Transvenous Cardiac Pacing

Technics for Optimal Electrode Positioning and Prevention of Coronary Sinus Placement

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SUMMARY
Optimal electrode position for long-term transvenous cardiac pacing is in the apex of the right ventricle. Intracardiac electrograms, surface electrocardiograms, frontal fluoroscopy, lateral roentgenograms, and pacing threshold levels were studied in two groups of patients: One group was comprised of five patients with permanent pacemakers who had inadvertent malplacement of the pacing catheter, and the second group was composed of six patients undergoing temporary pacing from selected sites within the coronary venous system. The results of this study indicate that the appearance of a characteristic right ventricular endocardial complex recorded from the catheter tip is the most reliable guide to proper electrode placement. Low threshold levels, good position demonstrated roentgenographically, and typical surface electrocardiographic patterns of left bundle-branch block were all noted during intentional and following inadvertent malpositioning of the electrode within the coronary venous system and do not, therefore, guarantee proper positioning.

A successful routine for pacemaker insertion has been established which includes fluoroscopy, lateral roentgenograms, intracardiac and surface electrocardiograms, and threshold analysis. Satisfaction of all these tests appears to insure proper electrode positioning.

Additional Indexing Words:
Coronary sinus pacing
Intracardiac electrograms
Pacing thresholds
Electrograms

The value of transvenous ventricular pacing for the treatment of heart block and its complications has been established beyond question. Despite meticulous positioning of the electrode catheter in the apex of the right ventricle, electrodes have been inadvertently placed in undesirable locations. Complete reliance on anteroposterior fluoroscopy alone, or on threshold analysis, or on the appearance of a standard electrocardiogram at the time of catheter insertion can be misleading and can result in malposition of the electrode catheter in the coronary sinus or its tributaries. Although one investigator has recommended initial placement in the pulmonary artery with subsequent withdrawal into the ventricular cavity to avoid malposition, the potential risks associated with such additional manipulation have apparently prevented its wide acceptance.

Recent experience in our laboratory has indicated that recording precordial electrocardiographic leads during a trial of pacing, measuring capture thresholds, and obtaining lateral chest roentgenograms during the implantation procedure will confirm the catheter position in the vast majority of cases, but that all three technics, alone or in combination, will be ineffectual in a small number of cases. To improve technics for proper electrode placement...
Fig. 1
Diagrammatic representation of the coronary venous system. The number, size, and location of tributaries vary from patient to patient, thus making the number of possible catheter configurations considerable.

Placement, the records of five patients in whom electrodes were inadvertently positioned in the coronary venous system for periods varying from 7 days to 24 mo were reviewed. In addition, six patients undergoing routine cardiac catheterization were evaluated during temporary cardiac pacing from multiple sites within the coronary sinus system. The results of these studies have enabled us to define a technic for electrode placement which ensures successful positioning in all cases.

Methods
Following routine diagnostic cardiac catheterization, a no. 6 French, single lumen, electrode catheter was introduced into the coronary sinus, advanced into the great cardiac vein and, when possible, into the middle cardiac vein (fig. 1). Coronary venous location was established by determination of the oxyhemoglobin saturation and by injection of contrast material through the catheter lumen.

Unipolar electrograms were recorded from various segments of the coronary venous system after which pacing stimuli were delivered from multiple sites, and the following data obtained: (1) threshold levels, as determined with the Medtronic threshold analyzer; (2) configuration of selected leads of the surface electrocardiogram, especially standard lead I and precordial lead V₁; and (3) spot films of the chest or brief cine recordings were obtained with the patient in the anteroposterior, right anterior oblique, left anterior oblique, and left lateral positions.

The catheter was then withdrawn from the coronary sinus and placed in the apex of the right ventricle, and the study was performed again to permit comparative analysis.

In order to better assess the value of the intracardiac unipolar electrogram, records obtained during this study were compared with those previously obtained from various sites within the right ventricle in patients with normal and abnormal conduction patterns.

Results in Experimental Group
Patient J. F. (Fig. 2)
Unipolar electrograms and threshold measurements were obtained from three different sites (fig. 2, GCV, left CS, and mid CS) in the coronary venous system and from the right ventricular apex (RV apex). Whereas frontal views of the chest clearly indicated an abnormal catheter position in the great cardiac vein (GCV), left coronary sinus (left CS), lateral views of the heart were needed to establish the posterior and anterior positions of the electrode at mid CS and RV apex, respectively. The ventricular electrogram (RS complex) recorded from GCV (fig. 2A), suggested that the electrode tip was in an epicardial position. Electrical stimulation at this site resulted in ventricular capture but only at an elevated threshold of 5.6 ma. The right bundle-branch block pattern appearing in leads I, V₁, and V₆ (fig. 2B and C) suggested that the electrical impulses initially stimulated the left ventricle.

