Pacemakers and ICDs- Anesthetic Considerations
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ABA/ASA CONTENT OUTLINE
Joint Council on Anesthesiology Examinations
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I. Basic Topics in Anesthesiology
C. Organ-Based Basic and Clinical Sciences
I.C.3 Cardiovascular
I.C.3.a Physiology
I.C.3.a.1) Cardiac Cycle
I.C.3.a.1) d) Normal ECG
I.C.3.a.1) e) Electrophysiology; Ion Channels and Currents

II. Advanced Topics in Anesthesiology
C. Organ-Based Basic and Clinical Sciences
I.C.3 Cardiovascular
I.C.3.b Clinical Sciences
I.C.3.b.3) Rhythm Disorders and Conduction Defects
I.C.3.b.3) a) Chronic Abnormalities: Etiology, Diagnosis, Therapy
I.C.3.b.3) a) (1) Automated Implantable Cardioverter/Defibrillator (AICD) Implantation
I.C.3.b.3) a) (2) Pacemakers: Permanent, Temporary, Transvenous, Transcutaneous, Ventricular Synchronization
I.C.3.b.3) a) (3) Ablations, Cryotherapy, Maze Procedure
I.C.3.b.3) b) Perioperative Dysrhythmia: Etiology, Diagnosis, Therapy
I.C.3.b.3) c) Perioperative Implication of Pacemaker and AICD

Helpful Link for Patients with a Pacemaker or an ICD at UCSF
I direct your attention to our internal anesthesia web site, anesweb.ucsf.edu. Log in, then go to the Education section and click on Resources, where you’ll find a .pdf entitled- UCSF Anesthesia Resident Pearls: Pacemakers and ICDs. Manny Zusmer, MD, a recent UCSF graduate, put together this resident-oriented handout. You will find it quite useful.

Content Outline- Terminology
Listed above is the most recent ABA/ASA Content Outline, prepared for the new Anesthesia specialty licensing exam scheduled to begin with the class starting July, 2013. Even for those scheduled to take the current exam, the content outline serves as a template for learning, and I will refer to it throughout this handout, using bold text to highlight relevant sections.

Perhaps I’m a little sensitive, but the abbreviation AICD (automatic implantable cardioverter-defibrillator), used in the Content Outline above, is not the preferred term chosen by cardiologists, cardiac electrophysiologists, nor is it used in current medical literature. The more frequent term is implantable cardioverter-defibrillator (ICD). The term internal has sometimes
been used with AICD, instead of implantable, especially in the non-medical literature. Nowhere in the Content Outline do you see the term cardiac implantable electronic device (CIED). CIED is typically used, refers to any both pacemakers and ICDs, and I will use it throughout this handout.

Finally, I will not discuss Temporary Pacemakers in this handout. This is best reviewed during your Cardiac Rotations. At each location, you might find a few differences in temporary pacing philosophies, and you will certainly learn first hand to use different temporary pacemakers.

A subject of some interest is how to use temporary pacemaker leads to diagnose the mechanisms of arrhythmias, then when, and how, to use a temporary pacemaker to treat some tachycardias. If there’s interest, I will find another time to talk about this subject.

Guidelines, and Their Limitations

All of medicine, and that includes the specialty of Anesthesia, is moving toward guidelines, care pathways, and whenever possible, a standardized approach for disease diagnosis and treatment. The care and feeding of CIEDs is no different. I refer you to the 2011 ASA Practice Advisory on CIEDs. Please familiarize yourself with the recommendations of our Society.1 Interestingly, the Canadian Anesthesiologists’ Society also has CIED Guidelines.2

The American College of Cardiology/American Heart Association Task Force on Practice issued a Guideline Update in 2008 for Implantation of Cardiac Pacemakers and Antiarrhythmia Devices.3 This followed a similar release in 2007 from The European Society of Cardiology in collaboration with the European Heart Rhythm Association.4

A note of caution: Guidelines, and there are likely more than I’ve listed here, are time-limited. New guidelines will replace older ones, and new data will modify previously established guidelines. Even expert opinions change over time. It has been suggested that guideline 'expert opinion' can be unduly influenced by conflict of interest of some of the very authors that create the guidelines, even if the guideline authors acknowledge their conflicts of interest.5 Remember, when it comes to Pacemakers and ICDs, future CIEDs will be different, requiring updates to our current guidelines.

Reasonable goals and expectations for anesthesiologists

The number of different electrical devices currently used to diagnose, treat, or prevent cardiac arrhythmias, guarantees that all anesthesiologists will manage patients with such devices over the course of their clinical practice.

By the early 1980’s, it was clear that permanent pacemakers used to treat bradycardia had become complex enough that it was difficult, if not impossible, for every anesthesiologist to know everything about each and every pacemaker. The trend toward increasing complexity continues as companies produce new pacemakers, advanced ICDs, cardiac resynchronization therapy (CRT) devices (Content Outline- I.C.3.b.3 a) (2) Ventricular Synchronization) all of which incorporate numerous additional complex-programming modes. Without industry-wide standardization of the relevant technology, it is unrealistic to expect every hard-working anesthesiologist to have competent working knowledge of all devices currently used.
This handout will review the common features seen in the majority of permanent pacemakers, highlight important aspects for their perioperative management, and address recent recommendations regarding intraoperative placement of a magnet over the pacemaker generator. I will review perioperative considerations for ICDs and discuss possible intraoperative ICD emergencies.

