AANA Journal Course

Update for nurse anesthetists

1

*6 CE Credits

Arrhythmia management devices and electromagnetic interference

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The technological complexity of implantable arrhythmia management devices, specifically pacemakers and defibrillators, has increased dramatically since their introduction only a few decades ago. Patients with such devices are encountered much more frequently in hospitals and surgery centers, yet anesthesia provider knowledge of safe and proper management is often incomplete.

Anesthesia textbooks and references may provide only short paragraphs on arrhythmia management devices that do not address important perioperative management strategies for this ever-growing patient population. It is no longer satisfactory to simply place a magnet over an implanted device during surgery and assume that this action protects the patient from harm due to electromagnetic interference from inappropriate device function.

This* AANA Journal *course serves as a concise review of basic device function, the sources and effects of electromagnetic interference in the operative setting, and patient management recommendations from current literature.

Key words: **Cautery, electromagnetic interference, implantable cardioverter-defibrillator, magnet, pacemaker.**

Objectives:

At the completion of the course, the reader should be able to:

1. Understand basic electrophysiologic mechanisms of the heartbeat.
2. Discuss pacemaker function as it relates to sensing intrinsic beats and producing pacing impulses.
3. Describe implantable cardioverter-defibrillator function as it relates to shocking of arrhythmias.
4. Recognize the dangers of electromagnetic interference when interpreted by devices as intrinsic cardiac activity.
5. List the potential hazards of intraoperative use and nonuse of a magnet over devices.

Introduction

Surgical implantation of pacemakers and defibrillators has become a routine procedure in many hospitals. Approximately 325,800 pacemakers and 127,300 defibrillators were implanted in the United States in 2003 (J. Roberts, Medtronic, Inc, written communication, March 2004). These devices have saved tens of thousands of lives and improved the quality of life of thousands more. Patients with arrhythmia management devices are treated more frequently in the operative setting and can be challenging to manage. This article reviews basic electrophysiology of a normal heart and the history of devices and discusses device functions and electromagnetic interference.

Anatomy of a heartbeat

Our understanding of the heart's conduction system can best be attributed to Suma Tawara (1873-1952), who first described the His-Purkinje system and its relationship to the atrioventricular node (AVN).[1] This research laid the groundwork for Willem Einthoven's theories and descriptions of electrocardiography, which earned him the Nobel Prize in Medicine in 1924.[2]

The heartbeat is initiated by the sinoatrial node (SAN), located at the junction of the superior vena cava and right atrium. The cells of the SAN allow for spontaneous depolarization and have an intrinsic rate of 60 to 80 impulses per minute that, under normal

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physiological conditions, allows the SAN to control the heartbeat. It takes 0.04 seconds for a SAN impulse to traverse both atria simultaneously and reach the AVN.

The AVN is located in the septal wall of the right atrium above the tricuspid valve. It is also capable of spontaneous depolarizations, but at a slower intrinsic rate than the SAN, approximately 40 to 60 per minute. The most important characteristic of the AVN is that of AV delay, which enables the AVN to protect the ventricles from excessive atrial beats and is due to slow calcium channels.

The lower portion of the AVN is called the bundle of His, which enters the interventricular septum and divides into the right and left bundle branches. The bundle branches continue on in each ventricle as the Purkinje network, which is responsible for simultaneous depolarization of both ventricles. Cells of the His-Purkinje system have the fastest conduction velocities of all myocardial cells, allowing for complete depolarization of both ventricles in 0.03 seconds. Thus, one heartbeat takes approximately 0.2 seconds from SAN initiation to complete ventricular depolarization.[3]

It is easy to consider the many possibilities of arrhythmias, given the complexity of electrophysiology and the many steps in the conduction pathway. In general, arrhythmias fall into two major categories—those associated with slow heart rates, known as bradycardias, generally treated by pacemakers, and those associated with fast heart rates, known as tachycardias, generally treated by implantable cardioverter-defibrillators (ICDs).

