The Ventricular Electrokymogram

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Over 200 left ventricular electrokymographic tracings were obtained in 32 normal adults, averaging more than six sites explored per individual. Records were analyzed with respect to the relationship of certain designated points to simultaneously recorded heart sounds. Considerable variability was demonstrated in these relationships both in tracings from different ventricular sites in the same individual and between comparable tracings from different individuals. The meaning of the ventricular electrokymogram and its clinical applicability are discussed in the light of these findings.

Since the development of the electrokymograph by Henny and Boone,1 many articles have appeared in the literature concerning its utilization in the study of cardiac dynamics. The resemblance between the ventricular volume curve, as obtained in the dog, and the electrokymogram has been repeatedly stressed, and the various points of the electrokymogram have been given meaning by analogy to the volume curve and on the basis of some investigations with roentgenkymography.2 However, conflicting viewpoints concerning certain phase relationships of the electrokymogram remain. These controversies, and the meanings that have been given by some to the electrokymogram, are such as to warrant further evaluation of their significance.

It is evident that significant advances in the use of the electrokymograph can be made only after complete clarification of the range of variability in tracings obtained from normal hearts. The present study concerns itself with a detailed analysis of left ventricular tracings obtained in 32 healthy young adults. A few tracings from the right ventricle in 5 normal subjects are included. Certain tracings obtained from abnormal hearts are presented in so far as they are pertinent to this analysis.

Method

The electrokymograph is a device by which graphic registrations of the movements of the heart and great vessel borders may be obtained. It consists essentially of a pick-up unit, which is mounted on a fluoroscopic screen, and a recording galvanometer. The pick-up unit contains a highly sensitive phototube and a narrow strip of fluorescent screen. The phototube converts light energy from the excited strip of fluorescent screen into electrical energy, the current thus produced being recorded by the galvanometer of an electrocardiograph. The excitation of the pick-up device is proportional to the amount of roentgen-ray transmission, the latter depending on the area, thickness and density of the tissue interposed between the x-ray tube and the slit of the pick-up. Connections are so arranged that an increase in x-ray transmission to the pick-up device causes a downward movement of the galvanometer string, and a decrease in x-ray transmission causes an upward movement of the string. Detailed descriptions of the electrokymograph are to be found elsewhere.1, 3

The equipment used in this study consisted of a Sanborn Electrolymograph with a modified mounting of the pick-up unit previously reported from this laboratory.4 The Sanborn Stetho-cardiometer was used for recording the heart sounds, which were used for time reference. Tracings were taken in midinspiration with the subjects in the upright position. The pick-up slit was placed perpendicular to the heart border so that one-third to one-half of its length fell within the cardiac shadow. The left ventricular border was explored in the postero-anterior and left anterior oblique positions. An apical tracing was obtained in the posterosuperior position and, in addition, three to four other tracings at equally spaced distances between the apex and the point of opposite pulsations. At least two other tracings were obtained from different sites on the posterior border of the heart with the patient in the left anterior oblique position. Thus, the left ventricle was explored by tracings taken from at least six different sites. The apical tracing, however, was not used for comparative measurements in this study. The heart sound pick-up device was placed in the left midaxillary line whenever possible. At no time was its position altered after satisfactory

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Aided by a grant from the National Heart Institute.

890 Circulation, Volume II, December 1949
placement while the several electrokymograms were recorded, though adjustments in its contact with the skin were sometimes necessary.

All tracings obtained were analyzed with regard to the relation of comparable points on different tracings from the same individual to fixed points on the heart sound recordings. In order to avoid existing disagreements as to the meaning of certain points on the electrokymogram, all measurable phases were labeled alphabetically. Five landmarks on the electrokymogram were chosen for measurements because of their frequency of occurrence and relative ease of identification. Figure 1 shows the five designated points in an idealized electrokymogram. During the course of this investigation it was found that in certain curves points A and B were not discernible. When this occurred, measurements were made from the middle of the upward arc preceding the major downward deflection of the electrokymogram. This point is designated as A-B.

![Diagram](image)

**Fig. 1.** Diagram on left indicates the 5 points chosen as landmarks in an idealized electrokymogram. The diagram on right indicates point references for curves in which the individual phases could not be identified. Explained in text.

(fig 1). Whenever the characteristic W shape of the trough of the electrokymogram was absent, measurements were made from the point of change in direction from a downstroke to an upstroke. This point is shown in figure 1 as C-E.