Later, there is a brief review of the basic concepts of pacemaker components and the pacemaker coding system. For those interested in some recent ICD historical events, I have included some information at the end of this handout.

There will always be new devices (recent FDA approval of a subcutaneous ICD system), new indications for electrical treatment of cardiac rhythm abnormalities, and more widespread deployment of automated external defibrillators (AEDs) in non-medical location. As anesthesia providers, we are expected to have basic knowledge of these advances, and we should know how to use AEDs and defibrillator devices as part of ACLS.

Indications for Permanent Pacemaker Insertion—
Content Outline: I.C.3.b.3) Rhythm Disorders and Conduction Defects

Permanent cardiac pacing is the only effective treatment for recurrent symptomatic bradycardia. Causes of bradycardia are multiple. The evaluation and management of bradycardia, including good examples of characteristic ECGs, is found in the review by Mangrum. Sick Sinus Syndrome (SSS) is generally considered the most common cardiac conduction disease causing bradycardia that requires permanent pacemaker insertion for treatment. First described in 1968, SSS is a primary degenerative disease of the sinus node and specialized conduction tissue, characterized by bradycardia; prolonged sinus pauses from the failure of sinus impulse formation (sinus arrest); block of the conduction of sinus impulses to surrounding atrial tissue (sinus exit block); or inability of the sinus rate to accelerate in response to exercise or illness (chronotropic incompetence). ECG manifestations include long sinus pauses, atrial asystole, and junctional escape rhythms. The disease is also associated with ventricular tachyarrhythmias, but to a far lesser degree. Recently, genome-wide association studies have identified a single nucleotide polymorphism in the MYH6 gene on chromosome 14q11. Carriers have a 50% increased risk of developing SSS as compared to non-carriers who have only a 6% risk. Atrio-ventricular block has various forms that result in bradycardia, and when permanent and symptomatic, a dual chamber permanent pacemaker is indicated. Refer to the Mangrum reference cited above. The frequency of the various causes of bradycardia will vary from study to study, but the need for a permanent pacemaker will always be determined by the fact that the symptoms are not transient and cannot be managed without a pacemaker.

Cardiac resynchronization therapy (CRT), referred to in the Content Outline as Ventricular Synchronization has become an area of rapid growth for pacemakers. These patients have a widen QRS complex, often associated with a dilated heart, reduced left ventricular systolic function, limited cardiac reserve, and poor functional status. Over 20 years ago, cardiologists wondered if simultaneous biventricular pacing would improve cardiac output?
Synchronization does just that by pacing both ventricles at the same time, resulting in a normal QRS complex duration, sometimes dramatically improving stroke volume, exercise tolerance, and overall patient satisfaction. The pacemaker lead that paces the left ventricle is actually in the coronary sinus, not the left ventricle itself. For patients identified to benefit from CRT pacing, the generator is often one that combines pacing and defibrillation. A recent review highlights the current knowledge, summary of clinical trials, proposed mechanisms, and provides additional insight into this novel, yet effective therapy.\(^9\)

Most, maybe all pacemakers, now change rate depending on the patient’s physical activity, giving the pacemaker patient the ability to live an active life, matching cardiac output to desired life style. This feature is referred to as rate-adaptive and is generally controlled by a motion detector built into the pacemaker’s sensing system. Pacemaker companies have experimented with rate-adaptive algorithms determined by changes in serum pH or serum PaCO\(_2\), but most currently use patient motion as the marker for activity that increases paced rate.

Preoperative cardiovascular evaluation of the patient with a CIED

All patients with a permanent pacemaker or ICD are given a “pacemaker card.” This card has information about the pacemaker generator and lead serial numbers, and the name of a physician who can provide answers to clinical questions when the patient cannot. The back of the card provides a technical support telephone number for the manufacturer. The phone numbers are answered 24-hours a day by a real person who is usually quite helpful.

Evaluating a preoperative ECG in a patient with a pacemaker can be difficult, particularly if the pacemaker has the rate-adaptive feature feature. Rate-adaptive pacing means the pacemaker can change the paced rate, the chamber(s) paced, and/or vary the A-V interval, making analysis of the surface ECG challenging. A pacemaker abruptly changing pacing characteristics might suggest that it is not functioning correctly, when in fact, it is doing exactly what it is programmed to do.

To verify proper pacemaker function, and or change the pacing mode (if necessary), it is useful to consult a cardiologist, talk with the pacemaker company, or examine the results of recent device interrogation.

Many, though not all patients who have a cardiac pacemaker have some degree of myocardial dysfunction or have just undergone cardiac surgery. Those with an ICD also are often being managed for significantly depressed cardiac function, characterized by little or no cardiac reserve. Preoperative evaluation of these patients must also focus on the non-CIED aspects of their cardiovascular system.

