41 Pacemakers and Defibrillators

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Pacemakers and implantable cardioverter defibrillators (ICD) are made of 2 major components: the generator (battery) and the leads connecting the generator to the heart. The leads can be attached to the heart by screwing them into the myocardium from the inside (endocardium) via a transvenous approach or they can be sutured to the outside of the heart (epicardium) via an epicardial approach. The anatomy and size of the patients are the main considerations when deciding upon the approach for device placement. Patients with systemic shunts or lack of access to intracardiac chambers from subclavian access (Fontan or Glenn physiology) will require an epicardial approach. A transvenous approach can be considered in patients without shunting lesions who are generally at least 20 kg in weight for pacemakers and 30 kg for ICD.

After a transvenous implant, patients are admitted and kept on IV antibiotics until discharge. Arm movement on the side of device placement should be limited. Patients should not be allowed to lift the arm above 90º or put their arm behind them. The evening of the procedure, a portable CXR is performed to evaluate for the presence of a pneumo- or hemothorax and for lead placement (Figure 41-1). The morning of discharge, all patients must have a complete physical exam including evaluation of the device pocket, in addition to an anteroposterior (AP) and lateral CXR, device interrogation, and device teaching by the electrophysiology (EP) nurses. Patients are discharged home to complete a 3-7 day course of oral antibiotics.

ICDs are able to treat tachyarrhythmias either via electrical cardioversion or though antitachycardia pacing. Heart rate zones are set to tell the ICD when therapies should be delivered. ICDs will use several discriminators to differentiate supraventricular, ventricular, and sinus tachycardia.

The number and type of lead placed depends on the indication for pacing and size of the patient. Indications for pacing are based on published guidelines. Regardless of approach to implant, it is important that sensed P and R waves are of sufficient size for the lifetime of the lead. Epicardial bipolar leads should be placed at a distance <5 cm apart. The minimal P-wave amplitude is 1.5 mV with a goal of at least 2 mV. For R waves, the minimal amplitude is 6 mV with an optimal value of 10 mV. Capture thresholds should ideally be <1 V at 0.5 msec with a maximum value of 2.5 V at 0.5 msec. Battery life is dependent on the amount of pacing and capture threshold. The higher the threshold, the faster the battery will drain.

All medical teams caring for a patient with a pacemaker or ICD need to be aware of the device type and programming of the implanted device. Device programming should be located in the patient's chart. Device programming is indicated by a three-letter code with an additional fourth letter "R" for devices with rate response (Table 41-1). The first letter refers to the chamber paced. The second letter refers to the chamber sensed. The third letter refers to what the device does with the information. The fourth letter "R" is a pacing mode termed "rate response" which is typically used in patients with sinus node dysfunction. It allows the generator to sense activity or chest wall movement that