Measurements consisted primarily of relating in time points A and B to the first major deflection of the first heart sound and points C, D, and E to the first major deflection of the second heart sound. Comparisons were then made of the intervals measured in tracings taken from different points on the left ventricular borders of each individual.

**Results**

**A. Measurements**

Over two hundred left ventricular tracings were obtained in the 32 young healthy adults, averaging more than six left ventricular sites explored in each individual. Tables 1 and 2 indicate the pertinent measurements that were made, and the range of variation in these measurements from one tracing to another in the same individuals.

A breakdown of the C to D and C to E intervals illustrates the range of variation noted in measuring the various phases of the electrokymogram. The duration of the period of “isometric relaxation” was measured according to the criteria of Luisada, Romano and Torre, that is, the time interval between points C and D. Ninety-three tracings taken in the posterior-anterior position gave measurable endpoints. The C to D interval was found to vary between 0.02 to 0.14 second. The C to E interval, which is considered to be the isometric relaxation phase by Boone and associates, varied between 0.08 and 0.23 second. Thirty-one tracings showed C to D intervals of 0.10 second or more, 57 were between 0.05 and 0.09 second, and 5 measured 0.04 second or less.

In 30 cases the C to D interval could be measured at more than one site. The difference in the duration of this phase between sites in the same heart was as much as 0.05 second. Twenty-two cases showed a variation of the C to D interval between sites of 0.03 second or less, and 8 cases showed a variation of 0.04 second or more. Points C and D did not always vary in the same direction, that is, a shift of point C or D to make the C to D interval longer was not necessarily counterbalanced by a shift of the other point in the same direction.

Multiple right ventricular sites were explored in the right anterior oblique position in five cases. The maximum differences in the duration of the C to D interval from various sites in the same cases were 0.05, 0.04, 0.03, 0.02 and 0.00 second, respectively.

**B. Contour**

Our studies indicate that contour variations in ventricular electrokymograms from normal adults are numerous. Nevertheless, there is a basic resemblance between tracings and a similarity in appearance of tracings taken from the same ventricular border.

Approximately half of the cases studied showed a rather characteristic left ventricular pattern in the left anterior oblique position. These, when present, were most marked at sites on the upper half of the visible border, and
were manifest in varying degree at sites on the lower half. The contour of these tracings tended to be smoothed-out and symmetrical. Usually, at approximately the beginning of the first heart sound, the curve showed a steep ascent. The descending limb after this ascent tended to mirror the ascending wave in its early portion, so that a smooth, relatively symmetrical, upward convexity was formed. The descending limb continued with little interruption to end usually 0.12 to 0.16 second beyond the first major deflection of the second heart sound. Figure 2 illustrates the prominent convexity just described. It is seen to occur during the early systolic phase of the cardiac cycle.

The contours of tracings obtained in the posteroanterior were more variable than those in the left anterior oblique position. Figure 3 illustrates a type of contour variation frequently found on exploration of the left ventricle in the posteroanterior position. It is seen that the single early systolic upward convexity in the lower tracing splits into two as tracings are taken from successively higher points on the ventricular border, until points A and B become discrete in the upper tracing. Figure 4 demonstrates variations in contour of the early systolic phase of the normal electrokymogram which simulate abnormal contrapulsatile movements in some tracings. Other examples of contrapulsatile movements in early systole in normal electrokymograms are shown in figures 2 and 3.

Figures 2, 3, 4, 6, 7 and 8 illustrate some of the normal contour variations that may be seen in diastole. Most commonly, the end of the systolic downstroke combines with the succeeding inscriptions to form a W-shaped trough; however, a V shape is not uncommon. In 19 individuals, one or more curves obtained in the posteroanterior position manifested a V-shaped, rather than the more characteristic W-shaped trough (figs. 5, 6). One case showed such a contour in all three of the left ventricular tracings obtained above the apex, two of which
Fig. 4. Tracings from 2 normal individuals illustrating the range of contour variation found on exploration of the left ventricle in the posterior-anterior position. From below upward the tracings are taken: 1 cm. above apex, from lower, from middle, from upper, and from high up on left ventricle.
Fig. 5. Tracings on left illustrate a contour variation found in a normal individual in the posteroanterior position. Tracings on right are from an individual with aortic insufficiency. The lower curves are from the lower left ventricle; the upper curves are from the middle left ventricle. Note the absence of points C, D and E in the normal case, and their presence in the case with dynamic aortic insufficiency.