History of pacemakers

External electrical stimulation of the heart was documented as early as 1870 and was investigated as a treatment for bradycardia in the 1920s.[4] Internally implanted pacemakers were developed in the 1950s and required a thoracotomy for placement of patches on the epicardial surface that functioned as pacing leads. These early devices were set at a constant rate, could not be programmed individually, and were capable of ventricular pacing only; the lack of sensing of the patient's intrinsic rhythm meant that the device actually competed with the patient's rhythm.

The first implanted pacemaker was developed by Rune Elmqvist, a Swedish engineer, and was implanted in a 43-year-old man with complete heart block on October 8, 1958, in Stockholm, Sweden. At the time of his death from cancer on December 28, 2001, he required replacement of 22 pulse generators and 5 lead systems.[2] Early pacemakers were large (similar to a deck of cards) and took more than an hour to implant, and battery life was approximately 12 months. Today's modern devices are one quarter the size with batteries lasting several years, and in experienced hands, "skin-to-skin" time can be as little as 22 minutes (M. Wish, MD, written communication, January 2002). Figures 1 and 2 show modern dual-chamber pacemakers with leads.

Pacemaker function

Pacemakers consist of 2 major components: the pulse generator (PG) and the lead(s). The PG houses the battery and computer components and is the brain of the device. It is palpable in the skin pocket after implantation. Most modern batteries are lithium iodide and last approximately 5 to 12 years. Battery life is highly variable, depending on how much time the device spends pacing and on other electrical and patient variables.[5] Leads are insulated wires that conduct electrical signals to and from the heart. The portion of the lead that makes contact with the heart is called an electrode.

Within the PG is a sensing circuit that receives the intracardiac electrogram signal traveling from the heart via the lead. This electrogram signal is filtered to remove unnecessary frequencies, and this new, processed signal is compared with a reference voltage. Signals with higher amplitude than the threshold voltage are interpreted as cardiac in origin, while signals of lower threshold voltage are interpreted as noise.

Figure 1. Modern dual-chamber pacemaker

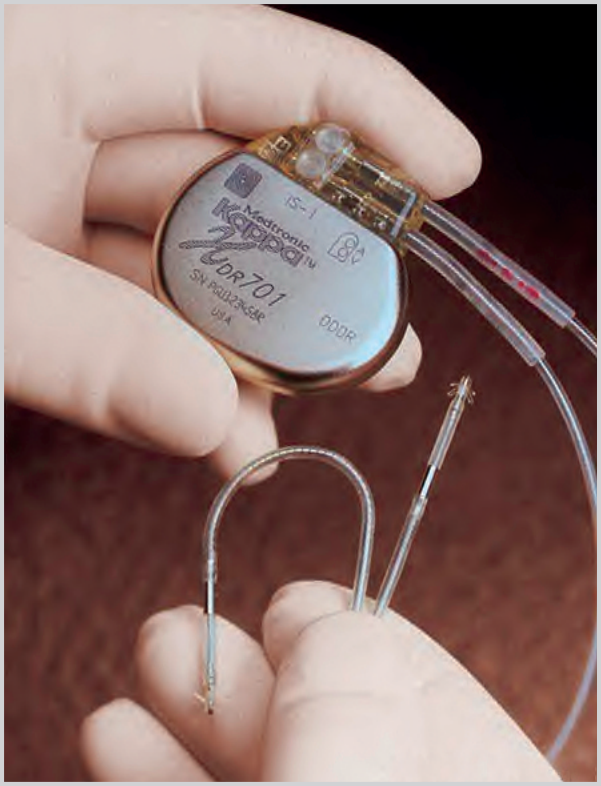

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Figure 2. Right-sided implantation of a modern dual-chamber pacemaker

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The signals that exceed threshold voltage (ie, cardiac signals) are marked and sent to the timing circuit of the device. The timing circuit keeps track of the signals it receives and also the signals that are absent to determine whether delivery of a pacing impulse by the device is necessary. In the presence of electromagnetic interference (EMI), most pacemakers interpret these signals as noise and they are not sent to the timing circuit. In some cases, signals that truly are noise are sent to the timing circuit, giving the device false information, resulting in the pacemaker withholding pacing impulses. This is because some sources of EMI are between 5 and 100 Hz (1 Hz equals 1 cycle per second), which overlaps intracardiac signal frequency, and, therefore, these signals are not filtered out by the device.[6] The sensing circuit sends these noise signals to the timing circuit, and, in turn, the timing circuit thinks the patient has a spontaneous heartbeat, and output of a pacing impulse by the device is inhibited.[7]

