

**Care of the Patient with Permanent Implantable Pacemaker  
In the Neonatal and Pediatric Cardiac Patient**

What the Nurse Caring for a Patient with Congenital Heart Disease Needs to Know

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**Introduction**

A pacemaker is an electronic device which provides repetitive electrical stimuli to the right atrium (RA), right ventricle (RV) or both in the case of dual chamber atrioventricular (AV) sequential pacing. Pacemakers initiate and maintain the heart rate (HR) when the natural pacemaker, the sinoatrial (SA) node fails to fire, is delayed, or does not conduct regularly to the ventricles. The latter occurs in advanced AV block.

Postoperative cardiac arrhythmias are a major cause of morbidity and mortality in pediatric patients following repair of congenital heart defects (CHD). (Batra, 2008) Failure of the cardiac rhythm to return to normal sinus rhythm (NSR) may necessitate insertion of a permanent pacemaker i.e. heart block that persists greater than 7-10 days. Patients with lethal arrhythmias are assessed for a permanent Implantable Cardioverter-Defibrillator (ICD) device with shock capability.

These guidelines review management of patients with permanent pacemakers. Nurses are encouraged to review their institutional policies and guidelines prior to caring for patients with pacemakers. Please refer to the Society of Pediatric Cardiovascular Nurses (SPCN)/ Pediatric Cardiac Intensive Care Society (PCICS) guidelines on Arrhythmia Management, Postoperative Care, and guidelines on specific Congenital Heart Defects.

## Critical Thinking Points

Nurses caring for infants and children requiring permanent pacemaker therapy must be competent with pacemaker technology. Competency includes:

- Knowledge of the types of pacemakers
- Knowledge of programmed modes
- Understanding of parameter settings
- Capability to recognize and interpret normal/abnormal device function.
- Nurses must understand the patient's
  - Underlying cardiac rhythm and myocardial function
  - Degree of device dependency
  - Interpretation of intrinsic and paced electrocardiograms
  - Patient response to pacing (cardiac output)
  - Fundamental skills include:
    - Recognizing complications
      - Failure to pace
      - Failure to capture
      - Failure to sense (undersensing and oversensing)
    - Recognizing changes in patient's clinical condition when device may be a contributing factor
- Nurses should have the following basic knowledge
  - Knowledge of appropriate heart rate for age in pediatrics
  - Knowledge of pediatric cardiac arrhythmias
  - Understand pediatric congenital and acquired heart disease and associated acute and chronic electro-physiologic sequelae
  - Appreciate the surgical history, cardiac anatomy and acute and chronic electro-physiologic sequelae as a result of cardiac repair

## Definitions

- **Pulse Generator:** Pacemaker box containing the microcircuitry and battery.
- **Permanent Pacemaker:** Implanted permanent pulse generator and lead(s) in patients who meet permanent pacing indication.
- **Epicardial Lead(s):** Lead(s) attached to the heart's epicardial surface.
- **Endocardial Lead(s):** Pacing lead(s) enters the heart chambers via a transvenous approach.
- **Inhibited:** Pacemaker does not pace when it senses an intrinsic beat.
- **Triggered:** When the pacemaker does not sense an event within a set amount of time an electrical current is delivered.
- **Implantable Cardioverter-Defibrillator (ICD):** A permanent implantable device that recognizes certain types of tachycardias including ventricular tachycardia or fibrillation and is able to deliver electrical energy converting shockable rhythms. (Everett, 2010)
- **Pacemaker dependent:** Patients are considered dependent on pacing if the intrinsic heart rate is < 30 bpm or if significant hemodynamic compromise occurs when pacing is stopped abruptly.

### **Indication for Permanent Pacing**

- Sinus node dysfunction with failure of the SA node to generate an appropriate heart rate response and correlation of symptoms with this bradycardia.
- Advanced atrioventricular (AV) block with inherent problems of delay or blocked conduction of electrical impulses from the atria to the ventricle as in 2<sup>nd</sup> and 3<sup>rd</sup> degree block. This can be congenital or acquired. Postoperative heart block persisting greater than 7-10 days may require a permanent pacemaker

### **Additional Pacemaker Therapies**

- **Cardiac Resynchronization Therapy (CRT)**
  - CRT is a three wire pacemaker system (atrial lead, RV lead and LV lead) that is used to manage patients with congestive heart failure, ventricular dyssynchrony whereby the loss of coordination between right and left ventricular contraction results in inefficient pumping of blood.
  - The goal of CRT pacing is to always biventricular pace in order to resynchronize the two ventricles for maximal effectiveness. When pacing occurs, two pacing spikes may be seen for ventricular capture and continuous biventricular capture should not show any changes in paced QRS morphology.
  - If changes in paced QRS are noted, then it is important to investigate to see if there is loss of biventricular capture. A 12 Lead ECG may be helpful along with a full pacemaker check for stimulation thresholds.
  - In rare instances, biventricular pacing may be proarrhythmic causing an electrical storm. The etiology is not clearly understood or it may be the sequelae of very sick patients. (Dubin 2005)

### **Pacing Coding System**

- A standardized generic coding system for anti-bradycardia pacing, rate responsive pacing and multisite pacing was established by:
  - The North American Society of Pacing and Electrophysiology (NASPE)
  - The British Pacing and Electrophysiology Group (BPEG)
- **Permanent Pacemaker Codes:** 4 or 5 letter coding system which includes a fourth letter for programmable functions and a fifth letter for special anti-tachycardia functions. The fifth letter code is rarely used and thus will not be further discussed in these guidelines.

