Pediatric Cardiac Intensive Care

Cardiac Pacing in Pediatric Intensive Care Unit

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Introduction

In both the intensive care and cardiac care units, we frequently deal with patients who require cardiac pacing. Depending upon the etiology, a child may require pacing support for a short duration or for a more prolonged time. Despite many existing indications for pacing, till now, it has been a dormant modality in pediatric intensive care units (PICU). This might be attributed to many factors like delayed or non-identification of suitable indications, non-availability of pacing facilities, less familiarization with pacing modes and some times pacing procedure phobia in nursing or medical staff. In this article, we have tried to simplify this fancy looking term called as 'pacing' with a systematic approach from basic physiology to bedside application.

Normal cardiac electrical activity

Electrical impulses are generated at the sinoatrial (SA) node, which is located in the right atrium of the heart. From SA node, the electrical impulse spreads through the right and left atria and then enters the atrioventricular (AV) node situated at the AV junction. The AV node is important as it slows down the conduction to allow time for atrial contraction and emptying (figure 1).

![Cardiac Electrical Impulse Generation and Conduction Through Normal Pathway](image)

Figure 1. Cardiac electrical impulse generation and conduction through normal pathway

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After the AV nodal delay, the impulse travels through the ventricles through a specialized conduction system called the bundle of His. The His bundles then divides in to two branches, the right bundle branch (RBB) that navigates its way through the right ventricle and the left bundle branch (LBB)
that navigates through the left ventricle. Following these bundle branches the impulse finally passes to the terminal points called Purkinje fibers. These Purkinje fibers are embedded in the entire thickness of the myocardium and activate the entire myocardial mass from the endocardial surface to the epicardial surface.

**Normal ECG**

Figure 2 depicts the normal ECG wave form. Each waveform may be simplified as below:

- P wave – atrial depolarization
- PR interval – time interval from beginning of P wave to beginning of QRS.
- QRS – Ventricular depolarization (duration of ventricular muscle depolarization).
- ST-T segment – Ventricular repolarisation.
- QT interval – duration of ventricular depolarisation and repolarisation.
- T wave – ventricular repolarisation.
- U wave – Purkinje system repolarisation.
- RR interval – suggests ventricular rate.

**Table 1.**

<table>
<thead>
<tr>
<th>Indications of cardiac pacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A <strong>rrhythmia with hemodynamic compromise</strong></td>
</tr>
<tr>
<td>I <strong>nappropriate slow rate with hemodynamic compromise</strong></td>
</tr>
<tr>
<td>I <strong>nappropriate fast rate with hemodynamic compromise</strong></td>
</tr>
</tbody>
</table>

**Reasons for arrhythmias requiring pacing**

- Short term – these might require temporary cardiac pacemaker (TCP)
  - Conduction pathway damage during surgery
  - Edema surrounding surgical site
  - Electrolyte imbalances
  - VSD/ASD patches
- Long term – these usually require permanent cardiac pace maker (PCP)
  - Congenital arrhythmias
  - Chamber hypertrophy
Types of cardiac pacing

Invasive electrical pacing is used to initiate myocardial contraction when intrinsic stimulation is insufficient, the intrinsic impulses are not being conducted or the heart rate is too slow to maintain an adequate cardiac output⁷. Electrical impulses of sufficient strength are delivered to and which then stimulate the myocardium to depolarize at a preselected rate⁴. There are a number of various routes and methods available to deliver cardiac pacing (figure 3). The common goal of each approach to pacing is to contribute to hemodynamic stability and to correct symptoms of reduced cardiac output through support of the heart rate by providing safe, potentially life-saving therapy in a variety of clinical situations⁴.

Temporary cardiac pacing sites

**Epicardial**

Epicardial pacing is the most commonly used pacing in post-op cardiac patients. During cardiac surgery, electrodes (epicardial wires) are attached directly to the epicardial surface of the atrium and/or the ventricle⁵. The wires then exit through the patient's sternum where they are then connected to a pulse generator. Epicardial pacing is often used following cardiac surgery for the management of surgically related bradydysrhythmias⁴.