Lead systems are available in unipolar and bipolar configurations. In unipolar lead systems, the PG functions as the anode, or positive electrode, and the lead tip functions as the cathode, or negative electrode. Unipolar systems are slightly smaller and simpler and may be more durable.[8] However, with a unipolar configuration, there is a larger "antenna" (the distance between the anode and cathode) to pick up signals, both cardiac and noise signals. In contrast, bipolar systems use the lead tip as the cathode and an area called the lead ring as the anode. The lead ring is a few centimeters more proximal from the tip on the lead. Bipolar systems are slightly larger in diameter but have the advantage of having a shorter antenna and are less likely to pick up noncardiac signals.[8] Bipolar configurations can be reprogrammed to function as unipolar systems, but unipolar systems cannot be reprogrammed to function as bipolar systems.

History of ICDs

The first successful human heart defibrillation was performed in Cleveland, Ohio, in 1947 by Claude Beck, MD. The patient was a 14-year-old boy undergoing open-heart surgery who had cardiac arrest after sternal closure. The sternum was reopened and a series of 2 shocks interposed with cardiac massage and injections of procaine converted ventricular fibrillation (VF) to cardiac standstill to supraventricular tachycardia (SVT).[9] The first external and portable defibrillator was designed by William Kouwenhoven, a professor of electrical engineering at Johns Hopkins University, and successfully used in 1957.[10] The first human implant of an ICD was in 1980, with subsequent US Food and Drug Administration (FDA) approval of the devices in 1985.[11,12] These early devices still required use of epicardial patches because the first *endocardial* lead was not approved by the FDA until 1993.[13] In 2002, devices for biventricular pacing with defibrillation were approved by the FDA.[12] Figure 3 shows the development of ICDs by Medtronic, Inc, Minneapolis, Minn. Figure 4 shows the evolution of ICD implantation.

ICD function

The PG of an ICD is driven by a lithium silver vanadium oxide battery that enables antitachycardia and antibradycardia pacing, shocking for cardioversion and defibrillation, telemetry, and storage of electrograms.[5] Antitachycardia pacing involves the use of short, rapid bursts of pacing with a faster rate than the tachycardia to essentially short circuit the tachycardia. The cardioversion function is used to convert sustained ventricular tachycardia (VT) and is in the range of 1 to 30 J, whereas defibrillation is used to convert VF and is in the range of 10 to 30 J.[14]

Single-chamber defibrillators use 1 lead implanted in the right ventricle (RV), which functions as the pacing, sensing, and shock lead. Dual-chamber defibrillators use the right ventricular lead as in single-chamber devices and the right atrial lead as the sensing and pacing lead for the right atrium. The right atrial lead also assists with tachycardia discrimination.