### The Revised NASPE and BPEG Pacemaker Codes

Temporary			Permanent	
I	II	III	IV	V
Chamber(s) Paced	Chamber(s) Sensed	Mode(s) of Response	Rate Modulation	Multi-Site Pacing
A=Atrium	A=Atrium	T=Triggered	R=Rate Modulated	A=Atrium
V=Ventricle	V=Ventricle	I=Inhibited	O=None	V=Ventricle
D=Dual (A&V)	D=Dual (A&V)	D=Dual Triggered/Inhibited		D=Dual (A&V)
O=None	O=None	O=None		O=None

Bernstein, et al., 2002

**Position I:** Refers to the specific chamber(s) being paced. The letter signifies the chamber: Atrium, Ventricular, and Dual for both, or neither.

**Position II:** Refers to the specific chamber(s) being sensed for intrinsic signals. These are not always the same letter as position I.

**Position III:** Action based on response to intrinsic signals that were sensed or not sensed (Position II)

- Inhibited mode will withhold pacing from the pacemaker if an appropriate timed intrinsic signal is sensed. If there is no intrinsic signal, the pacemaker delivers output.
- Triggered mode will provide output from the pacemaker after a programmed time interval from a sensed event. This is an uncommon setting and mostly used during testing.
- Dual mode is dependent on what chambers are sensed in order to provide atrioventricular synchrony. Most often dual sensing is preferred. (Miller, 2002) Dual mode uses both inhibited and triggered modes to function in order to provide atrioventricular synchrony.
- None mode where no action is taken.

**Position IV:** R indicates that the rate responsive feature is on. Rate responsive sensors were developed in pacemakers to respond to chronotropic incompetence such as the inability of the heart rate to increase with exercise. The pacing rate can be increased by the pacemaker if the sensor (example piezoelectric accelerometer sensor within the pacemaker) detects that the patient is active walking or running. When the sensor detects that patient is at rest, the pacing rate will gradually decrease back to the lower rate limit. (Miller, 2002, Ellenbogen, 2010).

**Position V:** Refers to the chamber but not specifically the location in the chamber of the multisite pacing wires. The current practice of multisite pacing is still within testing but has been hypothesized as a treatment to prevent atrial fibrillation as well as an accepted treatment for

dilated cardiomyopathy multisite ventricular pacing (Miller, 2002). Previously used to denote anti-tachycardia function, this was revised in 2002. (Bernstein, et al., 2002)

### **Permanent Pacemaker Codes:**

- Identified by a 4 letter coding system: AOO, VOO, DOO, AAI, VVI, DDD, and DDI. Common pacing modes are AAI, VVI, and DDD.
- **AAI** means the pacemaker paces and senses in the atrium and inhibits atrial pacing upon sensing an intrinsic atrial event.
- **VVI** means the pacemaker paces and senses in the ventricle and will inhibit ventricular pacing upon sensing a ventricular event.
- **DDD** means pacing and sensing occur in the atrium and ventricle. The pacemaker will inhibit atrial pacing upon sensing a P-wave. The pacemaker will track the P-wave with ventricular pacing (triggered) should a QRS not come within the specified AV interval (msec). A sensed R- wave will inhibit ventricular pacing.

### **Demand (Synchronous) Pacing**

- Demand pacing is the preferred form of pacing as it senses the patient's intrinsic rhythm preventing competition between intrinsic and paced beats. The sensitivity setting if set inappropriately causes inappropriate pacing.
- AAI, VVI, DDD, and DDI are examples of demand pacing which inhibit or pace in response to sensed activity.

### **Fixed Rate (Asynchronous) Pacing**

- AOO, VOO, and DOO are modes that have no capability to sense the patient's intrinsic beats and the pacemaker paces at a preset rate independent of the patient's rhythm. If the intrinsic heart rate rises above the paced rate, there can be competition between the pacemaker and the intrinsic rhythm. This can result in the pacemaker firing at inappropriate times and producing an "R on T" phenomenon. "R on T" is where the pacemaker fires and produces a QRS during the vulnerable T-wave, possibly precipitating ventricular tachycardia or ventricular fibrillation. Lack of sensed atrial beats may lead to atrial arrhythmias such as atrial fibrillation and flutter.