Unipolar electrograms from the left CS and the mid CS (fig. 2D and C) were characterized by prominent R waves indicating an epicardial location. Pacing thresholds were 1.6 and 1.3 ma, respectively, and each site produced a left atrial rhythm⁶ as demonstrated by inverted P waves in leads 1 and V₆ and upright P waves in V₁ (fig. 2E, F, H, and I). When the same electrode was positioned in the apex of the right ventricle, a typical endocardial complex with a prominent S wave was recorded (fig. 2J). Right ventricular pacing was achieved at a low threshold of 0.5 ma, and the resulting electrocardiogram resembled left bundle-branch block (fig. 2K and L).

Patient M. H. (Fig. 3)
The electrogram taken from the great cardiac vein (fig. 3A) revealed a large atrial complex slightly smaller than the ventricular complex. The latter resembled a left ventricular cavity tracing. Similar tracings recorded deep in the coronary sinus and great cardiac vein have been reported by others.⁷ Electrical pacing at this site was accomplished at a threshold of 1.0 ma and produced a left atrial rhythm (fig. 3B and C). Increasing the stimulus amplitude to 10 ma did not result in preferential ventricular stimulation.
Figure 2

Patient J.F. Catheter electrode in four positions (GCV, left CS, mid CS, and RV apex [endocardial]). Unipolar electrograms (ICS) and GCV, left CS, and mid CS demonstrate typical epicardial ventricular complexes (A, D, and G). Electrograms from RV apex produce typical endocardial complexes (J). Pacing from GCV results in LV stimulation and RBBB pattern in L1, V5, and V6 (B and C). Pacing from left and mid CS results in LA rhythm with negative P waves in L1 and V6 and positive P waves in V4 (E, F, H, and I). Pacing from RV apex results in the expected LBBB pattern in L1, V5, and V6 (K and L). (Catheters retouched by artist.) Abbreviations: CS = coronary sinus; GCV = great cardiac vein; L1 = lead I of standard ECG; LA = left atrium; LBBB = left bundle-branch block; LV = left ventricle; RBBB = right bundle-branch block; RV = right ventricle.

Electrograms from the midcoronary sinus (position 2) produced a ventricular epicardial complex (fig. 3D). Electrical pacing was achieved at an elevated threshold of 2.3 ma. The paced electrocardiogram revealed a pattern of left bundle-branch block in leads I and V6 and right bundle-branch block in leads V3R and V1 (fig. 3E and F) indicating that stimulation occurred...
Figure 3

Patient M.H. Roentgenographic views of the heart. (Top) AP and LAO views of electrode catheter in GCV. (Bottom) AP and LAO views with electrode catheter in midcoronary sinus. (A) Simultaneous L₁ and electrogram (ICS) from GCV. Pacing from this site produced an LA rhythm (B and C). (D) Electrogram (ICS) from mid CS revealed a typical epicardial complex. Pacing from this site produced an LBBB pattern in L₁ and V₆ but an RBBB pattern in V₃R and V₁ (E and F).

Figure 4

Patient A.M. AP views of electrode catheter in GCV (A) and CS (E). (B) Simultaneous L₁ and unipolar electrogram from GCV demonstrating an epicardial complex. Pacing from this site required a larger stimulus (5.0 ma) and resulted in an RBBB pattern in L₁ and V₆, but not in V₆ (C and D). (F) Simultaneous L₁ and unipolar electrogram from CS demonstrating an epicardial complex. Pacing from this site produced an LA rhythm (G).
Figure 5

Patient J.R. Lateral roentgenographic views of the chest with catheter tip in GCV (A) and mid CS (B). (C) Simultaneous L, and unipolar electrogram from GCV. Note the large atrial complex and smaller ventricular complex in the latter which resembles an LV cavity potential. In the mid CS and ostium of the CS, the ventricular deflection assumed the characteristics of an epicardial complex (D and E). Pacing from each of the above locations resulted in LA rhythms at thresholds of 0.8 to 2.8 ma.

posteriorly and close to the ventricular septum. Multiple x-ray views of the heart clearly defined the abnormal electrode position.

