Peculiarities of the First Heart Sound in Bundle Branch Blocks
A New Interpretation Based on Graphic Analysis

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SUMMARY
A phonocardiographic study in a medium frequency range was made over various areas of the precordium in 27 cases of right bundle branch block (RBBB), 28 cases of left bundle branch block (LBBB), and 30 normal subjects of the same age. The various components of the first heart sound plus the pulses at the suprasternal notch and the right carotid artery were studied in regard to timing, relationship with the ECG and the arterial pulses, intervals between components, and amplitude.

The timing and intervals of the three components of the first sound were found normal in RBBB and so were the arterial pulses; apparent wide splitting was occasionally noted, due to recording of the first (a) and third (c) components, the latter being larger, as frequently observed in old age. All three components of the first sound were found small and delayed in LBBB; a delay of the arterial pulses was also noted. No additional component that might be attributed to the right heart preceded the delayed first sound.

This study confirms that the first heart sound recorded on the chest wall originates only in the left heart and aorta.

Additional Indexing Words:
Heart auscultation Heart sounds First heart sound Bundle branch block Phonocardiography Carotid pulse Suprasternal notch pulse

Several medium frequency components can be identified within the first heart sound. The changes of this sound in the two main types of bundle branch block have been the object of several studies because the changes in activation and contraction that are typical of the two types of bundle branch block may give clues to the mechanism of production of the first heart sound.

A new study was undertaken in order to clarify this problem by non-
Table I. Mean and Standard Deviations of

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of cases</th>
<th>Age (years)</th>
<th>H.R.</th>
<th>QRS duration (msec)</th>
<th>Q-Ia (msec)</th>
<th>Q-Ib (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBBB</td>
<td>27</td>
<td>69.2±16.1</td>
<td>78</td>
<td>±15.1</td>
<td>130 ±18.4*</td>
<td>66 ± 8.8</td>
</tr>
<tr>
<td>Normals</td>
<td>30</td>
<td>67.4±16.6</td>
<td>78.8</td>
<td>±10.2</td>
<td>82 ± 9.1</td>
<td>64.6±9.2</td>
</tr>
<tr>
<td>LBBB</td>
<td>28</td>
<td>71.6±15.4</td>
<td>74</td>
<td>±12.4</td>
<td>137.5±21.2*</td>
<td>91.3±12.6</td>
</tr>
</tbody>
</table>

† Measured in 17 pts. with RBBB, 30 normals, and 19 pts. with LBBB.
* p<0.001, obtained with the two-sample Student's t test comparing the group of patients with normals.

When no asterisk appears, the difference from the normals is not significant.

invasive methods as systemic studies of cardiac catheterization are not indicated in these conditions unless myocardial or valvular lesions are also present.

MATERIAL AND METHOD

Our study included 27 patients with right bundle branch block (RBBB), 28 patients with left bundle branch block (LBBB), and 30 normal volunteers in the same age group (Table I). Physical examination, blood pressure measurement, electrocardiogram, and phonocardiogram were normal in all controls. Patients with valvular diseases, subaortic muscular stenosis, myocarditis, congenital heart disease or obvious pulmonary emphysema were excluded from all three groups. The patients with either RBBB or LBBB had their alteration caused by coronary heart disease.

Following a clinical and electrocardiographic study, phonocardiograms and a carotid tracing were recorded. Sanborn equipment and a velocity microphone were used in 10 patients with RBBB and in 9 patients with LBBB. In the remaining patients and in all controls, phonocardiogram, carotid pulse tracing (CAR), and suprasternal notch pulse tracing (SSN) were recorded with a Hewlett Packard equipment and a contact microphone. All tracings selected for study were recorded either at the third left i.c.s. or at the apex; they were taken with a high-pass filter at 100 Hz having a slope of 24 db/octave. The tracings recorded in a higher filter range were not considered because they often exclude significant components of the first heart sound. The following measurements were made.