## **General Principles: Permanent Pacing**

- **General Principles**
  - Permanent pacemakers can be interrogated by manufacturer specific computers (called pacemaker programmers). The interrogation generates a summary screen that shows the battery level, programmed mode and low rate, diagnostics such as percentage pacing, lead impedance trends and any significant observations or alerts.
  - Threshold testings and parameter adjustments can be performed using the pacemaker programmer.
  - Dual chamber pacing is useful for many rhythm disturbances particularly for those patients with congenital heart disease or poor function but in general, most children do well with a simple single chamber pacing system.
  - Sinus node dysfunction and bradycardia can be paced at an appropriate rate using atrial only pacing. Atrial pacing requires an intact conduction system to ensure the impulse conducts to the ventricles. (Payne, 2011)

- AV block of any level (1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> degree) can be paced to provide an adequate HR and AV synchrony using dual chamber AV sequential pacing. (Payne, 2011) First degree heart block rarely requires AV pacing unless it is associated with symptoms.
- Pacemaker output (visible spike) may not always equate to myocardial capture and cardiac output. Electrical events without evidence of mechanical contraction may occur and this is known as electromechanical dissociation. (Reade, 2007)
- Pacing threshold can deteriorate due to myocardial inflammation at the lead electrode attachment site. An increase in output voltage may be needed to achieve capture. (Bantra, 2008)
- **Pacemaker placement**
  - In infants, generators are placed in the abdominal area.
  - For older children placement is in the pectoral region usually on the side of the non-dominant hand, primarily left infra-clavicular area. (Hazinski, 2012)
  - Pacing leads can be placed on the epicardium, or transvenously to the endocardium.
- **Pacemaker response to magnet application**
  - Paces asynchronously at a fixed magnet rate
    - Example: If a pacemaker is inhibited from pacing due to oversensing of electromagnetic interference (EMI) or artifactual signals, applying a magnet over the pacemaker may help to achieve pacing since magnet will suspend sensing function for as long as the magnet is applied over the pacemaker.
    - Sensing function is restored when the magnet is removed.

### **Paced Rhythm Analysis**

- Nurses need to identify normal and abnormal atrial and ventricular pacing. The ECG lead on the bedside monitor should be setup to clearly show the P-wave and QRS. The pacemaker detection mode (pacemaker tracking) may be helpful.
- The bedside monitor alarm parameters are set to alarm for a low or high HR from the pulse of an arterial line or saturation probe.
- Normal pacing is identified by observing pacing spikes in relationship to the P-wave and QRS. Due to the bedside monitor's filter and the programmed pacing configuration, sometimes it is not possible to see the pacing spike. Pacing may be inferred by ECG morphology change.
- **Atrial Pacing**
  - An electronic pacing spike observed before a P-wave represents an atrial paced beat.
- **Ventricular Pacing**
  - An electronic pacing spike observed before a QRS complex represents a ventricular paced beat. The QRS complex that is induced by ventricular pacing may be wide.
- **Varying Degrees of Paced Fusion on electrocardiography**
  - **Fusion:** is present when the pacemaker's pacing impulse occurs at the same time as an intrinsic beat. The morphology is partial between the paced and the intrinsic QRS because the intrinsic beat is a combination of the pacemaker capture and intrinsic depolarization. This occurs because the timing of the pacemaker impulse was due at the same time as the intrinsic beat. If there are frequent fusion beats with intrinsic rhythm, consideration may be given to reduce the rate of the pacemaker to save battery life.

- **Pseudo fusion:** is present when there is a pacemaker spike in front of an intrinsic beat but the morphology is that of the intrinsic beat. The pacemaker spike occurred at a time when the myocardium is already fully depolarized by the intrinsic beat. A pseudo fusion beat does not provide any indication of pacing capture.
- **Pseudopseudo fusion:** is present in dual chamber pacemaker when an atrial pacing spike occurred in front of a spontaneous QRS, the atrial pacing spike having no impact on the intrinsic QRS.
- **Upper Rate Behavior**
  - In dual chamber pacemakers, when the atrial rate exceeds the maximum tracking rate (MTR) of the pacemaker, the pacemaker will not be able to track the atrial rate with ventricular pacing in a 1:1 manner.
  - Pacemaker will start to show upper rate behavior (some P-waves are not tracked) depending on the pacemaker setting of the total atrial refractory period (TARP) which equals the sum of post ventricular atrial refractory period (PVARP) and AV delay (see below for explanation).
  - When the atrial rate is between MTR and TARP, the ECG will show Wenckebach like group beating whereby occasional P-waves will not be tracked.
  - When the atrial rate exceeds TARP, then only every other P-wave is tracked, ECG will show 2:1 ventricular tracking of P-waves. Thus the atrial rate will help to confirm if the pacemaker is showing upper rate behavior.