Patient A. M. (Fig. 4)

Epicardial complexes with prominent R waves (fig. 4B and F) were recorded with the electrode
Figure 6

Patient E.D. Catheter electrode is in the middle cardiac vein. AP (A), left lateral (B), and RAO (C) views of the heart suggest the electrode is in the RV, but the epicardial complex (D) obtained from the tip electrode suggests it is in a coronary vein. Injection of contrast material through the catheter lumen opacified all portions of the GCV and CS, corroborating the coronary venous position of the catheter. (E) Electrode in RV apex showed typical endocardial complexes.

tip in the great cardiac vein (fig. 4A) and coronary sinus (fig. 4E). Electrical stimulation in the great cardiac vein resulted in ventricular pacing with an elevated threshold of 5.0 ma. Lead I had features of both left and right bundle-branch block (fig. 4C and D), while V1 had features resembling right bundle-branch block and V6 left bundle-branch block. Pacing from the left portion of the coronary sinus required a threshold amplitude of 4.7 ma and resulted in a
transvenous cardiac pacing

RV Endocardial Pacing  RV Epicardial Pacing (Small Cardiac Vein)  LV Epicardial Pacing (Great Cardiac Vein)

Lead 1

V1

V6

Figure 7

Patient L.P. AP and left lateral views of the heart with electrode catheter in the small cardiac vein. Position corroborated by injection of contrast material. Pacing at the RV epicardial site produced the expected pattern of LBBB (middle column). Note that the surface electrocardiogram cannot distinguish between RV endocardial pacing (column 1) and RV epicardial pacing (column 2). Pacing from the great cardiac vein resulted in stimulation of the LV and produced the pattern of RBBB in V1 and V6 (column 3).

Patient J. R. (Fig. 5)

Unipolar electrograms with the electrode in the great coronary vein demonstrated a large atrial complex and a smaller left ventricular cavity complex (fig. 5C). From the midcoronary sinus to the ostium of the coronary sinus, typical epicardial complexes with large R waves were recorded (fig. 5D and E). Pacing from each of these sites was achieved at thresholds ranging from 0.8 to 2.8 ma and resulted in left atrial rhythms. Increasing the amplitude to 10 ma failed to produce ventricular pacing. Lateral roentgenographic views of the chest (fig. 5A and B) clearly demonstrated the coronary venous position of the electrode.

Patient E. D. (Fig. 6)

With the catheter electrode placed well out in the middle cardiac vein, anteroposterior left lateral and right anterior oblique roentgenographic view of the chest (fig. 6A, B and C) failed to reveal the true catheter position and suggested that it was in the apex of the right ventricle. Injection of contrast material outlined the coronary venous system and demonstrated excellent communication between the middle cardiac vein posteriorly and the great coronary vein anteriorly. Electrograms at this site showed typical epicardial complexes with large R waves (fig. 6D). It was impossible to pace the ventricle from the middle cardiac vein despite stimulus amplitudes of up to 20 ma. The same electrode catheter was then positioned in the right ventricular apex where electrograms demonstrated typical endocardial complexes (fig. 6E). Electrical stimulation

left atrial rhythm (fig. 4G). Lateral views of the chest demonstrated the posterior location of the catheter.

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**Figure 8**

RV endocardial electrograms recorded from the apex in patients with various types of intraventricular conduction defects. The predominant wave in all cases is a deep S wave regardless of whether the patient had essentially normal conduction with left axis deviation (M.P.), intraventricular conduction defects due to multiple myocardial infarctions (L.V.), complete heart block with idioventricular rhythm (R.B.), complete LBBB (J.P.), complete LBBB with...
produced right ventricular capture at a threshold of 1.0 ma.

**Patient L. P. (Fig. 7)**

An anteroposterior roentgenogram of the chest suggested that the catheter electrode was in the right ventricular apex; however, the lateral film strongly suggested that it was in the small cardiac vein (fig. 7). This was corroborated by injection of contrast material. Electrical pacing of the right ventricle from this epicardial site produced electrocardiographic complexes indistinguishable from those produced by right ventricular endocardial pacing (fig. 7). Electrical stimulation of the heart through an electrode placed in the great coronary vein resulted in left ventricular pacing with a right bundle-branch block pattern in V₁ and V₆. Electrograms and threshold levels were not recorded in this patient.

