be conducted.

Advisory. Electrocardiography and peripheral pulse monitoring are important components of perioperative treatment of patients with CRMDs. The Task Force agrees that a patient's electrocardiogram should be continuously displayed, as required by ASA standards, from the beginning of anesthesia until the patient is transferred out of the anesthetizing location, with additional electrocardiographic monitoring in the postoperative period as indicated by the patient's medical condition.[45,51] The Task Force believes that these standards should apply to all CRMD patients receiving general or regional anesthesia, sedation, or monitored anesthesia care. Continuous peripheral pulse monitoring should be performed for all CRMD patients receiving general or regional anesthesia, sedation, or monitored anesthesia care. If unanticipated device interactions are found, consider discontinuation of the procedure until the source of interference can be eliminated or managed.

2. Managing Potential Sources of EMI. Procedures using electrocautery, radiofrequency ablation, lithotripsy, MRI, or radiation therapy may damage CRMDs or interfere with CRMD function, potentially resulting in severe adverse outcomes. Sources of EMI are often unique to specific procedures, and the management of each of these potential EMI sources is reported separately below.

A. Electrocautery. Management of potential sources of EMI associated with electrocautery includes (1) assuring that the cautery tool and current return pad‡‡ are positioned so that the current pathway does not pass through or near the CRMD pulse generator and leads; (2) avoiding proximity of the cautery's electrical field to the pulse generator or leads; (3) using short, intermittent, and irregular bursts at the lowest feasible energy levels; and (4) using a bipolar electrocautery system or an ultrasonic (harmonic) scalpel, if possible.

Two case reports[52,53] and one observational study[54] suggest that EMI may occur despite positioning the current return pad as far as possible away from the generator and leads. However, the majority of Consultants and ASA and HRS members agree that the current return pad should be positioned so that the electrosurgical current pathway does not pass through or near the CRMD pulse generator or leads.

One case report suggested that application of unipolar electrocautery on the sternum resulted in complete pacemaker inhibition.[55] Although some manufacturers suggest substituting bipolar for monopolar electrocautery to minimize CRMD interactions, no clinical literature was found to support this recommendation. The majority of Consultants and ASA and HRS members agree that direct contact between the electrocautery system and the CRMD pulse generator or its leads should be avoided.

Although no recent studies were found examining the benefit of using short, intermittent bursts at the lowest feasible energy levels, earlier literature§§ suggests that short, intermittent bursts may be useful in completing procedures without no¹table EMI interference.[56–60] The majority of Consultants and ASA and HRS members agree that short, intermittent bursts should be performed.

Finally, case reports suggest that surgery for pacemaker patients may proceed uneventfully when bipolar electrocautery systems[42,43,46] or harmonic scalpels[61,62] are used. The majority of Consultants and ASA and HRS members agree that bipolar electrocautery systems should be

‡‡ Although commonly referred to as the "grounding pad," most operating room power supplies in the United States are ungrounded.

§§ See appendix 3 for an explanation of the term *earlier literature*.

used when possible. The majority of Consultants and ASA members agree that harmonic scalpels should be used when possible, and HRS members are equivocal.

B. Radiofrequency Ablation. Management of potential sources of EMI associated with radiofrequency ablation primarily involves keeping the radiofrequency current path (electrode tip to current return pad) as far away from the pulse generator and lead system as possible. One observational study reports 3 of 12 cases that resulted in a significant decrease in resistance on the pacemaker leads when radiofrequency ablation was used in proximity to the leads.[63] One case report suggests that positioning of the radiofrequency ablation cluster electrode no closer than 5 cm from the pacer leads allowed the procedure to continue uneventfully.[40] The majority of Consultants and ASA and HRS members agree that the individual performing the procedure should avoid direct contact between the ablation catheter and the CRMD and leads and should keep the radiofrequency ablation current path as far away from the pulse generator and lead system as possible.

C. Lithotripsy. Management of potential sources of EMI associated with lithotripsy includes (1) avoiding focus of the lithotripsy beam near the pulse generator and (2) disabling atrial pacing if the lithotripsy system triggers on the R wave. The literature is silent regarding the benefits of focusing the lithotripsy beam away from the pulse generator as well as the benefits of disabling atrial pacing during lithotripsy. The majority of Consultants and ASA and HRS members agree that focusing the lithotripsy beam near the pulse generator should be avoided, and all three groups are equivocal regarding whether atrial pacing should be disabled before a procedure if the lithotripsy system triggers on the R wave.

D. Magnetic Resonance Imaging. The literature is not sufficiently rigorous to examine the effects of specific management activities related to CRMD patients receiving MRI. Some descriptive studies and case reports suggest that MRI may be completed without notable EMI under specific circumstances and with appropriate patient qualification and monitoring.[30,31,64–71] However, other literature generally suggests that MRI is contraindicated.[21–29] The majority of Consultants and ASA and HRS members generally agree that MRI is contraindicated for all CRMD patients.

E. Radiation Therapy. The literature does not provide sufficient guidance regarding specific management activities related to CRMD patients undergoing radiation therapy. However, none of the Consultants or HRS members and only 10% of the ASA members agree that radiation therapy is contraindicated for all CRMD patients. Fifty-seven percent of the Consultants, 59% of the HRS members, and 37% of the ASA members agree that radiation therapy is contraindicated for some but not all CRMD patients, whereas 43% of the Consultants, 41% of the HRS members, and 53% of the ASA members agree that radiation therapy is not contraindicated for any CRMD patient.

F. Electroconvulsive Therapy. No clinical studies were found that report EMI effects or permanent CRMD malfunction associated with ECT. One study reports two cases where patients' ICDs were turned off before ECT but does not report the effect of the therapy on ICD function.[72] However, the author indicates that treatment with ECT might be associated with significant cardiac risks. Transient electrocardiographic changes (*e.g.*, increased P-wave amplitude, altered QRS shape, T-wave and ST-T abnormalities) may result from ECT, and additional cardiac complications (*e.g.*, arrhythmia or ischemia) may occur in patients with preexisting cardiac disease. Finally, physiologic stresses after ECT, such as a period of bradycardia and reduced blood pressure, followed by tachycardia and an increase in blood pressure, may account for cardiac failure in the extended postoperative period (*i.e.*, several hours or days after ECT) among patients with marginal cardiac function.

Advisory. The Task Force believes that EMI could be minimized during certain procedures using a variety of intraoperative management techniques.

