Abstract—Emergency Department placement of a temporary transvenous cardiac pacemaker offers potential lifesaving benefits, as the device can definitively control heart rate, ensure effective myocardial contractility, and provide adequate cardiac output in select circumstances. The procedure begins with establishment of central venous access, usually by a right internal jugular or left subclavian vein approach, although the femoral vein is an acceptable alternative, especially in patients who are more likely to bleed should vascular access become complicated. The indications for the procedure, as well as the equipment needed, are reviewed. Both blind and ECG-guided techniques of insertion are described. Methods of verification of pacemaker placement and function are discussed, as are the early complications of the procedure. © 2007 Elsevier Inc.

Keywords—transvenous pacemaker; cardiac pacemaker; cardiac procedures

INTRODUCTION

Temporary cardiac pacing may be instituted in the Emergency Department (ED) for a variety of indications via several different modalities. The goal of temporary cardiac pacing is to restore effective cardiac depolarization and myocardial contraction, resulting in the delivery of adequate cardiac output. Whereas consideration of temporary cardiac pacing may begin early in the course of patient management in the ED—depending upon patient stability—placement of a transvenous cardiac pacemaker (TVP) usually is performed after other less invasive means of treatment (e.g., pharmacologic, treating the underlying cause, transcutaneous pacing) have been explored and exhausted.

Although a variety of pacemaker modalities exist—transesophageal, epicardial, endocardial, transcutaneous, and transvenous—it is the latter two methods that have applicability in the ED. Transcutaneous pacing, which is usually employed initially as a temporizing measure, will not be discussed here. Transvenous pacing, which involves placing a catheter-based electrode into the right side of the heart, is actually two procedures in one: establishing central venous access, and then introducing and directing the electrode through the venous system into the heart. Placement of a TVP involves placement of the electrode into the right ventricle with the goal of pacing the endocardium in a VVI mode (Ventricle-paced, Ventricle-sensed, Inhibited sensing response). This is the least complicated approach to reestablishing effective cardiac depolarization, and it allows the physician to pace the heart either asynchronously or in a demand mode, wherein the pacemaker is inhibited when a native impulse is sensed.

This review will focus on the indications for TVP placement and describe the two common ways the procedure may be performed in the ED—blindly and with
electrocardiographic (ECG) guidance. Confirmation of placement and function will be discussed, and commonly encountered complications will be reviewed.

**INDICATIONS AND CONTRAINDICATIONS**

Various authorities differ slightly when defining the indications for placement of a TVP (1–3). Indications can be viewed with several constructs in mind: emergency vs. prophylactic pacemaker placement; treatment of bradydysrhythmias vs. tachydysrhythmias; and in patients experiencing acute myocardial infarction vs. those who are not. Table 1 lists standard emergent indications for TVP placement, and Table 2 depicts commonly accepted prophylactic indications for the procedure. In most emergent circumstances, a transthepnic pacemaker is utilized initially while the patient is prepared for TVP placement. Transvenous pacing, and in fact pacing in general, does not seem to be beneficial in asystolic/bradyasystolic cardiac arrest, traumatic cardiac arrest, or in patients with profound hypothermia and bradydysrhythmias (3,4). In the latter group, aggressive treatment of the underlying condition is paramount, due to the theoretic concern that introducing a pacing wire into a hypothermic patient may precipitate terminal dysrhythmias. However, in-hospital cardiac arrest victims with complete heart block or bradycardia (not those with asystole) may receive some benefit from transvenous pacing unresponsive to pharmacotherapy (5).

**EQUIPMENT**

The equipment needed to insert a TVP includes an introducer sheath, pacing catheter, and external pacing generator. In addition, an ECG machine and cardiac monitor should be available. Several pre-packaged trays are available that contain the introducer sheath, pacing catheter, and other equipment necessary for pacemaker insertion.

The external pacing generator is used to deliver the electrical current, measured in milliamperes (mA), through the pacing catheter. Various available generators share the same basic features (Figure 1). The pacing generator has electrical output and cardiac sensing components, which are usually present as dials on the face of the generator. An output control dial allows for regulation of the current, usually from 0.1 to 20 mA. This principally determines the ability of the pacemaker to “capture” the heart. A rate control dial selects the pacing rate. The pacing generator also has a sensitivity control that establishes a threshold, based on the amplitude of the native R wave, required to suppress the pacemaker from firing. Turning the sensitivity control down will lead to fixed rate, or asynchronous, pacing, wherein the pacemaker fires regardless of the patient’s underlying rhythm. Increasing the sensitivity in concert with modifying the rate control will eventually lead to demand, or synchronous, pacing. This occurs when the pacing generator senses intrinsic cardiac activity and inhibits the TVP from firing. In demand mode, the pacemaker senses the patient’s underlying ventricular rate and will not fire as long as the patient’s rate is equal to or faster than the rate set on the pacing generator (2,3).

