The Effect of Cycle Length on the Time of Occurrence of the First Heart Sound and the Opening Snap in Mitral Stenosis

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Phonocardiography is often more valuable than electrocardiography in timing mechanical events in the cardiac cycle. This study shows that the opening and closing of the mitral valve are related to the length of the previous heart cycle as demonstrated by the variations occurring in auricular fibrillation. These variations in valve action are controlled by the pressure gradient between left auricle and ventricle.

The vibrations of the heart sounds are an immediate manifestation of various mechanical activities of the heart, and, when suitably recorded, provide an excellent way of timing events which comprise the cardiac cycle. It is important, therefore, to recognize the effect of disease on the time of occurrence of these vibrations, their probable mode of production, and their relationship to other events in the cardiac cycle.

It is agreed by most observers that the beginning of electrical activity in the heart muscle precedes mechanical activity as manifested by the vibrations of the first heart sound. However, this discrepancy between mechanical and electrical events is more apparent than real. The spread of electrical activity in the myocardium occurs with extreme rapidity and, while mechanical contraction probably begins almost simultaneously, a short interval of time is required to produce a significant shortening of the muscle fibers. During this initial phase of ventricular systole, a few low intensity, low frequency vibrations occur (first component of the first heart sound). These are followed by a group of large amplitude vibrations (second and third components), which comprise the main vibrations of the first heart sound. The beginning of these latter vibrations is generally accepted as being due to atrioventricular valve closure and time this event rather precisely. It is these large amplitude vibrations of the first heart sound, and therefore atrioventricular valve closure, which follow the beginning of electrical activity by an appreciable interval. The initial low frequency, low amplitude vibrations, which precede atrioventricular valve closure, may not be recorded if the technic is incorrect, or may be obscured by a diastolic murmur occurring during the presystolic interval. They occur, however, whether normal rhythm or auricular fibrillation is present.

Luisada has recently pointed out that the interval between the beginning of the upstroke of the electrocardiographic R wave and the main vibrations of a simultaneously registered first heart sound may not be a constant one. The reason for this variation has not been adequately elucidated; however, it is apparent that a delay in atrioventricular valve closure would increase this interval.

Opening of the atrioventricular valves results in certain vibrations related to the second heart sound (fourth component). These vibrations are frequently audible in mitral stenosis and are easily identified on an adequately recorded phonocardiogram. Margolies and Wolferth found that in patients with auricular fibrillation and mitral stenosis the time of occurrence of this sound (designated as the "opening snap" of the mitral valve) in relation to the beginning of the second heart sound varied with the pre-
ceeding diastolic interval, tending to become shorter as the preceding cycle duration decreased.

In a recent analysis of 55 cases of mitral stenosis, it was found that many of these cases showed a delay in the beginning of the main vibrations of the first heart sound with regard to the beginning of the upstroke of the R wave of a simultaneously recorded electrocardiogram. This indicated a delay in closure of the mitral valve and suggested two possible explanations: (1) that stiffening of the mitral leaflets rendering them less pliable might slow their movement or closure, or (2) that an increase in left atrial pressure might appreciably delay the mitral valve closure, since left ventricular pressure must exceed that in the left atrium in order to effect valvular closure.

The following study was undertaken in order to determine if the variations noted by us and others were chance variations or were significantly related to changes in the cardiac cycle affecting left atrial pressure. Patients with auricular fibrillation and high grade mitral stenosis were selected in order to exclude the effect of atrial contraction on intra-atrial pressure at the beginning of ventricular systole and to obtain frequent variations in cycle length.