Fig. 6. Tracings demonstrate marked plateau during diastole in a normal individual, posteroanterior position. Upper curve: upper left ventricle. Lower curve: 1 cm. above apex. The curves at right were taken at a slower camera speed.

are shown in figure 5. Eight cases demonstrated the same V contour at both sites explored in the left anterior oblique position.

The D to E interval was generally manifest on the major ascending limb of the left ven-

cular electrokymogram. In some instances it became flattened or smoothed out, so as to become almost absorbed into that phase which has been designated the rapid inflow of diastole. Generally, in the posteroanterior position, the
middle of the W (point D) tended to occur at about the first part of the second heart sound; on the other hand, in the left anterior oblique position, point D (or C-E) often occurred well after the beginning of the second sound. Individuals (fig. 8). Though this phenomenon may have been initiated by a premature beat, the latter was not observed during the period of recording. The contour of alternate beats is seen to be considerably different.

**Discussion**

Variations in the contour and time sequence of events in the normal electrokymogram are considerable. It would appear that interpretation of the electrokymogram on the basis of the volume curve may be misleading. Wiggers and Katz\(^7\) have stressed the variability of contour obtained in volume curves from dog hearts by the cardiometric method. Moreover, they have stressed that the periods immediately preceding the onset of ventricular ejection and rapid filling are particularly susceptible to artefacts and that interpretations of phenomena seen in these phases of the cardiac cycle must be made with caution. In spite of these admonitions, the electrokymogram has been given meaning, often unjustified, on the basis of analogy to the idealized volume curve. Within certain limits, and subject to further experimentation, this analogy is allowable. However, it must be clearly understood that the volume curve of the textbook is a synthesis of many real curves. Movements of the dog heart into and out of the cardiometer tend to cause artefacts within the phases mentioned above. There is no reason to assume that movements of the human heart do not cause similar variations in contour in the electrokymogram.

The measurements obtained in this study

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**Fig. 7.** Tracings showing contour variations in normal individual in posteroanterior position. Lower curve: lower left ventricle. Upper curve: middle left ventricle.

**Fig. 8.** Tracings showing mechanical alternans in a normal individual. Tracing obtained from the lower left ventricle in the posteroanterior position. Note the slight alteration in the first heart sound from one beat to the next.

Some of the tracings obtained were exceptionally smooth in contour, and symmetrical. In our series, such tracings appeared more apt to occur with slow heart rates (fig. 6). Mechanical alternans was noted in two normal individuals (fig. 8). Though this phenomenon may have been initiated by a premature beat, the latter was not observed during the period of recording. The contour of alternate beats is seen to be considerably different.
indicate that there is no consistent moment-to-moment time relationship between electrokymograms obtained at various sites on the left ventricular border and the heart sounds. Presumably this inconsistency could also be present in relation to other methods of timing, such as arterial or venous pulses. In at least 29 per cent of all cases in which comparative measurements could be made, the maximum variation in the timing of particular points on the electrokymogram from different sites in the same individuals was 0.04 second or more (table 1). A consideration of the magnitude of some of the phases which have been measured by electrokymography\textsuperscript{2, 6} accentuates the percentage error possible in this method.

Though different workers have used the volume curve and certain studies in roentgenkymography to analyze the electrokymogram, there is no complete agreement on the significance of all points. Boone and his co-workers\textsuperscript{2} have designated point \( A \) (fig. 1) as the beginning of ventricular ejection. This interpretation seems reasonable in many of the tracings we have obtained. However, not infrequently, this point has been seen to be synchronous with the beginning of the first heart sound, and, in one case, this point occurred before the first heart sound (fig. 7). It is questionable, therefore, that point \( A \) consistently represents the beginning of the ejection period, since it is unreasonable to have an absent isometric contraction period in a normal heart.

The meaning of points \( C \), \( D \) and \( E \) is also the basis of some controversy. In one of their earlier papers, Boone and associates\textsuperscript{2} designated point \( D \) as synchronous with closure of the aortic valve. However, in their paper on the isometric relaxation phase\textsuperscript{6} Boone and his co-workers used point \( C \) as the closure of the aortic valve. They measured isometric relaxation from point \( C \) to point \( E \). Luisada\textsuperscript{3} differs with Boone and associates\textsuperscript{6} in that he maintains the opening of the mitral valve to be approximately synchronous with point \( D \). Both groups of workers apparently now agree that point \( C \) is the beginning of isometric relaxation. However, in our experience, there may be a considerable time difference between the beginning of the second sound and point \( C \). It is readily seen that a difference between these two landmarks of 0.04 second would cause a gross error in measurement of the isometric relaxation phase.