Various transvenous pacing catheters are available with basic similarities. Most are bipolar, 3 Fr to 5 Fr in size, and approximately 100 cm in length (3). Lines marked at 10-cm intervals on the catheter surface can be used to estimate catheter position. Catheters are classified as flexible, semifloating, or rigid/non-floating catheters. The latter group carries a higher risk of cardiac perforation, and thus they are generally used only under fluoroscopic guidance, where their stiffness yields the benefit of easier manipulation (1). In emergency situations, a semifloating catheter with or without a balloon tip is used most commonly (1–3). In the patient in cardiac arrest, inflating the balloon carries no benefit, as

**Table 1. Indications for Emergent Transvenous Pacemaker Placement (1–3)*

<table>
<thead>
<tr>
<th>Bradydysrhythmias</th>
<th>Symptomatic sinus node dysfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symptomatic atrioventricular block</td>
<td>Sinus arrest</td>
</tr>
<tr>
<td>Third degree atrioventricular block</td>
<td>Symptomatic bradycardia</td>
</tr>
<tr>
<td>Tachydysrhythmias</td>
<td>Overdrive pacing of rhythms refractory to medical management</td>
</tr>
</tbody>
</table>

* The indications are listed with the assumption that: 1) less invasive means (e.g., pharmacologic agents and antidotes, transcutaneous cardiac pacing) have been tried without success or that success is judged to be short-lived; or 2) the patient is experiencing profound symptomatology (e.g., severe chest pain, dyspnea, or altered state of consciousness; hypotension; shock; pulmonary edema; or acute myocardial infarction).

**Table 2. Indications for Prophylactic Transvenous Pacemaker Placement (1–3)**

| Acute myocardial infarction (especially anterior distribution) |
| Symptomatic sinus node dysfunction |
| Second degree atrioventricular block, Mobitz type II |
| Third degree atrioventricular block |
| New left, right, or alternating bundle branch block |
| New bifascicular block |
| Symptomatic patient secondary to failure of permanent pacemaker |
there is no forward flow of blood to guide an inflated balloon through the venous system into the right side of the heart. The balloon holds approximately 1.5 cc of air and should be tested for air leak before insertion. At the leading end of the catheter are two electrodes, one of which is marked negative and lies distally. Adapters are supplied in the kit to allow the electrodes to be attached to the pacing generator or to an ECG lead (Figure 2).

The **introducer sheath** is used to establish central venous access. The sheath allows for passage of the pacing catheter into the vein and must be at least one size larger than the pacing catheter. Some sheaths will contain an additional port for administration of intravenous fluids or medications.

**PLACING THE TRANSVENOUS PACEMAKER**

*Preparation and Site Selection*

Once all the equipment is available, the patient is prepped in the usual sterile fashion. A wide area should be cleaned and the patient generously draped to ensure that all the equipment remains in a sterile field.

Choosing a central venous access site may depend on physician preference and experience. Options include the internal jugular, subclavian, femoral, or brachial veins. The right internal jugular and the left subclavian veins are often preferred, having demonstrated the highest rates of proper placement in code situations; these routes allow for smooth and direct placement, taking advantage of the natural curve of the pacing catheter (2,3). The right
internal jugular provides the most direct route to the right ventricle and is associated with the lowest complication rate (6). If the patient is anticoagulated or has received thrombolytics, the internal jugular or subclavian routes are not recommended due to poor compressibility of the vascular structures. In this case, establishing femoral venous access is more appropriate. The brachial vein is rarely used, as the catheter is easily dislodged and the site is associated with a higher risk of infection and thrombosis (1–3).