**Method of Study and Results**

Six sets of phonocardiograms were taken on 5 patients with auricular fibrillation and well-developed mitral stenosis; on one of the 5 patients, the records were retaken two years later (cases 64 and 338). Limb lead II of the electrocardiogram was recorded simultaneously as a reference tracing; although we realize a part of the QRS complex may be isoelectric in this lead, the error would be a constant one and would not affect the calculations in this study. The time between the beginning of upstroke of the R wave of the electrocardiogram and the beginning of the main vibrations of the simultaneously registered first heart sound was measured and correlated with the length of the preceding R-R interval of the electrocardiogram. The time between the beginning of the main vibration of the second heart sound and the beginning of the opening snap of the mitral valve was measured and correlated in a similar fashion with the preceding R-R interval of the electrocardiogram.

The results, with the coefficients of correlation for both variables and their standard error, are shown in table 1. It is apparent from these figures that a significant degree of correlation exists between the preceding cycle length as measured by the R-R interval of the electrocardiogram and the beginning of the R wave–first sound interval as well as the second sound–opening snap interval. For the purpose of this study a linear correlation was assumed; although it is probable that at the extremes of cycle length both variables approach maximum

<table>
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<th>Case Number</th>
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<th>Coefficients of Correlation</th>
<th>Standard Error</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>QRS–First Sound</td>
<td>Second Sound–Opening Snap</td>
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<tr>
<td>64</td>
<td>20</td>
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<td>0.8</td>
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<tr>
<td>302</td>
<td>43</td>
<td>-0.3</td>
<td>0.6</td>
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<tr>
<td>303</td>
<td>37</td>
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</tr>
<tr>
<td>338</td>
<td>22</td>
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</tr>
</tbody>
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and minimum values beyond which no variation occurs.

When the preceding cycle length is short the vibrations of the first sound are delayed with respect to the beginning of electrical activity and, as the preceding cycle length increases, the beginning of the R wave–first sound interval decreases. When the preceding cycle length is short, the second sound–opening snap interval is short and as the cycle length increases, the second sound–opening snap interval increases. Figure 1 illustrates these findings.

Additional evidence of the importance of left atrial pressure is provided by the following observations on the duration of the mitral diastolic murmur. When diastole is very long the murmur begins with the opening snap of the
mitral valve, reaches its maximum intensity very soon, then gradually decreases in intensity, completely fading out before the first heart sound. If diastole is short, the murmur begins in the same manner; however, since there is not sufficient time for the left atrium to empty before the next systole, the murmur lasts throughout diastole to the very beginning of the first heart sound. Under the latter condition, the murmur is not only presystolic but, since the

**Fig. 1.** A. Continuous apex phonocardiogram, apex cardiogram and electrocardiogram showing the variation of the first heart sound and the opening snap (OS) of the mitral valve with the preceding cycle length. There is a low intensity systolic murmur (SM) and a more intense low frequency diastolic murmur (DM).

B. Phonocardiogram recorded at the apex, venous pulse and electrocardiogram. During the short diastolic interval the diastolic murmur continues after the beginning of electrical activity up to the delayed first heart sound.
beginning of the first sound is delayed, actually extends for a short interval after the beginning of electrical systole (figure 1B).

While the correlation between the beginning of electrical activity and the beginning of the first heart sound is an inverse one, the relationship between the beginning of the second sound and the opening snap of the mitral valve is a direct one. When the preceding cycle length is short, the second sound—opening snap interval is short and increases directly with the duration of the preceding cycle length.

DISCUSSION

Luisada, in discussing the influence of cycle length on the time of occurrence of the first heart sound, suggested that "in some cases of auricular fibrillation when diastole is very short, the contraction of the ventricles is slightly delayed. This differing relationship between the electric and acoustic waves seems to point to the possibility of a dissociation between excitation and contraction of the ventricles." Our findings indicate there is no dissociation between electrical excitation and the beginning of mechanical contraction, but rather a delay between the beginning of contraction and the time of closure of the mitral valve. This delay is due to the time required for sufficient muscular tension to develop so that the left intraventricular pressure exceeds that in the left atrium. It is unlikely that stiffening of the mitral leaflets contributes to this delay since there is no delay when the preceding cycle length is great.

