The Atrial Border Electrokymogram in Mitral Regurgitation

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Border electrokymograms of the cardiovascular silhouette in various views were obtained at approximately 1.0 cm. intervals in 28 subjects to determine the constancy and the specificity of the atrial border motion and to determine its ability to differentiate organic from functional apical systolic murmurs. Although a “plateau” curve previously reported as pathognomonic of organic mitral regurgitation was obtained in 12 of the 13 individuals with various types of heart disease and with an apical systolic murmur, identical “plateau” curves were obtained in 10 of the 15 individuals with normal hearts and with no apical systolic murmur. Atrial curves previously reported as normal were also obtained in each of the 28 subjects studied. Some of the reasons for these results, which are at variance with those reported by others, are discussed.

The clinical significance of an apical systolic murmur may not be apparent even after the most thorough studies by conventional methods. Recently, it has been suggested that electrokymographic recordings of atrial border motion in individuals with organic mitral regurgitation are pathognomonic and differ significantly from those of subjects with physiologic mitral systolic murmurs. The atrial electrokymogram in the individual with organic mitral regurgitation is said to show a curve characterized by a positive “plateau” during ventricular systole due to a sustained outward movement of the left atrial border, beginning with the initial vibrations of the first heart sound and terminating soon after the second heart sound. Such an objective finding, if present, is obviously of extreme importance.

The purpose of this report is to present our findings in 15 individuals with normal hearts and 13 with various types of heart disease in an effort to determine the constancy and the specificity of the atrial border electrokymogram in those with organic mitral regurgitation and in those without it.

Methods and Material

The improved electrokymograph described by Henny, Boone and Chamberlain was used to record the cardiovascular border movements. The subject was in the sitting position and electrokymograms were obtained of the borders of the cardiovascular silhouette at approximately 1.0 cm. intervals, in the posteroanterior, left oblique and right oblique anterior views. The position of the pickup device was noted on an outline of the cardiovascular silhouette drawn on transparent paper superimposed upon the fluoroscopic screen. An average of 25 tracings was recorded for each subject. The exposure time varied from 14 to 22 minutes (10 roentgens per minute). The carotid pulse and heart sounds were recorded simultaneously for correlation of the electrokymogram with the mechanical cardiac cycle.

Twenty-eight subjects were studied. Of these, an apical systolic murmur was present in 13. Ten of the 13 had rheumatic mitral insufficiency, one chronic constrictive pericarditis, one Ebstein's anomaly and hypertension, and one a pulmonary artery aneurysm. Fifteen of the 28 subjects had no murmurs, including one with hypertension, two with sickle cell anemia, one with a gastric ulcer, and 11 normal male medical students. A summary of the clinical data may be found in table 1.

Results

Only the electrokymograms of the atrial borders will be discussed in detail in this study. Curves reported by others to be characteristic of atrial border motion in individuals with normal hearts are recorded as N (or “normal”) in table 1; and, those having a “plateau” configuration, reported by others to be characteristic of atrial borders in individuals with organic mitral regurgitation, are recorded as P (or “plateau”). If the electrokymogram did
not reveal either a "normal" or "plateau" atrial border motion, it was recorded as a question mark (?) in table 1, for then it was either not typical of any recognized border motion or was suggestive of an arterial or ventricular one, even though the fluoroscopist thought that the pickup device was over the atrial border.

The location refers to the region of the atrium in a specific positioning of the thoracic cage. Attempts to determine these regions more specifically were defeated by the variable results obtained even in the same tracing. Slight changes in positioning of the patient with respect to the fluoroscopic screen may also be responsible for the variability of the tracings.