### Testing & Calibration

- Capture and sensing thresholds should be checked routinely and with any noted change from normal pacing function. Threshold checks are done regularly, usually every 6 months.
- **Capture Threshold**
  - Pacemaker output is defined by the voltage (V) and the pulse duration in milliseconds (ms). Capture threshold is the minimum pacemaker output required to stimulate the myocardium.
  - Pacemaker settings for output should be programmed at twice the voltage capture threshold to provide for a margin of safety. (Hayes 2000, Reade 2007)
  - Evidence of capture is a pacing spike followed by a P-wave or QRS, depending upon whether the pacing is in the atrium or ventricle, or both.
- **Sensing Threshold**
  - Sensing is defined by the sensitivity setting in millivolts (mV).
  - Sensing threshold is the minimum amplitude of the intrinsic cardiac signal that the pacemaker is able to sense.
  - If the sensitivity is set too high [high mV number equals less sensitive], the pacemaker will fail to sense intrinsic events, and may result in over pacing, competing with the intrinsic rhythm. (Reade, 2007)
  - If sensitivity is set too low [low mV number equals more sensitive] the pacemaker may pick up electrical noise other than the cardiac signal and may lead to inappropriate pauses from pacing or inappropriate triggered activity, resulting in bradycardia or tachycardia respectively. (Reade, 2007)
  - The sensitivity is programmed to at least two fold more sensitive than the sensing threshold. (Hayes 2000)

## **Features of Permanent Pacemakers**

- Sometimes these normal pacemaker features may appear on the ECG and be interpreted as abnormal pacemaker function. It is important for nurses to be aware if any of these features are programmed in the device and to be able to differentiate from true abnormal pacemaker function.
- **Rate Limits and Intervals**
  - Low rate: If the patient's intrinsic rate falls below a set lower rate, the pacemaker will pace.
  - Upper rate: maximum rate a pacemaker will pace the myocardium
  - Hysteresis rate: The hysteresis rate allows the patient's intrinsic heart rate to drop to a lower level than the pacemaker's low rate (see below).
  - Atrioventricular (AV) interval or AV delay: the programmed time delay; in milliseconds from the sensed or paced atrial event to the time when the ventricle should be paced. (i.e. The PR interval of the pacemaker)
  - PVARP: It is the period of time when the atrial chamber is refractory from atrial sensing after a ventricular event. The purpose of PVARP is to prevent the pacemaker from sensing a retrograde conducted P wave, for example after a ventricular paced event or a PVC.
  - Rate response: is a programmed setting in permanent pacemakers that is capable of altering the pacing rate based on the patient's level of activity.
- **Minimal Ventricular Pacing Algorithm**
  - This feature is designed to minimize ventricular pacing by keeping the patient in AAI or AAIR mode and will switch to DDD or DDDR mode when AV block is detected.
  - The electrocardiogram (ECG) appearance may show intermittent appearance of dual chamber pacing after AV block is seen. Once in DDD mode, the pacemaker will occasionally extend the AV delay to search for AV conduction and if it is present, the pacemaker will revert back to AAI mode.
- **Automatic Capture Algorithm**
  - This mode is available in St. Jude Medical, Medtronic, Boston Scientific and other devices.
  - The pacemaker algorithm checks for local depolarization after pacing and will adjust the pacemaker output to a level of safety margin (e.g. 0.25V above capture threshold). If local depolarization is not detected, the pacemaker will deliver a higher output impulse 80 -100 ms after the initial pulse to achieve capture.
  - St. Jude Medical and Boston Scientific devices assess capture on a beat by beat basis whereas Medtronic's capture management occurs at a programmed time, once or twice daily.
  - If the patient is in intrinsic rhythm, the St. Jude and Boston Scientific devices will not perform capture threshold test. Medtronic device will force pacing at the programmed schedule to conduct the search.
  - The ECG appearance will show occasional double pacing spikes within about 80-100ms of each other. The measured low rate interval may thus be slower by this amount.
- **Hysteresis**
  - This feature is used for patients who are predominantly in their intrinsic rhythm with occasional need for pacing e.g. intermittent high grade AV block.