**Right Ventricle Endocardial Electrograms in the Presence of Conduction Disturbances**

To assess the validity of categorizing ventricular complexes displaying a prominent R wave as epicardial, electrograms were continuously recorded from many different parts of the right ventricle while an exploring electrode was slowly withdrawn from the main pulmonary artery to the right atrium. The results obtained were similar to those reported by Kossman and associates who demonstrated an extraordinary variability in right ventricular cavity potentials. Although the preponderant majority of ventricular complexes recorded throughout the right ventricle were of the rS configuration, a significant number of qR, qRs, QS, Rs, and RS complexes were encountered along the septum and the right ventricular inflow and outflow tracts. Thus, not all ventricular complexes having a major R-wave deflection necessarily originate from an epicardial location, and not all right ventricular cavity complexes are of the rS variety.

Variability appeared to be at a minimum in the right ventricular apex where unipolar electrograms were always characterized by a dominant S wave. This was true in the presence of left axis deviation, intraventricular conduction disturbances, complete heart block

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**Table 1**

**Analysis of Methods of Recording Electrograms Obtained from Pacing Electrodes**

<table>
<thead>
<tr>
<th>Patient</th>
<th>AP fluoroscopically</th>
<th>Multiple radiographic views</th>
<th>Threshold analysis</th>
<th>Standard &quot;paced&quot; ECG</th>
<th>Intracardiac electrograms</th>
</tr>
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<tr>
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<td>+</td>
<td>−</td>
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<td>ND</td>
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*Experimental group*

| J.F. P₁ | +       | +       | +       | +       |
| J.F. P₂ | +       | +       | +       | +       |
| M.H. P₁ | +       | +       | −       | +       |
| M.H. P₄ | −       | +       | +       | +       |
| A.M. P₁ | +       | +       | +       | +       |
| A.M. P₂ | +       | +       | +       | +       |
| J.R. P₁ | +       | +       | +       | +       |
| J.R. P₂ | +       | +       | −       | +       |
| E.D.   | −       | −       | ND      | NC      |
| L.P.   | −       | +       | ND      | ND      |

Abbreviations: AP = anteroposterior; ND = not done; NC = no capture; + = helpful; − = not helpful.

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2:1 A-V block (A.O.), right ventricular hypertrophy (A.P.), or complete RBBB (B.K.). This is in contrast to the predominant R waves observed in all epicardial tracings.
Patient 1. Pacing from a catheter positioned blindly into what was thought to be the RV apex revealed an RBBB pattern in lead V1, suggesting that the LV and not the RV was being stimulated. A left lateral roentgenogram of the chest revealed the electrode was posterior, deep in the CS, and probably overlying the LV.

with idioventricular rhythm, left bundle-branch block, right ventricular hypertrophy, and right bundle-branch block (fig. 8). It was apparent that a large current of injury pattern would distort the endocardial electrogram and render its interpretation difficult. Slight withdrawal of the catheter tip or recording from the proximal electrode of the bipolar catheter resulted in return of the typical pattern.

Since electrograms taken from coronary venous locations overlying ventricular mass were always characterized by dominant R waves, it seems reasonable to infer that when electrograms recorded from the apex of the heart are characterized by dominant R waves, then an epicardial or coronary venous position of the pacing electrode is likely. Conversely, a predominant S-wave deflection is highly suggestive of a right ventricular endocardial position.

Since the right ventricular apex is used almost exclusively for transvenous permanent electrode placement, this method of recording and analyzing electrograms obtained from the pacing electrodes affords a quick, reliable method of avoiding catheter malposition in
Patient 2. Both PA (A) and right lateral (B) roentgenographic views of the chest suggest excellent catheter position. Electrograms from the tip (C) and proximal (D) electrodes demonstrated epicardial complexes indicating their coronary venous position. Intracardiac electrograms from the RV apex produced typical RV endocardial complexes (E). L1 and V1 could not distinguish between endocardial (F and H) and epicardial (G and I) pacing of the RV.
the coronary veins (table 1). Proper grounding of all equipment and frequent compulsive checks for potentially hazardous current leaks will eliminate the danger of inducing ventricular fibrillation. In the absence of such assurances, this procedure is not recommended.