Pacemaker function, chemical abnormalities, and anti-arrhythmic agents

Electrolyte or acid/base abnormalities are rarely, if ever, the primary cause of pacing failure during elective surgery, particularly if the pacemaker was tested preoperatively and found to be functioning correctly. Hypoxia, acidosis, hyperkalemia, hypokalemia, or any other electrolyte abnormality severe enough to cause a pacemaker to fail, will likely first cause the patient to fail, necessitating systemic treatment first. Although some anti-arrhythmic medications can affect the pacing threshold, this effect should not produce clinically relevant problems under anesthesia.
Emergency surgery, especially when there is not enough time to gather device information, or if the patient is unable to provide information about a pacemaker or ICD, could very well result in device malfunction from hyperkalemia, hypoxia, or an unknown antiarrhythmic agent the patient may be chronically taking. The type of device, its settings, and the indication for its insertion may not be known at the time of emergency surgery.

Anesthetic choices
All anesthetic agents have been used safely in patients with CIEDs, and both regional and general anesthesia can be administered without detrimental effects on the device or its function. Thus, the presence of a device should not alter any planned anesthetic technique. Nevertheless, pacemakers programmed in the demand (or inhibited) mode may interpret shivering or other movement (such as suxchylcholine-induced fasciculations), and electrical interference, as intrinsic cardiac activity and become temporarily inhibited. If so, severe prolonged bradycardia may result.

Intraoperative monitoring of CIED function
Monitoring CIED function in the operating room or during procedures outside the OR is sometimes difficult due to electrical interference. In 2011, the ASA and the Heart Rhythm Society together published recommendations for the management of patients with a CIED needing anesthesia for surgery or procedures these environments. Other hospital environments including MRI diagnostic procedure areas must also be considered, though taking a patient with a CIED into an MRI scanner is generally not recommended.11

The ECG and pulse oximeter provide all the information necessary to evaluate pacemaker function during and after surgery. Some intraoperative ECG monitors offer a “pacemaker” mode for evaluating the ECG complex. This provides a filter to remove electrical artifact, helps enhance the pacemaker signal, and prevents "double" counting of the heart rate (pacemaker spike plus QRS complex). These ECG pacemaker display options are usually found in the ECG setup section. 60-cycle interference must be eliminated or minimized in order to see clear ECG complexes that include pacemaker spikes. Continuous invasive arterial pressure monitoring is not required for intraoperative pacemaker evaluation, however, when used, it is another source for analysis of pacemaker activity.

Electrical equipment, electro-surgical units, and the grounding pad
Electrosurgical unit (ESU) devices used to coagulate bleeding vessels and cut tissue are the most common cause of intraoperative ECG interference. Pacemakers programmed into the demand, or inhibited mode, are prone to temporarily ceasing pacing activity during unipolar ESU activation. If a pacemaker in the demand mode also includes the rate-adaptive feature, the result of ESU interference can be particularly vexing, since in this case, ESU interference might cause severe tachycardia if the device interprets the ESU interference as a need to increase its paced rate to meet a perceived increase in physical activity.12 Bipolar ESUs, and harmonic or electrically isolated scalpels13 are best to minimize such interference, but may not be used due to surgical preference or equipment availability.
It is interesting to note that filters to suppress ESU electrical interference from masking the ECG tracing have been available for over 20 years, but are not routinely built into OR ECG monitors.14

**Placement of the grounding pad**

The grounding pad should be placed according to the manufacturer’s recommendations and when possible, to those of the CIED company also. Ideally, the pad should be placed as far from the CIED generator as possible, and in such a way that a straight line between grounding pad and the surgical site does not intersect the CIED generator. Despite these precautions, experience has shown that no matter where the grounding pad is place, unipolar ESU interference might very well affect pacemaker circuitry, and inhibit pacing when the device is programmed into the demand mode. In pacemaker dependent patients, be prepared with strategies to ensure adequate pacing throughout surgery accompanied by unipolar ESU.

**Use of the magnet**

In the OR, **placing a magnet over the pacemaker generator changes the pacemaker from demand to fixed rate (or asynchronous) pacing.** Placing a magnet over an ICD prevents the ICD from delivering antitachycardia therapy. If a CIED is a combined ICD + pacemaker device, and if the pacemaker in this device is programmed in the demand mode, then placing a magnet over it will **only disable the ICD.** In this case, the magnet **will not convert** the demand pacing mode to fixed rate. If the goal for this device is to ensure uninterrupted pacing during surgery, then the pacing mode must be reprogrammed, **if possible,** to asynchronous, or fixed rate, before surgery begins. Please note, in some devices this is not possible!

Let me state the obvious, while a magnet is over an ICD generator, the ICD will not be able to deliver a shock if a life-threatening tachycardia starts.

In my opinion, the preoperative evaluation of an antibradycardia pacemaker must include the application of a magnet over the generator to document the pacemaker’s magnet response. This is especially important if the patient is pacemaker dependent. An excellent review of this topic was published in 2011.15

What does a magnet do?

