Dynamic Analysis of Heart Sounds in Right and Left Bundle-Branch Blocks

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SUMMARY

A clinical, electrocardiographic, phonocardiographic, and arteriographic study was made of 20 normal subjects, 20 patients with right bundle-branch block (RBBB) and 20 patients with left bundle-branch block (LBBB). Ventricular asynchronism was documented in nearly all cases of bundle-branch block by the behavior of the arterial pulse and the heart sounds. The first heart sound was of normal duration in all cases and usually had the normal number and position of its three components. The first sound had a normal relationship with the QRS component of the electrocardiogram in RBBB, but its onset was markedly delayed in LBBB. This fact confirms the exclusive left-sided origin of the first sound. The third (or ejection) component of the first sound had a greater delay in LBBB, due to intraventricular block, and this delay was closely related to that of the carotid pulse rise. Reversed splitting of the second sound in LBBB was common.

Additional Indexing Words:
Auscultation  Phonocardiography  Electrocardiography

O n the basis of theoretical considerations, splitting of the first heart sound has been considered typical of bundle-branch block (BBB) for a long time in spite of inadequate evidence supporting this view.

Studies based on clinical auscultation include those of King,1 King and McEachern,2 Cossio and associates,3 Laubry and Pezzi,4 Lewis,5 Lian and associates6 (quoted by Calo7), and Segall.8 Various percentages of splitting of the first sound were reported, from an occasional finding4,8 to a 50% incidence.2

Graphic studies were made by Wolferth and Margolies,9 Battro and associates10 and Contro and Luisada,11 Kelly,12 Haber and Leatham,13 and Brachetti and associates.14 Three components were described within the first sound in BBB by Battro and associates,10 and Contro and Luisada11 (at that time, the division of the normal first sound into three components had not been recognized as yet). Haber and Leatham13 described frequent splitting of the first sound in right bundle-branch block (RBBB) in contrast with left bundle-branch block (LBBB) where there was no splitting.

Studies based on auscultation or on phonocardiography gave a clear-cut description of the common abnormalities of the second sound. These were (1) wide, fixed splitting of the second sound with delay of the pulmonary component in RBBB, and (2) single second sound or reversed* splitting with delay of the aortic component in LBBB.

*“Reversed splitting” is a new term, which seems more appropriate than the older term “paradoxical splitting.”

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While the nature of the changes of the second sound has not been challenged, new concepts on the mechanism of production of the first heart sound suggested a new study of the problem.

Methods

Our study was conducted on 60 subjects: 20 normal control subjects ranging in age between 17 and 60 years; 20 patients with RBBB ranging in age from 17 to 83 years; and 20 patients with LBBB ranging in age from 26 to 74 years.

Patients with rheumatic valvular disease, subaortic muscular stenosis, obvious myocarditis, or uncorrected congenital heart disease were excluded in order to avoid limited conduction block or alterations of ventricular dynamics. Patients with systemic hypertension or pulmonary emphysema were excluded for the same reason.

The patients were selected following a clear-cut electrocardiographic diagnosis of BBB made according to Wilson's criteria.

Following a clinical and electrocardiographic study, phonocardiograms were recorded using a Sanborn multichannel apparatus that included two 1700-B amplifiers with high-pass filters and two dynamic microphones. Four tracings were simultaneously recorded: an electrocardiogram, two phonocardiograms in the same frequency band, and a carotid tracing, recorded as low as possible in the neck. The sound tracings were recorded, first, at the apex and over the second left interspace; then, over the third left and the second or third right interspaces. In addition to a nonfiltered tracing, records were taken with nominal frequencies of 50, 100, 200, 400, and 600 cps, respectively.

The data reported in table 1 summarize the averages of all cases.

The following measurements were made: (1) Q-Ia interval; (2) Q-Ib interval; (3) Q-Ic interval; (4) overall duration of first heart sound; (5) interval between the onsets of the aortic (A) and pulmonary (P) components of the second heart sound or vice versa; (6) Q-carotid pulse rise interval; and (7) Q-carotid pulse incisura interval.