Case Reports

Patient 1

This 89-year-old female was admitted to the hospital because of repeated Stokes-Adams attacks. A 5 F bipolar pacing catheter was passed blindly via the right basilic vein into what was thought to be the right ventricle. Complete ventricular capture occurred at a stimulus threshold of 0.8 ma, and an anteroposterior portable roentgenogram of the chest (fig. 9) suggested excellent catheter position. The electrocardiogram obtained during pacing of the heart resembled left bundle-branch block in the standard limb leads and right bundle-branch block in the precordial leads. These findings, in combination with the large negative deflections in leads II, III, and aVF, suggested that the heart was being stimulated at a site located in the midpostero-inferior portion of the ventricular myocardium. A lateral roentgenogram of the chest (fig. 9) confirmed that the catheter electrode was in the coronary sinus. Intracardiac electrograms were not obtained in this patient.

Intermittent pacing failure ensued 5 days later. The captured beats produced the same electrocardiographic pattern seen on the previous days, and increasing the stimulus amplitude from 2 to 12 ma did not increase the percentage of captured beats, suggesting that the inconsistencies in pacing were not related to gross changes in catheter position or thresholds levels. A permanent transvenous demand pacemaker was successfully implanted on the seventh hospital day.

Patient 2

This 84-year-old female had a permanent Medtronic demand pacemaker unit implanted because of recurrent Stokes-Adams attacks. Intracardiac electrograms and threshold measurements were not obtained. Following pacemaker insertion, the electrocardiogram, during periods of pacing, demonstrated the expected left bundle-branch block pattern in both the limb and precordial leads. Frontal and lateral x-rays of the
Patient 4. Posteroanterior (top) roentgenogram of the chest demonstrating what appears to be excellent catheter position. The lateral view (bottom) suggests abnormal placement. The electrocardiogram demonstrates a paced rhythm with an LBBB pattern in the limb leads and an RBBB pattern in the precordial leads. At autopsy, the catheter was in the middle cardiac vein.

The chest suggested excellent catheter position (fig. 10). Nevertheless, the patient was continuously plagued by intermittent contraction of the left hemidiaphragm synchronous with each pacemaker stimulus. Fourteen months after implantation, signs of battery failure necessitated replacement of the pulse generator. Electrograms recorded from each electrode clearly demonstrated typical ventricular epicardial complexes (fig. 10 C and D) which, in turn, suggested that the pacing electrodes were in the small coronary vein or an extension thereof (fig. 1). The capture threshold at the distal electrode was 16 ma, at the proximal electrode 20 ma, and at a bipolar system, 8 ma. The catheter was withdrawn from its coronary venous position with great difficulty—presumably due to catheter-coronary vein adhesions—and was replaced by another catheter which was positioned in the right ventricular apex. Intracardiac electrograms corroborated its endocardial position (fig. 10E), and the capture threshold of this bipolar system was 1.3 ma.

During periods of pacing, the electrocardiogram resembled left bundle-branch block in the limb and precordial leads—just as it did during epicardial pacing.

Patient 3

A 72-year-old white male had a permanent, stand-by transvenous, unipolar pacemaker (Ecto-
Patient 5. PA and RAO roentgenograms suggest catheter electrode is positioned in the RV apex. Electrocardiogram reveals a paced rhythm with an RBBB pattern in both the limb and precordial leads suggesting that the LV is being paced. Conducted sinus beats also demonstrate an RBBB pattern.

cor) implanted because of syncope associated with complete heart block. Intracardiac electrograms were not obtained; however, threshold measurements were made which indicated that complete capture could be accomplished with a stimulus amplitude of less than 0.75 ma. Anteroposterior fluoroscopy suggested adequate catheter position. A 12-lead electrocardiogram revealed that the demand pacing unit functioned well, but the paced beats had the configuration of right bundle-branch block (fig. 11). Lateral and oblique views of the chest clearly demonstrated the posterior location of the catheter electrode and indicated that it had been positioned in the coronary sinus (fig. 11). Because of the low capture threshold and the faultless performance of the demand unit, it was elected to leave the catheter in place.

Twenty-one months following implantation, signs of battery failure appeared requiring replacement of the pulse generator. Before removing the unipolar catheter, electrograms were obtained from the coronary sinus and great cardiac vein (fig. 11). Electrograms revealed that although the form of the QRS complexes varied, they were all characterized by a prominent R wave which always exceeded the Q or S wave in magnitude. The catheter was removed easily from the coronary sinus and a new bipolar electrode was positioned in the right ventricular apex where electrograms corroborated the endocardial position of the electrode (fig. 11). No complications from coronary sinus pacing were ever noted in this patient.