Depending on the manufacturer, and the CIED model, magnets may do one of two, possibly three things. It is important to realize that the magnet can do only one thing at a time. Contacting the company, and telling them the model and serial number of the generator will let them tell you what the possible magnet options are. **For ICDs, either alone, or ICDs with antibradycardia pacing capability, the magnet will turn off defibrillation.** For a pacemaker alone, either dual chamber, or biventricular, the **magnet will likely to convert the pacemaker to fixed rate.** The magnet can, if these options are are available, 1- do nothing (the magnet mode was turned off), or 2- initiate Threshold Testing (see Pacesetter® “Vario” magnet mode under Recent History- Updates- at the end of this handout).

The paced rate that results when the magnet is applied over a pacemaker is not programmable, and is manufacturer dependent. Therefore, the manufacturer can sometimes be identified by the rate
produced when a magnet is applied to the generator. For example, if application of the magnet produces fixed rate pacing at 100 beats per minute for 3 beats followed by 85 beats per minute, the pacemaker is a Medtronic® Guidant, now Boston Scientific®, pacemakers are programmed to pace at 100 beats per minute when a magnet is applied. St. Jude® pacemakers are programmed to pace at 98.5 beats per minute when a magnet is applied.

Magnet application was originally designed to test the battery life. In this case different magnet rates would signify the remaining battery life. When talking with the company, it is a good to ask if different magnet rates are possible and what each means.

**Recommendations for intraoperative use of a magnet**

At least one article recommends against the routine use of a magnet during surgery to avoid pacemaker reprogramming due to electrosurgical interference. However, ESU activation has been associated with pacemaker reprogramming whether or not a magnet was first placed over the generator.

Consequently, I see no reason to avoid the use of a magnet during surgery. In fact, I recommend testing the magnet mode in advance of surgery (see Pacesetter® “Vario” magnet mode). That way, you will know what the magnet will do. If the magnet response is one you might later want, then keep the magnet available throughout surgery, and use it use if necessary. Unless there is clinical reason to convert the pacemaker to the asynchronous mode, it may be best to allow the pacemaker to function as programmed during surgery.

**ICDs should be deactivated preoperatively** if electrocautery use is planned during surgery. This can be accomplished by placing a magnet over the ICD generator for the duration of ESU interference during surgery. This will prevent antitachycardia therapy, i.e., defibrillation, during the time the magnet is over the ICD generator. **There is one exception**– the Ventak™ ICD manufactured by CPI®. Placement of a magnet over this model will elicit an R-wave synchronous beep for 30 seconds followed by a continuous tone, indicating deactivation of the device. At this point, the magnet should be removed. Reactivation of the Ventak™ requires replacing the magnet over the ICD generator to elicit a continuous tone for 30 seconds, followed by R-wave synchronous beeping, indicating reactivation of the device. At this point, the magnet should be removed making the device available to resume antitachycardia therapy when needed.

Failure to deactivate such a Ventak™ ICD during surgery may cause the ICD to interpret ESU output as abnormal cardiac activity and to deliver an unneeded shock. Worse, failure to reactive a Ventak™ device after surgery has occurred, allowing patients to leave the hospital not knowing that the ICD was still turned off. CPI® was purchased by Guidant® then Boston Scientific® purchased Guidant®. Ventak™ICDs still exist in some patients. For this reason, it’s always a good idea to contact the manufacturer, provide the model and serial number of the ICD generator, and verify all possible magnet options before surgery starts.
Intraoperative Pacemaker Emergencies

Pacemaker wires in contact with the heart are potential sources for conduction of electrical current directly to the heart, that can result in ventricular.

"R on T" ventricular arrhythmia caused by a temporary or permanent pacemaker

If the pacemaker spike falls on the T-wave in a vulnerable heart, ventricular tachycardia or fibrillation may occur. Pacemakers, by the very nature of their therapy, introduce an extrinsic electrical signal that produces an R wave; and if the timing of that signal is not coordinated with the patient’s intrinsic cardiac impulse, the pacemaker can trigger an R on T event. Typically, an anti bradycardia pacemaker is set in the synchronous mode. This pacing mode ensures that each patient’s cardiac contraction is initiated from only one source, either the patient’s heart, typically from the sinus node, or from the pacemaker. Changing the pacemaker’s setting to fixed rate, or asynchronous, with a magnet, in a patient whose heart continues to initiate heartbeats, increases the likelihood of an R on T event. Either the patient’s own heartbeat can fall on the T wave of a paced beat, or vice versa. Regardless, there are now two independent sources of cardiac contraction, firing at different rates, is the perfect storm for an R on T event. Intermittent use of the magnet will limit the duration of R on T risk to the shortest possible intervals.

A Brief History of the R on T Phenomenon

In 1949, Smirk first described the EKG findings and clinical relevance of what we now refer to as R on T. In 35% of his cases, the R on T occurred during an acute myocardial infarction (AMI), a period known for cardiac electrical excitability. Smirk speculated that an extra systole occurring during the T wave in a damaged heart, or during an excited period, might initiate sustained malignant ventricular arrhythmias. He further speculated that if these extra systoles were prevented with treatment, such treatment might reduce the incidence of sudden cardiac death.