In 12 of the 13 subjects with an apical systolic murmur, a typical "plateau" curve was obtained in either or both oblique views and occasionally over the left third segment or

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Table 1.—Summary of Clinical Data and Electrokymographic Results

<table>
<thead>
<tr>
<th>Subject</th>
<th>Diagnosis</th>
<th>Right Oblique Anterior</th>
<th>Left Oblique Anterior</th>
<th>P-A (left border)</th>
<th>P-A (right border)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. A. K.</td>
<td>Rheumatic aortic and mitral stenosis and insufficiency.</td>
<td>Present</td>
<td>P</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>4. E. D.</td>
<td>Rheumatic mitral stenosis and insufficiency.</td>
<td>Present</td>
<td>P</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>5. A. D.</td>
<td>Rheumatic mitral stenosis and insufficiency and interatrial septal defect.</td>
<td>Present</td>
<td>?</td>
<td>N &amp; P</td>
<td>?</td>
</tr>
<tr>
<td>7. O. L.</td>
<td>Rheumatic mitral stenosis and insufficiency.</td>
<td>Present</td>
<td>N &amp; P</td>
<td>P</td>
<td>?</td>
</tr>
<tr>
<td>8. S. L.</td>
<td>Rheumatic mitral stenosis and insufficiency.</td>
<td>Present</td>
<td>N &amp; P</td>
<td>N &amp; P</td>
<td>?</td>
</tr>
<tr>
<td>15. D. F.</td>
<td>Sickle cell anemia. Normal heart.</td>
<td>None</td>
<td>N</td>
<td>N &amp; P</td>
<td>?</td>
</tr>
<tr>
<td>17. L. C.</td>
<td>Gastric ulcer. Normal heart.</td>
<td>None</td>
<td>N &amp; P</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>18. R. S.</td>
<td>Normal.</td>
<td>None</td>
<td>?</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>22. J. R.</td>
<td>Normal.</td>
<td>None</td>
<td>N &amp; P</td>
<td>N &amp; P</td>
<td>?</td>
</tr>
<tr>
<td>23. P. C.</td>
<td>Normal.</td>
<td>None</td>
<td>N</td>
<td>N</td>
<td>?</td>
</tr>
<tr>
<td>25. N. Y.</td>
<td>Normal.</td>
<td>None</td>
<td>?</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>27. J. A.</td>
<td>Normal.</td>
<td>None</td>
<td>?</td>
<td>P</td>
<td>N</td>
</tr>
<tr>
<td>28. R. S.</td>
<td>Normal.</td>
<td>None</td>
<td>P</td>
<td>X</td>
<td>?</td>
</tr>
</tbody>
</table>

(N—typical normal curve, P—typical plateau curve, ?—questionable curve).

If the electrokymogram did not reveal either a "normal" or "plateau" atrial border motion, it was recorded as a question mark (?), for it was then either not typical of any recognized border motion or suggestive of an arterial or ventricular one, even though the fluoroscopist thought that the pickup device was over the atrial border.
over the right border of the heart in the posteroanterior view. Typical electrokymograms are shown in figure 1, tracings J and L. The tracing made from a patient with constrictive pericarditis, who had an apical systolic murmur, did not have a "pleateau" curve. But normal atrial curves were also obtained in all of these patients, even at times in the same view in over the right border of the heart in the posteroanterior view. Typical electrokymograms are shown in figure 1, tracings J and L. The tracing made from a patient with constrictive pericarditis, who had an apical systolic murmur, did not have a "pleateau" curve. But normal atrial curves were also obtained in all of these patients, even at times in the same view in

A summary of these findings is given in table 1.

**DISCUSSION**

The normal atrial electrokymogram is didactically described as being composed of three waves, one occurring in atrial systole and two in atrial diastole.

The first, a downward curve, is interpreted as being due to inward movement of the contracting atrium. This wave

![Fig. 1. The electrokymograms of the various borders of the cardiovascular silhouette of a 36 year old white woman with compensated rheumatic heart disease, mitral stenosis and insufficiency, and auricular fibrillation. The phonocardiogram, obtained from the left fourth intercostal space parasternally, and the carotid sphygmogram were simultaneously recorded.](image)

which abnormal curves were previously or subsequently recorded.