Perhaps the most important part of an ICD is the

Figure 3. Development of the implantable cardioverter-defibrillator

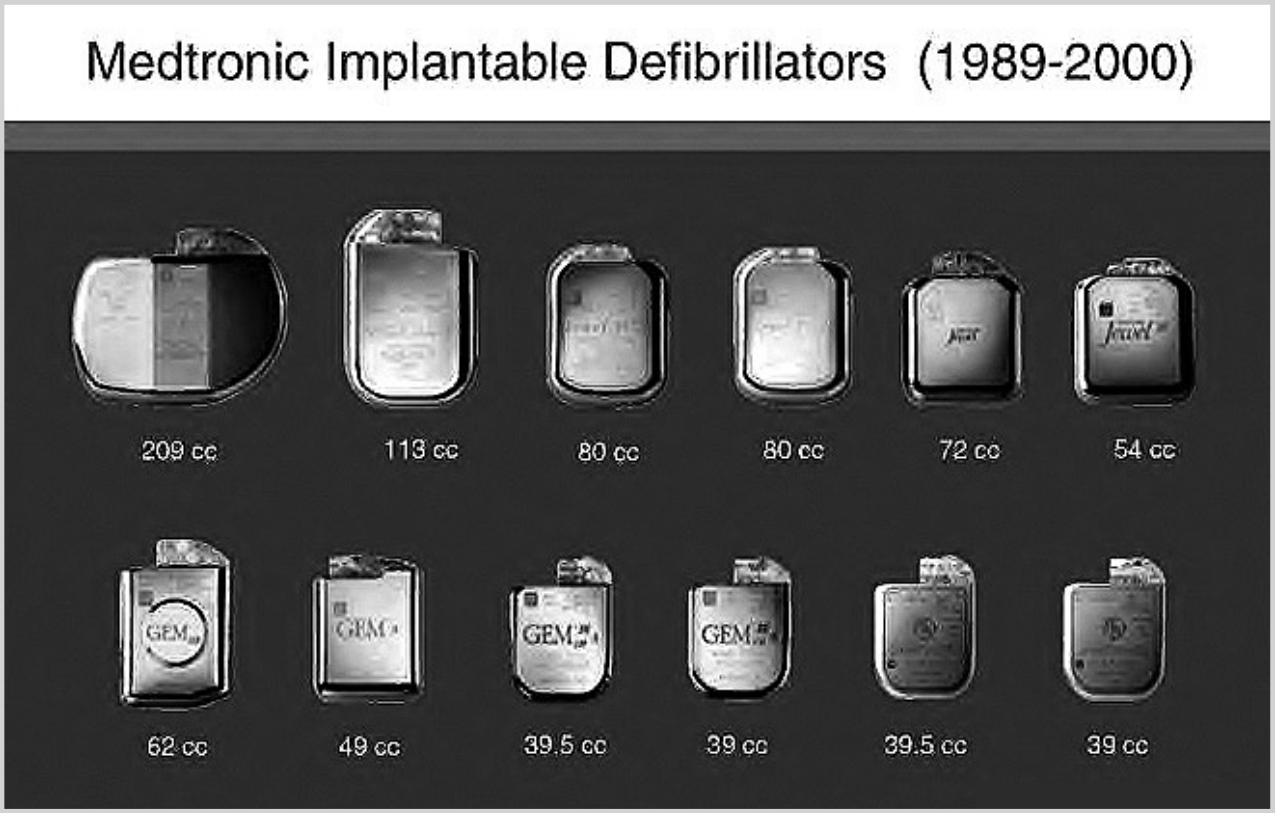

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Figure 4. Evolution of the implantable cardioverter-defibrillator implant

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capacitor, which enables a relatively small device to deliver enough energy (approximately 750 V) to defibrillate the heart. When shock is indicated, energy is transferred from the battery to the capacitor and the capacitor discharges its augmented energy through the leads and into the myocardium.[14]

The component of an ICD that detects an arrhythmia is the sense amplifier and is what records the R-R intervals of ventricular beats.[8] When ICDs are programmed at implantation, they are given a certain set of criteria by which to judge the arrhythmia, called an algorithm. For example, the device can measure the overall heart rate, judge abruptness of tachyarrhythmia onset and sustainability of the tachyarrhythmia, measure R-R intervals, and measure the width and amplitude of tachyarrhythmic complexes.

ICDs are programmed to divide all possible ventricular activity into nonoverlapping rate zones: bradycardia, normal, VF, and up to 3 VT zones.[5] These parameters are used to determine whether the device will shock. Once the determination is made that shock is indicated, the capacitor is charged, rhythm is reanalyzed, and, if still indicated, a shock is delivered. Most devices deliver up to 6 shocks per tachyarrhythmia episode. The device continues to analyze the post-shock rhythm to determine whether antibradycardia pacing or additional shocks are required.

Most ICD models currently on the market also incorporate all of the same complex *pacing* parameters as pacemakers. In fact, some ICDs have automatic mode switching that enables the ICD to switch pacing modes if atrial tachyarrhythmias are present.[14] For example, a device can temporarily switch from a mode that tracks the atrial rate to a mode that does not.

