ENDOCARDIAL ACTIVATION OF LEFT BUNDLE BRANCH BLOCK

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ABSTRACT Endocardial catheter mapping was performed in 18 patients with left bundle branch block (LBBB). Four patients had no organic heart disease (group 1), six had cardiomyopathy (group II), and eight had coronary artery disease and previous infarction (group III). Twelve patients had one septal site of left ventricular endocardial breakthrough, while six had two left ventricular endocardial breakthrough sites, with one site always being septal. There was no significant difference among the groups with respect to time of left ventricular breakthrough (group I, 44 msec after the onset of the QRS complex; group II, 58 msec; and group III, 51 msec). Total left ventricular endocardial activation time was significantly longer in group III (119 msec) than group I (81 msec; \( p < .05 \)) and group II (61 msec; \( p < .001 \)). Duration of total right ventricular endocardial activation was 36 msec (seven patients). The final site of right ventricular activation was at 44 msec after the onset of the QRS complex. We conclude that (1) right ventricular activation occurs before initiation of left ventricular activation in patients with LBBB, (2) left ventricular endocardial activation in patients with LBBB most likely occurs as a result of right-to-left transseptal activation, (3) left ventricular endocardial activation sequence in patients with LBBB is heterogenous, and (4) patients with coronary artery disease and LBBB have significantly longer total left ventricular endocardial activation times than patients with no organic heart disease or those with cardiomyopathies.


Our present understanding of ventricular activation in man is based on data derived from studies involving preparations in vitro and canine preparations and from intraoperative epicardial mapping of the human heart in a small number of patients.\(^1\)\(^-\)\(^9\) Our understanding of ventricular activation in the human heart with left bundle branch block (LBBB) in vivo is therefore limited by several factors. These include differences between the anatomic and functional properties of the conduction system of canine and human hearts, conduction properties in vivo as opposed to in vitro, and finally the effects of general anesthesia and the open chest on functional properties of the conduction system.\(^19\)-\(^20\) In addition, infarction, hypertrophy, fibrosis, and ischemia can affect activation during bundle branch block in man.

We performed endocardial catheter mapping in 18 patients with LBBB. The goals of our study were (1) to determine the ventricular endocardial activation sequence in patients with LBBB, (2) to determine the duration of total right and left ventricular endocardial activation during LBBB, (3) to assess the relationship of right ventricular endocardial to left ventricular endocardial activation during LBBB, and (4) to determine the effects of prior myocardial infarction and underlying heart disease on endocardial activation in patients with LBBB.

Materials and methods

Patient population. The study population consisted of 18 patients with LBBB that was evident on a surface electrocardiogram. The diagnosis was made based on the following criteria: QRS interval prolongation to 120 msec or longer, delayed intrinsicoid deflection in lead \( V_6 \), and RS or QS deflection in leads \( V_1 \) and \( V_2 \). The clinical data from these patients are listed in
The mean age was 56 ± 10 years, with a range of from 34 to 71 years. There were 14 men and four women. Ten patients had no history of coronary disease or previous myocardial infarction and of these, four had no evidence of heart disease, as determined by history, chest x-ray, and physical examination (in four), and echocardiography (in two) and at catheterization (in two). The remaining six patients had non–ischemic cardiomyopathies, as determined at cardiac catheterization (in five) and by echocardiography (in two) and MUGA (in two). Of these, one patient had rheumatic heart disease, one had hypertrophic cardiomyopathy, and four had dilated cardiomyopathies. The remaining eight patients had histories of coronary artery disease with previously documented myocardial infarction and persistent wall motion abnormalities (as determined by cardiac catheterization in eight patients and MUGA in four). Four of the patients had been on amiodarone therapy before the mapping study.

**Catheter mapping technique.** Catheter mapping studies were performed after informed written consent was obtained. Seventeen of the patients underwent mapping as an experimental study performed at the time of clinically indicated electrophysiologic evaluation. One patient underwent a purely experimental protocol. All protocols have been approved by the Hospital of the University of Pennsylvania Committee on Studies Involving Human Beings. A left ventricular catheter was positioned in each patient by the retrograde arterial approach. A catheter at the right ventricular apex remained fixed during left ventricular mapping. The left and right ventricular electrode catheters were used as exploring electrodes during the mapping procedure. The mapping sites in the right ventricle included the right ventricular apex, right ventricular outflow tract, anterior free wall of the right ventricle, and right ventricular septum. There were 12 standard mapping sites in the left ventricle (fig.