- The pacemaker low rate is set to the pacing rate that is appropriate for the patient but the hysteresis rate allows the patient's intrinsic heart rate to drop to a lower level than the pacemaker's low rate. E.g. The patient may have a programmed low rate of 60 bpm and a hysteresis rate set at 40 bpm. This would allow the patient's intrinsic heart rate to go to 40 bpm before pacing at 60 bpm.
- The ECG appearance will show slower intrinsic rate than the pacemaker's low rate and may appear as oversensing.
- This feature allows the amount of pacing to be reduced and pace only when necessary, thus helping to conserve battery life.
- **AV Search Hysteresis**
  - This feature is also used to minimize ventricular pacing for patients with a dual chamber pacemaker and intrinsic first degree or second degree AV block.
  - The device will have periodic search for AV conduction by extending the AV delay to determine if intrinsic conduction is present. The amount of AV delay extension for the search is programmable up to a maximum of about 350 or 400ms. When AV block occurs, the device will ventricular pace at the maximum AV extension for one cycle during the search and then pace at the programmed AV delay for subsequent cycles until when it is time to search again.
  - On the ECG this may appear as varying AV intervals and may appear as if it was ventricular oversensing during the AV extension, except that ventricular pacing does eventually occur. It will be helpful to observe the ECG for longer time to see if there is evidence of regular periodic search cycles.
- **Mode Switch**
  - In the presence of a pacemaker programmed to DDD mode that is tracking a rapid atrial tachycardia that meets the programmed atrial high rate detection, the pacemaker may automatically switch its mode from DDD to DDI (a non-tracking mode) or DDDR to DDIR to prevent sustained tracking at high rate. The device will switch itself back to DDD mode when the atrial tachycardia stops or slows out of the atrial high rate detection.
  - When the device is in mode switch, the ECG appearance will be similar to VVI or VVIR pacing in the presence of rapid atrial tachycardia.
  - In some devices (such as Medtronic pacemakers), the device may conduct a search to see if there is a P wave inside the atrial blanking period (where atrial events are not sensed at all or blanked) (called blanked flutter search) by occasionally extending the PVARP for one cycle to check if there are any P waves that are hidden in the post ventricular atrial blanking period (PVAB). The ECG appearance will be similar to that of intermittent atrial undersensing (a P wave that is not tracked).
  - This is a safety feature that should be programmed for patients who are at risk of developing atrial tachycardia e.g. post Fontan or Total Anomalous Pulmonary Venous Drainage (TAPVD) operations with permanent pacing indications. It should be adjusted to avoid inappropriate mode switch during sinus tachycardia.
- **Sleep Rate/Rest Rate**
  - Allows for a reduced lower rate during rest or sleep. The function is dependent on the type of pacemaker.
  - Sensor derived rest rate (e.g. St. Jude Medical) will determine that the patient is at rest through inactivity of the rate responsive sensor and is not dependent on clock time.

Thus for example, if the patient is in the ICU setting, one may observe that the patient is chronically pacing at the rest rate.

- Clock derived sleep rate (e.g. Medtronic) will reduce the low rate to the sleep rate during the programmed sleep and wake times.
- **Ventricular Safety Pacing**
  - This feature is designed to minimize cross talk in a dual chamber pacemaker. Cross talk occurs when the ventricular chamber senses the atrial pacing output and inhibits from ventricular pacing. This may be catastrophic if the patient has complete heart block and no escape rhythm. When a ventricular sensed event occurs during the noise sampling period within the AV delay after atrial pacing, the pacemaker will deliver ventricular pacing at a shortened AV interval (ventricular safety pacing interval), usually 100-120ms depending on the pacemaker manufacturer.
  - On the ECG this may appear as a shorter AV interval than the programmed AV delay. It may also appear to be undersensing if ventricular safety pacing is triggered by a PVC that is sensed after atrial pacing. But in fact the PVC was sensed as this is evident by the shortened safety pacing interval.
- **Pacemaker Mediated Tachycardia (PMT) Termination Algorithm**
  - PMT may occur in patients with dual chamber pacing that is programmed in DDD or DDDR mode and the patient has intact retrograde conduction usually through the AV node.
  - PMT may be initiated by loss of AV synchrony through a PVC, loss of atrial capture, untracked PAC, and tracking of myopotential or noise.
  - PMT is seen as ventricular pacing driven at a higher rate in a repeated cycle of tracking atrial sensing of a retrograde P-wave. The cycle of this sustained tachycardia can be stopped when there is loss of retrograde conduction (e.g. carotid sinus massage, giving adenosine to block retrograde AV node conduction) or P-wave that is not sensed e.g. extension of the post ventricular atrial refractory period (PVARP). Acutely PMT may be terminated by brief application of a magnet to the pacemaker causing asynchronous pacing.
  - The PMT algorithm in permanent pacemaker functions by automatically extending the PVARP after a few cycles of tracking at rates faster than 150 bpm.
  - PMT may be prevented by programming PVARP long enough to exclude sensing of retrograde P-wave.
  - If PMT is initiated by PVC that conducts retrograde, one can turn on PVC response feature which extends PVARP to about 400 ms after sensed PVC.

### **Diagnostic Evaluation**

- When pacemaker problems are suspected, it is important to perform diagnostic evaluation or troubleshooting in a systematic manner.
- Diagnostic tests that may be helpful include Holter monitoring, exercise testing, event monitoring or chest radiography.
- The pacemaker counter and marker channels can be useful to help troubleshoot the patient's arrhythmia status.

## Complications/Trouble Shooting Pacing Failures

- Fundamental pacing problems causing failure in pacing are outlined below.