We have repeatedly noted that whereas one tracing taken from a particular site on the left

\begin{table}
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
Reference point & Relation to 1st major deflection of 1st heart sound to point & Relation to 1st major deflection of 2nd heart sound to point \[ A \] & \[ B \] & \[ C \] & \[ D \] & \[ E \] \\
\hline
Number of cases in which measurements could be made at multiple sites on the left ventricle & 32 & 29 & 30 & 24 & 27 & \\
Number of cases showing maximum time variation between sites of 0.00 to 0.02 second. & 15 & 13 & 16 & 13 & 9 & \\
Number of cases showing maximum time variation between sites of 0.04 to 0.06 second. & 11 & 9 & 11 & 7 & 9 & \\
Number of cases showing maximum time variation between sites of 0.06 second or more. & 2 & 2 & 3 & 3 & 5 & \\
\hline
\end{tabular}
\caption{Variations in Time Relations of Points Under Consideration to the Heart Sounds (Postero-anterior Position).}
\end{table}

\begin{table}
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
Reference Point & Relation to 1st major deflection of 1st heart sound to point & Relation to 1st major deflection of 2nd heart sound to point & \[ A \] & \[ B \] & \[ C \] & \[ D \] & \[ E \] & \[ C-E \] \\
\hline
Number of cases in measurements could be made at multiple sites on the left ventricle & 16 & 20 & 3 & 5 & — & 9 & \\
Number of cases showing maximum time variation of 0.02 second or less & 10 & 12 & 1 & 3 & — & 4 & \\
Number of cases showing maximum time variation of 0.04 second or more & 5 & 3 & 2 & 1 & — & 3 & \\
\hline
\end{tabular}
\caption{Variations in Time Relations of Points Under Consideration to the Heart Sounds (Left Anterior Oblique Position).}
\end{table}
ventricle may clearly show points C, D, and E, another site may only show a V-shaped contour which we have labeled C-E (figs. 1, 5). It is unreasonable to assume that a particular part of the ventricular musculature manifests no protodiastolic and isometric relaxation phases while another part of the muscle does undergo these phases. Phillips has stated that the V shape described is due to absence of the isometric relaxation phase, and has correlated this contour with aortic insufficiency. It is impossible to reconcile these two phenomena in the light of our experience. It is apparent that, though the V-shaped contour may be seen in aortic insufficiency, it also occurs in perfectly normal hearts (figs. 5, 6). Moreover, some studies which we have made of patients with dynamic aortic insufficiency have failed to demonstrate the immediate upstroke after the ventricular ejection phase; instead, the tracings have shown points C, D, and E. Such a tracing is depicted in figure 5. It is from a 19 year old boy with rheumatic aortic insufficiency who had a systolic blood pressure of 140 mm. Hg, and an undetermined diastolic pressure since sounds were present to 0.

Boone, Randak, Ellinger and Oppenheimer have presented evidence for their interpretation of points C, D and E by correlating simultaneous recordings of the auricular electrokymogram, the carotid pulse and the heart sounds. Luisada and Fleischner correlated the right ventricular electrokymogram, the right ventricular pressure, and the heart sounds in the dog. The present series failed to demonstrate a consistent relationship between points C, D and E and the heart sounds in tracings from the same individual. Presumably a similar variation could be expected with the carotid pulse and the auricular electrokymogram. Our evidence fails to indicate either that the points in question are directly related to valve action, or that the tracing reflects the volume curve closely enough to be more than roughly approximate. It is generally agreed that the contour changes associated with points C, D and E are due to positional changes of the heart. It may be that these points are, at least in part, due to the changes in cardiac position produced by the diastolic rebound of blood in the aorta.

The coincidence of certain valve actions and changes in the graphic recording is most likely due to positional changes occurring in approximation to the valvular phenomena, and not to the valvular phenomena per se.

Illustrative electrokymograms have been chosen to demonstrate certain contours seen on exploration of the left ventricular borders. Additional tracings are shown to present examples of variations which we have found in normal individuals and which have been called abnormal by others. They have been aligned not only to show variations in normal cases, but also to demonstrate the variations in contour which occur from one site on the ventricular border to another.