Not every R on T event leads to a ventricular arrhythmia. The heart, or at least part of it, must be vulnerable to the event, such that an R wave falling on the T wave initiates a sustained ventricular arrhythmia. Any concurrent, or prior cardiac insult can make the heart more vulnerable to this phenomenon. For example, if the patient is experiencing an AMI, or has suffered previous cardiac damage resulting in depressed function, cardiac enlargement, or congestive heart failure, then an R on T event has a higher likelihood of resulting in a malignant ventricular arrhythmia.

In patients with a pacemaker who have an otherwise normal heart, an R on T event virtually never initiates a sustained arrhythmia. In most, if not all patients presenting for elective surgery who do not have a history of arrhythmias, even a pacemaker induced R on T is unlikely to cause an arrhythmia. In these cases, a pacemaker induced R on T will simply be blocked, or result in a single extra systole. Nevertheless, in any pacemaker patient undergoing surgery, if there is a reasonable concern that a sustained arrhythmia might occur as a result of an R on T event, a defibrillator should be nearby.
Temporary pacemaker failure

The most common cause of temporary pacemaker failure is the loss of contact between an electrode wire and the heart. In this case, pacemaker spikes appear on the monitor without QRS complexes. To restore cardiac pacing, the pacing electrode must be advanced until it comes into contact with the myocardium to “capture” or pace the heart. The second most common cause is inadequate pacemaker output. In this case, increase the mA or voltage output setting.

The absence of a pacemaker spike means one of two things — there is no energy left in the battery, or one of the electrode wires is disconnected from the generator. Temporary pacemakers are powered by a 9-volt batteries that are easily replaced. Most often, the problem is the loss of the connection between the generator and the wires.

The pacemaker "threshold" for capture (the energy required to pace the heart) usually is below 5 milliamps for ventricular pacing but can be as high as 20 milliamps for atrial pacing. Adjustments in pacemaker "output" may be required after the leads are placed and confirmed to be in contact with the myocardium and with the pacemaker generator unit. Like permanent pacemakers, ESU activation may inhibit a temporary pacemaker in the demand mode. When necessary, the pacing mode can be manually adjusted to the fixed rate (asynchronous) mode.

Permanent pacemaker failure

When the battery is completely depleted, pacing will stop. Modern pacemakers are designed to reduce their paced rate as the battery runs down, inspiring the patient to seek medical attention before the pacemaker stops. At these low rates, 30 to 40 beats per minutes, pacing can continue for up to several months before the pacemaker finally fails completely. As far as I can tell, abrupt failure to pace has not been reported to occur during surgery in devices that were confirmed to work just prior to taking the patient into the OR. However, if you have not checked a CIED prior to entering the OR, you will not know what the device is capable of doing, and whether or not it has any battery reserve.

Occasionally, the ESU will inadvertently reprogram a permanent pacemaker. The effect of this reprogramming is likely to change the pacing characteristics, but it will not turn off the pacemaker. If pacing is noted to change, a cardiologist should be consulted to reprogram the pacemaker. Surgery near a pacemaker generator is not usually a problem, however, if surgical manipulation of surrounding tissue results in disconnection of a lead wire, pacing will stop; at which time, emergent transthoracic pacing is indicated. Myocardial infarction of the right ventricle, the standard location of ventricular pacing wires, may result in failure to pace the heart, necessitating transcutaneous pacing until new lead wires can be placed in a more favorable location of the heart.

Transthoracic cardiac pacing

Transthoracic or transcutaneous pacing (the terms are used interchangeably) is the modality recommended for emergencies requiring cardiac pacing, and is now part of standard defibrillator units. If the patient is pacemaker dependent, it might be prudent to attach the pacing/defibrillation pads prior to the start of surgery. This will allow for emergency pacing without delay, if necessary.
Implantable cardioverter defibrillators

External defibrillator pads should be considered for all patients with an ICD who require anesthesia and surgery. Most of these patients have severe myocardial dysfunction, a history of coronary artery disease, or end-stage cardiomyopathy from any cause, and the ICD was inserted for a confirmed life threatening arrhythmia. Since ICDs are normally deactivated during surgery, it is important to be able to detect a true arrhythmia early, then initiate treatment promptly. If the ICD is a Ventak™ (see above), and it has been deactivated, treatment requires external defibrillation. For any other ICD, removing the magnet from the ICD generator will allow it to function normally and deliver a shock. However, external defibrillation is never contraindicated in a patient with an ICD. In fact, external defibrillation can deliver shocks of higher energy than the ICD, which may be required during surgery.

The majority of ICDs also function as anti-bradycardia pacemakers. For these units, a magnet placed over them will deactivate only the antitachycardia function, but will NOT alter the programmed anti-bradycardia function. Accordingly, in patients who are pacemaker dependent, the pacemaker spikes and cardiac pacing will remain unchanged after magnet placement. **It is important to remember that when a magnet is placed over a combined ICD + pacemaker, the magnet will NOT convert the pacing to asynchronous.** In these situations, **monopolar ESU will inhibit antibradycardia pacing.**

When a patient with an ICD is taken to the operating room, it may be prudent to alert a cardiologist or pacemaker nurse specialist that this patient is undergoing surgery. Such a specialist may be needed during surgery. Even if not, they should be called after surgery to verify proper device functioning before the patient leaves the hospital.