Patient 4

A 74-year-old white female was admitted to the hospital with syncope and complete heart block for which a permanent, fixed-rate, Medtronic pacemaker was implanted. The catheter electrode was guided fluoroscopically into what was thought to be the right ventricular apex where the capture threshold at the tip electrode was 0.7 ma and at the proximal electrode, 0.8 ma. Two hours later, it was noted that the left hemidiaphragm contracted synchronously with each paced heart beat. By reducing the amplitude of the stimulus from 5 to 3 ma, the diaphragmatic contractions were abolished while cardiac stimulation remained unchanged. The electrocardiogram re-
The electrocardiogram revealed normal sinus rhythm, pacemaker parasystole, and multiple ventricular premature beats. The pulse generator was inactivated percutaneously. On the tenth hospital day the patient sustained an acute myocardial infarction which was followed by cardiogenic shock and terminal ventricular fibrillation.

Postmortem findings of the heart revealed that the permanent catheter electrode entered the right atrium via the superior vena cava and then entered the ostium of the coronary sinus. The catheter turned posteriorly in the A-V groove, after which it entered the middle cardiac vein and coursed along the posterior surface of the left ventricle where both electrodes were easily seen through the intact middle cardiac vein. Thick fibrous adhesions prevented removal of the catheter from this structure.

The only undesirable effect produced by pacing from the coronary venous system was the persistent left diaphragmatic stimulation. The dense adhesions noted at postmortem examination between the catheter, right atrial endocardium, and middle cardiac vein suggested that any vigorous attempts to remove the catheter during life would have been hazardous.

Patient 5

This 76-year-old white male was admitted because of repeated episodes of syncope and complete heart block. Following implantation of a permanent, pervenous, fixed-rate Medtronic pacemaker, the electrocardiogram revealed normal sinus rhythm, right bundle-branch block, and pacemaker parasystole at the rate of 80 beats/min. The captured paced beats produced a right bundle-branch block pattern in the limb and precordial leads (fig. 13). Cardiac fluoroscopy revealed that the catheter electrode was well out to the apex of the heart. Several views of the heart, fortuitously obtained during a GI series, suggested that the catheter electrode was in the coronary sinus and middle cardiac vein. The catheter was noted to be anteriorly placed and to the left of the spine, but in the right anterior oblique view it could be clearly seen that the catheter bore a superficial relation to the inferior surface of the heart and appeared to lying under the heart rather than inside the heart (fig. 13). The patient died of extensive metastatic disease 17 mo after pacemaker implantation. A postmortem study was performed but, unfortunately, the catheter electrode was removed before the heart was examined. Nevertheless, there were no perforations of the right or left ventricles and the ventricular septum was intact. The right ventricular endocardium was smooth and glistening and free of areas suggesting chronic electrode contact. The coronary sinus and tributaries were free of clots, strictures, and perforations.

Discussion

Atrial or ventricular pacing from within the coronary sinus system is frequently characterized by a high initial pacing threshold, a rapid rise in threshold requirements, and early pacing failure. Although recent reports and the experience with two patients included in this report (patients 3 and 5) indicate that successful, uncomplicated, long-term pacing from the coronary venous system can indeed occur, the overall results from coronary sinus pacing have been inconsistent, unpredictable, and unreliable. Intermittent pacing failure developed rapidly in four of the five patients reported by Meyer and Millar, and early pacing irregularities were noted by Gordon in a patient undergoing temporary pacing. In the present study, patient 1, undergoing temporary pacing, developed intermittent pacing problems on the fifth day.

In patients 2 and 4, both of whom had permanent pacemakers, diaphragmatic stimulation proved to be the most distressing symptom. Although loss of pacemaker capture in patient 2 could be attributed to early battery failure, this was certainly not the case in patient 4 since testing of the pulse generator at the time of death indicated that it was still capable of delivering a stimulus of 9 ma. The inability to capture and pace consistently in patients 1 and 4 was probably related to the vagaries of coronary sinus pacing.

Thus, the accumulated experience to date seems to indicate that the coronary sinus and its tributaries are not the location of choice for cardiac pacing. Accordingly, all possible precautions are taken in our laboratory to preclude the placement of permanent catheter electrodes in the coronary venous system. Our
technics include the following: (A) anteroposterior fluoroscopy and lateral roentgenograms of the chest to assess catheter position, (B) intracardiac electrography, (C) threshold analysis, and (D) standard electrocardiography.