Measurements of left atrial pressure in patients with well-developed mitral stenosis have shown this pressure to be markedly elevated. Variations in the length of the cardiac cycle occur mainly at the expense of diastole. When diastole is short, less time is afforded the blood of the left atrium to pass through the narrowed mitral orifice; hence, at the beginning of the subsequent systole, mitral valve closure is not effected until left intraventricular tension exceeds that in the atrium. This is manifested by a delay in the beginning of the main vibrations (second component) of the first heart sound with respect to the beginning of electrical activity. The reverse of this takes place when diastole is long because left atrial emptying is more nearly complete at the beginning of the succeeding ventricular systole. Additional evidence of the importance of left atrial pressure and its relation to diastolic emptying time is shown by the configuration of the mitral diastolic murmur. When diastole is short this murmur continues with undiminished intensity to the beginning of the delayed first heart sound, but fades completely before the occurrence of the first sound when diastole is long.

The opening snap of the mitral valve was found to occur at varying times with regard to the second heart sound by Margolies and Wolferth. They suggested that the effect of the previous cycle length on the atrioventricular pressure gradient was the determining factor. Our finding of a significant correlation between the second sound—opening snap interval and the preceding cycle length confirms this view. Furthermore, the close correlation between this interval and that of the beginning of the upstroke of the electrocardiographic R wave—first sound interval with the preceding cycle length indicates a common mechanism is responsible for both. The second heart sound times precisely the closure of the semilunar valves and occurs when the ventricular pressures fall below that in the pulmonary artery and aorta. The beginning of ventricular diastole (relaxation) follows this event, and the mitral valve opens at the point where ventricular pressure falls below that in the left atrium. Following a short diastolic interval, left atrial pressure remains high during systole and, therefore, the mitral leaflets are forced open earlier during the succeeding diastole. If the preceding cycle length is long, the above factors do not occur and the interval between the second heart sound and the opening sound of the mitral valve increases.

The variations of these two intervals and their close correlation with the preceding cycle length confirm the importance of the atrioventricular pressure gradient as the determining factor. If stiffening of the mitral leaflets played an important role, the preceding diastolic interval should have little or no effect on these intervals. Furthermore we would not expect the beginning of the electrocardiographic R wave—first sound interval to be increased.
when in the same cycle the second sound-opening snap interval is decreased.

These findings confirm the clinical experience that patients with well-developed mitral stenosis do not tolerate rapid heart rates. When the diastolic interval is long enough for the left atrium to discharge its contents into the left ventricle even high grade mitral stenosis may be well tolerated. Tachycardia due to any cause, emotion, effort, infection, or an abnormal rhythm, is frequently sufficient, in these patients, to produce severe attacks of pulmonary engorgement and edema due to incomplete left atrial emptying.

SUMMARY AND CONCLUSIONS

1. Phonocardiograms registered simultaneously with the electrocardiogram on patients with auricular fibrillation and mitral stenosis show that the temporal relationships of the sounds produced by the opening and closing action of the mitral valve bear a relationship to the duration of the preceding cardiac cycle. When the preceding cycle length is short, the mitral valve closure is delayed with respect to the commencement of electrical activity (the beginning of the upstroke of the electrocardiographic R wave). Also, the interval between the second heart sound component (closure of the semilunar valves) and the opening snap of the mitral valve is shortened.

2. Evidence is presented which shows that in mitral stenosis the factor which relates preceding cycle length to the time of occurrence of the sounds of mitral valve closure and opening is the atrioventricular pressure gradient between the left heart chambers.

3. Due to the fact that the time intervals between electrical and mechanical cardiac events are variable and dependent upon the preceding cycle length, the usefulness of the electrocardiogram as a reference tracing for the precise timing of mechanical events is limited.

4. A suitably registered phonocardiogram provides a more accurate reference tracing for timing mechanical events in the cardiac cycle than does an electrocardiogram.

REFERENCES

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