The Kinetocardiogram

I. Method of Recording Precordial Movements

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A simple method of recording low-frequency precordial movements is presented and termed kinetocardiogram to indicate movements as the result of the motions of the heart. The normal precordial patterns are described as well as the time relationships to the cardiac cycle and ballistocardiogram.

STUDIES of the graphic representation of the apex beat are well known1, 2, 3, 4; however, they have not been widely used clinically. Recently, Johnston and Overy5 revived interest in low-frequency precordial vibrations with a review of the literature and a presentation of a few records obtained from normal and abnormal subjects. They employed an electromanometer with a pickup device that is maintained airtight against the chest. Luisada and Magri6 presented a series of similar low-frequency tracings obtained by use of a crystal microphone.

The present communication presents a simple method by which the movements of the chest wall can be recorded, and also deals with the general pattern of records obtained from young normal individuals.

METHODS

The pickup device employed is a metal bellows that transforms chest wall movements into a pulse wave in an airtight system, which in turn is transformed by a piezoelectric transducer* into an electric current. Almost any type of electrocardiographic apparatus can be used as a recorder. Figure 1 is a diagram of the apparatus. Attached to the bellows is a small metal arm approximately 1½ inches long, which has a flat endpiece 7 mm. in diameter that is placed against the chest wall. The bellows itself is approximately 2 inches in diameter, consists of two flanges, and is connected by a thick-walled rubber tubing to the piezoelectric transducer (fig. 1). Several other types of bellows were tested and, in general, were satisfactory, so that the dimension of the one used for this study is not necessarily essential. However, one should use a bellows with a relatively high degree of sensitivity, since the motions over the chest wall usually range from 5 microns in the left axilla up to 200 microns directly over the precordium. The bellows pickup, as described, responds to pure displacement of the inward and outward motions of the chest on the spot where the pickup arm is placed. Records are obtained during held end of normal expiration, thus eliminating respiratory movements. Over a wide range of motions these recordings proved to be linear in character, by comparison to a sine wave of known amplitude and frequency. Records of frequencies from 0.8 to 5 vibrations per second have been artificially produced with a fair degree of accuracy, and without appreciable fall in response. The lag in the system was found to be negligible, or less than 0.005 second. The pickup arm of the bellows is placed firmly against the chest; however, the degree of pressure need not be kept constant. Better records are obtained if the pickup is not placed on a rib, but this again is not necessarily essential. The entire bellows and pickup piece can usually be mounted on a crossbar, and, with the use of a universal-type clamp, the endpiece can easily be applied perpendicular to any place on the chest from which displacement records are desired. The recording equipment used in this study is the Cambridge 4-channel direct writer.

Procedure

Records were obtained in positions on the chest wall which corresponded to the conventional precordial electrocardiographic leads, V1 through V6. These were chosen, since they are related to known chest landmarks, and because they are over the basilar, mid, and apical regions of the ventricles. The terms KVI, etc., are used to avoid confusion with the precordial electrocardiographic terminology, and to designate the same location on the chest wall. Simultaneous heart sounds, carotid pulse, and
displacement ballistocardiograms were obtained. Records were made on normal male adults of ages between 20 and 30 years.

Calibration

A special apparatus was constructed that consists of a motor-driven eccentric, which moves a bar back and forth through a known distance in a manner to produce a sine wave.* Thus, by comparing the amplitude response from the sine wave generator, and the amplitude of the records produced on the chest wall, a direct estimation of the magnitude of the precordial pulsations could be made. From this it was determined that the amplitude of the precordial motions were from about one to 200 microns, depending on the location on the chest from which the record was obtained, and the physical characteristics of the chest wall. Thus standardization is possible at different times, as well as in different individuals.

* Constructed by The Turkey Creek Manufacturing Company, Birmingham, Ala.