The Task Force agrees that the risk of intraoperative interference from electrocautery systems may be minimized by (1) positioning the cautery tool and current return pad so that the current pathway does not pass through or near the CRMD system‖ ‖; (2) avoiding proximity of the cautery's electrical field to the pulse generator and leads, including avoidance of waving the activated electrode over the generator##; (3) using short, intermittent, and irregular bursts at the lowest feasible energy levels; and (4) using bipolar electrocautery systems or ultrasonic (harmonic) scalpels if possible. Advising or reminding the individual performing the procedure to implement these management techniques should be considered.

Risk of interference from radiofrequency ablation may be reduced by avoiding direct contact between the ablation catheter and the pulse generator and leads and by keeping the radiofrequency's current path (electrode tip to current return pad) as far away from the pulse generator and leads as possible. During all radiofrequency ablative procedures, consider discussing with the individual performing the procedure any concerns regarding the proximity of the ablation catheter to the CRMD leads.

During lithotripsy, the lithotripsy beam should not be focused near the pulse generator. If the lithotripsy system triggers on the R wave, atrial pacing might need to be disabled before the procedure.

‖ ‖ For some cases, the electrosurgical receiving plate will need to be placed on a site different from the thigh. For example, in head and neck cases, the receiving plate can be placed on the posterior superior aspect of the shoulder contralateral to the generator position.

An inhibitory effect could occur even when the active electrode of the electrocautery is not touching the patient.

The Task Force believes that MRI is generally contraindicated for CRMD patients. If MRI must be performed, consult with the ordering physician, the patient's pacemaker specialist or cardiologist, the diagnostic radiologist, and the CRMD manufacturer.

The Task Force believes that radiation therapy can be safely performed for CRMD patients.*** The device must be outside the field of radiation. Therefore, some pulse generators will require surgical relocation before commencing radiation. Most manufacturers recommend verification of pulse generator function during and at the completion of radiation. Problems may include pacemaker failure and runaway pacemaker.†††

Although transient or long-term myocardial and nervous system effects may be associated with ECT, the Task Force believes that such therapies may be administered to CRMD patients without significant damage to a disabled CRMD. If ECT must be performed, consult with the ordering physician and the patient's cardiologist to plan for the first and subsequent ECTs. All CRMDs should undergo a comprehensive interrogation before the procedure(s). ICD functions should be disabled for shock therapy during ECT; however, be prepared to treat ventricular arrhythmias that occur secondary to the hemodynamic effects of ECT. CRMD-dependent patients may require a temporary pacing system to preserve cardiac rate and rhythm during shock therapy. Also, the CRMD may require programming to asynchronous activity to avoid myopotential inhibition of the device in pacemaker-dependent patients.

3. Emergency Defibrillation or Cardioversion. During the perioperative period, emergency defibrillation or cardioversion may become necessary for a CRMD patient. In this case, the primary concern is to minimize the current flowing through the pulse generator and lead system. Recent and earlier case reports suggest that optimal positioning of the defibrillation or cardioversion pads or paddles may be an important factor in the prevention of adverse CRMD-related outcomes.[73–77] The majority of Consultants and ASA and HRS members agree that the defibrillation or cardioversion pads should be positioned as far as possible from the pulse generator. The majority of Consultants and ASA and HRS members also agree that the anterior–posterior position should be used and that a clinically appropriate energy output should be used regardless of the type of CRMD.

Advisory. The Task Force believes that before attempting emergency defibrillation or cardioversion of a patient with an ICD and magnet-disabled therapies, all sources of EMI should be terminated, and the magnet should be removed to reenable antitachycardia therapies. The patient should then be observed for appropriate CRMD therapy. For patients with an ICD and antiarrhythmic therapies that have been disabled by programming, consider reenabling therapies through programming. If the above activities do not restore ICD function, proceed with emergency external defibrillation or cardioversion.

Overriding the above discussion is the need to follow existing Advanced Cardiac Life Support and emergency guidelines[78] to provide rapid cardioversion or defibrillation, and attention should be turned to providing this therapy as quickly as possible.

If a life-threatening arrhythmia occurs, follow Advanced Cardiac Life Support guidelines for energy level and for paddle placement. If possible, attempt to minimize the current flowing through the pulse generator and lead system by (1) positioning the defibrillation or cardioversion pads or paddles as far as possible from the pulse generator and (2) positioning defibrillation or cardioversion pads or paddles perpendicular to the major axis of the CRMD pulse generator and leads to the extent possible by placing them in an anterior–posterior location. A clinically appropriate energy output should always be used regardless of the presence of a CRMD, and the paddles should be positioned as best as can be done in an emergency.

IV. Postoperative Management

Postoperative treatment of CRMD patients primarily consists of interrogating and restoring CRMD function. Although no recent studies were found examining outcomes associated with interrogating or restoring CRMD function, an earlier case report indicates that postoperative evaluation resulted in the discovery and correction of a pacemaker problem.[79] The majority of Consultants and ASA and HRS members agree that postoperative patient treatment should include interrogating and restoring CRMD function in the postanesthesia care unit or intensive care unit.

Advisory. The Task Force believes that cardiac rate and rhythm should be continuously monitored throughout the immediate postoperative period. Backup pacing capability and cardioversion–defibrillation equipment should be immediately available at all times.

Postoperative interrogation and restoration of CRMD function are basic elements of postoperative management. The CRMD first should be interrogated to assess postoperative device functions. If interrogation determines that CRMD settings are inappropriate, the device should be reprogrammed to appropriate settings. For an ICD, all antitachyarrhythmic therapies should be restored. Consultation with a cardiologist or pacemaker–ICD service may be necessary.

*** Radiation shielding may not be feasible for some patients because of the size and weight of the shield. This may be compensated for by relocating the generator.

††† *Runaway pacemaker* is a potentially catastrophic pulse generator malfunction characterized by the sudden onset of rapid, erratic pacing. Runaway pacemaker is the result of multiple internal component failure, and it is relatively uncommon in modern devices. Circuitry in modern pacemakers (and ICDs) limits the runaway pacing rate to less than 210 beats/min.

Appendix 1: Generic Pacemaker and Defibrillator Codes

The generic pacemaker and defibrillator codes were developed as joint projects by the North American Society of Pacing and Electrophysiology (NASPE)‡‡‡ and the British Pacing and Electrophysiology Group (BPEG).[80,81] The five positions refer to the order of the programmed settings on the CRMD (tables 1 and 2).

