Real-time, Two-dimensional Echocardiographic Features of Pacemaker Perforation

BAPINEEDU GONDI, M.D., AND NAVIN C. NANDA, M.D.

SUMMARY Five patients (four adults and one child) with clinically suspected myocardial perforation by temporary transvenous pacemakers were studied by real-time, two-dimensional echocardiography. In three patients, the catheters were visualized passing through the right ventricular apical wall with the tip located outside the cardiac border. In one patient the catheter perforated the atrioventricular septum and entered the left ventricle with the tip lodged against the posterior wall. In another patient, the catheter had partially penetrated the ventricular septum near the apex. Pericardial effusion was observed in two patients, in one of whom it was localized to the site of perforation. No patient had evidence of cardiac tamponade. In four patients, the catheters were withdrawn under echocardiographic visualization and the catheter tips could be seen moving from the abnormal locations back into the right-heart chambers. Perforation was verified at autopsy in two patients, including one in whom the catheter was not withdrawn.

Real-time, two-dimensional echocardiography appears to be valuable in the diagnosis of pacemaker perforation.

INTRACARDIAC PACING is invaluable in the management of patients with bradyarrhythmias and tachyarrhythmias, but may cause complications, including myocardial wall perforation, especially with temporary pacing catheters.1-13 Real-time, two-dimensional echocardiography is useful in the detection of myocardial wall perforation by temporary transvenous pacemakers.

Materials and Methods

We studied five patients in the Intensive Care Unit of Strong Memorial Hospital who developed problems with their temporary transvenous (arm vein) pacing catheters, such as loss of pacing, increased threshold or electrocardiographic evidence of catheter misplacement. These patients were part of an ongoing study in which 50 patients with right ventricular pacing catheters were evaluated by real-time, two-dimensional echocardiography.

Two-dimensional echocardiograms were performed using a commercially available, real-time, wide-angle (90°) mechanical sector scanner and a 3.0-MHz transducer (Advanced Technology Laboratories, Inc.). Images were recorded on videotapes for later analysis in real-time or slow motion. Polaroid photographs were made of stop-action frame images.

Standard echocardiographic examinations were performed with the patient in the supine and left lateral decubitus positions.15-18 Particular attention was given to the long-axis, apical and subcostal four-chamber planes. An attempt was also made to view the right atrium and right ventricle in long axis by rotating the transducer from the apical position.

In all five patients the temporary pacing catheters were imaged as thick, dense, linear echoes in the right-sided chambers.19 Catheter identification was supported by the presence of prominent posterior reverberatory echoes in four patients and a shadowing effect in the one patient.20 In all patients the catheter was followed distally to locate the tip. In three patients identification of the catheter tip was aided by the presence of two strong and constant posterior reverberatory bands produced by the proximal and tip electrodes, which are located 1 cm apart. The indications for pacing and the clinical profile of the patients are summarized in table 1.

Intracardiac electrograms were performed in two patients using a method described previously.21 The V lead of the standard ECG was attached to the distal electrode of the temporary pacemaker and limb leads were attached in the usual fashion. Electrograms were recorded before and during withdrawal of the pacemaker wire. In one patient, electrograms were obtained from both proximal and distal electrodes during withdrawal.

Results

During real-time, two-dimensional echocardiographic studies the pacing catheters could be seen extending beyond the cardiac border through the right ventricular apex in patients 1, 2 and 3 (figs. 1 and 2). Echocardiographic examination of patient 3 the day before, shortly after pacemaker implantation, revealed the pacing catheter tip appropriately positioned in the right ventricular apex. In patient 4, the catheter had extended through the right side of the distal ventricular septum and the tip was lodged in the septal muscle near the left surface. The left ventricular cavity was not entered (fig. 3). In patient 5, the catheter was visualized entering the left ventricle from the right atrium through the atrioventricular septum and the tip was in contact with the left ventricular posterior wall (fig. 4).

From the Cardiology Unit, Department of Medicine, University of Rochester School of Medicine and Dentistry, Rochester, New York.

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Address for correspondence: Bapineedu Gondi, M.D., Cardiology Unit, Box 679, University of Rochester Medical Center, 601 Elmwood Avenue, Rochester, New York 14642.