Insertion Techniques

After central venous access is obtained and the introducer sheath is secured in place, the TVP can be inserted using either ECG guidance or blindly. Many physicians prefer the blind technique because it is faster and technically less complex. To perform the blind procedure, the catheter electrodes are connected directly to the pacing generator. The catheter is then inserted and the pacing generator turned on. If the patient has a pulse, the balloon can be inflated once it has passed through the introducer sheath, approximately at the 20-cm mark on the catheter; otherwise, the catheter can be advanced with the balloon down. The pacing generator is set with the output to the maximal current, the pacing rate to between 60 and 80 beats/min, and the sensitivity to the lowest level (asynchronous). A left bundle branch block pattern (e.g., wide QRS complex) should be seen after every pacer spike on a surface monitor the progression of the catheter as it approaches the right ventricle by analyzing the various waveforms that appear as the catheter is advanced. The pacing catheter serves as an intracardiac ECG lead that localizes the position of the tip of the catheter. This technique requires that the negative (distal) electrode from the end of the catheter be attached to any of the precordial (V) leads on the ECG machine using an alligator clip. The rest of the leads should be connected to the patient in the usual fashion. Progression of the catheter can be marked by recognition of characteristic waveforms; the magnitude and polarity of these waveforms are subject to change as the catheter moves through the heart (Figure 3).

Superior vena caval location results in low amplitude P waves and QRS complexes, both with a negative polarity as the sensing electrode lies above the heart, with atrial and ventricular depolarization vectors directed (generally) downward and to the left—away from the catheter. As the catheter tip enters the right atrium, the P wave becomes larger (indeed larger than the QRS complex due to the tip’s closer proximity to the native atrial pacemaker), and both the P wave and the QRS complex are initially negative. However, the P wave will become biphasic and then positive as the catheter passes down through the right atrium and the tricuspid valve. Right ventricular entry is signaled by a small positive P wave followed by a deeply negative QRS complex. When the tip of the catheter engages the right ventricular endocardium, the QRS complex will show a current of injury with ST segment elevation. If the catheter exits the right atrium into the inferior vena cava, the P wave should maintain a positive polarity while the QRS complexes lose amplitude as the catheter courses further away from the heart. This would be the same pattern noted if the femoral approach were used, but in this case it would precede the right atrial tracing. If the catheter traverses the right ventricle and strays into the pulmonary artery, the P wave will again become negative as the catheter tip travels above the atria, and the QRS complex will become smaller due to the increased distance from the right ventricle (7). If a balloon tip catheter is employed, the balloon should be inflated when the catheter tip enters the right atrium and deflated when passing through the tricuspid valve, as this should help guide the catheter toward its ideal destination within the right ventricular apex. Migration toward the right ventricular outflow tract and pulmonary artery favored by forward flow will thus hopefully be avoided (1–3).

Placement with ECG Guidance

Placement with ECG guidance makes use of the TVP catheter’s sensing function and allows the physician to monitor the progression of the catheter as it approaches the right ventricle by analyzing the various waveforms that appear as the catheter is advanced. The pacing catheter serves as an intracardiac ECG lead that localizes the position of the tip of the catheter. This technique requires that the negative (distal) electrode from the end of the catheter be attached to
**Verification of Placement**

Chest radiography should be performed to verify positioning after the TVP is secured, as well as to exclude iatrogenic pneumothorax secondary to placement of a central venous line in the thorax if the subclavian or internal jugular approaches are employed. The catheter tip should be located ideally in the right ventricular apex. A portable anteroposterior chest X-ray study is most commonly used, and the catheter tip should be visualized at the anterior-inferior aspect of the cardiac shadow, usually slightly to the left of the thoracic spine. If proper placement is in question, a cross-table lateral view suggests right ventricular apex placement when the catheter tip overlies the inferior aspect of the cardiac shadow and points toward the sternum. One study using radiography to determine catheter placement after blind insertion in the ED found the right atrium to be the most common site of catheter misplacement, occurring in 50% of cases, due to both insufficient advancement as well as coiling within the right atrium. Successful placement in the right ventricle (10 of 36 cases) was significantly more likely if an internal jugular approach was used. Interestingly, two-thirds of TVP catheters in this study were placed via the less-preferred right subclavian vein approach, which may have contributed to the high rate of improper positioning—as this approach accounted for 16 of the 18 right atrial catheter placements. The left subclavian approach, used in six cases, led to two right ventricular and three inferior vena cava placements, and one right atrial placement (8).

Proper placement can be further verified by the 12-lead ECG. Right ventricular apical location will manifest as a left-bundle-branch-like pattern on the ECG, with the exception that there is usually precordial QRS complex concordance in a negative polarity (Figure 4), whereas a true left bundle branch pattern features QRS complex transition from negative to positive polarity in the midprecordial leads. The tracing will also feature a leftward frontal plane QRS axis deviation as the pacemaker-generated impulse emanates from the right ventricular apex and travels leftward and superiorly.

