Spread of the "Mitral" Sound over the Chest
A Study of Five Subjects with the Starr-Edwards Valve

By P. M. Shah, M.D., D. M. MacCanon, Ph.D.,
and A. A. Luisada, M.D.

In spite of evidence to the contrary, it is commonly held that closure of the A-V valves is primarily responsible for the first heart sound. A recent study by Faber and Burton measuring the exact time of arrival of the two components of the first sound at different locations over the precordium, showed that the first component arrived about 0.85 to 2.45 msec. sooner at the apex (so-called "mitral area") than on any other location. Assuming that the mitral valve was the source of this component, the authors confirmed the apical area as the "secondary source" for sounds arising at the mitral valve. Similarly, the second component was noted as arriving sooner at the fourth left interspace near the sternal edge (so-called "tricuspid area"), and this area was called the "secondary source" for sounds arising at the tricuspid valve.

Recent experiments in our laboratory demonstrated that mitral valve closure precedes the first component by an average of 28 msec. and is not primarily responsible for it. Also, the second component of the first sound, in our studies, was unrelated to tricuspid valve closure. These observations have been independently confirmed by other investigators.

In view of the disagreement regarding the precise source of the first heart sound, it seemed desirable to study the transmission characteristics of an artificial sound generated at the mitral valve. Such a circumstance fortunately arises in patients with a Starr-Edwards valve replacement of the mitral valve. The caged ball-valve generates audible sound vibrations at the onset of systole and in early diastole, corresponding to the closure and opening of the valve. Theoretically, if the mitral valve is the primary source of the normal first heart sound, the transmission characteristics of the abnormal sound produced by the Starr valve at the mitral ring should be similar to those described for the normal.

Transmission characteristics of these sounds over the precordium were studied in five patients with a Starr-Edwards valve at the mitral ring by a technic similar to that described by Faber and Burton.

Material and Methods

Five patients with caged ball-valve prosthetic replacement of the mitral valve were studied. Their ages ranged from 22 to 54 years. Two were men and three women. Four of these patients had been operated on 6 to 12 months prior to the present study. Follow-up studies in all these patients demonstrated a progressive functional improvement with marked reduction in heart size. The cardiothoracic ratio in the recent films was 45 per cent, 60 per cent, 52 per cent, and 60 per cent, respectively. The remaining patient was studied three weeks after his operation. Though his heart size was still large (C/T ratio 62 per cent), he was symptomatically improved. All the patients were examined clinically to evaluate the sounds produced by the ball-valve and the possible presence of residual valvular lesions.

Apparatus

Two Sanborn dynamic microphones were tested for equaphasic and identical response. These were placed over the anterior chest wall for simultaneous recordings from different locations over the precordium. The output of the microphones was amplified by DC amplifiers (DC amplifiers of Sanborn 350-3200 ECG preamplifiers), the frequency...
**Table 1**

*Summary of Observations on the Systolic Sound of the Starr Valve*

<table>
<thead>
<tr>
<th>Case</th>
<th>Age/sex (C/T ratio)</th>
<th>Level of Starr valve (x-ray)</th>
<th>Precordial location of earliest arrival</th>
<th>Relative delay at other areas (msec.)</th>
<th>Ratio of amplitudes</th>
<th>Derived ratio at other areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22/F 45%</td>
<td>3LIS—3 cm. from the midline</td>
<td>Apex—3.6</td>
<td>3LIS : 1.2 / Apex : 1</td>
<td>4LIS : 0.75 / Apex : 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3LIS—sternal edge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>53/F 60%</td>
<td>4LIS—3 cm. from the midline</td>
<td>Apex—3.3</td>
<td>3LIS : 0.36 / Apex : 1</td>
<td>4LIS : 0.58 / Apex : 1</td>
<td></td>
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<td></td>
<td></td>
<td>3LIS—sternal edge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>36/M 52%</td>
<td>4LIS—3 cm. from the midline</td>
<td>Apex—2.1</td>
<td>3LIS : 0.9 / Apex : 1</td>
<td>4LIS : 0.96 / Apex : 1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3LIS—sternal edge</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>43/M 62%</td>
<td>4LIS—3 cm. from the midline</td>
<td>Apex—1.5</td>
<td>3LIS : 2.43 / Apex : 1</td>
<td>4LIS : 3 / Apex : 1</td>
<td></td>
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<td></td>
<td>3LIS—sternal edge</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>54/F 60%</td>
<td>5LIS—4.5 cm. from the midline</td>
<td>Apex—0.0</td>
<td>4LIS : 0.83 / Apex : 1</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4LIS—sternal edge</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