The measurements of heart sounds were made mostly in the tracings with 0 or 50 filtration for the first sound and with 100 or 200 filtration for the second sound because, in BBB, high filtration often gives a poorly defined first sound. In normal subjects, the degree of splitting was measured only at the end of inspiration; in BBB, the interval was measured in apnea.

### Table 1

<table>
<thead>
<tr>
<th>Method</th>
<th>Normal subjects (20)</th>
<th>RBBB (20 patients)</th>
<th>LBBB (20 patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECG</td>
<td>Average age (yr)</td>
<td>Duration of QRS</td>
<td>Q-Ia interval Q-Ib interval Q-Ic interval</td>
</tr>
<tr>
<td></td>
<td>59</td>
<td>83</td>
<td>59</td>
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<tr>
<td></td>
<td>±1.6</td>
<td>±1.9</td>
<td>±4.3</td>
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<tr>
<td></td>
<td>55</td>
<td>97</td>
<td>133</td>
</tr>
<tr>
<td></td>
<td>±5.0</td>
<td>±4.0</td>
<td>±4.0</td>
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<tr>
<td></td>
<td>132</td>
<td>146</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td>±4.3</td>
<td>±4.0</td>
<td>±4.0</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>90</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>±3.4</td>
<td>±3.4</td>
<td>±3.4</td>
</tr>
</tbody>
</table>

*Statistical analysis of data in LBBB as compared with those of normals is significant: P < 0.001 for values indicated.*

Statistical variation is expressed as standard error of the mean.

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HEART SOUNDS

Case of right bundle-branch block. QRS = 0.12 sec. The (a) component of the first heart sound starts 0.05 sec after the R rise. Phonocardiograms at second left (5 L) intercostal space (above) and apical (4 L; below) areas, both with 50 cps filter. Three components within the first sound at apex, which has a normal amplitude.

Results

Auscultation

Right Bundle-Branch Block

Two of the 20 patients had muffled first sounds while the other 18 had normal first sounds; two patients out of 20 seemed to have splitting of the first sound on auscultation. Splitting of the second sound was heard in seven of the 20, and the splitting was considered wider than normal in four patients. A third sound was heard in one patient, and an ejection sound at the base was heard in one of the 20 patients.

Left Bundle-Branch Block

Seven of the 20 patients had a dull or muffled first sound; two had a split first sound on auscultation. The second sound was considered as having a reversed splitting in six of 20 patients; a third sound was heard in one; and a fourth sound was heard in six. An ejection sound was heard in one of 20 patients.

Phonocardiography

Normal Subjects

First Sound. The average duration of the first heart sound was 126 msec. Three components were recorded in all. The Q-Ia interval averaged 59 msec; the Q-Ib, 86 msec; and the Q-Ic, 125 msec.

Second Sound. Normal type of splitting was found in 18 subjects after the end of inspiration while two had a single second sound (ages, 33 and 60 years, respectively). The interval between the A and P components of the second sound averaged 42 msec.

Right Bundle-Branch Block (Figs. 1 and 2)

First Sound. The amplitude was normal in all 20 patients. Three components were recorded in all of them. The overall duration
of the sound varied from 80 to 160 msec (average, 116 msec). The Q-Ia interval averaged 55 msec with four of the 20 patients having 70 msec while the others had lower figures. The Q-Ib interval averaged 97 msec (average Ia-Ib interval, 42 msec). The Q-Ic interval averaged 133 msec (average Ia-Ic interval, 78 msec). The Ic component (ejection sound) was abnormally large in three of the 20 patients.

Second Sound. Normal type of splitting was found in 19 of the 20 patients, while a single sound was present in one. The average interval between the A and P components was 57 msec.

Third Sound. This sound was present in one of the 20 patients.

Fourth Sound. This sound was present in five of the 20 patients.

