Correlation of Simultaneously Recorded Electrokymograms and Pressure Pulses of Human Heart and Great Vessels

A Preliminary Report

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In order to define more precisely meaningful points on ventricular and great vessel electrokymograms, intraluminal and intracavitary pressures have been simultaneously recorded. Electrokymograms of the superior vena cava and the pulmonary artery show remarkable constancy of time relationships with simultaneously recorded intraluminal pressure curves. The ventricular electrokymogram is more difficult to define and its limitations are discussed.

Following the development of the electrokymograph by Henny and Boone, great interest in the use of this instrument as a tool in clinical investigation has been aroused. The application of this instrument to the study of many types of cardiac lesions has been reported.

During the past 18 months more than 100 normal and abnormal subjects have been studied with this instrument in our laboratory, utilizing the recorded heart sounds, the carotid sphygmogram or the electrocardiogram as the primary points of time reference. We have been impressed with the inconstancy in the timing of the electrokymographic events obtained in ventricular tracings when studied with any of the above methods. The objections to each of these timing devices are well known. Thus, the factors of variability in the carotid sphygmogram which may be consequent upon variation of the rate of blood flow, elasticity and distensibility of the vessel have been discussed. The validity of a comparison of the mechanical events in the cardiac cycle with the electrocardiogram has been called into question. The heart sounds represent a fusion of noises arising from both ventricles and are thereby limited as a timing device for events occurring separately in each chamber.

In an attempt to define more precisely the significance of the electrokymographic tracings obtained from the chambers of the heart and the great vessels in man we have undertaken a correlation of these tracings with the most direct measurements possible, the intraluminal and intracavitary pressure curves in man. Some data of this kind has been recently obtained in the dog.

Materials and Methods

Concurrent right heart catheterization and electrokymography of the cardiac silhouette were performed in 6 patients. One patient was a child of 5 in whom the diagnosis of tetralogy of Fallot was made. Another was a 68 year old man with arteriosclerotic heart disease and chronic cor pulmonale. Four patients were children of 8 to 15 years of age who were subsequently found to be normal.

Right heart catheterization was performed according to the technic previously described. The electrokymographic recordings were obtained with the patient in the recumbent position holding his breath in midinspiration.

Intraluminal and intracavitary pressures were recorded with a Sanborn electromanometer. The kymographic apparatus employed was essentially that developed by Henny and Boone as modified by Luisada and co-workers and Grossman and Tigar. Simultaneous recordings of Lead II of the electrocardiogram, intraluminal and intracavitary pressures obtained via the right heart catheter, direct brachial arterial pressure and the electrokymogram were made with a four channel direct writing Sanborn Poly-Viso apparatus.
The frequency response and sensitivity of the electrokymographic apparatus has been described elsewhere. The galvanometer response to a square wave input (damping 71 per cent of critical) is 95 per cent complete in 0.01 second. The time lag of an impulse through the catheter at 37°C was found to be 0.015 second. Therefore the time lag in the pressure and in the electrokymographic systems is approximately of the same order.

While some of the pressure pulses show artefacts, these were not serious enough to disturb the measurements made. No claim is made, however, that the pressure pulses are precise measures without phase lag of events recorded. They are adequate, none theless, for the purposes in hand, we believe.

Results

Pulmonary Artery Electrokymograms

Timing. We have compared the electrokymographic tracing obtained from the pulmonary artery with the pulmonary arterial pressure curves with respect to the points of origin of the anacrotic limb and of the dicrotic notch and the interval between these two points which delineates the ejection phase of the right ventricle.

Electrokymograms have been obtained with the slit of the "pick-up" device positioned perpendicularly to the lowest point of the main pulmonary artery (border tracing) and to the terminal 4 cm. of the indwelling catheter. The patient was placed either in the posteroanterior or left posterior oblique position.

In 3 normal cases the beginning of rise of the anacrotic limb of the electrokymogram of the pulmonary artery border (point Ak) preceded the beginning of the rise of the anacrotic limb in the pulmonary arterial pressure curve (point Ap), by an average of 0.02 second with a range of from 0.00 to 0.03 second (fig. 1). The dicrotic notch of the pulmonary arterial border electrokymogram (point Dk) followed that of the pulmonary pressure (point Dp) by an average of 0.03 second with a range of 0.01 to 0.04 second. The duration of the ejection phase, i.e., point A to point D, averaged 0.28 second with a range of 0.27 to 0.31 second in the pulmonary pressure tracings in comparable beats. This extent of variation was noted in the pulmonary artery border electrokymograms.