LIS, left intercostal space; RIS, right intercostal space; 0.0, simultaneous.

response of which was flat from 0 to 2500 cycles/sec. These were then filtered through a Krohn-Hite band-pass filter that cut off at 24 decibels per octave, to a maximal value of 60 decibels at 3 octave both below and above a selected frequency. The two frequencies used in the present study were two hundred to two hundred cycles/sec. and one hundred to one hundred cycles/sec. The latter was often found inadequate owing to high natural frequency of the sound under investigation. The filtered signals were displayed on a two-beam (Dumont 411) cathode-ray oscilloscope with self-contained DC amplifiers. The R wave of the electrocardiogram was used as a trigger and the
desired portion of the heart sounds was displayed. The sweep speed was increased to between 600 and 1300 mm./sec. in different observations. The speed was accurately timed with a 60-cycle/sec. signal. This speed allowed a measuring accuracy of ±0.3 msec. with the speed of 600 mm./sec., and greater accuracy with higher speeds. Starr valve vibrations from two simultaneous locations were recorded with a Polaroid camera.

Two matched microphones were secured over the precordium with rubber straps. Two locations were explored simultaneously. One was the third left interspace near the sternal edge; the other was the apex; then the fourth left interspace midway between apex and left sternal edge; and then the fourth right interspace near the sternal edge. The systolic and diastolic vibrations of the Starr valve were recorded at frequencies of 200 and 100 cycles/sec., respectively. Following the initial recording, the position of the two microphones was interchanged to evaluate the influence of possible difference in strap tension.

The systolic ("closing") and the diastolic ("opening") sounds of the Starr valve were carefully studied for the relative time of appearance over the different locations on the precordium, and for their relative amplitudes.

The maximum amplitude of the vibrations was correlated at two areas where simultaneous recordings were made. These were expressed as ratios for each individual sound studied, since absolute comparisons are invalid in view of considerable cycle-to-cycle variation in the amplitude of the sound. This was particularly relevant for patients with atrial fibrillation.

**Results**

On clinical auscultation, all patients had loud high-pitched clicking sounds heard early in systole and in diastole, respectively, corresponding to the closure and opening of the valve. Additional soft, high-pitched sounds were heard in diastole, which were believed to be caused by the valve during ventricular filling. These sounds were heard best along the left sternal edge at the third and fourth interspaces in three subjects, and at the apex in two. Residual tricuspid insufficiency was present in one subject.

On a recent chest x-ray, the prosthetic valve was seen at the level of the third left intercostal space, about 3 cm. from the midline, in one subject; at the fourth left inter-
costal space, about 3 cm. from the midline, in three subjects; and at the fifth left interspace, about 4.5 cm. from the midline, in one.

The results of the special studies of systolic and diastolic sounds of the ball-valve are summarized in tables 1 and 2.

**Systolic Sound**

The systolic sound of the ball-valve situated at the mitral ring arrived earlier over the surface of the precordium at the third left interspace near the sternal margin than over the apex in four subjects. Average time delay at the apex varied from 1.5 to 3.6 msec. in these subjects. In the remaining patient, in whom the valve was located at the fifth left interspace, the delay was relatively small, about 0.7 msec. Recordings over the fourth left interspace midway between the apex and the left sternal margin and over the third left interspace near the sternal edge revealed that the sound arrived simultaneously at the two locations in two subjects, while it was delayed by 1.1, 0.7, and 0.6 msec., respectively, in the remaining three subjects. The

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<th>Derived ratio at other areas</th>
</tr>
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<td>3LIS : 1.4</td>
<td>4LIS : 2</td>
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<td></td>
<td></td>
<td>4LIS—0.0</td>
<td>3LIS : 0.7</td>
<td>4LIS : 1</td>
</tr>
<tr>
<td>2</td>
<td>3LIS—sternal edge</td>
<td>Apex—1.6</td>
<td>3LIS : 3.1</td>
<td>4LIS : 1.9</td>
</tr>
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<td>4LIS : 1</td>
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<tr>
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<td>Apex</td>
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<td>3LIS : 0.3</td>
<td>4LIS : 0.27</td>
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<td>4RIS : 1</td>
</tr>
<tr>
<td>4</td>
<td>3LIS—sternal edge</td>
<td>Apex—1.9</td>
<td>3LIS : 1.9</td>
<td>4LIS : 4.75</td>
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<tr>
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<td></td>
<td>4LIS—0.0</td>
<td>3LIS : 0.4</td>
<td>4LIS : 1</td>
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<tr>
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<td>4RIS—1.7</td>
<td>3LIS : 1.4</td>
<td>4RIS : 1</td>
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<tr>
<td>5</td>
<td>3LIS—sternal edge</td>
<td>Apex—0.0</td>
<td>3LIS : 1.4</td>
<td>4LIS : 1</td>
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<td></td>
<td></td>
<td>4RIS—0.6</td>
<td>4LIS : 1.2</td>
<td>4RIS : 1</td>
</tr>
</tbody>
</table>

LIS, left intercostal space; RIS, right intercostal space; 0.0, simultaneous.