Furthermore, typical "plateau" curves were obtained in seven normal male medical students and in three hospitalized patients with normal hearts, none of whom had an apical systolic murmur. A typical example of this is shown in figure 2, tracing A.

![Fig. 2. Electrokymograms of a 30 year old normal white male medical student. Note the "normal" atrial curve at position B, and 1 cm. below this, at position A, the "abnormal" one revealing a typical "plateau."](image)

is followed by an upward one coincident with the first heart sound. This movement is said to be due to the sudden stretch of the mitral valve at the beginning of the isometric contraction of the ventricle.

The succeeding downward curve is believed to represent movement of the atrioventricular septum and attached atria toward the apex. A gradual upward movement, presumably due to gradual filling of the atria, is then recorded. It continues until shortly after the second heart sound. The curve then de-
clines slowly presumably due to atrial emptying and terminates in the sharp downward movement thought to represent atrial contraction (figure 2, tracing B).

The duration of the "presystolic" inward movement recorded over the atria varied from one individual to another and even in the same individual from one time to another. The time varied from 0.04 to 0.16 second compared with the average electrical atrial contraction of 0.11 second for a cardiac cycle length of 0.80 second. This "presystolic" movement was present in two individuals with auricular fibrillation, a rhythm that is said to abolish this type of motion. The electrokymograms of one of these patients is shown in figure 1.

There was no correlation between the magnitude of the upward movement coincident with the first heart sound and the amplitude of the carotid sphygmogram (fig. 1, tracing O). This lack of correlation appears to contradict the accuracy of the assumption that this movement is related to the force of systolic contraction.

The prediction that a "plateau" curve would appear in mitral regurgitation was based upon known clinical and experimental physiologic studies in man and in animals with mitral regurgitation. Mitral regurgitation is expected to occur in incompetency of the mitral valve because intraventricular pressure exceeds that of intra-atrial pressure during the phases of isometric contraction, ejection, protodiastole, and isometric relaxation. It appears likely that maximal regurgitation will occur during the phase of systolic ejection, when the intraventricular-intra-atrial pressure difference is greatest. Volume curves in experimental mitral regurgitation actually do show that the greatest increase in left atrial volume occurs when the blood is entering the aorta whereas only a small increase occurs during isometric contraction.

This type of upward movement during systolic ejection was recorded by Chamberlain and Dock with Ruggles' cinematograph. Similar curves recorded electrokymographically are shown in figures 3A and 3B. These curves were obtained from a 13 year old girl with inactive rheumatic mitral insufficiency and slight left ventricular enlargement. Over the left atrium, an accentuated upward movement occurs coincident with the first heart sound. A downward movement follows quickly. With systolic ejection as determined by the carotid sphygmogram (corrected by 0.01 second for the lag in the air-conduction system), an upward movement begins. It rises at first rapidly and then continues a slower ascent until the peak is reached shortly after the second heart sound.

It was therefore greatly disappointing to us that in this small group, typical "plateau" curves were derived not only from individuals with organic mitral regurgitation but also from many with normal hearts. It may be true that with isolated tracings, "plateau" curves are more commonly derived from those with regurgitation than from those with normal hearts, but with multiple explorations many "plateau" curves from individuals with normal hearts will be uncovered. A statistical analysis of limited electrokymographic exploration of left atrial border movements appears to us to be without meaning.

There are many possible explanations for our results being at variance with those of others. Some of these explanations are applicable to the problem of electrokymographic border motions in general.

1. Difficulty in reading records. The records were studied as carefully as one possibly could. This criticism that appears picayune must always be raised, for electrokymograms are difficult to read because of the frequency of minor deviations in succeeding complexes.

2. Inaccurate localization of the left atrium. All fluoroscopic localizations were made by one of us (H.M.S.). We should like to emphasize that the atrium is not easy to identify in its entirety especially when it is not enlarged.