**Transvenous (Endocardial)**

Transvenous leads may be balloon-tipped which will allow for floating placement in the ICU, or non-floating pacing catheters which require fluoroscopic guidance for placement⁴. A Swan-Ganz balloon-tipped floating bipolar transvenous pacing wire is a commonly used example. This is advanced via a vein (usually the subclavian routed through to the superior venacava) to the endocardial surface of right atrium (RA), or most commonly, the right ventricle⁵. The presence of pacing spikes and restoration of a fixed heart rate on the ECG will confirm placement of the wire.

**Transesophageal**

This method is used when there are no epicardial wires or when wires do not adequately pace the heart.

**Transcutaneous (External)**

External transcutaneous pacing is temporary means
of pacing a patient's heart during an emergency as it can be rapidly achieved. Adhesive skin pads (electrodes) are applied to the patient's chest and back, which are then connected to a defibrillator unit. A fixed rate is set and the output current is dialed up until capture is displayed on the ECG. Current between 50-150 milliampere (mA), depending upon the size of the patient and transthoracic impedance, are usually sufficient. This procedure can be painful for the patient, therefore, sedation and analgesia should always be considered.

**Indications for temporary cardiac pacing (TCP)**

**Table 2. Indications of temporary cardiac pacing (TCP)**

- **Bradydysrhythmias/Heart blocks**
  - Second degree AV block: Type I (occasionally) & Type II
  - Bifascicular or trifascicular block
  - Complete AV block
  - Complete asystole
- **Sick sinus syndrome**
  - Symptomatic sinus arrest
  - Atrial fibrillation (fast or slow)
  - Bradycardias/tachycardias
  - Symptomatic sinus bradycardia
- **Cardiovascular surgery**
  - Prophylactic use during cardiac surgery in patients with history of Acute Coronary Syndrome or cardiac dysrhythmias
  - Treatment for heart blocks developing during or after surgery
  - Cardiac output augmentation post-operatively
- **Drugs**
  - Digoxin
  - Amiodarone
- **Temporary Pacing**
  Temporary pacing of the myocardium is used for a variety of emergency and elective conditions (table 2). Sinus bradycardia and AV block are common early postoperative dysrhythmias and conduction block is more common and transient after valvular surgery as a result of direct injury and increased edema to the myocardium. Heart blocks following surgery are usually transient. It may be caused by ischemia, manipulation of cardiac tissue with resultant edema, perioperative myocardial infarction or mechanical injury during surgery.

- **Unipolar and Bipolar pacing**
  'Unipolar' and 'bipolar' pacing is not synonymous as 'single-chamber' and 'dual chamber' pacing. Terms unipolar and bipolar refers to the pacing electrodes. Unipolar pacing is usually used in permanent pacing systems. In this there is only one conducting wire and electrode, electric current returns to the pacemaker via body fluids.
  Bipolar pacing is the method of choice for TCP. There are two conducting wires and two electrodes. The impulse from the pulse generator passes down one electrode, then passes through cardiac tissue to cause depolarization and the circuit is then completed via second electrode, which delivers the current back to generator.

- **Demand and Asynchronous pacing**
  Demand pacing is most commonly used type of pacing. In this, pacing is provided on demand, when the patient's own rhythm falls below the set rate. If the pacemaker is sensing inappropriately, there is potential to deliver pacing stimulus during atrial or ventricular repolarisation, which could precipitate tachycardia and fibrillation as myocardial cells are vulnerable during this period.
  In asynchronous pacing, pacing stimulus is provided at a set rate regardless of underlying rhythm. It is safe only if there is no to minimal electrical activity. As soon as patient's native electrical activity re-emerges, demand mode must be introduced, to prevent tachyarrhythmias.
Pacing codes
The North American and British Group (NBG) generic pace maker codes are used for easy identification of pacing modes. The table 3 shows five pacing codes, however, in clinical practice the first three letters are predominantly used.