Defibrillation- insulation/Protection

Current permanent pacemakers and ICDs are designed and manufactured to prevent a strong external electrical current or electromagnetic interference from altering their programmed function. Nevertheless, defibrillation, as well as intraoperative ESU, may damage the CIED circuitry or alter its settings. For this reason, it is prudent to check all devices after defibrillation to ensure that the device is still programmed as intended. This is especially true for all patients with ICDs who have experienced life-threatening arrhythmias, and for those patients who are pacemaker dependent.

Pacemaker Basics

Historical background

As far back as the 1790’s, physicians attempted to revive drowning victims with artificial ventilation and electricity to stimulate the heart. Interestingly, at least one author emphasized the importance of re-establishing respiration and even suggested at that time that a tube be inserted into the trachea and attached to a bellows to ventilate the lungs and prevent gastric distention. By the 1880’s, animal experiments were successful in pacing the heart at 60-70 beats per minute. This inspired physicians to seek similar results in humans. During the 1920’s in Australia and the 1930’s
in the U.S., needle electrode devices were inserted directly into the hearts of patients after the accepted methods of resuscitation for this period failed to revive the heart. These reports are believed to be the first in which humans benefited from cardiac pacing devices, introducing the term “artificial pacemaker.”

“Modern” pacemaker history began in 1952 when Zoll developed the first external pacemaker. In 1958, Furman inserted a transvenous-pacing device into the right ventricle, first in animals, then in humans, and produced successful cardiac pacing. Pacemaker history, up to and including rate responsive technology has been recently reviewed.21

ICDs to treat ventricular tachycardia and ventricular fibrillation were first reported in humans in 1980. Numerous studies attest to their efficacy for symptomatic ventricular arrhythmias. Atrial fibrillation is an area of active device development.

**Pacemaker hardware and programming features**

No matter how complex a pacemaker may seem, the goal of cardiac pacing is simple. For patients with symptomatic bradycardia, or symptoms possibly due to bradycardia, the pacemaker provides a cardiac impulse. For adults, pacemakers rates are generally set between 60-90 beats per minute. Basic components are:

1. **Pulse generator.** The electrical impulse is formed in the pulse generator. Permanent pacing devices now use lithium-powered batteries with an operating life of 5 to 20 years depending on how often pacing is required. Standard 9-volt batteries usually power temporary pacemaker pulse generators. The terms "pulse generator" and "pacemaker" are often used interchangeably.

2. **Pacing electrode wires.** The electrical impulse formed in the pulse generator is transmitted to the endocardium (permanent or transvenous pacing) or epicardium (attached by the cardiac surgeon) through insulated stainless steel or platinum alloy wires. These wires also function as part of the pulse generator’s sensing system for detection of the patient’s intrinsic cardiac electrical activity.

3. **Pacemaker codes.** All pulse generators are assigned a five-letter NBG code that describes the pacemaker's potential pacing possibilities (See Table 1). The most common code for permanent pacemakers is the DDD code (see below). The acronym "NBG" represents the combined efforts of the North American Society of Pacing and Electrophysiology (NASPE) and the British Pacing and Electrophysiology Group (BPEG);22,23 the "G" actually stands for generic! Although this coding system is helpful (particularly the first 3 letters of the code), it is not complete — it does not identify electrode type, power source, whether the pacing system is temporary or permanent, or how the pacemaker will respond when a magnet is placed over the generator (the latter being essential information for anesthesiologists). Newer pacemakers sometimes defy even the five-letter NBG code, requiring further explanation to clarify some of their unique features. The increasing complexity of these devices often requires communication with a cardiologist.
Table 1

<table>
<thead>
<tr>
<th>Chamber Paced</th>
<th>Chamber Sensed</th>
<th>Response to Sensing*</th>
<th>Programmable Functions; Rate Modulation</th>
<th>Anti-tachycardia Function(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V—ventricle</td>
<td>V—ventricle</td>
<td>T—triggers pacing</td>
<td>P—programmable rate and/or output</td>
<td>P—pacing</td>
</tr>
<tr>
<td>A—atrium</td>
<td>A—atrium</td>
<td>I—inhibits pacing</td>
<td>M—multiprogrammable for rate, output,</td>
<td>S—shock</td>
</tr>
<tr>
<td>D—dual (A + V)</td>
<td>D—dual (A + V)</td>
<td>D—dual (T + I)</td>
<td>sensitivity, etc.</td>
<td>D—dual (P + S)</td>
</tr>
<tr>
<td>O—none</td>
<td>O—none</td>
<td>O—none</td>
<td>C—communicating functions (telemetry)</td>
<td>O—none</td>
</tr>
</tbody>
</table>

*Synonyms for terms:
O = asynchronous or fixed rate
I = synchronous or demand

Temporary cardiac pacing

Temporary transvenous or epicardial pacing is commonly used in acute settings such as a myocardial infarction, sudden onset of high degree second- or third-degree atrioventricular (A-V) block, and for postoperative management of cardiac surgical patients. Temporary devices also can be used for diagnosis as well as treatment of certain cardiac arrhythmias.