Table 1. Generic Pacemaker Code (NBG*): NASPE/BPEG Revised (2002)

Position I, Pacing Chamber(s)	Position II, Sensing Chamber(s)	Position III, Response(s) to Sensing	Position IV, Programmability	Position V, 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)

Examples:

AAI = Atrial-only antibradycardia pacing. In the AAI mode, any failure of the atrium to produce an intrinsic event within the appropriate time window (determined by the lower rate limit) results in an atrial pacing pulse emission. There is no ventricular sensing; thus, a premature ventricular event will not likely reset the pacing timer.

AOO = Asynchronous atrial-only pacing. In this mode, the pacing device emits a pacing pulse regardless of the underlying cardiac rhythm.

DDD = Dual-chamber antibradycardia pacing function in which every atrial event, within programmed limits, is followed by a ventricular event. The DDD mode implies dual-chamber pacing with atrial tracking. In the absence of intrinsic activity in the atrium, it will be paced, and, after any sensed or paced atrial event, an intrinsic ventricular event must occur before the expiration of the atrioventricular timer or the ventricle will be paced.

DDI = Dual-chamber behavior in which the atrial activity is tracked into the ventricle only when the atrial event is created by the antibradycardia pacing function of the generator. In the DDI mode, the ventricle is paced only when no intrinsic ventricular activity is present.

DOO = Asynchronous atrioventricular sequential pacing without regard to the underlying cardiac rhythm.

VOO = Asynchronous ventricular-only pacing without regard to the underlying cardiac rhythm.

VVI = Ventricular-only antibradycardia pacing. In the VVI mode, any failure of the ventricle to produce an intrinsic event within the appropriate time window (determined by the lower rate limit) results in a ventricular pacing pulse emission. There is no atrial sensing; thus, there can be no atrioventricular synchrony in a patient with a VVI pacemaker and any intrinsic atrial activity.

* NBG: N refers to NASPE, B refers to BPEG, and G refers to generic.

Table 2. Generic Defibrillator Code (NBD): NASPE/BPEG

Position I, Shock Chamber(s)	Position II, Antitachycardia Pacing Chamber(s)	Position III, Tachycardia Detection	Position IV,* Antibradycardia Pacing Chamber(s)
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)

* For robust identification, position IV is expanded into its complete NBG code. For example, a biventricular pacing–defibrillator with ventricular shock and antitachycardia pacing functionality would be identified as VVE-DDDRV, assuming that the pacing section was programmed DDDRV. Currently, no hemodynamic sensors have been approved for tachycardia detection (position III).

‡‡‡ Now called the Heart Rhythm Society (HRS).

Appendix 2: Summary of Practice Advisory

Preoperative Evaluation

- Establish whether a patient has a CRMD.
  - Conduct a focused history (patient interview, medical records review, review of available chest x-ray films, electrocardiogram, or any available monitor or rhythm strip information).
  - Conduct a focused physical examination (check for scars, palpate for device).
- Define the type of CRMD.
  - Obtain manufacturer's identification card from patient or other source.
  - Order chest x-ray studies if no other data are available.
  - Refer to supplemental resources (*e.g.*, manufacturer's databases).
- Determine dependency on pacing function of the CRMD.
  - History of symptomatic bradyarrhythmia resulting in CRMD implantation.
  - History of successful atrioventricular nodal ablation.
  - Inadequate escape rhythm at lowest programmable pacing rate.
- Determine CRMD function.
  - Interrogate device (consultation with a cardiologist or pacemaker–ICD service may be necessary).
  - Determine whether the device will capture when it paces (*i.e.*, produce a mechanical systole with a pacemaker impulse).
  - Consider contacting the manufacturer for perioperative recommendations.

Preoperative Preparation

- Determine whether EMI is likely to occur during the planned procedure.
- Determine whether reprogramming pacing function to asynchronous mode or disabling rate responsive function is advantageous.
- Suspend antitachyarrhythmia functions if present.
- Advise individual performing the procedure to consider use of a bipolar electrocautery system or ultrasonic (harmonic) scalpel.
- Temporary pacing and defibrillation equipment should be immediately available.
- Evaluate the possible effects of anesthetic techniques and of the procedure on CRMD function and patient CRMD interactions.

Intraoperative Management

- Monitor operation of the CRMD.
  - Conduct electrocardiographic monitoring per ASA standard.
  - Monitor peripheral pulse (*e.g.*, manual pulse palpation, pulse oximeter plethysmogram, arterial line).
- Manage potential CRMD dysfunction due to EMI.
  - Electrocautery.
    - Assure that the electrosurgical receiving plate is positioned so that the current pathway does not pass through or near the CRMD system. For some cases, the receiving plate might need to be placed on a site different from the thigh (*e.g.*, the superior posterior aspect of the shoulder contralateral to the generator position for a head and neck case).
    - Advise individual performing the procedure to avoid proximity of the cautery's electrical field to the pulse generator or leads.
    - Advise individual performing the procedure to use short, intermittent, and irregular bursts at the lowest feasible energy levels.
    - Advise individual performing the procedure to reconsider the use of a bipolar electrocautery system or ultrasonic (harmonic) scalpel in place of a monopolar electrocautery system, if possible.
  - Radiofrequency ablation.
    - Advise individual performing the procedure to avoid direct contact between the ablation catheter and the pulse generator and leads.
    - Advise individual performing the procedure to keep the radiofrequency's current path as far away from the pulse generator and lead system as possible.
  - Lithotripsy.
    - Advise individual performing the procedure to avoid focusing the lithotripsy beam near the pulse generator.
    - If the lithotripsy system triggers on the R wave, consider preoperative disabling of atrial pacing.
  - MRI.
    - MRI is generally contraindicated in patients with CRMDs.
    - If MRI must be performed, consult with the ordering physician, the patient's cardiologist, the diagnostic radiologist, and the CRMD manufacturer.
  - Radiation therapy.
    - Radiation therapy can be safely performed in patients who have CRMDs.
    - Surgically relocate the CRMD if the device will be in the field of radiation.
  - Electroconvulsive therapy.
    - Consult with the ordering physician, the patient's cardiologist, a CRMD service, or the CRMD manufacturer.
- Emergency defibrillation or cardioversion.
  - For a patient with an ICD and magnet-disabled therapies:
    - Advise individual performing the procedure to terminate all sources of EMI while magnet is removed.
    - Remove the magnet to reenable antitachycardia therapies.
    - Observe the patient and the monitors for appropriate CRMD therapy.
    - If the above activities do not restore ICD function, proceed with emergency external defibrillation or cardioversion.
  - For a patient with an ICD and programming-disabled therapies:
    - Advise individual performing the procedure to terminate all sources of EMI while magnet is removed.
    - Reenable therapies through programming if the programmer is immediately available and ready to be used.
    - Observe the patient and the monitors for appropriate CRMD therapy.
    - If the above activities do not restore ICD function, proceed with emergency external defibrillation or cardioversion.
  - For external defibrillation:
    - Position defibrillation/cardioversion pads or paddles as far as possible from the pulse generator.
    - Position defibrillation/cardioversion pads or paddles perpendicular to the major axis of the CRMD to the extent possible by placing them in an anterior–posterior location.
    - If it is technically impossible to place the pads or paddles in locations that help to protect the CRMD, defibrillate/cardiovert the patient in the quickest possible way and be prepared to provide pacing through other routes.
    - Use a clinically appropriate energy output.