Problem/ Criteria	Cause	Treatment
<b>Failure to Capture</b>		
<p>Delivered pacemaker output does not evoke myocardial depolarization, resulting in asystole or no output.</p> <p>Problem may be capture threshold changes or lead hardware issue.</p>	<ul style="list-style-type: none"> <li>• Scar tissue</li> <li>• Poor myocardial function</li> <li>• Electrolyte or metabolic imbalance</li> <li>• Class IC antiarrhythmic drugs</li> <li>• Lead fracture or insulation damage as suggested by impedance changes. (McPherson 2004)</li> </ul>	<ul style="list-style-type: none"> <li>• Check threshold and pacemaker output immediately.</li> <li>• For threshold problems: Increase voltage and or pulse width to achieve capture.</li> <li>• For lead hardware issue: May consider reprogramming pacing polarity from bipolar to unipolar to see if this can restore capture.</li> </ul>
<b>Failure to Sense</b>		
<p><b><u>Undersensing</u></b> Present when pacemaker inappropriately paces after a spontaneous P-wave (atrial undersense) or R-wave (ventricular undersense).</p> <p>Appears as too much pacing on ECG.</p>	<ul style="list-style-type: none"> <li>• Changes in intrinsic signal amplitude (scarring).</li> <li>• Insufficient safety margin in the programmed sensitivity.</li> <li>• Lead fracture or insulation damage or loose setscrew.</li> </ul>	<ul style="list-style-type: none"> <li>• Check sensing threshold and adjust sensitivity setting.</li> <li>• Sensitivity setting should be set to half the threshold level. Decreasing the mV number increases the sensitivity.</li> <li>• Inappropriate pacing may induce arrhythmias and thus should be recognized and corrected quickly.</li> </ul>
<p><b><u>Oversensing</u></b> Present when the pacemaker inappropriately inhibits pacing, resulting in pauses or inappropriate tracking in DDD mode.</p>	<ul style="list-style-type: none"> <li>• Sensitivity may be too sensitive and the pacemaker picks up (over senses) other electrical signals such as T wave or muscle noise or electromagnetic interferences.</li> <li>• Unipolar sensing configuration may be more prone to oversensing due to a larger sensing antenna.</li> </ul>	<ul style="list-style-type: none"> <li>• Inappropriate sensing will require the sensing thresholds to be checked by MD and reset. Increasing the mV number (decreasing the sensitivity). Emergency management of oversensing (e.g. When there are prolonged pauses) may be by magnet application to disable sensing and pacemaker paces at a fixed rate (asynchronous pacing).</li> </ul>

<b>Failure to Pace</b>		
<b>Lead Fracture</b>	<ul style="list-style-type: none"> <li>Evident by very high lead impedance, possible visible presence of lead conductor discontinuity on chest x-ray. Patients may show symptoms of fatigue; however some may be completely asymptomatic (i.e. if patient has dual chamber device with heart block and primarily ventricular paces in the presence of an atrial lead fracture). This will be confirmed by elevation in impedance. This can sometimes be seen by radiographic images; however there can be subtle breaks in lead that is not evident by X-ray film.</li> </ul>	<ul style="list-style-type: none"> <li>The chest x-ray should include visualization of the entire lead course and the pacemaker generator in both endocardial and epicardial systems. If the patient has a bipolar lead, it may be worthwhile to check the pacing and sensing in unipolar configuration as the cathodal conductor may still be intact and one can restore pacing and sensing through unipolar mode. Replace leads.</li> </ul>
<b>Lead Dislodgment</b>	<ul style="list-style-type: none"> <li>Lead dislodgement may result in increased pacing thresholds, failure to capture, or failure to sense. Lead dislodgement is not always visible by radiographic images, but there is significant increase in pacing threshold or a deterioration in sensing.</li> </ul>	<ul style="list-style-type: none"> <li>Reposition or replace lead.</li> </ul>
<b>Lead Insulation Breach</b>	<ul style="list-style-type: none"> <li>This is evident by very low lead impedance, usually no abnormality is seen on chest x-ray but areas of tight turn or tie down may be sites of insulation damage.</li> </ul>	<ul style="list-style-type: none"> <li>Replace lead.</li> </ul>
<b>Battery Depletion</b>	<ul style="list-style-type: none"> <li>Depending on the level of battery voltage and the specific manufacturer and type of pacemaker, the pacemaker's low battery pacing mode and rate may be different. If the battery level is totally depleted, then there may not be any pacing output and it may not be</li> </ul>	<ul style="list-style-type: none"> <li>Depending on the pacemaker dependence of the patient, temporary pacing (transvenously or transcutaneously) may need to be setup. Pacemaker replacement should be performed.</li> </ul>

	possible to interrogate the device.	
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### **Extracardiac Stimulation**

- Usually involves inadvertent stimulation of the diaphragm, pectoral or intercostal muscles.
- Diaphragmatic stimulation may be caused by direct stimulation of the phrenic nerve; it may be caused by micro-dislodgment of the pacing lead or the proximity of the pacing electrode to the phrenic nerve or diaphragm.
- Pectoral stimulation may be due to local capture of the muscle from the pacemaker generator or current leak from a lead insulation failure or connector.
- Stimulation can be minimized or alleviated by decreasing the voltage output and/or pulse width, an adequate pacing margin of safety must be maintained. If programming cannot correct the problem, then the lead may need to be repositioned.

### **Battery Life**

- Battery life is dependent upon device, usage, pacing settings, and device features (e.g. anti-tachycardic function. (Park, 2016)
- Permanent pacemaker batteries are usually lithium type with a life is usually about 5-10 years depending on the pacing output and amount of use.

