The Significance of Changes in Amplitude of the First Heart Sound in Children with A-V Block

By Martin A. Shearn, M.D., Elizabeth Tarr, M.D., and David A. Rytand, M.D.

Curves which relate the peak intensity of the first heart sound to the P–R interval have been obtained from seven children with complete A-V block. The first sound is accentuated with short P–R intervals, becomes faint when the P–R interval is in the neighborhood of 0.20 to 0.30 second, and becomes loud again with relatively long P–R intervals. Repeated observations over a number of years demonstrated the effects of growth and aging on these phenomena. The data appear to indicate that the variable intensity of the first sound in complete A-V block is related to the position of the mitral valve at the time of ventricular systole.

Although the variable intensity of the first heart sound in complete A-V block has been recognized for years, the mechanism of this phenomenon is still not thoroughly understood. Previous studies\(^1\), \(^2\) have suggested that a semiquantitative method of analysis of the amplitude of the first sound in relation to the P–R interval might yield information in this connection. In the present report this method has been used in a group of children with complete A-V heart block. There are several advantages in using children instead of adults for such a study. In our experience, auricular sounds are usually absent in children, and, therefore, need not be considered as a cause for accentuation of the first heart sound. Also, in children with A-V block, there is regularly a secondary zone of intensification of the first heart sound associated with long P–R intervals, a phenomenon which is not present ordinarily in adults. Finally, by repeated study over a number of years, the effect of growth and aging on the character of the first heart sound may be assessed.

Method

Phonocardiograms from the cardiac apex were recorded in recumbency during quiet respiration in seven ambulatory children aged 4 to 20 years with complete heart block. For this purpose, a Sanborn Tribeam Stethocardiette was employed. In each child there was a history which suggested the congenital origin of the heart block. One child (case 7) had tetralogy of Fallot, a second (case 5) had cor triloculare biaatriatum with dextrocardia, and the remaining five were diagnosed as having interventricular septal defects. Congestive failure was present in none of the children at the time of examination. One child was studied on three occasions, spanning a 10-year period, two other children were studied twice, and the remaining four were observed once.

The P–R intervals in consecutive ventricular cycles were measured on each record and plotted against the peak amplitude of the corresponding first heart sound in arbitrary units. The peak amplitude was used for this purpose because of its ease of measurement and because it correlates well with the loudness on auscultation.\(^3\), \(^4\) In all, 985 cycles were studied, an average of 90 cycles for each record.

Observations

The results are presented in figures 1 through 7 and the pertinent facts summarized in table 1. The dots indicate for each cycle the relationship of the peak amplitude of the first sound to the time interval between the onset of the corresponding QRS complex and that of the P wave preceding it. Where a P wave was so situated that the first sound could have been interpreted as being associated either with a long P–R or a short R–P interval, both cycles are plotted; a horizontal line is used to represent the relationship for the long P–R and a vertical line for the short R–P interval. When two or more dots occurred with identical P–R

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intervals, the mean of the observations was calculated and designated by a circle. The circles were then used as guides in drawing the curves. As a check on reproducibility of results, two separate observations in one patient on the same day were plotted and proved to be essentially identical.

Examination of figures 1 to 7 discloses a marked similarity in the pattern of all the curves. Figures 1 to 3 show that this similarity is most striking for any one patient, with the curves retaining a high degree of "personality" over a number of years. The greatest change in shape of the curve for any one individual occurs during the rapid growth phase of early childhood in case 1, but even here the alteration is more a quantitative than a qualitative one. Similar curves obtained elsewhere for young people with A-V heart block also demonstrated slight variations from one individual to another, while such curves for most elderly patients with A-V block look alike.

Surprisingly little scatter is present in most of the figures. Case 6, however, is an exception and for that reason we refrained from constructing a curve in this case. In cases 1, 5, and 7, it appears that the data at long P-R intervals are best fit by two or even three (case 1) segments of curves. Further examination of the records failed to reveal the cause for such divergence. It is suspected that this may be of respiratory origin, effected chiefly through the influence of respiration on cardiodynamics and occasionally exceeds (cases 2a, 6, and 7) the intensity of the sounds recorded in the primary zone. Between the two zones of accentuation the amplitude of the first heart sound is not "normal," but is actually considerably below that which accompanies P-R intervals in the usual range.