Postoperative Management

- Continuously monitor cardiac rate and rhythm and have backup pacing and defibrillation equipment immediately available throughout the immediate postoperative period.
- Interrogate and restore CRMD function in the immediate postoperative period.
  - Interrogate CRMD; consultation with a cardiologist or pacemaker–ICD service may be necessary.
  - Restore all antitachyarrhythmic therapies in ICDs.
  - Assure that all other settings of the CRMD are appropriate.

Refer to Table 3 for an example of a stepwise approach to the perioperative treatment of the patient with a CRMD.

ASA = American Society of Anesthesiologists; CRMD = cardiac rhythm management device; EMI = electromagnetic interference; ICD = implantable cardioverter–defibrillator; MRI = magnetic resonance imaging.

Table 3. Example of a Stepwise Approach to the Perioperative Treatment of the Patient with a CRMD

Perioperative Period	Patient/CRMD Condition	Intervention
Preoperative evaluation	Patient has CRMD	• Focused history • Focused physical examination
	Determine CRMD type (pacemaker, ICD, CRT)	• Manufacturer's CRMD identification card • Chest x-ray studies (no data available) • Supplemental resources*
	Determine whether patient is CRMD-dependent for pacing function	• Verbal history • Bradyarrhythmia symptoms • Atrioventricular node ablation • No spontaneous ventricular activity†
	Determine CRMD function	• Comprehensive CRMD evaluation‡ • Determine whether pacing pulses are present and create paced beats
Preoperative preparation	EMI unlikely during procedure	• If EMI unlikely, special precautions are not needed
	EMI likely: CRMD is pacemaker	• Reprogram to asynchronous mode when indicated • Suspend rate-adaptive functions§
	EMI likely: CRMD is ICD	• Suspend antitachyarrhythmia functions • If patient is dependent on pacing function, alter pacing functions as above
	EMI likely: all CRMD	• Use bipolar cautery; ultrasonic scalpel • Temporary pacing and external cardioversion–defibrillation available
	Intraoperative physiologic changes likely (*e.g.*, bradycardia, ischemia)	• Plan for possible adverse CRMD–patient interaction
Intraoperative management	Monitoring	• Electrocardiographic monitoring per ASA standard • Peripheral pulse monitoring
	Electrocautery interference	• CT/CRP—no current through PG/leads • Avoid proximity of CT to PG/leads • Short bursts at lowest possible energy • Use bipolar cautery; ultrasonic scalpel
	Radiofrequency catheter ablation	• Avoid contact of radiofrequency catheter with PG/leads • Radiofrequency current path far away from PG/leads • Discuss these concerns with operator
	Lithotripsy	• Do not focus lithotripsy beam near PG • R wave triggers lithotripsy? Disable atrial pacing‖
	MRI	• Generally contraindicated • If required, consult ordering physician, cardiologist, radiologist, and manufacturer
	RT	• PG/leads must be outside of RT field • Possible surgical relocation of PG • Verify PG function during/after RT course
	ECT	• Consult with ordering physician, patient's cardiologist, a CRMD service, or CRMD manufacturer
Emergency defibrillation–cardioversion	ICD: magnet disabled	• Terminate all EMI sources • Remove magnet to reenable therapies • Observe for appropriate therapies
	ICD: programming disabled	• Programming to reenable therapies or proceed directly with external cardioversion–defibrillation
	ICD: either of above	• Minimize current flow through PG/leads • PP as far as possible from PG • PP perpendicular to major axis PG/leads • To extent possible, PP in anterior–posterior location
	Regardless of CRMD type	• Use clinically appropriate cardioversion/defibrillation energy
Postoperative management	Immediate postoperative period	• Monitor cardiac R&R continuously • Backup pacing and cardioversion/defibrillation capability
	Postoperative interrogation and restoration of CRMD function	• Interrogation to assess function • Settings appropriate?# • Is CRMD an ICD?** • Use cardiology/pacemaker–ICD service if needed

* Manufacturer's databases, pacemaker clinic records, cardiology consultation. † With cardiac rhythm management device (CRMD) programmed VVI at lowest programmable rate. ‡ Ideally CRMD function assessed by interrogation, with function altered by reprogramming if required. § Most times this will be necessary; when in doubt, assume so. ‖ Atrial pacing spikes may be interpreted by the lithotriptor as R waves, possibly inciting the lithotriptor to deliver a shock during a vulnerable period in the heart. # If necessary, reprogram appropriate settings. ** Restore all antitachycardia therapies.

CRP = current return pad; CRT = cardiac resynchronization therapy; CT = cautery tool; ECT = electroconvulsive therapy; EMI = electromagnetic interference; ICD = internal cardioverter–defibrillator; MRI = magnetic resonance imaging; PG = pulse generator; PP = external cardioversion–defibrillation pads or paddles; R&R = rhythm and rate; RT = radiation therapy.

Appendix 3: Literature Review and Consensus-based Evidence

A. State of the Literature

For this Advisory, a literature review was used in combination with opinions obtained from experts and other sources (*e.g.*, professional society members, open forums, Web-based postings) to provide guidance to practitioners regarding the perioperative treatment of patients with CRMDs. Both the literature review and opinion data were based on *evidence linkages*, consisting of directional statements about relations between specific perioperative management activities and CRMD function or clinical outcomes.

A study or report that appears in the published literature is included in the development of an advisory if the study (1) is related to one of the specified linkage statements, (2) reports a finding or set of findings that can be tallied or measured (*e.g.*, articles that contain only opinion are not included), and (3) is the product of an original investigation or report (*i.e.*, review articles or follow-up studies that summarize previous findings are not included). Because CRMDs represent a rapidly changing technology, earlier literature (*i.e.*, literature published before 1990) was rarely included in the evaluation of evidence for this Practice Advisory.