**Anteroposterior and Lateral Roentgenography**

Although good oblique and lateral films of the heart will correctly identify catheter positions in the large majority of cases, on occasion, malplacement of the electrode in the coronary sinus will not be detected. In the present study, three patients with permanent pacemakers (patients 2, 4, and 5) and one patient (L.P.) in the experimental group demonstrated the pitfalls inherent in this technic. Clearly, reliance on radiographic studies alone will unquestionably result in a significant number of catheters being lodged in the coronary sinus position.

**Intracardiac Electrography**

Previous authors7-9, 12-14 have described the configuration of intracardiac potentials with the recording electrode located in the superior vena cava, inferior vena cava, right atrium, right ventricle, pulmonary artery, and coronary sinus. Although electrograms obtained from the pulmonary artery and right atrium showed little variation, the variations encountered in the right ventricular cavity were significant. Ventricular complexes encountered in the right ventricle included rS, RS, Rs, R, qRs, qR, QR, Qr, and QS patterns. Minute shifts in catheter position in the right ventricular outflow tract were often sufficient to change an rS to an rSr or qR complex. Small, almost indiscernible, changes in the electrode position occurring close to the tricuspid valve would change an rS to an RS or Rs complex. The only area in the right ventricle where the variability of endocardial potentials was minimal was deep in the apex of the right ventricle. As mentioned previously, this holds true only in the absence of a significant current of injury. Right ventricular apical endocardial potentials have been recorded in the presence of many types of conduction defects, and all are characterized by a predominant, negative deflection in the ventricular complexes (fig. 8). Predominant R waves have not been recorded in the right ventricular apex. Consequently, if a predominant R wave is recorded from an electrode presumed to be in the right ventricular apex, the probability of improper electrode placement is very high.

In 1948, Groedel and Borchardt15 analyzed the configuration of electrograms obtained from the ventricular surface in approximately 100 patients undergoing pneumonolysis. They demonstrated that the epicardial complex obtained over the midportion of the anterior right ventricular wall had an rS configuration, and over the conus arteriosus the complexes were usually m or w shaped. In all other right and left ventricular locations the major ventricular deflection was a positive R wave.

Levine and Goodale7 studied the potentials recorded from several branches of the coronary venous system in six normal patients and found prominent R waves in the coronary sinus, great cardiac vein, and distal middle cardiac vein and reasoned that they, in fact, were recording left and right ventricular epicardial potentials. After withdrawing to the proximal portion of the middle cardiac vein, they recorded QS and rS patterns which, they suggested, were right ventricular epicardial complexes. The possibility that they had slipped into the right ventricular cavity was not considered.

Levine and associates12 studied right ventricular endocardial potentials in 27 patients, 24 of whom had normal hearts and recorded rS complexes for the most part but noted occasional RS complexes. In two of our patients (patients 2 and 3) with permanent pacemakers, electrograms clearly indicated the epicardial location of the pacing electrodes. In patient 2, both the roentgenographic studies and the standard electrocardiogram suggested excellent catheter placement. The Rs complexes recorded from both electrodes and the high stimulus threshold provided the definitive evidence for catheter malplacement.

In the entire experimental group only the intracardiac electrograms confirmed the true
electrode position with 100% accuracy. In no case was an endocardial complex recorded from the coronary sinus, middle cardiac vein, or proximal portion of the great cardiac vein. Only when the electrode was in close apposition to the left atrium were a large atrial complex and a smaller left ventricular cavity complex (QS) recorded.

Because of the extreme variability of the right ventricular endocardial potentials, we reemphasize that the foregoing observations are valid and useful only when electrodes are positioned in the apex of the right ventricle.

**Threshold Measurement**

This simple measurement is routinely performed with a Medtronic digital threshold stimulator (model 1187) in all patients about to receive an implantable pulse generator. It is well known that threshold levels are usually high in the coronary venous system; consequently, by not settling on a pacing site with a capture threshold greater than 1.5 ma, extracardiac positioning of the catheter electrode in the coronary sinus or its tributaries will be avoided in the majority of patients. That threshold analysis is not an infallible indicator of an epicardial versus endocardial position of the stimulating electrode is clearly demonstrated by the normal levels obtained in two of the three patients studied before permanent pacemaker implantation (table 1).