It was observed by Wolferth and Margolis that accentuated first heart sounds occasionally occur in cycles with short R-P intervals. Thus, it might appear at first glance that the increased amplitude is in some way related to the short R-P interval, although it should be obvious that accentuation could scarcely be the result of auricular systole which has not yet occurred. The explanation of this phenomenon is found in the secondary zone of intensification of the preceding cycle. In instances in which

### Table 1.—Data Concerning Seven Patients with Complete A-V Block

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (Yrs.)</th>
<th>Weight (Kg.)</th>
<th>Number of Cycles</th>
<th>Interval (Sec.)</th>
<th>P-R interval at peak of primary zone of accentuation (sec.)</th>
<th>P-R interval at end of primary zone (sec.)</th>
<th>P-R interval at onset of secondary zone (sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>4</td>
<td>15</td>
<td>81</td>
<td>0.52</td>
<td>1.12</td>
<td>0.09</td>
<td>0.18-0.25</td>
</tr>
<tr>
<td>1b</td>
<td>9</td>
<td>36</td>
<td>186</td>
<td>0.66</td>
<td>1.30</td>
<td>0.07</td>
<td>0.21-0.31</td>
</tr>
<tr>
<td>1c</td>
<td>14</td>
<td>54</td>
<td>137</td>
<td>0.80</td>
<td>1.62</td>
<td>0.09</td>
<td>0.28-0.36</td>
</tr>
<tr>
<td>2a</td>
<td>15</td>
<td>59</td>
<td>38</td>
<td>0.85</td>
<td>1.58</td>
<td>0.10</td>
<td>0.20-0.26</td>
</tr>
<tr>
<td>2b</td>
<td>20</td>
<td>75</td>
<td>80</td>
<td>0.81</td>
<td>1.25</td>
<td>0.13</td>
<td>0.20-0.42</td>
</tr>
<tr>
<td>3a</td>
<td>16</td>
<td>42</td>
<td>111</td>
<td>0.63</td>
<td>1.34</td>
<td>0.06</td>
<td>0.20-0.54</td>
</tr>
<tr>
<td>3b</td>
<td>19</td>
<td>45</td>
<td>102</td>
<td>0.70</td>
<td>1.50</td>
<td>0.08</td>
<td>0.23-0.58</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>19</td>
<td>50</td>
<td>0.84</td>
<td>1.32</td>
<td>0.11</td>
<td>0.23-0.31</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>27</td>
<td>50</td>
<td>0.58</td>
<td>0.80</td>
<td>0.08</td>
<td>0.26-0.28</td>
</tr>
<tr>
<td>6</td>
<td>13</td>
<td>41</td>
<td>100</td>
<td>0.92</td>
<td>1.82</td>
<td>0.11</td>
<td>0.08</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
<td>55</td>
<td>50</td>
<td>0.80</td>
<td>1.04</td>
<td>0.11</td>
<td>0.31</td>
</tr>
</tbody>
</table>
the P–R interval corresponding with the time of onset of the secondary zone is much shorter than the P–P interval, it is apparent at once that the succeeding auricular cycle could play no part in the phenomenon of sound intensification. This is the situation in case 1, where the onset of the secondary zone in the three observations accompanies P–R intervals of 0.25 to 0.36 second with P–P intervals of 0.52 to 0.80 second. A similar relationship obtains in case 2, and it is therefore highly unlikely that an error of interpretation would occur in cases 1 and 2. This is not so in case 3, however, where the onset of the secondary zone occurs with P–R intervals only a little shorter than the P–P intervals. Figures 3a and 3b illustrate how this late secondary rise (represented by the broken line) immediately precedes the primary zone of accentuation of the next cycle, so that it might appear as if the accentuated sound were related to the negative P–R (R–P) interval.

There appears to be a relationship between growth and aging of the subject and the onset of the secondary zone; that is, with passage of time, the secondary zone appears at progressively longer P–R intervals.

In elderly patients with complete A–V block the secondary zone is most often absent; it was present in only one of the patients studied in a previous report. We have recently seen a 55 year old man with complete heart block which was first noted during the course of mumps, in whom a secondary zone, with late onset (0.6 second), was present. Of a total of 13 elderly patients, with the exception of these two, the curves for elderly patients with complete heart block are dissimilar from those of children with respect to the secondary zone of accentuation. The delay in the appearance of the secondary zone with aging is readily seen in the observations in case 1, in which the P–R interval associated with the onset of the secondary zone increased from 0.25 second to 0.37 second at the ages of 4 and 14 years, respectively. Figure 8 shows the relationship of the onset of the secondary zone to both weight and age in the 11 observations. In view of the fact that the point taken to represent

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**Fig. 1.** Relationship between peak amplitude of first heart sound, in arbitrary units, and P–R interval in seconds. Each dot represents one cycle. (a) Case 1, age 4 years. (b) Case 1, age 9 years. (c) Case 1, age 14 years.
CHANGES IN AMPLITUDE OF FIRST HEART SOUND

Fig. 2. Relationship between peak amplitude of first heart sound, in arbitrary units, and P–R interval in seconds. Each dot represents one cycle. (a) Case 2, age 15 years. (b) Case 2, age 20 years.