RESULTS

Figures 2A and B are records of two normal subjects. Systole and diastole are delineated in one cycle of each record. Note the similarity of patterns from records obtained from comparable positions on the chest in different subjects. Figure 3 is a record obtained from one normal subject with simultaneous heart sounds, carotid pulses, and displacement ballistocardiogram. The demarcation of the phases of the cardiac cycle is slightly modified from that described by Wiggers. Ejection was assumed to begin 0.02 second before the upswing noted on the carotid pulse.* The characteristic pattern of these precordial movements may be analyzed in some detail in relation to the various phases of the cardiac cycle.

Protosystole† or Early Isometric Contraction

Figure 3 is a detailed record of KV₁ through KV₄, while figure 4 is a composite diagram of KV₁ and KV₄. Both figures can be used to refer to this phase, as well as the subsequent phases in the preceding paragraph. About 0.04 second before the first heart sound, and approximately with the onset of Q in the electrocardiogram, an outward motion is noted over the base of the ventricles (KV₁ through KV₄), and may occasionally be noted as far over as the apex. This outward motion is present in subjects with auricular fibrillation and complete heart block. Thus it apparently represents some ventricular activity taking place before the closure of the atrioventricular valves.

Late Isometric Contraction

The outward movement which begins in protosystole continues into isometric contrac-
Fig. 2A and B. Records obtained from two normal subjects. Systole, as indicated by "S," and diastole, as indicated by "D," are indicated in one of the cycles for orientation purposes. An upward motion indicates an outward movement of the chest, while a downward motion indicates an inward motion of the chest wall. Note the similarity of records obtained in comparable positions on the chest, while there is some dissimilarity between records obtained in the different positions on the chest wall. In figure A, note the marked outward movement occurring just after the beginning of systole in KV. This is probably the graphic representation of the apical thrust.

Fig. 3. The records are obtained from positions KV₁ through KV₆ in a normal individual, with simultaneous carotid and jugular and carotid pulse, heart sounds, and displacement ballistocardiograms. The phases of the cardiac cycle are demarcated below by a short line, numbers 1 through 6. The phase from 1 to 2 represents protosystole; from 2 to 3 late isometric contraction; from 3 to 4 ejection systole; from 4 to 5 protodiastole; and from 5 to 6 isometric diastole. Note that records obtained from KV₂ and KV₃ are somewhat intermediate in pattern from those of KV₁ and KV₆.
Fig. 4. This represents a composite diagram of the records obtained from KV1 and KV4, as compared with the heart sounds, a carotojugular pulse, displacement ballistocardiogram, and electrocardiograms (lead II). Note that in KV1 there is an outward motion occurring almost simultaneously with the peak of the P wave, which probably is the result of auricular contraction. An outward movement begins approximately 0.04 second before the first heart sound, during the period which has been designated as protodiastole. The outward movement, which begins in protodiastole in KV1, continues almost to late isometric contraction, and roughly parallels the GH upstroke on the ballistocardiogram. Almost simultaneous with the first heart sound, there is an inward motion noted in KV4, followed quickly by an outward movement which is probably the apical thrust. By the beginning of ejection systole, both

tion (in KV1 and sometimes in KV2), and may parallel the GH upstroke of the ballistocardiogram. A quick inward motion in KV2 through KV3 and sometimes KV4 occurs almost synchronously with the first heart sound, or approximately 0.01 to 0.02 second following it. This inward motion does not necessarily start at the same time in the various positions, and occurs too soon after the first heart sound to indicate the beginning of ejection. This inward motion is followed by a marked outward movement, most prominent in KV4 or at the apical region. However, it may be present over the base of the heart (KV2), or as far out as KV4. This outward movement is probably a graphic representation of the apical thrust. Usually, an inward motion is noted in KV1 at the same time the outward motion occurs in KV4, which may be synchronous with the beginning of the H-I downstroke in the ballistocardiogram.