• *Effects of EMI on devices.* In the operative setting, EMI most often occurs as a result of use of cautery during the procedure. Cautery is a source of conducted EMI because the source is in direct contact with body tissues.[15] Cautery for coagulation uses short bursts, whereas cautery for cutting uses sustained current and, thus, is more likely to produce EMI that can be detected by a pacemaker or an ICD.

Cautery also has polarity, not to be confused with the polarity of implanted lead systems. Unipolar cautery uses the wand tip as the cathode (where current escapes) and the ground pad as the anode. Current gets passed through the body from the wand tip to the grounding pad. If an implanted device is between the cautery wand and the pad, current can pass through the leads and even into the PG, causing not only EMI but also myocardial damage or circuitry failure. Bipolar cautery, the less commonly used arrangement, houses both the anode and cathode in the wand tip, such that current is passed back and forth at the tip. Bipolar cautery has less output and less current dispersion through the body and is less likely to cause problems from EMI.[15] However, because it has less energy output, surgeons are less likely to use it.

Vibrations caused by a forced-air warming blanket or an intravenous fluid warming device in contact with the operating table can also cause EMI. Fasciculations from succinylcholine use can be misinterpreted as cardiac signals.[15] Fortunately, mechanical and chemical causes of oversensing are not considered true EMI; only conducted electromagnetic signals are considered EMI. When conducted EMI is misinterpreted as a cardiac signal by a pacemaker, pacing output can be inhibited. This could be especially detrimental in a patient with complete heart block who is completely dependent on pacing output. Pacemakers with rate-responsive features have the unique ability to increase the pacing rate to meet increased demands, such as during exercise, through use of motion sensors to trigger increased pacing. The EMI sensed by this type of programming feature can be misinterpreted as increased metabolic activity and can unnecessarily increase pacing rates.[14] Because EMI misinterpreted as a cardiac signal by an ICD could be misidentified as VT or VF, the patient may receive an inappropriate shock (inappropriate because the rhythm is not true VT or VF).

The effect that EMI has on a device depends on the intensity of the source and its distance from the leads and the frequency of the signal. Possible effects of EMI on devices are listed in Table 1. Understanding these potential consequences is important in understanding the rationale for preoperative interrogation of every patient with a device. Interrogation of a device is performed by trained personnel from the cardiac electrophysiology department or the device manufacturer. A specialized magnet, called a programmer head, is placed over the device and is connected to a computer. Device information can be downloaded from the device, and the programming settings can be analyzed and changed if necessary when the device is in contact with the programmer head.

Table 1. Device responses to electromagnetic interference (EMI)

Pacemakers

- EMI source interpreted as cardiac; pacing is inhibited or triggered*
- Source interpreted as noise, and pacemaker resets itself to asynchronous pacing
- Induction of atrial or ventricular fibrillation
- Burns at lead-myocardium junction with subsequent myocardial damage
- Transfer of EMI from lead to pulse generator, causing damage to circuitry and/or battery, possibly resulting in asystole
- Source interpreted as a programming signal, and device is reprogrammed

Defibrillators

- Inappropriate antitachycardia pacing, shocks, or suspension of arrhythmia detection
- Inappropriate reprogramming
- Burns at lead-myocardium junction with subsequent myocardial damage
- Damage to pulse generator circuitry

*** Devices programmed to be inhibited by intrinsic activity also will be inhibited from pacing by EMI; devices programmed to be triggered will trigger pacing output in response to EMI.**

(Adapted from Madigan, et al.[15])

• *Device behaviors in the presence of a magnet.* When a magnet is placed over a *pacemaker*, it activates the *reed switch* within the device. A reed switch is simply 2 magnetic strips that are forced together in the presence of a magnetic field. The reed switch closes when the strips come together, which inactivates the sensing circuit.[7] (This is true for older pacemakers. Newer pacemakers use a different type of magnetically sensitive device that essentially performs the same function.) With no input from the sensing circuit into the timing circuit, the device thinks there is no heartbeat and it will pace at an asynchronous (pacing without regard to intrinsic cardiac activity) rate, also called the magnet rate. Magnet rates are usually between 60 and 70 paces per minute. Presence of the reed switch feature is what enables use of a magnet intraoperatively to prevent EMI signals from cautery from being misinterpreted by the device as cardiac signals and thus inhibiting pacing output.