When the slit of the "pick-up" device was placed completely within the visible shadow of the main pulmonary artery and parallel to the terminal 4 cm. of the indwelling catheter, densograms were recorded with the following results (fig. 2). Point Ak was found either to precede, coincide or follow point Ap, ranging from preceding by 0.03 second to following by 0.07 second. The dicrotic notch, point Dk, was found to follow point Dp by an average of 0.02 second, with a range of 0.01 to 0.03 second. The duration of the ejection phase of the right ventricle as reflected in the pulmonary artery densogram was found to average 0.31 second. Comparable beats of the pulmonary artery pressure curve demonstrated a ventricular ejection time of 0.28 second.

The time relationship of the curves under consideration to the onset of the QRS deflection of the Lead II electrocardiogram were as follows: The beginning of the rise of the anacrotic limb of the pulmonary pressure curve (point Ap) followed the onset of the initial deflection of the QRS by an average of 0.08 second (corrected for time lag of 0.015), with a range of 0.05 to 0.11 second. However, in each individual case the variation was only 0.02 second from beat to beat. The electrokymogram of the border movement revealed point Ak to follow the onset of QRS by an average of 0.07 second with the same order of variation observed in the pulmonary artery.
pressure tracings. The electrokymogram of the pulmonary artery density revealed point A_k to fall off slowly. In most instances a discernible dicrotic notch is present.

**Fig. 2.** Pulmonary arterial electrokymogram (densogram tracing). Recorded at 50 mm./sec. I. Pulmonary arterial pressure (distorted by artefacts). II. Pulmonary arterial electrokymogram. III. Electrocardiogram.

**Fig. 3.** Right ventricular electrokymogram (mid-border tracing). Recorded at 50 mm./sec. I. Right ventricular pressure (distorted by artefacts.) II. Right ventricular electrokymogram. III. Electrocardiogram. See text.

follow the onset of QRS by an average of 0.06 second with a variation of only 0.02 second within a single case (fig. 2).

**Contour.** The similarity of the contour of the electrokymograms obtained from the border movement of the pulmonary artery to the density changes within the pulmonary artery is apparent. In both instances well defined, steeply rising anacrotic limbs are present. These reach a rather rounded peak and then

**Right Ventricular Electrokymograms**

**Timing.** Following the withdrawal of the catheter into the right ventricle, the patients were rotated into the left posterior oblique position. Electrokymograms of the border movement of the right ventricle were then obtained in the region of the tip of the catheter (fig. 3). The beginning of the fall in the electrokymogram, which is considered by some to represent the beginning of ventricular ejection (point E_k), may precede, coincide or follow the rise in the ascending limb of the ventricular pressure curve (point E_p), varying from 0.03 before to 0.06 second after this event. Point R_k, marking the end of the fall in the ventricular electrokymogram, varied considerably when compared with the change in slope of the fall-off in the ventricular pressure curve (point R_p), sometimes preceding and sometimes following this point. This is in part due to the difficulty in determining the point R_k on the ventricular electrokymogram. However, it may also represent errors inherent in the measurement of the ventricular pressure curves. The difficulty in accurately defining the points on the ventricular electrokymograms obtained in this study prevents the comparison of ventricular ejection times as determined by the border
electrokymogram with those obtained from intracavitary pressure tracings. It is apparent that the declining limb of the ventricular electrokymogram represents more than the motion imparted to the heart border by ventricular emptying.

Of particular interest is the change in contour of the ventricular electrokymogram with the occurrence of a premature beat (fig. 4). It will be seen that this change is accompanied by a change in the intracavitary pressure curve. In this instance the border electrokymogram closely reflects the mechanical activity of the ventricle.

**Electrokymograms of the Right Auricle and Large Veins**

In two instances, electrokymograms of the border movements of the right auricle were recorded after the catheter had been withdrawn into this chamber (fig. 5). The beginning of the fall of the A wave of the auricular electrokymogram followed the beginning of the rise of A wave of the auricular pressure curves by 0.05 second. The A waves of both the auricular electrokymogram and the auricular pressure curve bore precise relationships to the end of the inscription of the P wave of the electrocardiogram. As will be noted the other points of the auricular electrokymogram tend to follow those of the auricular pressure curve.