Although evidence linkages are designed to assess causality, few of the reviewed studies exhibited sufficiently acceptable quantitative methods and analyses to provide a clear indication of causality. Therefore, the published literature could not be used as a source of quantitative support (required for the development of practice guidelines). However, many published studies were evaluated that provided the Task Force with important noncausal evidence. For example, descriptive literature (*i.e.*, reports of frequency or incidence) is often useful in providing an indication of the scope of a problem. Information regarding whether a particular adverse outcome is common or rare may have considerable bearing on the practicality of an advisory. Case reports are typically used as a forum for reporting and recognizing unusual or adverse outcomes and may suggest caution when devising an advisory.

For the literature review, potentially relevant studies were identified *via* electronic and manual searches of the literature. The electronic search covered a 39-yr period from 1966 through 2004. The manual search covered a 45-yr period from 1961 through 2005. More than 1,500 citations were initially identified, yielding a total of 411 nonoverlapping articles that addressed topics related to the evidence linkages. After review of the articles, 283 studies did not provide direct evidence and were subsequently eliminated. A total of 128 articles (from 39 journals) contained direct linkage-related evidence. No evidence linkage contained enough studies with well-defined experimental designs and statistical information to conduct a quantitative analysis (*i.e.*, meta-analysis).

§ § § International Anesthesia Research Society; 78th Clinical and Scientific Congress, Tampa, Florida, March 28, 2004, and NASPE Heart Rhythm Society Annual Meeting, San Francisco, California, May 20, 2004.

Interobserver agreement among Task Force members and two methodologists was established by interrater reliability testing. Agreement levels using a κ statistic for two-rater agreement pairs were as follows: (1) type of study design, $\kappa = 0.72–0.90$; (2) type of analysis, $\kappa = 0.80–0.90$; (3) evidence linkage assignment, $\kappa = 0.84–1.00$; and (4) literature inclusion for database, $\kappa = 0.70–1.00$. Three-rater chance-corrected agreement values were (1) study design, Sav = 0.81, Var (Sav) = 0.010; (2) type of analysis, Sav = 0.86, Var (Sav) = 0.009; (3) linkage assignment, Sav = 0.82, Var (Sav) = 0.005; and (4) literature database inclusion, Sav = 0.78, Var (Sav) = 0.031. These values represent moderate to high levels of agreement.

Future studies should focus on prospective methodologies, when possible, that use traditional hypothesis testing techniques. Use of the following methodologic procedures for assessing the impact of perioperative management of CRMDs is recommended: (1) comparison studies (*i.e.*, one technique *vs.* another) when clinically feasible; (2) randomization; and (3) full reporting of sample size, effect size estimates, test scores, measures of variability, and *P* values.

B. Consensus-based Evidence

Consensus was obtained from multiple sources, including (1) survey opinion from Consultants who were selected based on their knowledge or expertise in perioperative management of CRMDs, (2) survey opinions from randomly selected samples of active members of the American Society of Anesthesiologists and active members of the HRS, (3) testimony from attendees of two publicly held open forums at a national anesthesia meeting and at a major cardiology meeting,§ § § (4) Internet commentary, and (5) Task Force opinion and interpretation. The survey rate of return was 56% (n = 23 of 41) for Consultants, 15% (n = 89 of 600) for the ASA membership, and 15% (n = 44 of 300) for the HRS membership. Survey results are presented in the text of the document and in table 4.

The ASA Consultants were also asked to indicate which, if any, of the evidence linkages would change their clinical practices if the Advisory was instituted. The rate of return was 39% (n = 16 of 41). The percent of responding Consultants expecting *no change* associated with each linkage were as follows: preoperative evaluation—67%; preoperative patient preparation—67%; intraoperative monitoring of CRMDs—67%; emergency defibrillation or cardioversion—87%; postoperative monitoring of CRMDs—73%; postoperative interrogation and restoration of CRMD function—60%; intraoperative management of EMI during: electrocautery—73%, radiofrequency ablation—73%, lithotripsy—80%, MRI—80%, radiation therapy—80%, and electroconvulsive therapy—73%. Forty percent of the respondents indicated that the Advisory would have *no effect* on the amount of time spent on a typical case. Nine respondents (60%) indicated that there would be an increase in the amount of time they would spend on a typical case with the implementation of this Advisory. The amount of increased time anticipated by these respondents ranged from 5 to 30 min.

Table 4. Consultant and Membership Survey Responses: Percent Agreement/Disagreement*

Survey Item	Consultants		ASA Members		HRS Members	
	n	% Agree/Disagree	n	% Agree/Disagree	n	% Agree/Disagree
1. To perform a preoperative evaluation:						
Establish whether a patient has a CRMD.	23	100/0	89	100/0	44	100/0
Define the type of device.	23	100/0	87	95/0	44	100/0
Determine whether a patient is CRMD dependent for pacemaking function.	23	96/0	89	96/0	44	96/4
Determine CRMD function.	23	96/0	89	88/3	44	71/11
2. To prepare a CRMD patient for a procedure:						
Determine whether EMI is likely to occur.	23	96/4	89	91/2	44	96/2
Turn pacemaking rate-adaptive therapy off.	23	52/35	89	35/35	44	34/34
Program pacemaking function to asynchronous mode:						
All CRMD patients.	22	0/82	88	21/48	43	9/84
Pacemaker-dependent patients only.	22	73/23	83	47/27	43	54/28
Suspend antitachyarrhythmia functions.	21	86/5	87	54/21	43	63/21
Consider using a bipolar electrocautery system (when applicable).	22	91/0	86	90/2	44	77/14
Consider using an ultrasonic (harmonic) scalpel (when applicable).	22	68/18	88	63/3	44	34/9
Assure the availability of temporary pacing and defibrillation equipment.	22	100/0	87	95/1	44	89/7
Consider the possible effects of anesthetic agents or techniques on CRMD function.	22	64/18	86	779	44	66/21
3. Intraoperative monitoring should include:						
Continuous electrocardiography.	23	100/0	88	100/0	44	100/0
Continuous peripheral pulse monitoring.	23	96/0	88	86/11	44	61/18
4. For procedures using electrocautery:						
Position the electrosurgical receiving plate so current pathway does not pass through or near the generator or leads.	23	100/0	88	97/0	44	96/0
Avoid proximity of the cautery's electrical field to the pulse generator or leads.	23	100/0	87	100/0	44	96/2
Use short, intermittent, and irregular bursts at the lowest feasible energy levels.	23	96/0	87	83/2	44	91/7
Use a bipolar electrocautery system (when applicable).	23	91/0	88	94/1	44	84/2
Use an ultrasonic (harmonic) scalpel (when applicable).	23	57/13	88	65/1	44	41/9
5. For radiofrequency ablation:						
Avoid direct contact between the ablation catheter and the CRMD and leads.	23	83/0	87	76/0	44	91/2
Keep the current path (electrode tip to return plate) as far away from the pulse generator and lead system as possible.	23	87/0	87	78/0	44	89/5
6. For lithotripsy:						
Avoid focusing the lithotripsy beam near the pulse generator.	23	91/0	86	78/1	44	86/0
If the lithotripsy system triggers on the R wave, disable atrial pacing before procedure.	23	39/26	86	38/13	44	39/9
7. For MRI:†						
MRI is contraindicated for all CRMD patients.	21	81	79	80	44	55
MRI is contraindicated for some but not all CRMD patients.	21	19	79	18	44	39
MRI is not contraindicated for any CRMD patient.	21	0	79	2	44	6
8. For RT:†						
RT is contraindicated for all CRMD patients.	21	0	73	10	44	0
RT is contraindicated for some but not all CRMD patients.	21	57	73	37	44	59
RT is not contraindicated for any CRMD patient.	21	43	73	53	44	41
9. For emergency defibrillation or cardioversion:						
Position the defibrillation or cardioversion pads as far as possible from the pulse generator.	23	83/0	87	69/13	44	91/7
Use an anterior–posterior position.	23	74/9	84	61/6	44	68/25
Use a clinically appropriate energy output regardless of the device.	23	100/0	87	87/0	44	100/0
10. To treat CRMD patients postoperatively:						
Interrogate and restore CRMD function in the PACU or ICU.	23	96/4	88	98/1	44	77/21