The tracings in figure 4 (left column) reveal variations in the systolic slope due primarily to contour changes in relation to point A. In the high left ventricle tracing, the systolic phase following this point is such as to simulate a variant of decreased amplitude of contraction. Many tracings we have obtained in normals are similar to illustrations and diagrams shown by Sussman and co-workers and by Luisada and associates as occurring after myocardial infarction. The latter authors make no differentiation, in their diagrams of abnormal tracings with myocardial infarction, between tracings taken in the posterolateral position and tracings taken in the left anterior oblique position. Certain of the tracings classified as abnormal are illustrated here as occurring in normal individuals. They are: (a) decreased amplitude of the ventricular wave (figs. 4 and 7); (b) early systolic distention (figs. 3 and 4); (c) late onset of ventricular systole (fig. 4); (d) presystolic distention (fig. 4); (e) early diastolic rebound (figs. 3, 4 and 7). Figure 4 (right column) illustrates, in a normal case, a contour indicated by Sussman and associates as abnormal. We have also noted that the left anterior oblique tracing in the second case reported by these workers is not unexpected as a tracing from that border.

Although many of the tracings reported by Luisada and co-workers in myocardial infarction are undoubtedly abnormal, a number fall well within the range of normal as seen in our study. The factor of standardization must be
considered when dealing with suspected abnormalities due to decreased amplitude of contraction. A few of our tracings (figs. 5, 6) are of the type considered by Gillick and associates\textsuperscript{12} to be indicative of constrictive pericarditis. Again, although this type of curve may be seen in constrictive pericarditis, it is also seen in the normal. It would appear that the demonstration of this contour is more frequent in the presence of slow ventricular rates.

The differences in contour found in tracings from different sites on the left ventricular surface indicate the need for a more careful consideration of just how closely the electrokymogram reflects the volume curve and how much it reflects only positional movements of either the whole or parts of the heart. Though it is generally agreed that the electrokymogram is not a volume curve, the resemblance between the two makes their identification extremely tempting. A combination of many factors determines the character of the tracing obtained from any particular site on the ventricular border, and the effects of certain of these factors are opposite to each other and to that of the total ventricular volume change. The influences of rotational and positional change have been noted repeatedly.\textsuperscript{2, 6, 13, 14} The latter, as mentioned above, we believe to be of primary importance in producing points C, D and E. In addition, consideration must be given to changes in configuration of the heart during the early systolic phase in producing the points found so often in the electrokymogram. Roentgenographic studies have demonstrated the preponderant shortening of the long axis of the heart during contraction so that it tends to assume a globular shape and increase its anteroposterior diameter. It is well known that the base of the heart moves toward the apex. This has been repeatedly demonstrated in this laboratory and elsewhere. Hamilton and Rompf,\textsuperscript{15} observing fluoroscopically the movements of metal markers implanted in the dog heart, and Wolfarth and Margolies,\textsuperscript{16} studying the movements of cardiac calcifications in the human heart by means of roentgenkymography, have shown the important feature of left ventricular contraction to be shortening of the long axis. Both papers note the great part played by movement of the A-V septum, not visible normally by fluoroscopy, in decreasing ventricular size during contraction. Wolfarth and Margolies also observe that, because of the preponderant shortening of the longitudinal axis of the heart, the left border may actually move outward during early systole. Roesler\textsuperscript{17} reported, on the basis of roentgenkymography studies after lipiodol instillation into the pericardial sacs of rabbits, a movement of the atrioventricular groove of one third to one fourth the total length of the heart while the border and apex moved but little. These studies would indicate that, with a stationary slit as used in electrokymography, the tracing does not depict the movement of any one point on the heart, but rather reflects the movements of the heart that occur under the slit.

The relation of various points on the electrokymogram to the phases of the heart cycle is variable. It is concluded that great caution should be used in the judgment of contour changes in the electrokymogram before considering them abnormal.

**SUMMARY**

1. Left ventricular electrokymograms from normal individuals have been analyzed with respect to the relationship of certain designated points to simultaneously recorded heart sounds.

2. Considerable variability has been shown to exist in these relationships, both between comparable tracings from different individuals and in tracings obtained from different sites on the ventricular border in the same individuals.

3. The implications of these findings are discussed with reference to the meaning of the left ventricular electrokymogram.

4. It is concluded that certain electrokymographic contours previously considered abnormal can be found in tracings from normal hearts. Caution must therefore be used in the interpretation of electrokymograms both as to contour and their depiction of the phases of the heart cycle.

**Acknowledgments**

We are indebted to other members of the department, and especially to Mr. Walter Brotherton, for assistance in carrying out these studies.
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Circulation. 1950;2:890-899
doi: 10.1161/01.CIR.2.6.890

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