Figure 6 presents an electrokymogram obtained as a density recording over the superior vena cava. In this instance the patient was in the posteroanterior position and the tip of the catheter had been withdrawn into this vessel and was lying approximately 2 cm. from the slit focus of the pick-up device. It will be noted that the electrokymogram obtained shows prominent A and C waves. These waves follow their counterparts in the superior vena caval pressure curve by 0.04–0.05 and 0.07–0.09 second respectively. The P-R interval of the electrocardiogram averaged 0.16 second at this time as did the A-C interval of the electrokymogram.

**Correlation of Electrokymograms and Pressure Curves in the Presence of Intraventricular Conduction Defect**

In the course of the catheterization of a 15 year old girl, a right bundle branch system block of the “S” type appeared and persisted throughout the procedure. The bundle branch block disappeared 45 minutes after comple-
tion of the catheterization. The patient was reexamined two weeks later and electrokymograms of the cardiac chambers and great vessels obtained. At this time no evidence of defective intraventricular conduction was present. There was no evidence of organic heart disease.

The electrokymograms of the aortic and pulmonary artery borders are presented in figures 7 and 8 both during and after the production of the right bundle branch system block. During the time of block the beginning of rise in the anacrotic limb of the pulmonary artery electrokymogram followed the nadir of the R wave by 0.11 second, and the beginning of the rise of the anacrotic limb of the electrokymo-
gram obtained from border of the aortic knob followed the nadir of the R wave by 0.07 second. Following the disappearance of the block, the time relationship of the aortic electrokymogram after the nadir of the R wave of the electrocardiogram. Thus, an average prolongation in the time of onset of filling in the pulmonary artery, as judged by these measurements, of 0.04 second existed during the period of right bundle branch system block.

**Discussion**

While the data presented in this report must be considered as preliminary, certain facts are clear from the material presented.

First, the electrokymographic deflections obtained from the superior vena cava and the pulmonary artery show a remarkable constancy of time relationship with simultaneous intraluminal pressure curves. The densograms obtained over these areas follow with a somewhat greater variation. The resemblance of the contours of both the border and density electrokymograms of these vessels to the intraluminal pressure pulses is evident. Thus, these electrokymograms may be said to reflect closely the mechanical activity of the heart as it is propagated to the adjacent major vessels. Distortions due to impacts of adjacent structures appear to play an insignificant role. However, elongation and pendulum motion of the great vessels occurring with the systolic descent of the base of heart may in part explain the earlier rise of the anacrotic limb of the pulmonary artery electrokymogram over comparable points in the pulmonary artery pressure curves.

The ventricular border electrokymogram is more difficult to define. The inability to establish closely meaningful points on these tracings as compared with those in the large vessels may be responsible for this difficulty. It is apparent that the declining limb of the ventricular electrokymogram represents more than the systolic emptying of the ventricle. However, the respective contribution of isometric contraction, rotation of the heart, isometric relaxation, and other factors cannot be evaluated at this time.

Further study of this problem is in progress. It is our opinion, however, that until more complete definition of the physiologic meaning of these tracings is obtained, clinical applications must be approached with great caution.
SUMMARY

1. The correlation of electrokymographic tracings obtained from the pulmonary artery, right ventricle, right auricle and superior vena cava with simultaneously recorded intraluminal and intracavitary pressure curves is presented.

2. A case of transient right bundle branch system block produced during cardiac catheterization has been studied. Asynchronism of ventricular ejection during the period of block was demonstrated by means of electrokymography of the great vessels.

3. Electrokymographic deflections obtained from the pulmonary artery and superior vena cava show a remarkable constancy of time relationships with simultaneous intraluminal pressure curves. The densograms obtained over these areas follow with a somewhat greater variation.

4. Meaningful points on the ventricular electrokymogram are difficult to define and until more precise definition of the physiologic meaning of these tracings is obtained, clinical applications must be approached with great caution.

REFERENCES


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Circulation. 1950;2:900-906
doi: 10.1161/01.CIR.2.6.900
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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