![FIGURE 1. Mapping scheme. Right ventricle (RV): site 13, atrioventricular junction; site 14, RV apex; site 15, RV septum; site 16, RV septum; site 17, RV outflow tract; site 18, RV free wall. Left ventricle (LV): site 1, LV apex; sites 2, 3, and 4, LV septum; site 5, inferior wall; sites 6 and 8, posterior base; sites 7 and 9, lateral wall; site 10, posterolateral; sites 11 and 12, superior free wall.](image)

**TABLE 1**

Clinical data

<table>
<thead>
<tr>
<th>Group</th>
<th>No.</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Cardiac DX</th>
<th>QRS (msec)</th>
<th>HV interval (msec)</th>
<th>Medications</th>
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<td>Amiodarone</td>
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<td>62</td>
<td>M</td>
<td>CAD</td>
<td>200</td>
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<td>39</td>
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</table>

DX = diagnosis; MVP = mitral valve prolapse; IHSS = idiopathic hypertrophic subaortic stenosis; RHD = rheumatic heart disease; CAD = coronary artery disease; NR = not recorded.
mm/sec. Local electrograms were recorded (for determination of activation times) with a 10 mm interelectrode distance at variable gain. The onset of the QRS complex taken from three simultaneous surface leads (I, aVF, and V₁) was used as a zero point of reference to determine activation sequence. The ventricular electrogram recorded from the right ventricular apex was also used as a reference. The local activation time at each site was taken as the point on the 10 mm variable-gain electrogram at which the largest rapid deflection crossed the baseline. In instances in which the local electrogram was fractionated and had no discrete deflection greater than 1 mV in amplitude, the rapid deflection of the highest amplitude component was used as the local activation time. In addition to determining local activation time using the largest rapid deflection, we also carried out an analysis of the onset and offset of local electrograms.

Definitions. QRS: Total duration of the surface QRS complex measured from three simultaneous limb leads (I, aVF, and V₁) recorded at paper speeds of 150 to 200 mm/sec.

Ventricular endocardial breakthrough: The earliest site of activation of the right and/or left ventricular endocardium.

Transapical time: The difference in milliseconds between local activation of the right ventricular apex and the earliest left ventricular activation time. This value was used as an index of transapical activation time.

Total ventricular endocardial activation time: Time (msec) from the earliest site of right and/or left ventricular local activity to the latest site of ventricular local activity.

Latest site of ventricular activation: Last site of endocardial activation of the right and/or left ventricle.

Statistical analysis. Analysis of data was performed with student's t test for unpaired data.

Results

Analysis of the mapping data was carried out for the whole study group and for subgroups of patients based on their underlying heart disease. Group I consisted of four patients without previous infarction and no evidence of heart disease, group II of six patients with nonischemic heart disease, and group III of eight patients with previous myocardial infarction and persistent wall motion abnormalities apparent on their left ventriculograms (table 1).

QRS duration. The mean duration of the QRS complex as measured on the surface electrocardiogram was 171 ± 21 msec. The QRS durations were 156 ± 5, 158 ± 15, and 191 ± 14 msec in groups I, II, and III, respectively (table 2). The difference between the QRS durations in group I and group III and between those in group II and group III was significant at p < .001. There was no significant difference between group I and group II with respect to QRS duration.

Left ventricular mapping sites. The mean number of left ventricular sites mapped was 14 ± 3 per patient (range was 8 to 19). In group I 14 ± 1 sites were mapped per patient, in group II 13 ± 2 sites were mapped per patient, and in group III 15 ± 4 sites were mapped per patient. There were no significant differences with respect to the number of left ventricular sites mapped per patient among the three groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Earliest LV site</th>
<th>Latest LV site</th>
</tr>
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<tbody>
<tr>
<td>I</td>
<td>2-3</td>
<td>8-10</td>
</tr>
<tr>
<td>II</td>
<td>2-3</td>
<td>6</td>
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<td>III</td>
<td>3</td>
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</table>

Sequence of left ventricular endocardial activation.

Twelve patients had only one site of left ventricular endocardial breakthrough, four in group I, three in group II, and five in group III. In nine of these patients the site of left ventricular endocardial breakthrough was at the middle one-third of the left ventricular septum and in three patients it was at the apical one-third of the left ventricular septum. The remaining six patients had left ventricular endocardial breakthrough simultaneously at two sites. In three patients one site of breakthrough was at the middle one-third of the septum and one site was at the superior basal anterior free wall of the left ventricle. Two patients had one site of breakthrough at the middle one-third of the septum and one at the apical septum and these were separated by a distinct area in the septum activated later in the QRS complex. One patient had one site of breakthrough at the apical septum and a second at the superior base.