1. **Q-Ia interval** = the interval between the onset of the Q-wave of the ECG (or the upstroke of R) and the onset of the first component (a) of the first heart sound;
2. **Q-Ib interval** = the interval between the onset of the Q wave of the ECG (or the upstroke of R) and the onset of the second component (b) of the first heart sound;
3. **Q-Ic interval** = the interval between the onset of the Q-wave of the ECG (or the upstroke of R) and the onset of the third component (c) of the first heart sound;
4. **Ia-Ib and Ib-Ic intervals** = the time intervals between first and second, and
second and third components of the first heart sound, respectively.
5. \( Q\text{-CAR} \) and \( Q\text{-SSN} \) = the intervals between the onset of the Q wave of the ECG (or the upstroke of R) and the upstroke of the carotid pulse or the suprasternal notch pulse (indirect aortic pulse), respectively.
6. **Amplitude of the first heart sound.** The relative amplitude of the three components of the first heart sound was calculated in each subject as the ratio of their amplitude to the amplitude of the aortic component of the second heart sound. The groups of subjects were reselected for this measurement with special attention to the diastolic blood pressure which is known to influence the intensity of the aortic component of the second sound. Thus, only 21 cases of LBBB were included in this measurement because their diastolic pressure was similar to that of the other two groups.

Measurements were made in at least five consecutive cardiac cycles and were then averaged. The analysis of the data was performed by using the t statistic evaluation for comparing the means of the measured parameters.

### RESULTS

Three components of the first heart sound were observed in all normal subjects (Fig. 1) and in all patients (Figs. 2–5) by using filter scanning and recording over different areas of the precordium. The \( a \) and \( c \) components were always best recorded at the apex. The \( b \) component was better recorded over the third left intercostal space close to the sternum\(^*\) in 58 cases (18 cases of RBBB, 20 cases of LBBB and 20 normal controls). It was not clearly observed in one case of LBBB. In the remaining cases, it was better recorded at the apex.

The mean and standard deviations of the measured parameters are reported in Table I. As the three groups are comparable for age, sex and heart rate, no correction was needed for the measured time intervals. The \( b \) and \( c \)

\*It should be kept in mind that this location is much close to the aortic valve than is the "apex" (5th L i.c.s.).
Fig. 1. Three simultaneous phonocardiograms (from above: 3R, 3L, 5L) recorded in a 17-year-old male athlete with sinus bradycardia. The tracings were recorded with a high-pass filter at 25 Hz having a slope of 24 dB/octave. This low frequency filtration gave the best picture of the three components of the first sound at the apex. As known, athletes have a first sound of low frequency.

Fig. 2. Two simultaneous phonocardiograms (from above: 3L, 5L) recorded with high-pass filters (50 Hz at left, 100 Hz at right) in a 79-year-old patient with RBBB. A PCG recorded at the apex (right) seems to demonstrate a wide splitting of the first sound. However, a tracing recorded over the third left i.c.s. with lower filtration (left) reveals three components and a normal a-b interval. The c component was the one recorded as a larger vibration at the apex simulating a b component.
Fig. 3. Phonocardiograms recorded at 3L (above) and apex (below) and carotid tracing recorded in a 76-year-old man with LBBB. The entire first sound is severely reduced; it is markedly delayed, and so is the carotid pulse. The three components of the first sound can still be recognized. There is a small aortic flow murmur that would be better recorded at a higher frequency. Tracings recorded with high pass filters (50 Hz 24 dB/octave slope).

Fig. 4. Phonocardiogram at the third left i.c.s. (3L) recorded in a 48-years-old woman with LBBB. Tracing taken with a high pass filter at 100 Hz, 24 dB/octave slope. In spite of the small amplitude of the first heart sound, three components can be still recognized. Below is the first derivative of an impedance cardiogram. Both the first sound and the ejection wave of the impedance tracing are markedly delayed.
Fig. 5. Phonocardiogram at the third left i.c.s., carotid and jugular tracings recorded in an 89-year-old woman with LBBB. The ECG is recorded in a CL5 position in order to avoid muscular currents. It was typical of LBBB in other leads, though marred by artifacts.

components of the first heart sound followed the a component after the same intervals both in normal controls (Fig. 1) and in the two types of bundle branch block (Figs. 2–5). This was proven by the fact that, in both RBBB and LBBB the intervals I_a-I_b and I_b-I_c did not differ significantly from those of the normal controls. However, while in RBBB the first heart sound followed the QRS of the ECG after a normal interval, in LBBB the entire sequence of components (a, b, c) was delayed, and a similar delay was found for the aortic and carotid pulses.