### **Critical Thinking Points**

- In the critically ill patient, pulseless electrical activity (PEA) or electromechanical dissociation may occur despite presence of pacemaker capture of myocardium. The main causes of PEA may be severe hypovolemia, pump failure or obstruction to circulation. PEA is present when there is no corresponding arterial pulse with each paced QRS. Patient may require emergency Extracorporeal Membrane Oxygenation (ECMO). (Beun 2015; Girotra 2013)
- The permanent pacemaker programmer (computer) is specific to the device manufacturer that permits the clinician to interrogate or adjust the device parameters e.g. Medtronic pacemaker should use the Medtronic programmer to interrogate. Pacemaker checks and adjustment should be conducted by the electrophysiology team or staff trained in device follow-up. (Fraser J 2000; Gura M 2003)
- Most permanent pacemaker systems have the ability to perform programmed electrical stimulation (EPS) to pace terminate arrhythmias through the pacemaker programmer. This should be performed by the electrophysiologist. The pacemaker may also have high rate data collection such that detailed electrogram, tachycardia rate or cycle length, time and duration of episodes are stored and can be interrogated.
- Patients with permanent pacemakers should have their underlying intrinsic rhythm and pacemaker functionality reviewed by a Cardiologist and device clinic every 6 months with more frequent visits in the early post implant phase.

### **Special Considerations**

- **Problems Specific to Pediatrics**
  - Very premature or low birth weight babies' size may limit the placement of a permanent pacemaker. (Batra, 2008)
- **Magnetic Resonance Imaging (MRI) Safety**

- Pacemaker patients who need to undergo MRI must be cleared first by checking to see if the pacemaker system (generator and leads) is MRI conditional or compatible with MRI testing. Abandoned leads or hardware is a contraindication for MRI.
- Concerns with MRI testing are related to heating at the lead tip-tissue interface which may result in tissue damage or changes in thresholds. Magnetic induced force or torque on the device resulting in lead dislodgement or pulling sensation and RF noise that may induce pacing inhibition or rapid pacing that result in arrhythmias. (Reade, 2007)

### **Acute Monitoring and Documentation for Permanent Pacemakers**

- Shift check between off-going and oncoming nurses ensures paced settings are in accordance to medical orders.
- Continuous EKG monitoring noting HR, pacemaker dependence, presence or absence of atrial and ventricular pacing vs. intrinsic rhythm.
- At least every 1- 4 hours depending on patient stability, phase of recovery i.e. fresh post-operative or rehabilitation, and hospital guidelines, the following checks should be performed and documented:
  - Vital signs. The pacemaker ECG does not always translate into myocardial contractions. Include patient intrinsic rhythm and rate if the heart rate is above pacemaker rate settings.
  - Type: epicardial, transvenous
  - Programmed settings: rate (bpm); output (V); sensitivity (mV) of atria and ventricle as applicable; AV interval (ms) and any pertinent pacemaker features that are programmed on.
  - What is the pacemaker doing? Rate, atrial sensing, atrial pacing, ventricular sensing, ventricular pacing.
  - Complications: failure to pace, sense (under or over sensing), capture.

### **Complications**

- **General**
  - Bleeding, infection, myocardial damage, arrhythmias, myocardial perforation, and pneumothorax. (Batra, 2008)
  - Hematomas and seromas. Small hematomas can be closely monitored and managed with warm compresses to improve the absorption process. Large hematomas that compromise the suture line or skin integrity may have to be surgically evacuated. Needle aspiration increases risk of infection and is not recommended.
  - Patients who are anti-coagulated are at increased risk of bleeding. In patients requiring oral anticoagulants, refer to 2014 American Heart Association /ACC Anticoagulation Guidelines.
- **Permanent Pacemaker Infection**
  - Signs of skin breakdown at incision site(s), elevated white cell count, fever, malaise, localized edema, increasing erythema, and increase in warmth at incision, discharge, dehiscence or pain. Non-specific signs and symptoms of systemic infection may be the only clinical features of pacemaker infection including fevers, chills, night sweats, malaise and anorexia, and elevated white cell count. Wound inflammation can be an early presentation of generator pocket infection. Generator pocket infection and