Of the 12 patients with one left ventricular site of breakthrough, the latest site of activation was at the inferior basal or lateral free wall in seven (sites 6, 7, and 8). The latest site of activation was at the anterior superior free wall (sites 11 and 12) in three patients and at the posterior basal left ventricular free wall (site 10) in the remaining two patients. Of the six patients with two left ventricular endocardial sites of breakthrough, the latest site of activation was at the inferior-basal or lateral free wall in five and at the left ventricular apex (site 1) in one.

The relationship between earliest and latest site of left ventricular endocardial activation and QRS axis is shown in table 2.
TABLE 3
Results of left ventricular (LV) mapping

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>LV endo. break. (msec)</th>
<th>Latest endo. site (msec)</th>
<th>Total LV act. (msec)</th>
<th>Total LV act. (%) QRS</th>
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<tr>
<td>18</td>
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<td>113</td>
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</table>

Endo. = endocardial; act. = activation.

Left ventricular endocardial breakthrough. Local left ventricular endocardial breakthrough, as measured by the rapid deflection of the earliest local electrogram, occurred at 52 ± 17 msec after the onset of the surface QRS complex (table 3). In group I it occurred at 44 ± 13 msec, in group II at 58 ± 13 msec, and in group III at 51 ± 20 msec. There was no significant difference among any of the groups with respect to left ventricular endocardial breakthrough time. The earliest activity recorded at the septal sites (i.e., onset of the fixed high-gain electrogram) was 16 ± 15 msec after the onset of the surface QRS complex. The earliest activity was recorded at 23 ± 9, 23 ± 19, and 11 ± 11 msec in groups I, II, and III, respectively. Earliest activity was recorded significantly earlier in group III than in group I (p < .05).

Total left ventricular endocardial activation time. The mean total duration of left ventricular endocardial activation was 91 ± 36 msec (table 3). This corresponded to 52 ± 16% of the surface QRS complex. Respective total left ventricular endocardial activation times for groups I, II, and III were 81 ± 26, 61 ± 15, and 119 ± 32 msec. There was no significant difference between total activation times in group I and group II. The difference between group I and group III was significant at p < .05 and that between group II and group III was significant at p < .001. When expressed as a percentage of the surface QRS complex, the duration of left ventricular endocardial activation was 52 ± 18% of the surface QRS complex in group I, 39 ± 10% of the QRS in group II, and 62 ± 14% of the QRS in group III. The differences between group I and group II and group I and group III were not significant, but this value was significantly less in group II than in group III (p < .005).

Total left ventricular activation time measured from the onset to the offset of the local electrogram was 170 ± 75 msec. In group I this value was 126 ± 37 msec, in group II it was 125 ± 22 msec, and in group III it was 219 ± 77 msec. There was no significant difference between group I and group II, but in group I this value was significantly less than in group III (p < .05) and in group II it was less than in group III (p < .01). When expressed as percentage of total QRS complex, total left ventricular electrical activity was 96 ± 32% of the surface QRS complex and was 81 ± 27% of the QRS in group I, 80 ± 13% of the QRS in group II, and 113 ± 34% of the QRS in group III. There was no significant difference between group I and group II or between group I and group III, but total left ventricular endocardial activation time in group II was significantly less than that in group III (p < .05).

Latest site of left ventricular endocardial activation. The latest site of local left ventricular endocardial activation was at 142 ± 36 msec from the onset of the surface QRS complex (table 3). The latest site of activation in group I was at 125 ± 31 msec, in group II it was at 119 ± 17 msec, and in group III it was at 170 ± 31 msec. There was no significant difference between group I and group II. The difference between group I and group III was significant at p < .05, and the difference between group II and group III was significant at p < .005.

The values for latest activity recorded in groups I and II were similar (149 ± 36 vs 148 ± 21 msec). The latest activity in group III was at 229 ± 72 msec, which was significantly later than that in group I (p < .05) or group II (p < .01).

The relationship between the latest site of endocardial activation and site of wall motion abnormality is shown in table 4. The latest site of left ventricular activation was at a site of abnormal wall motion in four patients; all patients had sites with wall motion abnormalities activated earlier in the QRS complex. Thus, sites of previous infarction were activated throughout the QRS.