Terminology
- **Threshold** – the least amount of electrical current required to cause depolarisation of myocardium
- **Capture** – the ability of the pacing box's electrical impulse to initiate a cardiac response (indicated by pacing spike followed by respective wave, P or QRS, on ECG)
- **Sensitivity** – the ability of the pacemaker to sense the intrinsic (patient's own) cardiac electrical activity. This prevents pacemaker from competing with the patient's own rhythm. The pacemaker should initiate a contraction if does not sense the patients own rhythm.
- **Triggered** – the atrial rate can be measured (sensed) by the box and the ventricle will be paced at the same rate, even if that is higher than the rate set in the box.

Table 3

<table>
<thead>
<tr>
<th>Position I</th>
<th>Position II</th>
<th>Position III</th>
<th>Position IV</th>
<th>Position V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber (s) paced</td>
<td>Chamber (s) sensed</td>
<td>Response to sensing</td>
<td>Rate modulation</td>
<td>Multisite pacing</td>
</tr>
<tr>
<td>O = None</td>
<td>O = None</td>
<td>O = None</td>
<td>O = None</td>
<td>O = None</td>
</tr>
<tr>
<td>A = Atrium</td>
<td>A = Atrium</td>
<td>T = Triggered</td>
<td>R = rate modulation</td>
<td>A = Atrium</td>
</tr>
<tr>
<td>V = Ventricle</td>
<td>V = Ventricle</td>
<td>I = inhibited</td>
<td></td>
<td>V = Ventricle</td>
</tr>
<tr>
<td>D = Dual (A+V)</td>
<td>D = Dual (A+V)</td>
<td>D = Dual (T+I)</td>
<td></td>
<td>D = Dual (A+V)</td>
</tr>
</tbody>
</table>

Figure 4 a
Inhibition – the patient can inhibit the pacing box. This means that if the patient's heart rate is faster than the box, the box should not pace the chamber. However, the box should not allow the patient's rate to go below the rate set on the box.

Depending upon first three positions (Table 3 ?), cardiac chambers can be paced independently (Figure 4 a) or simultaneously (Figure 4 b), hence pacing modes may be described accordingly.

Hemodynamic effects of TCP

The common goal of all techniques of cardiac pacing is to contribute to hemodynamic stability by resuming cardiac output through support of heart rate, as cardiac output depends upon the heart rate and stroke volume.

Single chamber pacing

Atrial pacing (AOO or AAI) is preferable to ventricular pacing (VOO or VVI) as this maintains AV synchrony. However, for applying atrial pacing, AV nodal pathway must be intact with normal functionality. Ventricular single chamber pacing can reduce cardiac output significantly as AV synchrony is absent.

Dual chamber pacing

Stimulation of both atria and ventricles can be accomplished by using a dual chamber pacing mode (DDD) with a set interval between atrial and ventricular stimulation (AV interval). AV interval must be set as close as possible to the normal PR interval, which is normally 140 to 200 msec. This allows optimization of cardiac filling for ventricular contraction. As, DDD pacing ensures synchrony, it is superior to VVI pacing.

Capturing and sensing

Capturing is the ability of an electrical impulse to initiate a cardiac response and is detected by examining an ECG. It is both an electrical and mechanical event. Capture is indicated by a pacer spike followed by a corresponding P wave in atrial pacing and QRS complex in ventricular pacing or both in dual chamber pacing. When a pacing stimulus successfully generates ECG wave (P or QRS), it is said to have captured the corresponding chamber (atria or ventricles).

Sensing refers to ability of the generator to detect and recognize the myocardial intrinsic activity. In demand pacing, sensing of an intrinsic QRS complex will inhibit the pacemaker from delivering an impulse so as not to interfere with patient's own electrical activity. The sensitivity is measured in millivolts (mV) and is initially set to about 2-5 mV. Failure to sense means pulse generator is undersensing and has not seen the heart's intrinsic beat and
so continues to pace, even when not required, causing dysrhythmias such as ventricular fibrillations. This can be managed by decreasing the sensitivity threshold (making the pacer more sensitive). If pacemaker is over sensing then it may be detecting beats that are not actually occurring, from electronic devices which causes electromechanical interference. This is bad because patient will not get a pacing stimulus when one is required and will be hemodynamically compromised. In this scenario, sensitivity threshold should to be increased to block out the artifacts (thus making the pacer less sensitive).