- device lead infection frequently coexist.
- Fewer than 10% of patients present with septic shock.
  - Clinical diagnosis of pacemaker pocket infection can be challenging and is often delayed.
  - Pacemaker infection may present with secondary foci, such as spinal or pulmonary infection.
  - The Duke Criteria for diagnosing infective endocarditis can be used to assist the diagnosis of pacemaker infection. These criteria include minor and major criteria such as positive blood cultures, positive echocardiograms for masses, regurgitant or stenotic valves, fever, and vascular phenomena. (Hoen, 1999)
  - Most common microbial present in device infections are Staphylococci (and Gram-positive bacteria in general) causing the majority (68%–93%) of infections. Gram-negative bacteria cause fewer than 18% of infections. Approximately 15% of device infections are culture negative.
  - Blood cultures should be drawn prior to treatment with antibiotics. Three sets of aseptically collected optimally filled blood cultures should be taken from peripheral sites with greater than or equal to 6 h between them. Antibiotics are to be given after the first set of cultures. Repeat blood cultures should be taken 48–72 h after removal of an infected pacemaker.
  - A chest X-ray (CXR) should be obtained for all patients with suspected pacemaker infection. A CXR may show evidence of consolidation suggestive of embolic foci of infection supporting a diagnosis in difficult cases. Pulmonary involvement occurs in 10% – 45% of patients with infection and can sometimes be seen on a CXR appearing as consolidation, loss of vascular markings or pleural effusion. The CXR will also provide additional information regarding the presence and position of the pacemaker, allowing for comparison with previous X-rays in the event of generator migration. CT pulmonary angiography should be considered when pacemaker infection is suspected and may confirm presence of pulmonary involvement and also assist diagnosis.
  - Transesophageal or transthoracic echocardiography (TEE or TTE) when suspected infection or systemic infection.
  - Antibiotics may not be necessary in instances of erythema that is present at the site without purulent exudate, dehiscence, or systemic signs of infection and occurs within 30 days of implantation, close surveillance and resolution should occur within 2 weeks. If erythema and drainage is presumed to be associated with a stitch this should resolve with removal of the suture. If resolution does not occur, then one should obtain blood cultures, and a short course of empiric antimicrobial therapy should be considered if clinically indicated. The patient should be reassessed in 1 week. If there is clinical improvement, it may be appropriate to complete the oral antibiotics course and follow up. If no improvement is noted at 1 week follow up and antibiotics were not initiated, initiate oral 7-10 day regimen.
  - If symptoms of infection have progressed, re-obtain blood cultures x 3 and begin empiric IV antibiotic regimen. Echo within 24 hrs. TTE is sufficient for pediatrics with good echo windows, TEE is recommended for adults to assess for vegetation on the device, or valves.
  - Complete removal of all hardware, regardless of location (subcutaneous, transvenous, or epicardial), is the recommended treatment for patients with established pacemaker

infection. This includes cases in which a localized pocket infection occurs in the absence of signs of systemic infection. Removal is needed because infection relapse rates due to retained hardware are significant. Erosion of any part of the pacemaker should imply contamination of the entire system, including the intravascular portion of leads, and complete device removal should be performed. If the patient is pacemaker dependent then a temporary pacing system is necessary.

- Complete pacemaker removal should be performed when patients undergo valve replacement or repair for infective endocarditis. The pacemaker could serve as a source for relapsing infection and subsequent seeding of the surgically treated heart valve. An epicardial system is considered if a new pacemaker is required after valve surgery with initial pacemaker removal.
- Generator-pocket tissue gram stain, culture, and lead-tip culture should be obtained when the pacemaker is explanted.
- **Venous Thrombosis (Endocardial Pacing)**
  - There is a greater than two-fold increased risk of systemic thromboemboli in patients with intracardiac shunts and transvenous pacemaker systems. Therefore transvenous leads are avoided in the presence of an intracardiac shunt or elimination of the shunt should be pursued before transvenous lead implantation if feasible. (Khairy et al., 2006)

#### **Accept Natural Death in Patients with a Permanent Implanted Pacemaker**

- Ethical concerns and timing need to be considered with pacemaker deactivation in the ICU setting at end of life, or withdrawal of life-sustaining care.
- Consider appropriate timing of discontinuing the device when there is no longer a need for pacemaker therapy. Pacemakers are different from an ICD, which delivers a shock to treat an abnormal fast rhythm. A pacemaker may potentially prolong life since it paces to maintain a regular heart rate. Once adequate oxygenation ceases resulting in myocardial ischemia, the pacemaker may no longer effectively capture the heart muscle. At this point it may be helpful to reprogram the pacemaker to turn it off (OAO/ODO/OVO). It is important that the physician responsible for the active care of the dying patient consult with the electrophysiologist or pacemaker team to determine the need to turn pacemaker off and to identify who will turn off the pacemaker. Clearly the family members of the dying patient must be aware of the plan and the implications. The pacemaker may be turned off once the order is received and this can be performed by the physician or allied professional who are part of the pacemaker team. The patient's chart should have the documentation of the order to turn off the pacemaker, the individual who turns off the pacemaker and what the final setting of the pacemaker is. Any printouts from the pacemaker should be included in the chart.

In summary, permanent pacemakers are implanted devices that deliver an electrical impulse when the patient's intrinsic conduction system or heart rate is inadequate. Depending upon the mode and programmed settings, pacemakers have the capability to sense inherent cardiac electrical activity and pace the heart. Nurses must have a solid understanding of these devices and be able to recognize normal and abnormal pacing. Pacemaker lead system malfunctions include undersensing, oversensing, loss of capture, no pacing output, battery depletion and pacemaker mediated tachycardia. It is important to understand how pacemaker features work such as automatic capture

feature, mode switch, hysteresis, sleep rate, minimal ventricular pacing function, AV search hysteresis, safety pacing, upper rate behavior, cardiac resynchronization therapy to avoid misinterpreting these features as abnormal pacemaker function. Consultation with the electrophysiology team and other experts is vital to successful pacemaker therapy.

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