*Summary of Observations on the Diastolic Sound of the Starr Valve*

**Table 2**

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sound was delayed at the fourth right interspace near the sternal edge by an interval varying from 0.86 to 2.6 msec.

Figure 1 shows the arrival of the systolic sound at various areas in a representative patient (case 1). The location of the valve in the chest x-ray of this case is shown in figure 2.

Diastolic Sound

The time delay of the diastolic (opening) sound at the apex as compared to the third left interspace was 3.2, 1.6, and 1.9 msec., respectively, in three subjects (fig. 3). In a fourth case, the sound arrived simultaneously at the two locations, whereas, in the remaining patient, it was delayed by 0.7 msec. over the third left interspace. The onset at the third and fourth left interspaces was simultaneous in all five subjects. In two subjects, it was delayed over the fourth right interspace by an interval of 0.6 to 1.7 msec., respectively, while it was simultaneous over the third left and the fourth right interspaces in one case. Simultaneous recordings at these two locations for the diastolic sounds were not made in the remaining two subjects.

Amplitude

Amplitude measurements for purpose of comparison over the different locations have been expressed as ratios. The systolic sound was larger over the third left interspace than at the apex in two subjects, was equal at two locations in one, and was smaller in two. The diastolic sound was larger in amplitude at the third left interspace than over the apex in four instances, and was smaller in one. Ratios of fourth left interspace to apex were derived by computing from the known ratios at third left interspace to apex and third left interspace to fourth left interspace. In four subjects, the systolic sound was smaller at the fourth left interspace as compared to the apex, while the diastolic sound was larger. In one instance, the relationship was reversed.

Discussion

The results of the present study clearly demonstrate that the sounds arising at the mitral valve were transmitted earliest to the surface of the third and fourth left interspaces near the sternal margin in four subjects. This site closely corresponded with the location of the Starr valve as indicated by roentgenogram in each of them. In one case, in which the valve was located at the fifth left interspace, 4.5 cm. from midline, the sound arrived simultaneously over the fourth left interspace and the apex, and almost so over these areas and the third left interspace. Further, in each subject, the systolic sound of closure of the valve was delayed more over the apex than the diastolic sound of valvular opening. This is probably not related to the position of the mitral ring because it is closer to the apex in systole and farther in diastole. The true explanation may be found either in the transmission of sound along the blood stream flowing into the ventricle during diastole, or in the different transmission characteristics of the myocardium in systole and diastole.

It is obvious, therefore, that the preferential transmission of sounds arising in the prosthetic valve at the mitral ring is probably in the form of a transverse vibration and not along a devious course. A recent study by Faber and Purvis5 on the conduction of sound
along arteries also demonstrated that most of the energy of the murmur was transmitted in the form of a transverse vibration in the aortic wall.

The exact mechanism and path of transmission of sound from the heart to the surface of the chest is not clearly understood, partly due to lack of knowledge regarding the precise source of the sound. It has, however, been observed that certain sounds arrive at some point on the surface of the chest earlier than at others. Faber and Burton,¹ in a recent study with high-speed recordings, demonstrated that the first component of the first heart sound arrived earlier at the apex while the second component arrived earlier at the third left interspace near the sternal edge. Our recent studies conducted along the same lines confirm these observations in most normal subjects, though some individual variability exists (unpublished observations). Faber and Burton¹ further assumed that the source of the first component was the mitral valve while that of the second was the tricuspid valve. On the basis of these assumptions, the apex ("mitral area") was considered the secondary source of "mitral" heart sound, and the lower left sternal edge ("tricuspid area"), the secondary source for the "tricuspid." This seemed to confirm earlier impressions that, for reasons not fully clear, vibrations arising at the mitral valve are transmitted preferentially to the apex, and those arising at the tricuspid valve, preferentially to the left sternal edge.