Transseptal activation. The interval between local activation at the right ventricular apex and the earliest
TABLE 4
Relationship between site of infarct and latest site of endocardial activation

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Site of infarct</th>
<th>LV wall motion abnormality</th>
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<td>LV wall motion abnormality</td>
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<td>13 AMI</td>
<td>Anterolateral, apical akinesia</td>
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<td>Anteroseptal aneurysm</td>
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<td>15 AMI</td>
<td>Apical, basal, apical-septal dyskinesia</td>
<td>LV wall motion abnormality</td>
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<td>16 IMI</td>
<td>Inferobasilar aneurysm</td>
<td>LV wall motion abnormality</td>
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<td>Inferior aneurysm</td>
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TABLE 5
Results of right ventricular (RV) mapping

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<th>Patient No.</th>
<th>QRS break-through (msec)</th>
<th>Latest RV endo. site (msec)</th>
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<th>Total RV act. (% of QRS)</th>
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</table>

Endo. = endocardial; act. = activation.

flow tract (figure 2). Total right ventricular endocardial activation from the first to the last rapid deflection was complete in 36 ± 13 msec, which corresponds to 21 ± 7% of the surface QRS complex. The latest site

FIGURE 2. Isochronic map of right ventricular activation. Numbers represent local activation times (mean values based on data from seven patients); lines represent 10 msec isochrones.
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of right ventricular endocardial activation occurred at 44 ± 12 msec beyond the onset of the surface QRS complex. This corresponds to 26 ± 6% of the surface QRS complex. Although the numbers are small, there were no apparent differences among groups I, II, and III with regard to right ventricular activation. When total right ventricular electrical activity was analyzed with the use of a fixed high-gain electrogram, the earliest electrical activity recorded was at −6 ± 9 msec (6 msec before onset of the QRS). The latest electrical activity was at 69 ± 8 msec. Total electrical activity was therefore 75 ± 11 msec, which corresponds to 41 ± 9% of the surface QRS complex. Again, there were no significant differences among groups I, II, and III with regard to right ventricular endocardial activation.

Effects of amiodarone. Four patients had been taking amiodarone before the time of left ventricular mapping. Excluding data from patients that had been taking amiodarone did not significantly alter the results of mapping.

Discussion

Most of our present knowledge of ventricular activation during LBBB is based on studies in vitro as well as experimental data and hypotheses based on results of dog experiments. It has been established that, in the presence of LBBB, the right ventricle is activated first, followed by right-to-left transseptal activation and then activation of the remaining part of the left ventricle.21 It has not been established whether the increase in duration of the surface QRS complex in patients with LBBB is due to slowing of transseptal activation, either local or diffuse,21,22 or rather to the diffuse slowing present in the septum as well as in the remainder of the left ventricle.22,23 It also has not been established what percentage of the surface QRS complex correlates with endocardial activation as opposed to intramural activation, i.e., with endocardial-to-epicardial spread of activation. Since LBBB may be found in a heterogeneous group of patients, our study attempted to address the effect of underlying heart disease on the LBBB pattern.

Right ventricular endocardial activation. Our data suggest that right ventricular endocardial activation is relatively uniform in patients with LBBB. In our series previous infarction and underlying heart disease had no effect on the duration of right ventricular endocardial activation. The endocardial site of breakthrough of right ventricular activation was on the right ventricular septum in six of the seven patients and this occurred earlier than left ventricular breakthrough in all patients. The concept of normal right ventricular activation in patients with LBBB is consistent with results of previous canine studies and with Van Dam’s work.20 Wyndham et al.21 also reported early right ventricular activation in patients with LBBB.

Transseptal activation. Transseptal activation cannot be recorded with present techniques in the closed-chest human heart. Most available information on transseptal activation is based on data obtained in vitro and epicardial data.24-26 Nonetheless, our data clearly suggest that right ventricular endocardial activation began before initiation of left ventricular endocardial activation in all patients studied and was completed before initiation of left ventricular activation in four of seven patients in the presence of LBBB. Right-to-left transseptal spread of activation most likely occurs next, followed by left ventricular endocardial activation. This is consistent with results of canine studies that have demonstrated initial right ventricular endocardial activation in the presence of LBBB, followed by right-to-left transseptal spread. It is of interest that the earliest activity recorded in the left ventricle by the fixed (high) gain bipolar electrode pair appeared significantly earlier in the patients with ischemic heart disease than in the other two groups of patients. This was found despite the fact that the initial rapid deflection recorded in the left ventricle was not significantly different among the groups. This may be the result of a thinner septum in patients with previous anterior septal infarction; this early activity may represent right ventricular (distant) electrical activity recorded from the left ventricle. Another explanation is that in the presence of ischemic heart disease with prior infarction the LBBB pattern on the surface electrocardiograms may represent generalized slow conduction in the left ventricle that is related to ischemic endocardial damage rather than to discrete bundle branch disease.