* The percentages of respondents who agreed/disagreed with each item are presented. The percentages of respondents who were uncertain are not presented. † Respondents were asked to select one of the three choices. Therefore, the numbers represent percent agreement only.

ASA = American Society of Anesthesiologists; CRMD = cardiac rhythm management device; EMI = electromagnetic interference; HRS = Heart Rhythm Society; ICU = intensive care unit; MRI = magnetic resonance imaging; PACU = postanesthesia care unit; RT = radiation therapy.

References ‖ ‖ ‖

1. Barold S, Zites D: Cardiac pacemakers and antiarrhythmic devices, Heart Disease, 5th edition. Edited by Braunwald E. Philadelphia, WB Saunders, 1997, pp 705–41
2. Mychaskiw G, Eichhorn JH: Interaction of an implanted pacemaker with a transesophageal atrial pacemaker: Report of a case. J Clin Anesth 1999; 11: 669–71
3. Purday JP, Towey RM: Apparent pacemaker failure caused by activation of ventricular threshold test by a magnetic instrument mat during general anaesthesia. Br J Anaesth 1992; 69:645–6
4. Kellow NH: Pacemaker failure during transurethral resection of the prostate. Anesthesia 1993; 48:136–8
5. Bernstein AD, Irwin ME, Parsonnet V, Wilkoff BL, Black WR, Buckingham TA, Maloney JD, Reynolds DD, Saksena S, Singer I, Nickelson DE, Schurig L: Report of the NASPE policy conference on antibradycardia pacemaker follow-up: Effectiveness, needs and resources. Pacing Clin Electrophysiol 1994; 17:1714–29
6. Ahern TS, Luckett C, Ehrlich S, Pena EA: Use of bipolar electrocautery in patients with implantable cardioverter-defibrillators: No reason to inactivate detection or therapies. PACE 1999; 22:776
7. Bailey AG, Lacey SR: Intraoperative pacemaker failure in an infant. Can J Anaesth 1991; 38:912–3
8. El-Gamal HM, Dufresne RG, Saddler K: Electrosurgery, pacemakers and ICDs: A survey of precautions and complications experienced by cutaneous surgeons. Dermatol Surg 2001; 27:385–90
9. Rozner MA: Review of electrical interference in implanted cardiac devices. PACE 2003; 26:923–5
10. Wilson JH, Lattner S, Jacob R, Stewart R: Electrocautery does not interfere with the function of the automatic implantable cardioverter defibrillator. Ann Thorac Surg 1991; 51:225–6
11. Wong DT, Middleton W: Electrocautery-induced tachycardia in a rate-responsive pacemaker. ANESTHESIOLOGY 2001; 94:10–1
12. Chang AC, McAreavey D, Tripodi D, Fananapazir L: Radiofrequency catheter atrioventricular node ablation in patients with permanent cardiac pacing systems. Pacing Clin Electrophysiol 1994; 17:65–9
13. Chin MC, Rosenqvist M, Lee MA, Griffin JC, Langberg JJ: The effect of radiofrequency catheter ablation on permanent pacemakers: An experimental study. Pacing Clin Electrophysiol 1990; 13:23–9
14. de Chillou C, Sadoul N Beurrier D, Bizeau O, Aliot E, Dodinot B: Effects of radiofrequency catheter ablation on the behavior of permanent pacemakers. Pacing Clin Electrophysiol 1996; 19:680
15. Ellenbogen KA, Wood MA, Stambler BS: Acute effects of radiofrequency ablation of atrial arrhythmias on implanted permanent pacing systems. Pacing Clin Electrophysiol 1996; 19:1287–95
16. Pfeiffer D, Tebbenjohanns J, Schumacher B, Jung W, Luderitz B: Pacemaker function during radiofrequency ablation. Pacing Clin Electrophysiol 1995; 18:1037–44
17. Pfeiffer D, Tebbenjohanns J, Schumacher B, Jung W, Manz M, Luderitz B: Pacemaker behaviour during radiofrequency current delivery. J Am Coll Cardiol 1994; 23(suppl A):324A
18. Moore S, Firstenberg M, Simmons TW, Trohman R: The interaction between radiofrequency ablation and permanent pacemakers. Circulation 1992; 86(suppl 1):I-449
19. Trohman RG, Simmons TW, Moore SL, Firstenberg MS, Williams D, Maloney JD: Catheter ablation of atrioventricular junction using radiofrequency energy and a bilateral cardiac approach. Am J Cardiol 1992; 70:1438–43
20. Wolfe DA, McCutcheon MJ, Plumb VJ, Kay N: Radiofrequency current may induce exit block in chronically implanted ventricular leads. Pacing Clin Electrophysiol 1995; 18:919
21. Achenbach S, Moshage W, Diem B, Bieberle T, Schibgilla V, Bachmann K: Effects of magnetic resonance imaging on cardiac pacemakers and electrodes. Am Heart J 1997; 134:467–73
22. Fontaine JM, Mohamed FB, Gottlieb, Callans DJ, Marchlinski FE: Rapid ventricular pacing in a pacemaker patient undergoing magnetic resonance imaging. Pacing Clin Electrophysiol 1998; 21:1336–9
23. Garcia-Bolao I, Albaladejo V, Benito A, Alegria E, Zubieta JL: Magnetic resonance imaging in a patientv with a dual-chamber pacemaker. Acta Cardiol 1998; 53:33–5
24. Gimbel JR, Johnson D, Levine PA, Wilkoff BL: Safe performance of magnetic resonance imaging on five patients with permanent cardiac pacemakers. Pacing Clin Electrophysiol 1996; 19:913–9
25. Gimbel JR, Lorig RJ, Wilkoff BL: Safe magnetic resonance imaging of pacemaker patients. J Am Coll Cardiol 1995; 25:11A
26. Hayes DL, Holmes DR Jr, Gray JE: Effect of 1.5 Tesla nuclear magnetic resonance imaging scanner on implanted permanent pacemakers. J Am Coll Cardiol 1987; 10:782–6