Single-chamber pacemakers always pace asynchronously (VOO mode) in response to application of a

magnet, yet the rate will vary. Magnet rates vary between manufacturers, different models, and even different programmed modes of the same model.[14] Dual-chamber pacemakers usually respond to a magnet by DOO pacing (dual-chamber asynchronous), and again, the rate varies.[14] A much slower than anticipated magnet rate is an indicator of a low battery, and the PG may need to be replaced.

It is important to understand that magnet application over a pacemaker does not turn it off; *in general*, it allows the pacemaker to pace asynchronously and does not allow the EMI signals to inhibit pacing. Unfortunately, magnet application on older models may make the device vulnerable to reprogramming because application of a magnet actually prepares a pacemaker to be programmed. The programmer head that is placed over the pacemaker during device checks and interrogations is actually a large magnet. Therefore, in the presence of a magnet, an older device may be reprogrammed from EMI that is misinterpreted as a programming signal. Fortunately, this is virtually impossible with modern pacemakers and ICDs. Devices require very specific codes that make it unlikely that random EMI will "push the right keys," akin to monkeys typing Shakespeare (J. Roberts, Medtronic, Inc, written communication, November 2004).

When a magnet is placed over a *defibrillator*, detection of tachyarrhythmias is suspended. Because the device cannot detect any tachyarrhythmias, it cannot deliver any shock therapies. However, ability of the ICD to provide bradycardia pacing is *not* interrupted. (J. Roberts, Medtronic, Inc, written communication, March 2004). The ICDs manufactured by Medtronic and all other companies can behave this way, such that shock therapies are suspended only when the magnet is in proximity to the device. As soon as the magnet is removed, ie, the magnetic switch is opened, ability to provide shock therapy resumes. In addition to this standard operation, ICDs manufactured by Guidant, Inc, (Indianapolis, Ind) can be programmed to turn off tachyarrhythmia detection when the magnet is placed over the device for 30 seconds, at which time a constant beeping will be heard. Even if the magnet is removed, the device is still deactivated and will be unable to provide shock therapy. To reactivate a Guidant ICD programmed in this manner, the magnet is again placed over the device until one hears synchronous beeps with the QRS complex of the electrocardiogram.[13,14] The ICDs manufactured by St Jude Medical (St Paul, Minn) can be programmed to ignore the presence of a magnet and continue to deliver therapies.

It is important to disable detection in defibrillators in some manner during surgery to help prevent the interpretation of EMI as VT or VF. For example, if the ICD was not interrogated preoperatively and its tachyarrhythmia detection turned off, failure to use a magnet during surgery could result in a shock for EMI-induced noise signals. Table 2 describes magnet responses for different manufacturers (J. Roberts, Medtronic, Inc, written communication, November 2004).

Perioperative management recommendations

The safest recommendation for patient management is to have the device interrogated and properly reprogrammed before surgery.[8,14-18] Any printouts generated at this time should be placed in the patient's chart so that all providers have access to the current programming. A manufacturer-specific programmer should be readily available if the device needs immediate reprogramming during surgery.

Even if a device is interrogated and reprogrammed to a mode believed safe for the surgical procedure, unanticipated conditions may arise intraoperatively.[18] Both external temporary pacing and defibrillation capability should be immediately available, as should a resuscitation cart well stocked with antiarrhythmic drugs. It is recommended that transcutaneous defibrillation pads be placed anteriorly and posteriorly on the patient before surgery, and they should be con-

Table 2. ICD magnet responses by manufacturer

Manufacturer	Magnet responses possible	Tones generated
Medtronic (Minneapolis, Minn)	Suspends VT/VF detection	Patient alert tones generated (may be continuous or intermittent)
Guidant (Indianapolis, Ind)	1. Suspends VT/VF detection 2. Turns OFF VT/VF detection when magnet placed over ICD for 30 s	1. R-wave synchronous tones when detection is active but suspended 2. Continuous tone when VT/VF detection is OFF
St Jude Medical (St Paul, Minn)	1. Suspends VT/VF detection 2. No response	No tones emitted

ICD indicates implantable cardioverter-defibrillators; VT, ventricular tachycardia; and VF, ventricular fibrillation.