**Verification of Function**

Pacing (output) thresholds and sensing thresholds need to be tested after the operator has demonstrated pacing capture; the latter threshold only pertains to those patients who have some sort of underlying rhythm to sense. The **pacing threshold** is the minimum current needed to obtain capture. To determine this, the pacing generator is set to a high level of current output, and the pacing rate to between 60 and 80 beats/min, or at least 10 beats/min.
above the native rate, if one exists. The output is then slowly reduced until capture is lost. This test is repeated several times to verify this threshold value. The current should then be set to roughly 2–2.5 times the threshold to ensure capture. The ideal pacing threshold is \(1 \text{ mA}\), so the pacing output is usually set to no more than 2–3 mA; the catheter should be repositioned if this threshold is above 5–6 mA (1–3).

The **sensing threshold** needs to be tested only if the pacemaker is going to be used in the synchronous or demand mode; i.e., if the patient has an underlying rhythm to be “sensed.” To test the sensing threshold, the rate is set to about 10 beats/min below patient’s intrinsic rate and the sensitivity dialed clockwise to the highest value (demand mode). With these settings, the pacemaker should not be firing, only sensing, as indicated by the flashing of the sensing light and the absence of paced beats. The sensitivity is then dialed counterclockwise and lowered until the pacer starts firing again. This value is the sensing threshold. The sensitivity control should then be lowered to below the sensing threshold to ensure adequate sensing, and to ensure that inappropriate stimuli such as T waves, artifact, and muscle twitches are not “oversensed” by the unit, resulting in inappropriate suppression of the pacemaker (1,2).

A more recent advance in the emergent placement of transvenous pacemakers in the ED has been the use of bedside ultrasound guidance. Ultrasound imaging provides real-time visualization of the passage of the pacing wire into the right ventricle, and can demonstrate contact of the pacing wire with the right ventricular myocardium. Ultrasound may also be used to verify positioning of blindly placed pacing wires, and to detect complications of this procedure such as interventricular septal perforation (9,10).

Most commonly, a 3.5-MHz linear array probe is used in the subcostal (also known as subxiphoid) position. The subcostal view is preferred, as it allows excellent views of all four cardiac chambers as well as cardiac wall motion. This position also does not interfere with necessary monitoring equipment such as transcutaneous pacing pads or ECG leads. The pacing wire appears as a bright linear hyperechoic structure as it enters the heart, and can be followed as it traverses the tricuspid valve into the right ventricle and contacts the myocardium of the right ventricular apex. Capture is quite apparent sonographically as the rhythmic contraction of the heart can be seen at the pacing rate.

Two small case series have described success using ultrasound assistance for the placement of transvenous
pacemaker wires (9,11). The study by Aguilera documented successful placement of tranvenous pacemaker wires using ultrasound guidance in 8 of the 9 patients (89%) in whom it was attempted, a huge improvement over previously reported success rates as low as 10% (8,9).

COMPLICATIONS

Complications of the TVP can be classified as those related to the various phases of the procedure. First, obtaining central venous access carries the risk of arterial puncture, pneumothorax, and infection as the most commonly encountered complications, as well as the more unusual, including air embolism, venous thrombosis and thrombophlebitis, and catheter/guidewire looping and entrapment. Next, there are the risks associated with right-heart catheterization. These include dysrhythmias, failure to capture, failure to sense, and oversensing. Furthermore, the catheter may be misplaced, such as in the coronary sinus, clues to which include an unexpectedly high pacing threshold, failure to capture, a right bundle branch block ECG pattern despite right ventricular placement, and a posteriorly directed catheter on lateral chest X-ray. The catheter may perforate the septum, also leading to a right bundle branch block pattern on the 12-lead ECG. Clues to ventricular free wall perforation include loss of capture, chest pain, a new pericardial friction rub, and pacing of the thoracic wall musculature. Ventricular perforation may result in hemopericardium, tamponade, and death. Cardiac ultrasound is useful in detecting this complication (1–3,6,12–14).

Three case series from cardiology critical care settings highlight the relatively high rate of TVP complications (6,12,13). The number of complications has been demonstrated to increase the longer the catheter stays in place (6). Failure to capture or failure to sense are relatively common complications, occurring in 37–43% of cases (12,13).

SUMMARY

TVP placement is a potentially life-saving procedure that involves placing a catheter-based electrode within the right ventricle via central venous access, and then stimulating that electrode and the heart with an external pacing generator to optimize cardiac output. In the Emergency Department, the procedure can be performed either blindly or with ECG guidance. After placement, the TVP must be tested to ensure adequate capture of the myocardium, as well as to assess its sensing abilities if a native rhythm remains.

REFERENCES