27. Luechinger R, Duru F, Scheidegger MB, Boesiger P, Candinas R: Force and torque effects of a 1.5-Tesla MRI scanner on cardiac pacemakers and ICDs. Pacing Clin Electrophysiol 2001; 24:199–205
28. Pavlicek W, Geisinger M, Castle L, Borkowski GP, Meaney TF, Bream BL, Gallagher JH: The effects of nuclear magnetic resonance on patients with cardiac pacemakers. Radiology 1993; 147:149–53
29. Vahlhaus C, Sommer T, Lewalter T, Schimpf R, Schumacher B, Jung W, Luderitz B: Interference with cardiac pacemakers by magnetic resonance imaging: Are there irreversible changes at 0.5 Tesla? Pacing Clin Electrophysiol 2001; 24:489–95
30. Martin ET, Coman JA, Shellock FG, Pulling CC, Fair R, Jenkins K: Magnetic resonance imaging and cardiac pacemaker safety at 1.5-Telsa. J Am Coll Cardiol 2004; 43:1315–24
31. Rozner MA, Burton AW, Kumar AJ: Pacemaker complication during MRI. J Am Coll Cardiol 2005; 45:161–2
32. Raitt MH, Stalzer KJ, Laramore GE, Bardy GH, Dolack GL, Poole JE, Kudenchuk PJ: Runaway pacemaker during high-energy neutron radiation therapy. Chest 1994; 106:955–7
33. Rodriguez F, Filimonov A, Henning A, Coughlin C, Greenberg M: Radiation-induced effects in multiprogrammable pacemakers and implantable defibrillators. Pacing Clin Electrophysiol 1991; 14:2143–53
34. Hurkmans CW, Scheepers E, Springorum BG, De Ruiter GS, Uiterwaal HA: Influence of therapeutic irradiation on the latest generation of pacemakers. Heart Rhythm 2004; 1(suppl):S53–4
35. Drach GW, Weber C, Donovan JM: Treatment of pacemaker patients with extracorporeal shock wave lithotripsy: Experience from 2 continents. J Urol 1990; 143:895–6
36. Vassolas G, Roth RA, Venditti FJ Jr: Effect of extracorporeal shock wave lithotripsy on implantable cardioverter defibrillator. Pacing Clin Electrophysiol 1993; 16:1245–8
37. Theiss M, Wirth MP, Frohmuller HG: Extracorporeal shock wave lithotripsy in patients with cardiac pacemakers. J Urol 1990; 143:479–80
38. Vaidyanathan S, Hirst R, Parsons KF, Singh G, Soni BM, Oo T, Zaidi A, Watt JW, Sett P: Bilateral extracorporeal shock wave lithotripsy in a spinal cord injury patient with a cardiac pacemaker. Spinal Cord 2001; 39:286–9
39. Venditti FJ Jr, Martin D, Long AL, Roth RA: Renal extracorporeal shock wave lithotripsy performed in patient with implantable cardioverter defibrillator. Pacing Clin Electrophysiol 1991; 14:1323–5
40. Hayes DL, Charboneau JW, Lewis BD, Asirvatham SJ, Dupuy DE, Lexvold NY: Radiofrequency treatment of hepatic neoplasms in patients with permanent pacemakers. Mayo Clin Proc 2001; 76:950–2
41. O'Donoghue JK: Inhibition of a demand pacemaker by electrosurgery. Chest 1973; 64:664–6
42. Smith CL, Frawley G, Hamar A: Diathermy and the telectronics "META" pacemaker. Anaesth Intensive Care 1993; 21:452–4
43. Kleinman B, Hamilton J, Heriman R, Olshansky B, Justus D, Desai R: Apparent failure of a precordial magnet and pacemaker programmer to convert a DDD pacemaker to VOO mode during the use of the electrosurgical unit. ANESTHESIOLOGY 1997; 86:247–50
44. Mangar D, Atlas GM, Kane PB: Electrocautery-induced pacemaker malfunction during surgery. Can J Anaesth 1991; 38:616–8
45. American Society of Anesthesiologists: Standards for basic anesthetic monitoring, In ASA Standards, Guidelines and Statements. Chicago, American Society of Anesthesiologists, October 2004
46. Baller MR, Kirsner KM: Anesthetic implications of implanted pacemakers: A case study. AANA J 1995; 63:209–16
47. Celentano WJ, Jahr JS, Nossaman BD: Extracorporeal shock wave lithotripsy in a patient with a pacemaker. Anesth Analg 1992; 74:770–2
48. Chew EW, Troughear RH, Kuchar DL, Thorburn CW: Inappropriate rate change in minute ventilation rate responsive pacemakers due to interference by cardiac monitors. Pacing Clin Electrophysiol 1997; 20:276–82
49. Rubin JM, Miller ED: Intraoperative pacemaker malfunction during total hip arthroplasty. Anesth Analg 1995; 80:410–2
50. Samain E, Marty J, Souron V, Rosencher N, Eyrolle L: Intraoperative pacemaker malfunction during a shoulder arthroscopy. ANESTHESIOLOGY 2000; 93:306–7
51. Society of Anesthesiologists: Standards for postanesthesia care, In ASA Standards, Guidelines and Statements. Chicago, American Society of Anesthesiologists, October 2004
52. O'Donoghue JK: Inhibition of a demand pacemaker by electrosurgery. Chest 1973; 64:664–6
53. Rubin JM, Miller ED: Intraoperative pacemaker malfunction during total hip arthroplasty. Anesth Analg 1995; 80:410–2
54. Heller LI: Surgical electrocautery and the runaway pacemaker syndrome. Pacing Clin Electrophysiol 1990; 13:1084–5
55. Mychaskiw G, Eichhorn JH: Interaction of an implanted pacemaker with a transesophageal atrial pacemaker: Report of a case. J Clin Anesth 1999; 11: 669–71
56. Batra YK, Bali IM: Effect of coagulating and cutting current on a demand pacemaker during transurethral resection of the prostate: A case report. Can Anaesth Soc J 1978; 25:65–6
57. Erdman S, Levinsky L, Servadio C, Stoupel E, Levy MJ: Safety precautions in the management of patients with pacemakers when electrocautery operations are performed. Surg Gynecol Obstet 1988; 167:311–4