(Table provided by J. Roberts, Medtronic, Inc., Minneapolis, Minn.)

nected to the defibrillator. Should the patient experience VT or VF, shock therapy can be initiated quickly. If transcutaneous pads are not on the patient and external defibrillation is required, it is best to use anterior-posterior placement of paddles, avoiding placement of the paddles directly over the implanted ICD. The lowest energy setting should be used first because with increases in energy levels, damage to the device may occur. Thus, external temporary pacing should be available.[15] If damage to the device is suspected, the manufacturer's representative or the cardiac electrophysiology department should be notified as soon as possible.

Ideally, only bipolar cautery should be used. If this is not feasible, unipolar cautery can be used if several measures are taken. First, the grounding pad should be placed as far as possible from the device and should be completely adhered to the skin. Initiation of cautery should not take place until the tip is in contact with tissue. If the cautery wand is in the air and near the device when the button is pressed to start flow of current, the current can arc through the air and come down on or near the device. Unipolar cautery should be used in short bursts only. Table 3 summarizes safe cautery use for patients with devices.

Rate-responsive pacemakers should have this feature turned off before surgery via use of a programmer; simply using a magnet will not tell the anesthesia provider the status of this feature.[18] It is well known that EMI also interferes with electrocardiographic monitoring. It is imperative to continuously monitor the patient's rhythm intraoperatively to determine whether adverse effects from EMI or inappropriate responses to EMI are occurring. One may consider using an arterial line to help detect hemodynamic changes secondary to arrhythmias.[15]

Table 3. Strategies for safe cautery use

1. Use bipolar cautery.
2. If unipolar cautery is used:
   - Place ground pad as far from device as possible, and adhere it completely to skin.
   - Never have the device between the ground pad and the cautery wand.
   - Initiate cautery only when the tip is in contact with tissue. Do not initiate cautery when the wand is in the air.
   - Use short bursts only.
   - Continuously monitor the electrocardiogram for rate and rhythm changes.
   - Consider using an arterial line.

(Adapted from Stone and McPherson.[14])

If preoperative device interrogation is not feasible (such as emergency surgery, rural hospital without immediate manufacturer support), a chest radiograph can determine the type of device (pacemaker or ICD), whether it is a single- or dual-chamber device, and lead location. Remember that even if it is known that the device is a dual-chamber pacemaker, it is still impossible, without a programmer, to know parameters such as magnet rate, adaptive-rate pacing capability, and other programmable features.[14] In emergency situations, use the electrocardiogram to determine rhythm and whether pacing is occurring. A magnet can be used as a last resort to inhibit pacemaker sensing or to inhibit shock therapies of an ICD, yet one must pay constant attention to the rhythm on the electrocardiogram and be prepared to treat arrhythmias, including asystole. Postoperatively, the device should be interrogated as soon as possible to return it to the original programming modes and to determine whether the PG or leads have been damaged.

For the safest patient management, current literature supports the practice of preoperative device interrogation by properly trained personnel because it is impossible for anesthesia providers to know how a pacemaker or an ICD is programmed.[8,14-18] Patients with implanted devices should be considered "cardiac" patients and be equally entitled to a preoperative device interrogation, just as patients with coronary artery disease require meticulous preoperative preparation. One is not likely to take a patient with a history of coronary artery bypass grafting into the operating room without a cardiac clearance; patients with implanted devices should be availed similar preoperative clearance. Simply placing a magnet over a device cannot account for the myriad of programming possibilities and responses to EMI of arrhythmia management devices. This practice is obsolete, not supported by the literature, and may result in harm to the patient and/or the device itself.

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