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Table 1. **Clinical Profile and Echocardiographic Findings**

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Indication for pacing</th>
<th>Site of pacer perforation by echo</th>
<th>Pericardial effusion by echo</th>
<th>Direct evidence for pacer perforation</th>
<th>Other evidence for abnormal catheter location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>M</td>
<td>RV infarction, inferior wall infarction, COPD</td>
<td>Complete AV block</td>
<td>RV apex</td>
<td>Absent</td>
<td>Perforation verified at autopsy</td>
<td>Increased pacing threshold</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>M</td>
<td>Myotonia dystrophica, atrial flutter</td>
<td>Digoxin begun; prophylactic pacer against AV block</td>
<td>RV apex</td>
<td>Localized 8-mm space increased to 10 mm after catheter removal</td>
<td>Catheter echo moved from the PE space into the RV during withdrawal</td>
<td>Increased pacing threshold, loss of sensing, new pericardial rub</td>
</tr>
<tr>
<td>3</td>
<td>56</td>
<td>F</td>
<td>Pneumonia, malignant lymphoma</td>
<td>Long sinus pauses, hypotension</td>
<td>RV apex</td>
<td>10 mm anterior and posterior spaces</td>
<td>Echo visualization of catheter tip moving from PE space into RV apex during withdrawal; verification of perforation and pericardial effusion at autopsy</td>
<td>Increased pacing threshold, loss of sensing, new pericardial rub, withdrawal ICE consistent with perforation</td>
</tr>
<tr>
<td>4</td>
<td>72</td>
<td>F</td>
<td>Rheumatic mitral valve disease, CHF, TI</td>
<td>Sick Sinus Syndrome, syncope</td>
<td>Partial perforation of VS near apex</td>
<td>Absent</td>
<td>Echo visualization of catheter tip moving from within VS into RV cavity during withdrawal</td>
<td>Catheter malposition on lateral chest x-ray, RBBB on 12-lead pacing ECG, withdrawal ICE consistent with perforation</td>
</tr>
<tr>
<td>5</td>
<td>58</td>
<td>F</td>
<td>RV and inferior wall infarction</td>
<td>Complete AV block</td>
<td>AV septum; catheter in left ventricle</td>
<td>Absent</td>
<td>Catheter echo seen to move from LV into RA during withdrawal</td>
<td>Catheter malposition on AP chest x-ray, RBBB on 12-lead pacing ECG</td>
</tr>
</tbody>
</table>

Abbreviations: RV = right ventricle; COPD = chronic obstructive pulmonary disease; AV = atrioventricular; VS = ventricular septum; ICE = intracardiac electrogram; PE = pericardial effusion; RBBB = right bundle branch block; LV = left ventricle; CHF = congestive heart failure; TI = tricuspid insufficiency; PA = posteroanterior; AP = anteroposterior; RA = right atrium.
Pericardial effusion was noted in two of three patients with right ventricular apical perforation. In patient 3, the effusion space was 10 mm in maximal width and extended around both ventricles (fig. 2). There were no previous echocardiographic studies for comparison. The patient died on the next day and fibrinosanguinous pericardial fluid was found at autopsy. In patient 2, a baseline echocardiographic study on the day of pacemaker implantation showed no evidence of pericardial fluid. On the second day, a repeat echocardiogram was performed after a pericardial friction rub was heard and increased pacing threshold and loss of sensing were noted. A localized, 8-mm pericardial effusion space developed around the cardiac apex and the catheter tip was seen in the fluid space. The catheter was withdrawn under echocardiographic visualization on the same day and the pericardial effusion space increased to 10 mm. Subsequent echocardiograms showed no further increase in the pericardial effusion space. No patients had clinical evidence of cardiac tamponade.

The tricuspid septal leaflet prolapsed into the right atrium during systole in patient 1, who was admitted with diaphragmatic myocardial infarction and right ventricular involvement. The other four patients had no abnormalities of the tricuspid valve.

In all patients except patient 1, the pacing catheters were withdrawn under direct echocardiographic visualization. In patients 2 and 3, who had apical perforation, the catheter tip could be seen leaving the pericardial space and entering the right ventricular cavity as the catheter was withdrawn slowly. Pacing was no longer deemed necessary in patient 2 and the catheter was taken out. In patient 3, the catheter was repositioned in an adjacent area of the right ventricular apex under echocardiographic control, and the pacing threshold decreased significantly from 15 mA to 0.5 mA. Patient 3, who also had malignant lymphoma, died the next day of pneumonia complicated by septicemia. Perforation of the right ventricular apex was verified at autopsy. There was no cardiac involvement by the lymphoma. Patient 1 had reverted to sinus rhythm, but the catheter was left in place as a prophylactic measure because capture could still be effected at a high threshold. On the next day, the patient’s clinical condition deteriorated, with increasing cardiac failure and hypotension, and he died. At autopsy, the pacing catheter was found to have penetrated the right ventricular apical wall and the tip was seen just outside the epicardium. Recent infarction of diaphragmatic walls of both ventricles was noted but the right ventricular apex was spared. There was no evidence of pericardial effusion.