‖ ‖ ‖ The references listed here do not represent a complete bibliography of the literature reviewed. A complete bibliography is available by writing to the American Society of Anesthesiologists or by accessing the ANESTHESIOLOGY Web site: http://www.anesthesiology.org.

58. Dresner DL, Lebowitz PW: Atrioventricular sequential pacemaker inhibition by transurethral electrosurgery. ANESTHESIOLOGY 1988; 68:599–601

59. Lerner SM: Suppression of a demand pacemaker by transurethral electrocautery. Anesth Analg 1973; 52:703–6

60. Wajszczuk WJ, Mowry FM, Dugan NL: Deactivation of a demand pacemaker by transurethral electrocautery. N Eng J Med 1969; 280:34–5

61. Epstein MR, Mayer JE Jr, Duncan BW: Use of an ultrasonic scalpel as an alternative to electrocautery in patients with pacemakers. Ann Thorac Surg 1998; 65:1802–4

62. Ozeren M, Dogan OV, Duzgun C, Yucel E: Use of an ultrasonic scalpel in the open-heart reoperation of a patient with pacemaker. Eur J Cardiothorac Surg 2002; 21:761–2

63. Val-Majias JE, Diehl T, Quesada LC: Long-term effects of RF ablation on pacemakers leads. Pacing Clin Electrophysiol 1996; 19:635

64. Alagona P, Toole JC, Maniscalco BS: Nuclear magnetic resonance imaging in a patient with a pacemaker. Pacing Clin Electrophysiol 1989; 12:619

65. Inbar S, Larson J, Burt T, Mafee M, Ezri MD: Case report: nuclear magnetic resonance imaging in a patient with a pacemaker. Am J Med Sci 1993; 305:174–5

66. Lauck G, Sommer T, Wolke S, Luderitz B, Manz M: Magnetic resonance imaging in patients with implanted permanent pacemakers. Pacing Clin Electrophysiol 1995; 18(suppl):1168

67. Lauck G, von Smekal A, Wolke S, Seelos KC, Jung W, Manz M, Luderitz B: Effects of nuclear magnetic resonance imaging on cardiac pacemakers. Pacing Clin Electrophysiol 1995; 18:1549–55

68. Roguin A, Zviman MM, Meininger GR, Rodrigues ER, Dickfeld TM, Bluemke DA, Lardo A, Berger RD, Calkins H, Halperin HR: Modern pacemaker and implantable cardioverter/defibrillator systems can be magnetic resonance imaging safe. Circulation 2004; 110:475–82

69. Shellock FG, O'Neil M, Ivans V, Kelly D, O'Connor M, Toay L, Crues JV: Cardiac pacemakers and implantable cardioverter defibrillators are unaffected by operation of an extremity MR imaging system. Am J Roentgenol 1999; 172: 165–70

70. Sommer T, Valhaus C, Lauck G, von Smekal A, Reinke M, Hofer U, Block W, Traber F, Schneider C, Gieseke J, Jung W, Schild H: MR imaging and cardiac pacemakers: In vitro evaluation and in vivo studies in 51 patients at 0.5 T. Radiology 2000; 215:869–79

71. von Smekal A, Wolke S, Seelos KC, Hermans J, Lauch G, David P, Reiser M, Biersack HJ: Cardiac pacemaker in magnetic resonance studies: Influence of the static magnetic field on hardware components. Eur Heart J 1993; 14:335

72. Goldberg RJ, Badger JM: Major depressive disorder in patients with the implantable cardioverter defibrillator: Two cases treated with ECT. Psychosomatics 1993; 34:273–7

73. Alyward P, Blood R, Tonkin A: Complications of defibrillation with permanent pacemaker in situ. Pacing Clin Electrophysiol 1979; 2:462–4

74. Das G, Eaton J: Pacemaker malfunction following transthoracic countershock. Pacing Clin Electrophysiol 1981; 4:487–90

75. Gould L, Patel S, Gomes GI, Chokshi AB: Pacemaker failure following external defibrillation. Pacing Clin Electrophysiol 1981; 4:575–7

76. Palac RT, Hwang MH, Klodnycky ML, Loeb HS: Delayed pulse generator malfunction after DC countershock. Pacing Clin Electrophysiol 1981; 4:163–7

77. Zullo M: Function of ventricular pacemakers during resuscitation. Pacing Clin Electrophysiol 1990; 13:736–44

78. ACLS Provider Manual. Edited by Cummins RO. Dallas, American Heart Association, 2003

79. Levine PA, Balady GJ, Lazar HL, Belott PH, Roberts AJ: Electrocautery and pacemakers: Management of the paced patient subject to electrocautery. Ann Thorac Surg 1986; 41:313–7

80. Bernstein AD, Daubert JC, Fletcher RD, Hayes DL, Luderitz B, Reynolds DW, Schoenfeld MH, Sutton R: The revised NASPE/BPEG generic code for antibradycardia, adaptive-rate, and multisite pacing. North American Society of Pacing and Electrophysiology/British Pacing and Electrophysiology Group. Pacing Clin Electrophysiol 2002; 25:260–4

81. Bernstein AD, Camm AJ, Fisher JD, Fletcher RD, Mead RH, Nathan AW, Parsonnet V, Rickards AF, Smyth NP, Sutton R: North American Society of Pacing and Electrophysiology policy statement: The NASPE/BPEG defibrillator code. Pacing Clin Electrophysiol 1993; 16:1776–80