Fig. 3. Relationship between peak amplitude of first heart sound, in arbitrary units, and P–R interval in seconds. Each dot represents one cycle. (a) Case 3, age 16 years. (b) Case 3, age 19 years.

Fig. 4. Relationship between peak amplitude of first heart sound, in arbitrary units, and P–R interval in seconds. Each dot represents one cycle. Case 4, age 5 years.

the onset of the secondary zone is at best an estimate, we feel it is not worthwhile subjecting the data to statistical analysis. The data in figure 8, however, disclose that a better relationship exists for age than for weight.

With regard to the P–R interval corresponding to the primary zone of intensification, the data reveal no appreciable difference in the various age groups. A range of 0.06 to 0.13 second is encountered, with a mean of 0.09 second. This may be compared with a range of 0.09 to 0.14 second for a similar relationship noted in elderly patients with complete A–V block.
The P–R interval which occurs at the junction of the zone of primary accentuation with that of minimal intensity of the first heart sound varies but little in the cases studied. The range is from 0.18 to 0.28 second and there is little if any relationship to either age or weight.

**Discussion**

Several theories have been advanced in explanation of the varying intensity of the first heart sound. It is held by some that accentuation of sound is an additive phenomenon. Cossio and Fongi have stated that “when the auricular sound coincides by chance with the sound that appears at the beginning of the ventricular systole, both acoustic phenomena are added and in this case the first sound acquires unusual intensity.” In the present study auricular sounds were not heard in any of the subjects in spite of careful auscultation, and corresponding vibrations did not appear except with very high amplification, when minute vibrations were detected. Under these circumstances the first auricular vibrations followed the onset of the P wave by 0.13 second, while the second vibrations occurred after 0.29
second. Although the first component of the auricular vibrations occurred at the time of the primary zone of accentuation, the second component, which was identical with the first, occurred during the time when the first sound was at its lowest amplitude. Because auricular sounds are so frequently heard in adults with complete A-V block, the absence of auricular sounds in these children was quite striking. Since, to the best of our knowledge, this dis-

![Diagram](chart.png)

**Fig. 9.** Time relationships after onset of P wave of movements of the mitral valve’s septal cusp in the perfused cat heart (above, after Dean), compared with curve relating amplitude of first sound to the P-R interval in case 1a (below). Data from the patient have been corrected by the addition of 0.03 second, the interval observed in this patient as that from the onset of the QRS to the onset of the first heart sound.

tinction between children and adults with A-V block has not been made heretofore, we surveyed the literature and found that auricular sounds have been noted only rarely in children with complete heart block. In any event, accentuation of the first heart sound in the subjects of the present study could scarcely have been due to any additive auricular factor since auricular sounds were inaudible in all.

Another commonly encountered belief regarding variations in the intensity of heart sounds is that the sounds are related to the strength of muscular contraction; louder sounds are therefore expected to occur when cardiac contractions are stronger and vice versa. In actual fact, the reverse is often true. For example, in certain patients with auricular fibrillation, the first sound is found to be diminished after long diastolic pauses despite the greater force of contraction. In complete A-V block, the force of contraction with each beat is constant as judged by arterial pulse waves, yet marked variations in the amplitude of the first sound are observed.

Although there is still disagreement as to the cause of the first heart sound, the data from this and other studies strongly support the concept that the mitral valve is the primary factor in the genesis of the sound. In 1933, Dock, through his now classic experiments, redirected attention to the fact that the first heart sound is almost solely valvular in origin. He demonstrated that the first heart sound virtually disappeared following the immobilization of the auriculoventricular leaflets, despite continued forceful ventricular contraction. These findings have been confirmed by Luisada and co-workers as well as by Smith, Essex and Baldes. The valvular hypothesis relates changes in the intensity of the first sound to variations in the position of the valves at the time of ventricular systole. It is believed that accentuation of the first heart sound takes place whenever “systole occurs at an instant when inflow from the auricle is pushing the valve toward the apex and separating the leaflets as much as possible.” If the position of the valve is the determining factor in heart sound, it is then helpful to know the movements of the mitral valve throughout the cardiac cycle.

In this regard, the work of Dean with perfused cat heart remains unchallenged. He showed that the septal cusp of the mitral valve underwent slight upward movement during the last moments of passive filling, then sharp downward opening movement with auricular contractions; after that there occurred an upward incomplete closure followed by a secondary downward drop, though not as far down as in auricular systole. In figure 9, Dean’s results are shown diagrammatically and compared with the curve derived from case 1a, the youngest and smallest patient in this group. Despite the difference in size between cat and
human heart, the agreement in the two curves is strikingly close. Moreover, the fact that the P–R interval at the maximal peak amplitude of the first sound is relatively constant both within the present group of small children and among adults\textsuperscript{2} further justifies this comparison. It can be seen that the occurrence of the two zones of loud heart sounds coincides with the time when the valves are open widest and that the zone of faint heart sounds occurs when the valves are almost closed. This close correlation between the heart sound and valve position seems to us to be fairly strong evidence in support of the valve position being the most important cause of the variations in the heart sounds.