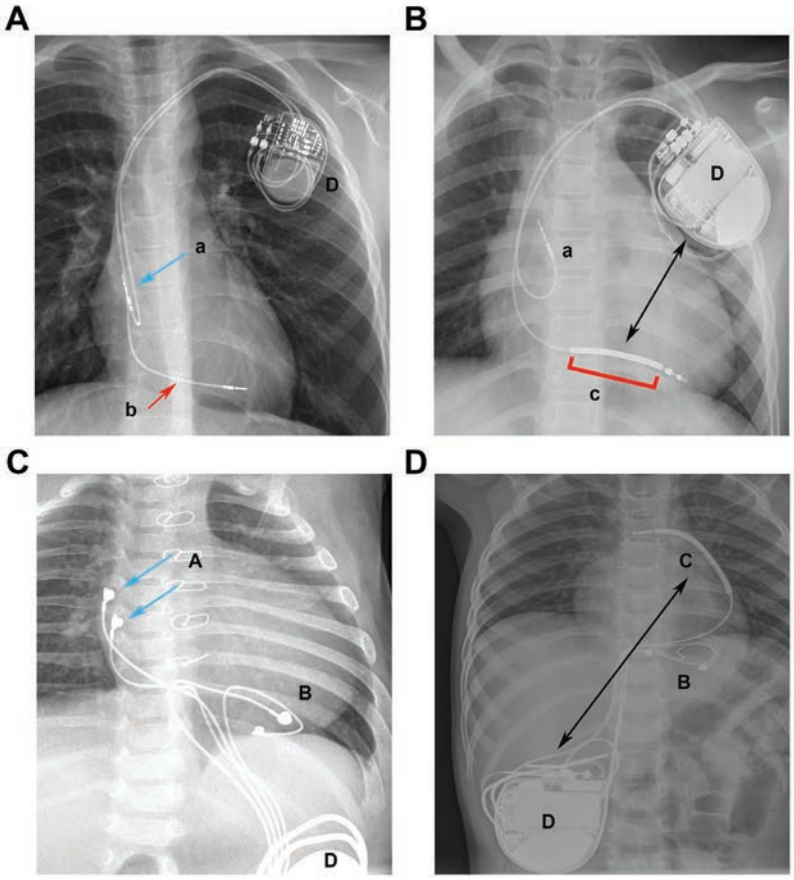

Figure 41-1. Images A-D are AP CXR views of transvenous (A-B) and epicardial (C-D) pacing and ICD systems. Lowercase letters refer to transvenous leads and uppercase letters refer to epicardial leads. A) Dual-chamber transvenous pacemaker. B) Dual-chamber transvenous ICD. C) Dual-chamber epicardial pacemaker. D) Single-chamber epicardial ICD. Transvenous and epicardial systems can be differentiated by imaging the lead and system. Transvenous systems utilize the subclavian veins to access the heart. The leads have a screw to attach the lead to the endocardial surface (a: atrial transvenous lead in the atrial appendage, b: ventricular transvenous lead in RV apex). Epicardial leads look like buttons which are sewn to the outside of the heart (A with blue arrows showing each of the buttons). If there is only one button, this means the systems is unipolar (not shown) and the other pole is the generator. Two buttons mean the lead is a bipolar lead. The generator (D) in transvenous systems is located in the prepectoral chest (most commonly left side, although the generator can also be placed in the right chest). For epicardial systems, the generator is typically in the abdomen. An ICD lead can be distinguished from a pacing lead by the presence of a thicker coil (see red bar labeled c and compare this to the pacing lead b). The ICD coil can be placed transvenously (c) or epicardially (C). The vector for the ICD system is important and one should imagine the coil as one shocking paddle and the generator as the second shocking paddle. Each "paddle" needs to surround the heart to defibrillate. The black arrows represent the shocking vector for the ICD system.

Table 41-1. Pacemaker nomenclature.

	1st	2nd	3rd
	Chamber Paced	Chamber Sensed	Mode of Response
	A = Atrium V = Ventricle D = Both	A = Atrium V = Ventricle D = Both O = None	I = Inhibit (sensed event inhibits pacing) T = Trigger (sensed event triggers pacing) D = Both (inhibits and triggers pacing) O = None
AAI	This mode will sense the atrial activity and will pace the atrium at the lower rate limit (LRL) unless the sinus/atrial rate is above the LRL.		
VVI	This mode will sense the ventricular activity and will pace the ventricle at the LRL unless the ventricular rate is above the LRL.		
DDD	This mode can sense both the atrium and the ventricle. It can perform 4 different functions: AsVs = senses both the A and V AsVp = senses the atrium and paces the ventricle ApVs = paces the atrium and senses the ventricle ApVp = paces the atrium and ventricle		
AAI→ DDD	This mode (typically programmed in Medtronic devices) means the device will function in the AAI mode but if there are 2 out of 4 p waves without a QRS, the device will switch to the DDD mode to allow dual chamber pacing, if needed. This program is for patients with generally intact AV conduction with intermittent heart block. It encourages normal AV conduction as much as possible.		
AOO/ VOO DOO	This mode will pace the atrium (AOO) or ventricle (VOO) or both (DOO) at the set rate and will not look for any sensed beats. It is important that while pacing in this mode, one is well above the normal heart rate. Otherwise, inappropriate pacing can induce atrial or ventricular arrhythmias.		
VDI	This is an unusual mode to be programmed. The device will sense both the atrium and ventricle but will only pace the ventricle.		

occurs with physical activity. In response, the pacemaker will automatically increase the pacing rate of the chamber programmed.

Placing a magnet over the pacemaker will force the device to operate in an asynchronous mode: DOO in a dual-chamber device or VOO/AOO in a single-chamber device. Placing a magnet over an ICD will turn off therapies.