Atrial pacemaker wires may be helpful in the diagnosis of wide complex rhythms. This requires two atrial electrode wires: one is attached to the right arm lead of the ECG machine, the other to the left arm lead of the ECG machine. The remaining ECG leads are then placed in the standard locations. In this configuration, lead I will record an atrial electrogram, revealing the relationship between atrial activity and the QRS complex. This can be useful to identify the origin of a wide complex QRS arrhythmia, especially a tachycardia where P waves are typically difficult to see.

Temporary atrial and ventricular lead wires also can be useful to treat some tachycardias. New onset atrial flutter and/or non-hemodynamically significant supraventricular or ventricular tachycardia may be terminated by "overdrive" pacing of the appropriate cardiac chamber. Using temporary pacemaker wires to terminate these arrhythmias may avoid the need for pharmacological management with undesirable side effects. Atrial pacing cannot terminate atrial fibrillation.

Permanent cardiac pacing: the DDD Pacing System

The DDD pacing system is the most commonly used programming mode for pacemakers implanted today. In this pacing mode, both atria and ventricle electrical activity can be sensed and paced (as programmed), and the A-V interval can be programmed to change with changes in heart rate. This versatility improves hemodynamic performance both at rest and during exercise, decreases the incidence of atrial fibrillation, and thromboembolic events, and reduces the incidence of pacemaker syndrome (Pacemaker syndrome describes the fact that patients just feel better when the atria and ventricle are paced, rather than when the ventricle alone is paced).
Implantable cardioverter defibrillators

ICDs defibrillate life-threatening tachycardia, most often either ventricular tachycardia (VT) or ventricular fibrillation. In 1993, a four-letter coding system was established to describe various features that can be programmed into an ICD. Originally, all devices were VVEO (see Table 2); the common code now is VVEV. In this mode, the ICD can analyze the ventricular electrogram, then decide to initiate anti-tachycardia ventricular pacing if the VT rate is “slow,” or defibrillate if the VT rate is rapid. Changes in ICD technology make today’s devices smaller and lighter, and improved algorithms means these devices are also capable of functioning as antibradycardia pacemakers when necessary.

Table 2

<table>
<thead>
<tr>
<th>I Chamber shocked</th>
<th>II Anti-tachycardia pacing chamber</th>
<th>III Tachycardia detection</th>
<th>IV Anti-bradycardia pacing chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>O--none</td>
<td>O--none</td>
<td>E--electrogram</td>
<td>O--none</td>
</tr>
<tr>
<td>A--atrium</td>
<td>A--atrium</td>
<td>H--hemodynamic</td>
<td>A--atrium</td>
</tr>
<tr>
<td>V--ventricle</td>
<td>V--ventricle</td>
<td></td>
<td>V--ventricle</td>
</tr>
<tr>
<td>D--dual (A + V)</td>
<td>D--dual (A + V)</td>
<td></td>
<td>D--dual (A + V)</td>
</tr>
</tbody>
</table>

Future Directions

Early pacing devices were large and simple by today's standards. Today CIEDs are smaller and they possess abundant programming options. Current pacemakers do not abruptly stop, but will decrease the paced rate as the battery is depleted, forcing patients to seek medical attention. New rate-adaptive sensors are improving the pacemaker patient's quality of life. These features all result in CIEDs that require device specific interrogation to know how they are programmed, how they will respond to application of a magnet, and how much battery life remains.

There is no industry-wide standardization of pacemaker or ICD components, no universal response to a magnet, and no identifying marks available on a CXR. The development of a "universal" interrogating machine would allow us to have a single device to evaluate or program any pacemaker or ICD, regardless of the manufacturer.

Future CIEDs will be able to remember abnormal rhythms, store electrograms, will be interrogated remotely, and have their information stored in a company database.

Electrical therapy for cardiac rhythm disturbance continues is a very active area of investigation for researchers, and quite lucrative for device companies. There will no doubt be significant health benefits for patients and economic rewards to these companies.
Conclusion

Pacemakers and ICDs are inherently simple devices: they provide a cardiac impulse when one is lacking or defibrillate a heart whose rate is too fast. CIED complexity derives from the increasing number of possible programmable modalities and the increase in memory storage. Before the patient enters the operating room, clinicians should obtain as much information as possible about the specific device. For permanent pacemakers, a magnet should be placed over the pacemaker generator before surgery to verify that it can be converted to fixed rate-pacing. ICD devices should be deactivated preoperatively, then reactivated after an ESU is no longer used. An ESU can inhibit a pacemaker programmed in the demand or synchronous mode no matter where the grounding pad is placed. If the ESU results in pacemaker inhibition, a magnet placed over the generator will convert the pacemaker from synchronous or demand mode to a fixed rate or asynchronous mode. ESU interference with the demand mode is much less likely to occur when a bipolar unit is used. ESU activation also can inadvertently reprogram a permanent pacemaker whether or not a magnet has been applied. After surgery, all CIEDs should be checked with the appropriate interrogating device to confirm proper settings before a patient is discharged. A cardiologist, or pacemaker specialist, should be consulted to assist with CIED evaluation and programming whenever necessary.

Recent History

Here is some newsworthy information in CIED technology that the public might well know.