Threshold levels from the coronary venous system were measured in six patients in the experimental group and were found to vary significantly even in the same patient acting as his own control. Thus, thresholds ranged from 1.3 to 5.6 ma in J.F., 1.0 to 2.3 ma in M.H., and 0.8 to 2.8 ma in J.R. The threshold was elevated in A.M. and greater than 20 ma in E.D., the only patient in whom complete capture was not achieved. In patient 1 undergoing temporary pacing, ventricular capture occurred with a stimulus amplitude of 0.8 ma despite the coronary sinus position. Threshold measurements are helpful only if high levels are encountered. Normal thresholds still require further investigation.

**Surface Electrocardiograms**

Inasmuch as electrical pacing of the right ventricle produces the electrocardiographic pattern of left bundle-branch block, left ventricular pacing produces a pattern of right bundle-branch block, and atrial pacing produces an atrial rhythm, abnormal catheter positions can, as a rule, be detected with a standard 12-lead electrocardiogram.

A total of six documented cases of permanent electrical pacing of the ventricles from the coronary sinus has thus far been reported. In all cases the precordial electrocardiographic leads demonstrated a right bundle-branch block pattern suggesting that the electrical impulse stimulated the left ventricle. The standard limb leads resembled right bundle-branch block in two patients and left bundle-branch block in four patients.

In the present study, patients 3 and 5 (figs. 11 and 13) demonstrated right bundle-branch block in both limb and precordial leads while patient 4 demonstrated right bundle-branch block in the precordial and left bundle-branch block in the limb leads (fig. 12).

In the experimental group, ventricular pacing via the coronary sinus produced right bundle-branch block in both leads I and V1 in patients J.F. and A.M. (figs. 2 and 4), but in M.H. the limb leads demonstrated left bundle-branch block while V1 and V5 were typical of right bundle-branch block (fig. 3).

The combined patterns of right and left bundle-branch block merely indicate that the mean electrical QRS vector is anterior and to the left, a situation which is compatible with stimulation of the left ventricle posteriorly close to the interventricular septum and which coincides exactly with the electrode position when it is lodged in the middle cardiac vein or in the midportion of the coronary sinus. Clearly, the single best surface electrocardiographic lead for determining the pacing electrode location is lead V5, since a right bundle-branch block in this lead indicates a posterior position of the stimulating electrode and always indicates catheter malposition. The presence of a left or right bundle-branch block pattern in lead I does not alter this fact.
On the other hand, the presence of left bundle-branch block in lead V1 during a trial of pacing does not guarantee a right ventricular intracavitary position of the electrode as evidenced by patient 2 (fig. 10), who had a permanent pacemaker, and patient L.P. (fig. 7), who was in the experimental group. In both of these patients the catheter electrodes were lodged in a right-sided coronary vein and were, in fact, contiguous to the epicardial surface of the right ventricle. Pacing from these sites produced the expected left bundle-branch block in the standard and precordial leads in both these patients, and if other means of detecting catheter position had not been employed, their true location would not have been ascertained.

These observations clearly indicate that the surface electrocardiographic pattern observed during electrical stimulation of the heart will vary depending on the position of the pacing electrode in the coronary sinus or its tributaries.

**Suggested Procedures**

The following routine is rigidly adhered to in our laboratory and has proved to be successful. Under frontal plane fluoroscopic guidance, the catheter electrode is introduced into what appears to be the right ventricular apex. Intracardiac electrograms are then recorded and, with the appearance of characteristic endocardial complexes, threshold levels are measured. The electrode site is acceptable only if the stimulus threshold is less than 1.5 ma (usually less than 1.0 ma). Pacing is then instituted and electrocardiographic leads I, V1, and V6 are recorded. The presence of a left bundle-branch block pattern in all these leads confirms that the right ventricle is being paced. A lateral roentgenogram of the chest is obtained, and if it corroborates satisfactory positioning of the electrode catheter, the pulse generator is implanted and the wound is closed.

Unless there is proper grounding of all equipment, the use of intracardiac electrography is not recommended.

**References**

2. **SPITZBERG JW, MILSTOC J, WERTHEIM AR**: An unusual site of ventricular pacing occurring during the use of the transvenous catheter pacemaker. Amer Heart J 77: 529, 1969
3. **STILLMAN MT, RICHARDS AM**: Perforation of the interventricular septum by transvenous pacemaker catheter. Amer J Cardiol 24: 269, 1969
6. **MIROWSKI M**: Left atrial rhythm: Diagnostic criteria and differentiation from nodal arrhythmias. Amer J Cardiol 17: 203, 1966
11. **GORDON AJ**: Catheter pacing in complete heart block. JAMA 193: 1091, 1965
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