In patient 4, in whom the catheter had penetrated the ventricular septal muscle, the temporary pacing catheter was withdrawn under ultrasonic visualization after a permanent pacemaker had been positioned in the right ventricular apex from the right cephalic vein for the management of symptomatic sinus bradycardia. A repeat echocardiogram showed the pacemaker tip lodged in the right ventricular apex and the patient was discharged from the hospital. However, she was readmitted 4 days later when noncapture was noted during routine telephonic monitoring. The chest x-ray showed the catheter tip outside the cardiac border below the level of the diaphragm, suggesting myocardial wall perforation or catheter displacement into the inferior vena cava (fig. 5). A two-dimensional echocardiographic study showed catheter echoes in the right atrium and inferior vena cava, with the tip lodged in a hepatic vein (fig. 5). There was no evidence of myocardial wall perforation. This patient, with rheumatic mitral valve disease, had clinical evidence of significant tricuspid insufficiency, which may have contributed to the displacement of the catheter into the inferior vena cava. The catheter was withdrawn and a new pacing wire was repositioned in the right ventricular apex, with good capture. However, over the next 4 weeks the patient’s clinical status deteriorated and she died from intractable car-
Diagnosis failure. No evidence of pacemaker dysfunction was noted at any time. Autopsy was not obtained.

In patient 5, who had atrioventricular septal perforation, echocardiographic monitoring was also used to follow the course of the pacing catheter as it was withdrawn from the left ventricle into the right atrium. No complications occurred and because the atrioventricular block had reverted to stable sinus rhythm, the pacer wire was removed completely.

All patients with pacing catheter perforation showed evidence of pacemaker dysfunction, surface or intracardiac electrocardiographic abnormalities or catheter malposition on the chest roentgenogram. Increased pacing threshold without loss of sensing occurred in patient 1, in whom right ventricular infarc-
Figure 3. Partial perforation of the ventricular septum in patient 4. (A) Two-dimensional echocardiogram in the four-chamber view showing the entire extent of the pacing catheter (P) in the right ventricle (RV). Both ring electrodes (R) are embedded in the ventricular septum (VS) near the left side, but the left ventricle (LV) is not entered. A = anterior; CW = chest wall; I = inferior; LA = left atrium; MV = mitral valve; P = posterior; RA = right atrium; S = superior; TV = tricuspid valve. (B) Twelve-lead pacing ECG tracings showing complete right bundle branch block pattern of stimulation. (C) The chest x-rays on the left taken at the time of the echocardiographic study show the temporary pacing catheter directed toward the cardiac apex in the posteroanterior view, but on the lateral film the pacer tip position is abnormal, as it points posteriorly toward the left ventricle. The chest x-rays on the right were obtained after permanent pacemaker implantation in the right ventricular apex. The catheter tip is directed anteriorly on the lateral film. (D) Withdrawal intracardiac electrogram. The tracing obtained before withdrawal from both distal (top panel, left) and proximal (lower panel) electrodes show prominent S waves and isoelectric ST segments. During withdrawal, marked ST-segment elevation and progressive decrease in R-wave amplitude is seen in the distal electrode. The proximal electrode was not monitored during withdrawal.
FIGURE 4. Perforation of the atroventricular septum in patient 5. (A) Two-dimensional echocardiograms in the apical four-chamber (top) and the long-axis (bottom) views show the pacing catheter (P) entering the left ventricle (LV) from the right atrium (RA) through an area of the septum between the mitral (MV) and tricuspid valves (TV). The tip of the catheter is lodged against the middle portion of the left ventricular posterior wall. AV = aortic valve; CW = chest wall; I = inferior; L = left; LA = left atrium; R = right; RV = right ventricle; S = superior; TV = tricuspid valve; VS = ventricular septum. (B) Twelve-lead pacing ECG tracings show complete right bundle branch block pattern of stimulation. (C) The anteroposterior chest x-ray shows an abnormal location of the temporary pacing catheter tip, which is directed upward toward the left cardiac border. This patient also has a Swan-Ganz catheter in the right pulmonary artery.