Since we have been relating heart sounds to P–R intervals throughout this study, it should be understood that the P–R interval was not taken to represent its literal mechanical counterpart, but was rather employed as a readily measurable, convenient timing device. The relationship of electrical to mechanical events in the cardiac cycle has been the subject of intensive investigation.\textsuperscript{15–18} It was found\textsuperscript{18} that the interval from the onset of the P wave to the onset of auricular systole averaged 0.09 second in essentially normal subjects. From the start of auricular systole to its peak takes about 0.05 second,\textsuperscript{15, 17} so that auricular systole reaches its maximum about 0.14 second after the onset of the P wave. The large vibrations of the first heart sound may be taken roughly to represent the onset of ventricular systole. In our patients the mean interval from the onset of the QRS to the onset of the first sound was 0.035 second. If this interval is added to the mean peak amplitude at the primary zone of accentuation it is seen that the loudest sounds occurred 0.125 second after the P wave or during the time when the auricle is reaching its maximum contraction. Thus it seems evident that intensified sounds are produced when ventricular contraction occurs at a time when the A–V valves are being widely separated.

In regard to the belief expressed by Wolferth and Margolies\textsuperscript{19} that the amplitude of the first sound is related to the rate of rise of intraventricular tension, it is of some interest to note that in right ventricular pressure curves in case 7 obtained by Dr. Herbert N. Hultgren in cardiac catheterization, no correlation could be found between the rate or height of rise and the P–R intervals of the associated cycles.

When the curves are examined in the light of mitral valve movement, there appears to be an explanation for the change in the shape of the curves over the years. Since the secondary zone is related to the secondary floating-apart of the valve leaflets, its onset at progressively later time intervals with the passage of time would indicate that with aging the valves delay longer in the approximated position before floating apart. It follows, then, that the absence of the secondary zone in adults\textsuperscript{2} with A–V block implies a failure of the secondary separation of the valves. Since movement of the valve leaflets is most probably related to thinness and flexibility, the delay and eventual disappearance of the secondary zone of intensification would be due to a loss of flexibility of the valve leaflets with aging. It is obvious too that A–V valves should be wider apart or open more of the time during diastole in the young than in the old, since flow of blood through the heart is relatively (allowing for size) greater in the young.

**Summary**

1. The peak amplitude of the first heart sound has been analyzed with regard to the P–R interval in 985 cycles of 11 phonocardiograms of seven ambulatory children with complete heart block. Repeated observations were obtained in three of the subjects.

2. Qualitatively similar curves were obtained for all the subjects. These show two zones of accentuation of the first heart sound, the first at short and the second at long P–R intervals. Between the two zones the amplitude of the first sound is diminished below normal. The intensity of the heart sound in the secondary zone of accentuation occasionally exceeds that of the sounds in the primary zone. The secondary zone of intensification is believed to account for the loud heart sounds occurring in cycles in association with short R–P intervals.

3. With advancing age, the secondary zone of accentuation occurs with increasingly long P–R intervals. Despite this change, the curves
for each individual retain their characteristic configuration over the years.

4. The P-R intervals which correspond to the maximal and to the minimal intensity of the first sound show little variation in different subjects and do not appear to be influenced by aging.

5. In no case could auricular sounds be heard, although tiny vibrations corresponding to two components of auricular activity could be identified in the tracings. Accentuation of the first sound, therefore, is not the result of simple addition of sounds.

6. It appears from these and other studies that loudness of the first sound is related to position of the A-V valves at the onset of ventricular systole. If this is so, the results suggest that the leaflets of children, but not those of adults, open widely again following their narrowing or closure after the conclusion of auricular systole. This might be related to greater flexibility of the leaflets in the young, and is compatible with diminution in cardiac index associated with aging.

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SUMARIO ESPAÑOL

Curvas se han obtenido en siete niños con bloqueo A-V completo que relacionan la intensidad máxima del primer ruido cardíaco con el intervalo P–R. El primer ruido cardíaco se intensifica con intervalos P–R cortos, se disminuye cuando el intervalo P–R se encuentra en la vecindad de 0.20 a 0.30 segundos, y se intensifica nuevamente con intervalos relativamente largos. Observaciones repetidas por un número de años demostraron los efectos de crecimiento y edad en estos fenómenos. Los datos aparecen indicar que la intensidad variable del primer ruido cardíaco en bloqueo A-V completo se relaciona a la posición de la válvula mitral al tiempo del sístole ventricular.

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