Comparison of the timing of the upstroke of the arterial pulses with that of the three components of the first heart sound revealed that both the SSN and the CAR pulse upstrokes occurred after the b and before the c component, not only in normal subjects and RBBB, but also in LBBB. Analysis of the tracings revealed that this was true, not only as an average, but also in each individual patient.

In RBBB, the relative amplitude of the a component was similar to that of the normal subjects (Table II). The relative amplitude of the b component was highly significantly reduced. On the contrary, the relative amplitude of the c component was significantly increased (Table II). In LBBB, all three components of the first sound were reduced in intensity; however, the decrease of the a component did not reach the level of statistical signifi-
Table II. Relative Amplitude of the Three Components of the First Heart Sound in Normal Subjects, RBBB, and LBBB Matched for Age and Blood Pressure, and Measured in the Third Left Intercostal Space

<table>
<thead>
<tr>
<th>Group</th>
<th>No. of subjects</th>
<th>Age (years)</th>
<th>Blood pressure (mmHg)</th>
<th>$I_a/I_A$</th>
<th>$I_b/I_A$</th>
<th>$I_c/I_A$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Systolic</td>
<td>Diastolic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RBBB</td>
<td>27</td>
<td>69.2±16.1</td>
<td>134±24</td>
<td>81±13</td>
<td>0.84±0.34</td>
<td>0.58±0.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n.s.</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>Normals</td>
<td>30</td>
<td>67.4±16.6</td>
<td>136±25</td>
<td>80±15</td>
<td>0.82±0.32</td>
<td>0.92±0.30</td>
</tr>
<tr>
<td>LBBB</td>
<td>21</td>
<td>70.7±14.9</td>
<td>132±20</td>
<td>77±14</td>
<td>0.65±0.29</td>
<td>0.67±0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>n.s.</td>
<td>p&lt;0.01</td>
</tr>
</tbody>
</table>

The reported significances are against the normals and were calculated with the two-sample Student's test.

n.s. = not significant; $I_a$, $I_b$, $I_c$ = first, second, and third component of the first heart sound; $I_A$ = aortic component of the second heart sound.

**DISCUSSION**

The first heart sound is a long series of vibrations within which different components have been recognized. One of us (AAL)\(^1\) described in 1949 two medium frequency components and Leatham\(^2\) in 1954 also described two high frequency components within this sound in normal subjects. Studies in animals\(^3-6\) from the laboratory of one of us (AAL) subsequently led to the description of three components\(^4\), and a similar sequence of vibrations was also found in man (Fig. 1). While Leatham and his coworkers attributed the two components to mitral and tricuspid closure, respectively, we labeled descriptively the three components as $a$, $b$, $c$ with the general concept that they were related to accelerations and decelerations of the left heart and aorta. Subsequent studies demonstrated that the mitral valve is dynamically closed at the time of the first component;\(^3-6\) that tension of such valve (obviously involved in the first sound) accounts only for a fraction of the sound energy;\(^7\) that the second component is intimately connected with the dynamic changes that occur with aortic valve opening\(^8\) while the third is especially influenced by changes in tension of the aortic walls.\(^6\)

Haber and Leatham\(^9\) described a wide splitting of the first sound in RBBB while they found no splitting or delay of this sound in LBBB, partly due to difficulty in the study of a fainter series of vibrations. Recently, Leatham and his associates\(^10\) studied 20 cases of RBBB. The first heart sound was found to be either single (10 patients), not recordable (2 patients), or widely split (8 patients). Thus, in 12 out of 20 patients, there was no
recordable "tricuspid" component despite the fact that the echocardiogram revealed a mitral-tricuspid valve closure interval ranging from 10 to 72 msec. In 5 patients, this interval was from 30 to 72 msec and still the "tricuspid" component was not recorded.