Pattern of left ventricular endocardial activation. Our data suggest that left ventricular endocardial activation in patients with LBBB is heterogeneous. In the 12 patients with a single site of left ventricular endocardial breakthrough, all of the sites were septal in location (figure 3). This is consistent with all previous reports on canine preparations, as well as with results of epicardial human mapping.21

However, four of the six patients with two sites of left ventricular endocardial breakthrough had sites both on the left ventricular septum and at the superior base of the left ventricle (figure 4). This has not been reported previously and is more consistent with two of the three sites of endocardial breakthrough reported by Durrer et al.27,28 in the normal heart without conduction disturbance. Of our four patients with this pattern
of left ventricular breakthrough, one had a normal left ventricle, one had rheumatic heart disease, and two had previous anteroseptal myocardial infarction. These data suggest that perhaps the proximal left bundle (which is still distal to the site of the block) may be engaged early in left ventricular endocardial activation in some patients with bundle branch block.

The latest site of left ventricular endocardial activation also showed a heterogeneous pattern. The inferior-basal or lateral free wall was the latest site of activation in seven of 12 patients with single sites of left ventricular endocardial breakthrough and in five of six patients with two sites. This is consistent with normal left ventricular endocardial activation. However, two patients with single sites had the latest site of activation at the superior base, and two had the latest site of activation in the posterior-basal free wall. One patient with two sites of endocardial breakthrough had the latest site of activation at the left ventricular apex. We did not find a relationship between QRS axis during LBBB and earliest or latest site of endocardial activation (table 2).

**Duration of left ventricular endocardial activation.** Complete endocardial activation of the left ventricle after left ventricular endocardial breakthrough was heterogeneous in duration as well. The spectrum varies from a patient (No. 7) with a cardiomyopathy in whom left ventricular endocardial activation was complete in 40 msec, which corresponds to 25% of the surface QRS complex (figure 5), to a patient (No. 12) with an anterior septal infarction and total left ventricular endocardial activation of 143 msec duration, which corresponds to 72% of the surface QRS complex (figure 6). These patients had comparable timing of their sites of left ventricular endocardial breakthrough as well as a comparable number and distribution of sites mapped.

In considering total left ventricular endocardial activation time in our patient population, we have found significant differences among patients, depending on underlying heart disease and prior myocardial infarction. This was found to be the case whether we defined local activity as the most rapid deflection of the local electrogram or if we took the entire local electrogram as local activity. There was no significant difference between total left ventricular endocardial activation times for patients with no known heart disease and those with nonischemic heart disease. Patients with previous infarction had significantly longer left ventricular endocardial activation times than did those in either of the other two groups. This was found despite the fact that left ventricular endocardial breakthrough...
was not different in the groups and the number of sites mapped per patient, as well as the distribution of sites mapped, were not significantly different among the groups. In addition, the surface QRS complexes in patients with LBBB and previous myocardial infarction were significantly longer than those in patients with no known heart disease or patients with nonischemic cardiomyopathies.

Although previous studies have not reported such a heterogeneous pattern of duration of left ventricular activation in the presence of LBBB, others have reported varying rates of ventricular activation. It has been shown by Venerose et al.\textsuperscript{25} that in patients with LBBB the Purkinje system is invaded, at least in short-term experiments, as soon as the activation wave progressing from the right ventricle has reached the left side of the intraventricular septum. Gelband et al.\textsuperscript{26} showed late activation of the peripheral network of the left bundle branch beyond lesions, and subsequent rapid spread of the impulse through the subendocardial layers. Van Dam\textsuperscript{20} also found a wider spacing of epicardial isochromes, suggesting a more rapid spread of activation that possibly may be due to participation of the Purkinje system. Wyndham et al.\textsuperscript{21} similarly found widely spaced isochromes over the left ventricular free wall epicardium, suggesting more rapid conduction.