Perforation and pacemaker perforation were confirmed at autopsy. In this patient, perforation was not suspected on the anteroposterior chest roentgenogram. Considerable increase in the pacing threshold with associated loss of sensing was noted in patient 2, but pacemaker perforation was not evident on fluoroscopy and the 12-lead pacing ECG showed a left bundle branch block pattern. In patient 3, who had increased pacing threshold and loss of sensing, a portable anteroposterior chest roentgenogram had shown an increase in cardiac size, but the catheter tip was seen in the region of the right ventricular apex and perforation was not suggested. The pacing 12-lead ECG showed evidence of bundle branch block pattern with significant R waves in leads V₁ and V₂ and prominent QS patterns in leads V₄ to V₆ (fig. 2). After repositioning of the pacing catheter the 12-lead ECG showed typical left bundle branch block pattern (fig. 2). The intracardiac electrograms obtained before withdrawal from both distal and proximal electrodes showed tall R waves and small S waves (type III) in this patient (fig. 2). During withdrawal, marked ST-segment elevation developed in the proximal electrode and the amplitude of the R wave decreased progressively in tracings from distal and proximal electrodes, suggesting perforation, which was confirmed at autopsy.

The patient with partial ventricular septal perfora-
tion (case 4) had a right bundle branch block pattern on the pacing ECG (fig. 3). The posteroanterior chest x-ray showed the catheter directed toward the cardiac apex, but on the lateral chest x-ray the pacer tip was directed posteriorly (fig. 3) toward the left ventricle, in contrast to the usual anterior direction.\textsuperscript{23, 24} The intracardiac electrograms obtained from distal and proximal electrodes revealed prominent S waves and isoelectric ST segments (type I pattern).\textsuperscript{21, 22} As the catheter was withdrawn, the distal electrode showed marked ST-segment elevation and progressive decrease in R-wave amplitude suggestive of intramural or extramycocardial position of the catheter tip (fig. 3). In patient 5, in whom the catheter was wedged against the left ventricular posterior wall, the 12-lead pacing ECG showed a right bundle branch block pattern of stimulation (fig. 4) and an anteroposterior chest roentgenogram showed an abnormal position of the catheter tip, which was directed upward toward the left cardiac border rather than downward toward the apex (fig. 4). Because the patient was hospitalized in the intensive care unit, a lateral chest film was not obtained.

**Discussion**

Myocardial wall perforation by pacing catheters probably occurs more frequently than is realized. It may be asymptomatic\textsuperscript{23, 26} or associated with increased pacing threshold, loss of sensing, diaphragmatic and intercostal muscle stimulation, pericarditis or hemopericardium.\textsuperscript{3} Cardiac tamponade is the most serious complication of pacemaker perforation and requires emergency pericardiocentesis or pericardectomy.\textsuperscript{27-29}

Twelve-lead electrocardiography, chest roentgenogram or fluoroscopy, "epicardial fat pad sign"\textsuperscript{30} and ascorbic acid polarization curves\textsuperscript{35} are helpful in diagnosing myocardial perforation, but their specificity and sensitivity are limited.\textsuperscript{30, 33, 34} Although a lateral chest x-ray is useful in locating the position of the pacing catheter tip, it is generally difficult to obtain with portable equipment in a patient in the intensive care unit. Also, it may not detect myocardial wall perforation, as the right ventricular walls and the apex are not directly visualized by this technique, which only shows the cardiac silhouette. Intracavitary elec-
trographic studies have been reported to be fairly specific in the diagnosis of myocardial perforation, especially when performed during withdrawal of the pacing catheter.11, 22, 36-39