Commonly used pacing modes with their indications

**VOO** – used in emergency situation in complete heart block or severe bradycardia

**VVI** – used as backup in sudden unexpected bradycardia or in patients with identified AV conduction block in whom AV synchrony is not thought to be necessary or achievable.

**Atrial pacing** – used in patients with sinus bradycardia or sinus arrest with intact AV conduction

**AOO** – advantage of simplicity, may cause arrhythmia as asynchronous

**AAI** – advantage of adding atrial systolic contribution to cardiac output

**DVI (AV sequential)** – usual indication is AV conduction block

**DDD (AV universal)** – paces and senses the atrium and ventricle and can act in different modes depending on the underlying rhythm.

**Initiating TCP**

Epicardial wire identification – During cardiac surgery, epicardial wires are pulled through the skin and secured to the external chest wall, ready to be attached to a temporary pulse generator. The patient may have only atrial wires or ventricular wires or both atrial and ventricular wires.

Atrial wires – The wires exiting the sternum on the right side are always atrial wires, one each for positive and negative electrode.

Ventricular wires – The two wires, for positive and negative electrodes, exiting on left side of sternum are ventricular wires.

Connecting pacing wires to a bipolar pacing cable – The two metal pins (positive and negative electrodes) of pacing wires (both atrial and ventricular wires separately) are plugged in the pacing cables, which are then connected to pacing box (Figure 5).

Figure 6 demonstrates operational instructions of TCP.

Setting the pacing box

Rate – set according to age and physiological needs of patient

Output – start with 10 milli ampere (mA) and increase until the capture is gained

Sensitivity – start at 0.5 mV for atria and 2-5 mV for ventricles and adjust according to sensing

AV sensing – set AV interval to 140-200 ms (pulse generator defaults to 170 ms)

The intensivist should recognize the pacemaker generated cardiac rhythm and associated problems and their solutions (figure 7 a & b).
How to lock and unlock the dial

To prevent accidental adjustment to the pacemaker, the three upper dials that control rate and output automatically lock after 10 seconds after the last adjustment. Pressing the on/off, memo, emergency phone, and lock/undo keys will unlock the three upper dials.

How to change to AAI mode

Verify that the setup indicators are [AA] [Y] [AA Y]. This indicates that the pacemaker is set to pace and sense in both chambers. Turn the Y output dial counterclockwise until Y is highlighted. Now pacing and sensing will only occur in the atrium. The setup indicators will now be [AA] [Y] [A].

Viewing the intrinsic rhythm

The recommended method for viewing the patient's intrinsic rhythm is to reduce the pacing rate. Either method is to press and hold the pause key. Pacing will be suspended for up to 30 seconds each time the pause key is pressed.

Emergency pacing

When the emergency key is pressed high output dual chamber asynchronous pacing is started at the current setting if the pacemaker was never or the pacemaker was not synchronized. If it was set to require dual chamber demand synchronous pacing press the on key.

How to stop pacing

To turn the pacemaker off, press the off key once.

How to replace the battery

First turn the pacemaker off. Then press the button on the bottom of the pacemaker. Remove the battery. Insert the new battery. Close the battery case and make sure it clicks. The pacemaker will work with the battery polarity reversed. Battery change during pacemaker operation is not recommended. In an emergency the battery can be changed with the battery door open. Make sure the pacemaker is locked when you replace the battery. Pacing will be maintained for 15 to 30 seconds.

Figure 6. Operational instructions of Medtronic 5388 dual chamber temporary pacemaker

Figure 7a An ECG of a paced rhythm
Consideration for transition to a Permanent pacemaker
Occasionally, a patient may become permanently dependent on the PCP and should consider transitioning to a permanent pacemaker. Optimal timing for this decision will depend on clinical course, but at 4-5 days it is reasonable to consider a PPM as by then epicardial wires may begin to fail.

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