In June 2005, the FDA issued a safety alert for a Guidant ICD: In December 2005, Guidant recalled 109,000 devices. Guidant company internal documents show that they were aware of the problem in 2002, but did not share this information with the doctors until forced to in May 2005. The FDA said that they learned in March 2005 that a college student died after receiving a flawed Guidant ICD. Since that first death, at least 6 other patients died when their Guidant ICD failed to work properly. A front-page article in the New York Times on September 12, 2005 documents that the FDA actually had information about these flawed devices as early as 2003. In spite of knowing about the FDA alert and the Guidant recall, Boston Scientific, in December 2005, announced plans to purchase Guidant. The deal closed in April 2006. In June 2006, Boston Scientific announced the recall of an additional 27,000 ICDs, and stated that it would be likely that additional recalls would be made. On July 13, 2007, Boston Scientific said that it agreed to pay $195 million to settle claims by ‘thousands of patients’ who received potentially flawed Guidant defibrillators. This settlement, announced 2 weeks before the start of the first trial, is not the end. Possible criminal charges are still being considered by the Justice Department. We will provide anesthesia for these patients who choose to exchange their ICD, based on these recalls, and possibly to patients who still have defective ICD devices.

Saturday, March 14, 2009, New York Times: Medtronic Links Device For Heart to 13 Deaths: Yet another almost unbelievable story showing that the company, Medtronic, knew as early as 2004,
that there were complaints about fractures in a cable, known as the Sprint Fidelis, that connects the ICD to the heart. In spite of the concern first raised in 2004, more than ‘tens of thousands’ of additional patients received this device before Medtronic recalled the Sprint Fidelis cable from the market in October 2007. Only after the FDA got involved did Medtronic agree to the withdrawal.

*Saturday, April 7, 2012, New York Times: Troubling Flaws in Heart Device Shake Industry:* This article highlights the problems with ICD lead wires. The article starts out describing the lead wire problems with the St. Jude Medical ICDs, then goes on to point out how money trumps patient safety for all three CIED companies when it comes to full disclosure about problems with ICDs. While this article highlights a patient who received unnecessary and inappropriate shocks but did not die, it goes on to review the history where companies have known about device flaws but did not report them until forced to by the FDA after patients died!

I find it fascinating that many of these articles first appear in Saturday editions.

**Updates**

*MRI compatible pacemaker:* In 2009, Medtronic reported at the European Society of Cardiology on a study of 245 patients with a new type of cardiac pacemaker that is safe for patients undergoing an MRI examination. It is estimated that between 50%-75% of all patients with pacemakers will, in their lifetime, need at least one MRI exam. Medtronic stated that their goal is to develop an MRI-safe ICD, and an MRI-safe cardiac resynchronization device. European and American companies are now manufacturing MRI compatible CIEDs, both pacemakers and ICDs. We will see them soon in patients requiring anesthesia for a diagnostic MRI procedure. Anesthesia considerations for these devices are the same as described above in this handout.

*Pacesetter® “Vario” magnet mode:* Normally, every pacemaker manufacturer builds their permanent pacemaker to respond to a magnet placed over the pacemaker generator by changing the pacing mode to asynchronous or fixed rate pacing. The “Vario” mode is a threshold-testing mode that is activated when the magnet is placed over the pacemaker generator. In this mode, the magnet initiates a 16-beat sequence of decreasing energy to identify the threshold energy required to “capture” or pace the heart. This particular pacemaker has two “magnet mode” options available but how the device will respond to a magnet cannot be known until the magnet is placed over the generator. Once chosen, the threshold testing mode remains the “magnet” mode until the magnet mode is changed. Models with the “Vario” threshold-testing magnet mode are still manufactured and patients with pacemakers having this option might still present for surgery. Therefore, it is important to verify *preoperatively* what the magnet does when it is placed over the pacemaker generator. If the “Vario” mode is the magnet mode, then the magnet mode should be reprogrammed to become a fixed rate mode during the operative procedure. St. Jude Medical now owns Pacesetter®.
The author wishes to thank Charles Witherell RN, CS, MSN Clinical Nurse Specialist, cardiac electrophysiology, for his technical assistance.

Internet sites that may be helpful:

http://www.fda.gov/MedicalDevices/Safety/default.htm
US Food and Drug Administration- An interesting site about medical devices, including pacemakers, and implantable cardioverter defibrillators. Check here for device recall details.

http://www.heart.org/HEARTORG/Conditions/Arrhythmia/Arrhythmia_UCM_002013_SubHomePage.jsp
American Heart Association information for patients with arrhythmias, pacemakers and ICDs. No doubt, this is a site patients frequently look to for information.

References


10. Crossley GH, Poole JE, Rozner MA, et al. The Heart Rhythm Society (HRS)/American Society of Anesthesiologists (ASA) Expert Consensus Statement on the perioperative management of patients with implantable defibrillators, pacemakers and arrhythmia monitors: facilities and patient management this document was developed as a joint project with the American Society of Anesthesiologists (ASA), and in collaboration with the American Heart Association (AHA), and the Society of Thoracic Surgeons (STS). *Heart Rhythm*. Jul 2011;8(7):1114-1154.


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