M-mode and two-dimensional echocardiographic features of pacemaker electrodes in our laboratory have been described.17, 19 With the two-dimensional echocardiographic technique, pacing catheters are identified as single or multiple dense, closely packed linear echoes in the cardiac chambers (figs. 6 and 7). Permanent pacing catheters frequently present as two prominent echoes that are linear and parallel, with an echo-free space between them (fig. 8). Intracardiac catheters are strong reflectors of ultrasound and are often associated with a localized hazy of small echoes in the area posterior to the catheter, producing a characteristic tail-like appearance (figs. 6 and 7). These represent artificial reverberatory echoes resulting from repeated reflections of the ultrasonic beam at the catheter and transducer interfaces. Occasionally, a relatively sonolucent vertical band may be visualized posterior to the catheter as a result of incomplete penetration of the catheter by the ultrasonic beam, producing a shadowing effect.40 Both the reverberatory echoes and the shadowing effect are useful in differentiating an intracardiac catheter from normal intracavitary structures such as muscle bands and papillary muscles. The thick metallic (platinum) ring electrode at the tip of a pacing catheter is often the source of strong and constant reverberations that aid in its identification. Reverberations from other portions of the catheter, which consist of very thin metallic wires ensheathed in a Silastic sheath, are usually inconstant and weak. With bipolar catheters, a second area of strong reverberations may be seen at the proximal ring electrode, which is also thick and metallic, located 1 cm from the tip22 (fig. 7). The technique can also identify catheters in the extracardiac soft tissues and we have successfully identified epicardial pacing leads in the vicinity of the ventricular walls (fig. 9).

To our knowledge, echocardiography has not been used before to diagnose pacing catheter perforation. The pacing catheter extended through the right ventricular apex in three patients and the septum in two patients (partial perforation of the interventricular septum in one and atrioventricular septum in the other). In four patients, echocardiographic visualization of the catheter tip moving from the extracardiac region (cases 2 and 3), intraseptal location (case 4), or the left ventricle (case 5) into the right ventricular or right atrial cavity during slow withdrawal provided direct evidence for its identification and for the abnormal location of the catheter tip. Autopsy verification of perforation was available in patient 1, in whom the catheter was not withdrawn, and in patient 3.

The etiology of systolic prolapse of the tricuspid valve in patient 1 is not clear. It may be related to the distortion of subvalvular tricuspid apparatus produced by the catheter tip. The two-dimensional echocardiogram in this patient shows a characteristic tail-like appearance of the catheter tip, which is evident in the precordial view (fig. 6). The reverberations from the catheter tip are often faint, and may be confused with reverberations from the tricuspid valve. The presence of reverberations from the tricuspid valve may indicate that the catheter tip is near the valve. The two-dimensional echocardiogram in this patient shows a characteristic tail-like appearance of the catheter tip, which is evident in the precordial view (fig. 6). The reverberations from the catheter tip are often faint, and may be confused with reverberations from the tricuspid valve. The presence of reverberations from the tricuspid valve may indicate that the catheter tip is near the valve.
by the pacing catheter or papillary muscle dysfunction resulting from right ventricular infarction.

Echocardiography has been widely accepted as the most sensitive method for diagnosing pericardial effusion; this is an advantage in the follow-up of patients with myocardial wall perforation. Although one of our two patients with pacemaker perforation showed evidence of increased pericardial effusion space after catheter withdrawal, cardiac tamponade did not develop and no further increase in fluid space was noted on subsequent echocardiographic studies, probably owing to the “sealing effect” from myocardial contractions. Serial echocardiographic studies would be useful in detecting significant increases in effusion size that may lead to cardiac tamponade. Baseline echocardiographic examinations before pacemaker implantation also aid in excluding the presence of preexisting pericardial effusion and delineate the small anterior echo-free space produced by epicardial fat.

Real-time, two-dimensional echocardiography has many advantages in the evaluation of pacing catheters. It is a noninvasive, nonionizing technique that can be used at the bedside, and the examination is easily repeated. To date, no side effects have been reported. As in one of our patients, pacing catheters can be manipulated and repositioned under echocardiographic monitoring without the aid of fluoroscopy because the right ventricular apex can be visualized directly. Echocardiographic monitoring may be the method of choice for pacemaker implantation in pregnant patients, in whom fluoroscopy is relatively contraindicated.

However, the echocardiographic technique has limitations. In patients with small cardiac windows, the right ventricle may be visualized incompletely and the images may be of poor quality. Because only one cardiac plane can be visualized at a time, with this technique complete mapping of the catheter course may not always be possible and often the ultrasonic transducer must be tilted to delineate catheter segments in other planes. It is necessary to examine the catheter tip area from different transducer positions and angulations using both precordial and substernal sites before excluding myocardial wall perforation.

In conclusion, our preliminary experience indicates that real-time, two-dimensional echocardiography is a valuable noninvasive technique for diagnosing pacemaker perforation. Studies of a large number of patients are needed to define the sensitivity and specificity of this technique.

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B Gondi and N C Nanda

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