If such an assumption were correct, one would expect the artificial sound located at the same source to behave in a similar fashion. The present study on five subjects with a prosthetic ball-valve at the mitral ring does not seem to confirm this. In all cases, the sounds produced at the artificial valve were

**Figure 3**

*Simultaneous recordings of the diastolic sound (f 200 cycles/sec.; speed 1,100 mm./sec.) of the Starr valve (case 3) at (A) third left interspace at sternal edge (top) and apex (bottom); (B) third left (top) and fourth right (bottom) interspaces and sternal edge. The sound is delayed both at the apex and the fourth right interspace as compared to the third left.*

*Circulation, Volume XXVIII, December 1963*
recorded earliest on the surface of the chest in an area corresponding to its roentgenographic localization. The frequency components of the sound studied were in the range of 100 to 200 cycles/sec., which approximates that of the normal heart sounds. This would indicate that the first component of the first heart sound, which is known to arrive earlier at the apex, has a source other than the mitral valve.

Our results on the relative amplitudes have been somewhat variable. Since there is considerable variation of amplitude from one beat to another, the ratios of amplitudes were compared. The amplitude appeared to be variably maximal at the third left interspace, fourth left interspace, or the apex in different patients. Some uniformity was, however, noted by comparing the fourth left interspace to the apex. In four instances, the systolic sound was larger at the apex, while the diastolic sound was larger at the fourth left interspace. This may be related to the position of the mitral ring, which descends toward the apex in systole and rises in diastole. Another possible factor is the difference in proximity of the apex to the chest wall in the two phases.

Lack of uniformity in the amplitude of these sounds, as recorded over the surface of the chest, is probably related to several ill-defined factors. This serves to emphasize the limitations of interpreting amplitude as indicative of the source of the sound. Such, unfortunately, has been a common practice. Leatham, for instance, offered the location of amplitude as a proof for attributing the two components of the first heart sound as "mitral" and "tricuspid."

Since several variables affect the amplitude of a sound, as recorded over the chest wall, an accurate measurement of the time of onset of a given sound at different areas by a technic described by Faber and Burton is of great value in the study of transmission characteristics. Earlier appearance of the "mitral" sound over the third and fourth left interspaces at the sternal edge in contradistinction to the first component of the first sound seems to indicate a different source for the two sounds, the "artificial" sound being obviously related to the valve and the normal sound having a different source and mechanism.

It is fully realized that the basic characteristics of the sounds produced by the caged ball-valve are dissimilar from that of the normal heart sounds. The basis of the present work rests, however, on comparative evaluation of the source of the sounds as indicated by their points of emergence on the external surface. Even though the predominant frequency of the sounds produced by the Starr-Edward valve is much higher, vibrations in the 100- and 200-cycles/sec. frequencies were chiefly studied. This corresponds to the predominant frequencies of the rapid components of the first heart sound, which have been attributed to valvular mechanisms in the past. Under these conditions, a comparison seems valid.

**Summary**

Five subjects with prosthetic Starr-Edward valve replacement of the mitral valve were studied in order to delineate the transmission characteristics of the sounds produced by this valve. In sharp contrast to the first (so-called "mitral") component of the first sound, this sound, arising at the mitral ring, arrived earlier on the surface of the chest in the third and fourth left interspaces near the sternal edge as compared to the apex. This was well correlated to the location of the prosthetic valve as seen from roentgenogram of the chest. It is concluded that the transmission of sound from the prosthetic mitral valve is mainly in the form of transverse vibrations. Different transmission characteristics of this sound, as compared to the first component of the first heart sound, indicate a different source for the two sounds.
Acknowledgment

We are indebted to Drs. W. Dye, L. Head, J. Hunter, O. C. Julian, W. R. Meadows, W. Neville, and J. T. Sharp for their excellent cooperation in making this study possible.

References


William Withering

Withering had always been interested in geology, mineralogy and antiquarian matters. He seems to have found time for still lighter things. He frequented the bowling green at Wolseley Bridge, was a member of an amateur dramatic club which presented Shakespeare in Shakespeare's own countryside, and took part in musical gatherings, being a performer on the flute and bagpipe. He had learned to play the latter in Scotland and no doubt astonished his West Country friends with his performance on this instrument, then relatively unknown in that part of England.

Like many naturalists Withering was a lover of poetry and was particularly fond of those poets whose works contained allusions to natural objects and descriptions of scenery. It is known that at this time he read extensively in Tasso and Horace, as well as the poems of Miss Carter, Young's "Night Thoughts," and Thompson's "Seasons." He made a complete MS index of the latter for his own pocket copy. It was perhaps the study of this poem also that interested him in climatology. In any event, he began about this time to keep a meteorological journal.—Louis H. Roddis, M.D. William Withering: The Introduction of Digitalis Into Medical Practice. New York, Paul B. Hoeber, Inc., 1936, p. 23.
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