Pacemaker-mediated tachycardia (PMT) refers to tachycardia caused by interaction of the pacing system with the patient. Classically, this is an endless-loop tachycardia typically in a dual-chamber system when a premature ventricular contraction (PVC), loss of atrial capture, a prolonged PR, or atrial under- or oversensing result in retrograde atrial conduction that is sensed as an atrial event by the pacemaker, which then triggers DDD pacing.

Transesophageal Pacing

Transesophageal pacing (TEP) can be used for diagnostic and therapeutic intervention. The 5 Fr soft bipolar catheter is placed through the nares into the esophagus, similar to a feeding tube. It can be placed at the bedside. Once the lead is placed, the location is confirmed using a standard ECG. TEP is helpful to diagnose relationships between

atrial and ventricular electrograms and can be used to pace the atrium to terminate reentrant supraventricular tachycardia (SVT). This method can be particularly helpful in the neonate with SVT or intra-atrial reentrant tachycardia (IART) in CHD.

Temporary Pacing

Temporary pacing wires are placed following certain cardiac operations. By convention, atrial wires usually exit to the right of the sternum and ventricular wires to the left. Temporary pacing wires are usually unipolar, have a single electrode, and require a second electrode to be able to pace. This can be achieved with a second temporary pacing lead or with a subcutaneous grounding wire. Pacing energy is delivered from the negative end of the temporary pacing box. The pacing wire is placed on the negative end and the grounding or second wire is placed on the positive end.

Programmable settings available in external temporary pulse generators include: pacing rate, atrial and/or ventricular output amplitude (milliamperes, mA), atrial and/or ventricular sensitivity (millivolts, mV) or asynchronous mode, A-V interval (milliseconds, msec), postventricular atrial refractory period (PVARP), and upper rate tracking. Programming of a temporary pacemaker should be guided by the clinical scenario and by testing of sensing and stimulation thresholds:

- **Rate.** Should be set at a physiological rate for age that provides adequate cardiac output for their postoperative hemodynamics. For overdrive suppression of an arrhythmia, the rate is set 10 to 20% higher than the arrhythmia rate.
- **AV delay.** This is the PR interval and is usually set automatically based on the rate, or between 100 and 150 msec.
- **Upper rate.** Represents the upper rate that the pacemaker will track the atrium in DDD mode. How high this is set is determined by the clinical scenario and by the total atrial refractory period (TARP) (AV delay + PVARP). The maximum the upper rate can be programmed will be 60,000/TARP.
- **Sensitivity.** The sensing threshold is the minimum electrical activity that the pacemaker is *able to sense*. The lower the sensitivity setting, the less electrical activity needed for the pacemaker to sense (i.e., greater sensitivity). In order to determine sensitivity, the patient must have an underlying rate in the chamber that is being tested. The pacemaker is set on a synchronous pacing mode (AAI, VVI, or DDD) and the rate is set lower than the underlying rate. The sensitivity setting is increased (i.e., decreasing sensitivity) until the pacemaker stops sensing and starts pacing. The sensitivity setting is then decreased (i.e., increasing sensitivity) until every cardiac depolarization is sensed. This represents the sensing threshold. The sensitivity should then be set at half of that sensing threshold. In patients with no underlying rhythm, sensitivity is typically set at 2 mV. If the sensitivity is set too high, the pacemaker can potentially not see electrical activity and overpace, which can lead to pacemaker-induced arrhythmias. If the sensitivity is set too low, the pacemaker might underpace due to inhibition by electrical noise.
- **Capture thresholds.** It is the minimum amount of energy required to stimulate the myocardium. To determine the threshold, the pacemaker rate is set above the underlying rate so the pacemaker is consistently pacing. The output is then decreased

until capture is lost. In order to provide a safety margin, the output should be set at twice the capture threshold.

For patients requiring temporary pacing, pacemaker settings should be interrogated daily. This should also include determining underlying rhythm and continued need for pacing. A second pulse generator and battery should be available at all times.

An atrial ECG obtained using temporary atrial pacing wires can provide diagnostic information in certain arrhythmias. To perform an atrial ECG, the temporary atrial wire can be hooked up to V1, or if two leads are available, hooked up to "right arm" and "left arm", which will display in lead I.

Suggested Readings

Valdes SO, Kim JJ, Miller-Hance WC. Arrhythmias: Diagnosis and management. In: Andropoulos DB, Stayer S, Mossad EB, Miller-Hance WC (eds). Anesthesia for Congenital Heart Disease. 3rd ed. John Wiley and Sons; 2015.