Left Bundle-Branch Block (Figs. 3 and 4)

First Sound. The amplitude was decreased in 10 of 20 patients, especially with filters 200 or higher. In all of them, three components were recorded. The overall duration of the first sound had an average of 110 msec.
Figure 3

Case of left bundle-branch block. QRS = 0.12 sec. Phonocardiograms at second right (above) and third left intercostal spaces (unfiltered). The first sound at the left of the sternum starts 0.08 sec after the rise. Three components (a, b, and c) are visible at the right of the sternum while only components (a and c) are visible at the left. The first sound has a normal amplitude. There is a close but reversed type of splitting of the second sound (interval P-A = 0.04 sec). There is a low frequency fourth sound in both sound tracings.

The average Q-Ia interval was 90 msec. The average Q-Ib interval was 134 msec (average Ia-Ib interval, 44 msec). The average Q-Ic interval was 171 msec (average Ia-Ic interval, 81 msec). The Ic component (ejection sound) was abnormally large in two of the 20 patients.

Second Sound. The second sound had a normal type of splitting in one patient and was single in two of the 20 patients (in one there was reversed splitting only in expiration). There was a reversed type of splitting in 17. The average interval between the P and A components of these patients was 53 msec.

Third Sound. This sound was present in four of the 20 patients and was low pitched.

Fourth Sound. This sound was present in 13 of 20 patients. In two, it was prolonged causing a short presystolic rumble.

Carotid Pulse

The interval Q-rise of the carotid pulse averaged 120 msec in normal subjects, 114 msec in RBBB, and 167 msec in LBBB. The interval Q-incisura of the carotid pulse averaged 400 msec in normal subjects, 395 msec in RBBB, and 435 msec in LBBB.

Auscultatory-Graphic Correlations

Splitting of the first heart sound was noted on auscultation in two of 20 patients with RBBB and in two of 20 patients with LBBB. In all these patients, the first heart sound had a large c component (ejection sound) in graphic tracings. Four other patients might have been considered as having a split first sound by a casual observer; however, a correct statement of "loud fourth sound" was
made in these patients by our personnel prior to recording phonocardiograms.

**Discussion**

The graphic studies on the first sound from our laboratory\(^{15-18}\) have demonstrated the existence of three components or groups of vibrations within the normal first heart sound. They demonstrated that the first two (Ia, Ib) were of ventricular origin while the third (Ic) was of aortic origin. They further showed that they originated in the left heart while the right heart contribution to the first sound was minimal and unrecognizable in the normal phonocardiogram.\(^{19}\) These findings were confirmed by van Bogaert and associates.\(^{20}\)

*In the normal heart, van Bogaert and associates\(^{21}\) recognized two groups of vibrations, a pre-ejectional and an ejectional. The former resolves itself to two components (Ia and Ib) with high-frequency galvanometers and filters. This explains the difference between the findings of the two laboratories.*

**Figure 4**

Case of left bundle-branch block. QRS = 0.14 sec. Phonocardiograms at second right (above) and fifth left intercostal spaces (filter = 50). Following a fourth sound (IV), the first sound at the apex shows the components (a, b, and c). The first sound (Ia) at the apex starts 90 msec after the R rise. The Ia-Ib interval is 42 msec; the Ia-Ic interval is 80 msec. There is a wide and reversed splitting of the second sound (interval P-A = 65 msec). The carotid rise starts 0.16 sec after the R rise.
This being the case, several statements of the past should be revised:

1. The first sound is split on auscultation in bundle-branch block. This statement is meaningless because the normal first sound may be split (both on auscultation and in phonocardiograms) due to separate audition of the first (Ia) and second (Ib) components. This fact has been widely recognized since the study of Leatham\(^2\) on the first heart sound.

2. The first sound is divided into two or three components in the phonocardiogram of bundle-branch block. This statement is meaningless because either two or three components are found in the normal first sound. Moreover, auscultation may give the impression of a splitting of the first sound due to two other possibilities:

a. There is a fourth sound; this plus the first component of the first sound simulates a splitting.
b. The third component (Ic) is louder than normal on account of alterations of the aorta (so-called aortic ejection sound); this, following a larger component Ia (and a smaller, inaudible component Ib), again may simulate splitting on auscultation. Both possibilities were considered, and their occurrence was demonstrated by van Bogaert and associates\(^2\) in their experimental and clinical study on BBB.