3. Misinterpretation of positional changes. Any movement of the ventricles produces a shift in the position of the atria because the two are intimately attached to each other. Furthermore, the heart is an irregular three-dimensional object that has complex simultaneous motions composed of (a) change in position as a whole, (b) contraction or relaxation and (c) rotation. All of these motions are transmitted to some extent to the atria, which in turn are undergoing their own independent
complex motions. The individual contributions of rotation, displacement and contraction of the heart cannot be determined from a one-dimensional picture of the motion of the heart. For instance, to determine the importance of positional changes on the resultant curve, electrokymograms were recorded at opposite sides of the cardiovascular silhouette of an individual.

4. Changing position of the patient. This factor may actually be an important contributing cause of (1), (2) and (3). Because of the difference in magnitude of rotational, positional and contractional changes of various portions of the heart, slight changes in the position of the subject with reference to the fluoroscopic screen may produce significant changes in the result-

![Electrokymograms](image)

**Fig. 3.** The electrokymograms of the cardiovascular borders in A, the posteroanterior view, and B, the left anterior oblique view obtained in a 13 year old white girl with inactive, compensated, rheumatic heart disease with mitral insufficiency and slight left ventricular enlargement.

with an aneurysm of the pulmonary artery proved by angiocardiography. These curves, illustrated in figure 4, indicate that an outward motion recorded on one side is accompanied by a simultaneous inward movement on the other side, regardless of the underlying anatomic structure. Perhaps simultaneous recordings of this sort may help to differentiate positional outward movements from true “plateau” movements.

5. Inability of the photoelectric cell to discriminate anatomic causes for changes in light intensity. Too often it is said that the photoelectric cell is more sensitive to changes in light intensity than the human eye and is therefore superior in detecting motion which is translated into changes in light intensity. The photoelectric cell is more sensitive than the
human eye to a change in light intensity but is less sensitive in its discrimination of the components contributing to the changing light intensity. The human eye sees the atrium moving; the photoelectric cell cannot register the change in light intensity produced by the movement of the atrium without including all changes in light intensity produced by movements of all structures beneath the photoelectric cell through the entire thickness of the chest wall. There are important structures anterior and posterior to the atrium depending upon the position of the chest wall with reference to the fluoroscopic screen which may contribute largely to changes in light intensity either in the same direction or in opposite direction to the change produced by the atrium. For instance, the atrium may partly overlap a pulmonary artery, or the aorta, or even a portion of the ventricle depending upon the relationship of the thoracic cage to the

photoelectric cell. A great vessel or ventricular curve may then be superimposed upon the atrial curve and if large enough could produce a distortion sufficient to give rise to a “plateau” curve.

For all these reasons, there is no such thing as an atrial border electrokymogram in the purest sense and interpretations of individual features of the curve derived as a single perpendicular motion is extremely difficult or impossible. Perhaps multiple simultaneous border electrokymograms or some type of quantitative electrokymogram may permit interpretations. Notwithstanding these inherent difficulties, it is also possible that an empiric analysis of a large number of electrokymograms may define those curves that do not occur in the normal.

**SUMMARY AND CONCLUSIONS**

1. Border movements of the cardiovascular silhouette in various views were recorded electrokymographically at approximately 1.0 cm. intervals in 28 subjects. The atrial border electrokymogram is discussed in detail in this study.

2. In 12 of 13 subjects with an apical systolic murmur, a typical “plateau” curve, reported by others to be characteristic of left atrial border motion in organic mitral regurgitation, was obtained in either or both oblique views and occasionally in the posteroanterior view over the left third segment or over the right border of the heart.

3. Identical “plateau” curves were obtained from the atrial borders of 10 subjects with normal hearts, including seven normal male medical students and three hospitalized individuals with no apical systolic murmur.

4. Curves said to be characteristic of atrial border motion in subjects with normal hearts were also recorded at various positions in each of the 28 subjects studied.

5. A “plateau” curve was more frequently obtained in those with organic mitral regurgitation.

6. Some explanations for these results are discussed.
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