A study from the laboratory of one of us demonstrated a normal duration and composition of the first sound in both types of bundle branch block. While patients with RBBB had a normal interval between QRS onset and the first component of the first sound, those with LBBB had a marked delay of such sound; three components were recorded in each of the two types. The carotid pulse was delayed in LBBB, not in RBBB.

The effects of lesions at various levels of the left conduction system were studied by Lenègre and coworkers, Longhini et al., and Adolph et al., the former two by means of the apex cardiogram. Gorlin and coworkers and ourselves studied the uprise of pressure within the two ventricles. Finally, the changes in amplitude of the first heart sound in LBBB were studied by one of us by echo- and phonocardiography and interpreted on the basis of the dynamic changes of left ventricular contraction.

These authors concluded that, in most cases of LBBB, there is a delay in the onset of left ventricular contraction, a prolongation of the isovolumic tension period, and a delay of the arterial pulse that is greater than that of ventricular contraction.

The decrease of the entire sound was explained by us as the result of abnormal activation and contraction of the ventricular septum. This also explains the relative lower amplitude of the c component, which is related to the rapidity of distention of the aortic walls. It should be noted that the tracings of the British authors show an interval of 70–80 msec between the two alleged mitral and tricuspid components of the first sound in cases with RBBB. This interval corresponds to the normal interval between the first (I) and the third (I\(_a\)) medium frequency component of the first sound. As the third component is frequently larger in old persons (occasionally also in adolescents), it is not surprising that old patients with either type of bundle branch block have prominence of a and c instead of a and b. This possibility had been mentioned in a book by one of us and is considered as a definite probability by Tavel. A tiny additional component is actually visible in Haber and Leatham's tracings of RBBB between the first and last component of the first sound; this was obviously the b component that was attenuated by too high frequency filtration.

It should be remembered that 1) a close splitting of the first sound (I\(_a\)–I\(_b\)) is present in a large number of normal subjects so that only a widening of such splitting would represent abnormality; 2) that a wide splitting is frequent
in old subjects (Ia-Ie) due to a small b component and a large c component; 3) that specific names applied to certain components are not necessarily correct unless there is constant correlation with dynamic events; 4) that normal tricuspid closure may occur either simultaneously with or after mitral closure, as proven by animal experiments\(^{13}\) and by echocardiograms in normal subjects;\(^{18,19}\) 5) that tricuspid closure coincides with the second component of the first sound only in a percentage of normal subjects, as proven by echocardiography,\(^{18,19}\) while aortic opening coincides with this component in all of them\(^{18,19}\) confirming our animal studies of pressure and flow.\(^{8}\)

Our present study was made in patients who only had bundle branch block caused by ischemic heart disease and no other myocardial or valvular lesions. Our finding generally confirm those of Oravetz et al.\(^{11}\) They are the followings:

1. The timing and intervals of the three components of the first sound are normal in RBBB and so is the timing of the upstroke of the arterial pulses; while the b component is often decreased, the c component is increased.

2. The three components of the first sound are delayed in LBBB over onset of QRS but the intervals separating them are still normal. The upstrokes of the arterial tracings are also markedly delayed in this type of block. The amplitude of the first sound is reduced.

The statements regarding splitting of the first sound in RBBB can be explained as based on the recording of a normal first (a) and an increased third (c) component of the first sound (Table II). In regard to LBBB, the first sound is often decreased\(^{9,17}\) or difficult to record, and special care is needed for finding the best area of recording of the three components. When this is done, the delay of the total first sound, the normal intervals between components, and the reduced amplitude of this sound become obvious (Tables I and II).

The above results add new evidence to the concept that the various components of the first heart sound originate only in the left heart and aorta; that they are delayed in LBBB; that no right heart vibration precedes them in LBBB as it should if the right heart were capable to produce one and transmit it to the chest wall; and that no typical abnormality of the first sound occurs in RBBB.

In conclusion, no typical and abnormal splitting of the first sound can be found in cases of either right or left bundle branch block.
REFERENCES

22. Luisada AA: The Sounds of the Normal Heart. W. H. Green, St Louis, p 59, 1972