The theoretical possibility of splitting of the first sound as a result of BBB was based on two assumptions: the existence of left and right ventricular (or mitral and tricuspid) components within the first sound, and the delay of activation and contraction of one ventricle in BBB.

The first assumption has been challenged by our studies, which showed that only the left ventricle and aorta contributed to the generation of the first heart sound.

The second assumption has been challenged in LBBB (not in RBBB) by Braunwald and associates\(^2\), following a study of the timing of electric and mechanical events in the normal heart.\(^2\) These authors pointed out that lesions of the left ventricle can produce the pattern of complete LBBB by causing a conduction block in some of the left ventricular branches without delay of initiation of left ventricular contraction. For this reason, we accepted only patients with a typical electrocardiographic pattern of BBB and excluded patients with congenital or rheumatic heart disease, as well as those with systemic or pulmonary hypertension. This selection tried to avoid a partial "conduction block" with an ECG pattern of left BBB. We also tried to avoid the occurrence of a one-sided overload causing prolongation of either the tension or the ejection of one ventricle. As experimental interruption of the left bundle branch causes a delayed contraction of the left ventricle,\(^2\) we have assumed that this may also occur in man.

Our study of the arterial pulse showed a normal (114 msec) Q-carotid rise interval\(^a\) in RBBB (no left ventricular delay) and a prolonged interval (167 msec) in LBBB (left ventricular delay). One might postulate that this fact merely revealed a delay in left ventricular ejection and not a delay in left ventricular contraction. However, study of the first sound proved to be revealing for an understanding of the facts:

The beginning of the first sound was not delayed over the Q wave in RBBB (55 msec versus 59 msec for normal subjects). On the contrary, this beginning was delayed over Q in LBBB (91 msec versus 59 msec for normal subjects).

In all cases, three components were observed within the first sound, and no basic difference was found in such respect between right and left bundle-branch blocks.

The interval between the first (Ia) and the second (Ib) components (Ia minus Ib) was only minimally longer in left versus right BBB (44 versus 42 msec), and the difference (2 msec) was insignificant.

The interval between the first (Ia) and the third (Ic) components (Q-Ia minus Q-Ic)

\(^*\)This interval is identical with that mentioned by Braunwald and associates\(^2\) as representing the Q to onset of ventricular ejection in normal man.
was slightly longer in LBBB than in RBBB (81 msec versus 78 msec), probably due to myocardial fibrosis, but this difference was minor.

The prolongation of the Q-Ic interval in LBBB was similar to that of the Q-carotid rise interval.

It was concluded, therefore, that, even though the tension period is slightly longer in LBBB than in either normal subjects or patients with RBBB, the onset of left ventricular contraction is delayed in LBBB.

The second sound showed the anticipated changes, that is, wider splitting of normal type in RBBB and reversed splitting in LBBB. Reversed splitting was common in LBBB (17 of 20 patients) and the average interval between the P and A components in these patients (53 msec) was similar to that between the A and P components of RBBB (57 msec).

Conclusions

The following conclusions were reached:

1. When pressure alterations, shunts, or valvular defects causing ventricular hypertrophy or overload are excluded, ventricular asynchrony is constant in bundle-branch block.

2. The second heart sound reflects this asynchrony in nearly all cases by revealing a wide splitting in right bundle-branch block and a reversed splitting in left bundle-branch block.

3. The first sound, being related only to events of the left heart and aorta, shows a normal relationship to the Q wave of the electrocardiogram in right bundle-branch block, a marked delay in left bundle-branch block.

4. The first sound, being related only to events of the left heart and aorta, has three components in both types of bundle-branch block.

5. Occasional simulation of splitting of the first sound on auscultation was explained by incorrect evaluation of either a fourth sound preceding the first sound or an ejection sound. Therefore, “splitting” of the first sound is not a feature of bundle-branch block.

References


Recordings by Einthoven circa 1900

(Courtesy Dr. George Fahr)
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