\textbf{Factors responsible for QRS duration in LBBB.} We have found that in our group of patients with left bundle branch block, duration of the QRS complex varies depending on the underlying heart disease. Patients with prior myocardial infarction have significantly longer surface QRS complexes than patients with normal left ventricles or patients with nonischemic cardiomyopathies. We have found that there is a longer duration of endocardial activation correlating with this increase in QRS duration. It is possible that the heterogeneous duration of left ventricular endocardial activation
tion in the patients with LBBB in our series is the result of varying degrees of integrity of the distal specialized conduction system. It has been shown in most anatomic and electrophysiologic studies that the LBBB is more complex than an anterior and posterior branch block. It may be postulated that, in our series of patients with previous infarction, seven of eight of which had large anterior infarctions involving the septum, the distal specialized conduction system had been damaged and did not contribute to endocardial activation. On the other hand, our group I patients (patients without heart disease) may have a more intact and functioning distal conducting system, and thus may be more likely to have rapid spread once left ventricular endocardial activation has occurred. Consequently, these patients would have shorter total left ventricular endocardial activation times and shorter QRS complexes despite the presence of LBBB. Similarly, in patients with nonischemic cardiomyopathies, in which disease is thought to predominantly involve the myocardium, the specialized conducting system may remain intact. This may result in rapid left ventricular endocardial activation once the left ventricle has been activated. Further studies are needed to assess the electrophysiologic properties of the endocardium in patients with nonischemic cardiomyopathies.

It is assumed that the remainder of the surface QRS complex in those with LBBB is made up of intramural or endocardial-to-epicardial spread of activation. It is of interest that in patients with ischemic heart disease left ventricular endocardial activation is not only longer in duration, but also comprises a greater percentage of the surface QRS complex. Thus, endocardial activation via the specialized conducting system may play only a minor role in prolongation of the QRS complex in the presence of LBBB in patients with endocardial scars, in whom spread of activation may occur primarily through the myocardium. This is in contrast to the case in patients with no ischemic heart disease, in whom an intact distal specialized conduction system may allow left ventricular endocardial activation to occur relatively quickly.

Limitations. There are several limitations to this type of analysis of endocardial activation. Catheter mapping is based on the ability to define sites in the heart based on fluoroscopic guidance. The question of accuracy of site selection has not been answered. However, we have demonstrated a reasonable correlation between sites mapped in the catheterization laboratory and endocardial mapping performed in the operating room. Another limitation is the number of sites mapped. The mean number of left ventricular sites mapped in this series was 14 per patient. Precise definition of endocardial spread of activation is not possible based on this number of sites. However, we believe that the general activation sequence and sites of breakthrough and final site of activation were accurately identified. This was accomplished by mapping a similar number of sites in each patient group, as well as having a similar distribution of sites mapped among the various groups. Another problem involves the definition of local activation in intracardiac electrograms. In the case of a normal electrogram, the point at which the most rapid deflection crosses the baseline is customarily considered local activation. However, when analyzing an abnormal electrogram, it is not well established at which point “local” activation occurs. Although we have taken the point at which the highest amplitude deflection crosses the baseline in these abnormal electrograms to be local, other data have suggested that, in fact, all electrical activity recorded in these abnormal electrograms may be local. For this reason, we have also analyzed our data in terms of total electrical activity recorded based on onset and offset of local electrograms. As noted previously, this does not alter the data on the differences among the patient groups. Finally, it should be pointed out that neither in our series nor in other series involving ventricular activation of the human heart has the correlation between rapid spread of activation and engagement of the His-Purkinje system been demonstrated. Other factors, such as orientation of left ventricular fibers, may play a role as well.

On the basis of our data, we conclude the following.

1. In patients with LBBB right ventricular endocardial activation is initiated before the initiation of left ventricular endocardial activation and often completed before initiation of left ventricular activation.
2. Left ventricular endocardial activation most likely occurs as a result of right-to-left transseptal spread of activation.
3. Left ventricular endocardial breakthrough has a heterogeneous pattern. Most patients have a single site of left ventricular septal breakthrough; however, there can be two distinct sites of left ventricular endocardial breakthrough at “normal” breakthrough sites.
4. The sequence and duration of left ventricular endocardial activation in the presence of LBBB is heterogeneous.
5. Patients with LBBB and no known heart disease and patients with nonischemic heart disease have significantly shorter total left ventricular endocardial activation times than patients with previous infarction. It is our hypothesis that the duration of left ventricular endocardial activation may depend on the functional integrity of the distal specialized conduction system.
system. In patients with no known heart disease and nonischemic heart disease with LBBB there may be
engagement of the distal specialized conduction system. On the other hand, patients with previous infarc-
tion may require more muscle-to-muscle spread of endocardial activation in the presence of LBBB.

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