**Ejection Systole**

Approximately 0.02 second before the carotid upstroke there is a general inward motion noted from KV1 to KV6, and often as far out as KV4, as ventricular ejection occurs. It was noted that this inward motion does not occur simultaneously in all positions and, in general, was 0.02 second earlier in KV2 and KV3 than in KV4. Following this inward motion, during ejection, there occurs a relatively slow outward motion in mid-systole, most prominent in KV1, and occasionally in KV2, and seldom noted as far over as KV4. The onset of this slow outward motion in the apical and basal regions of the heart are moving inward. A slow outward motion is noted in mid-systole, which corresponds to the JI upstroke, reaching a peak approximately at the same time as the J, and subsequently subsiding, paralleling the JK downstroke on the ballistocardiogram. This is noted most frequently in KV1. However, in this instance it is noted as far away as KV4. In both KV4 and KV1 there is noted a sharp upstroke just before protodiastole and paralleling the KL upstroke on the ballistocardiogram. This is followed by an inward motion, usually most prominently noted in KV4. However, it may be present over both the apical and the basilar regions of the heart. During isometric relaxation there is a marked outward motion noted in both apical and basilar regions of the ventricles, which may parallel the MN upstroke on the ballistocardiogram.
ward motion is usually simultaneous with the IJ upstroke in the ballistocardiogram, and its peak is reached approximately at the same time as the J peak. Usually, this is followed by an inward motion corresponding to the JK downstroke in the ballistocardiogram.

**Protodiastole**

Approximately 0.01 to 0.02 second before or after the second heart sound, there occurs a sharp outward motion most prominent in leads KV₂ and KV₄; however, it may be seen over the entire precordium. It will be noted that this is not always synchronous with the second heart sound, but corresponds more closely to the KL upstroke of the ballistocardiogram. During this upstroke* there are sometimes a few vibrations which probably represent some of the vibrations of the second heart sound.

**Isometric Relaxation or Isometric Diastole**

Simultaneous with the incisura of the carotid pulse there is noted a fall or an inward motion occurring prominently in KV₂ and KV₄. This is immediately followed by a general outward motion, noted in all positions, which begins before the “V” peak on the jugular tracing. If one assumes that the “V” peak represents the opening of the auriculoventricular valves, the outward motion is, therefore, not related to ventricular filling. This outward motion also corresponds to the MX upstroke on the ballistocardiograph, and, at approximately the peak of the N wave, there is a change in gradient of this pattern, or a slight inward motion which varies from one subject to the other. When the inward motion does occur, it is noted most prominently on the lateral aspect of the chest.

**Rapid Filling**

There are no characteristic movements noted in rapid filling, but only a continuation of the preceding movement. A change in gradient is noted, occasionally. Whether this corresponds to the end of rapid filling is not known at this time.

**Auricular Systole**

There is a small slow outward movement noted most frequently over the base of the ventricle, just preceding the phase of protodiastole. This begins at about the peak of the P wave on the electrocardiogram, or just before the QRS deflection, indicating that this is probably the result of atrial systole. It has been noted to be absent in patients with auricular fibrillation.

**Interference of the Heart-Sound Vibrations**

It is apparent, from a study of the records, that all motions which have been discussed are below the range of 30 vibrations per second, or below the audible frequency range of vibrations, and represent inward and outward motions of the chest wall, occurring on the spot where the endpiece is placed. During the first heart sound, motions similar to those noted in KV₂, KV₃, and KV₄, have been recorded previously in linear phonocardiograms. It seems unlikely that these inward motions are the result of only the closure of the auriculoventricular valve, since the onset of the motion is not necessarily synchronous in all positions over the anterior precordial area. One would expect that the vibrations as the result of the closure of the A-V valves would reach all anterior V leads simultaneously, and produce, in general, the same type of deflection, which is not the case. Thus other factors are probably the cause for the inward movement, and not the closure of the A-V valves, per se. Similarly, the marked outward motion occurring at or just before the beginning of protodiastole precedes the second heart sound by as much as 0.04 second, and is probably not directly related to the closure of the semilunar valves. The small higher-frequency vibrations, which occur at the peak of this outward movement, are probably the result of the second heart sound.

**The Interference of the Chest Wall**

It is believed that the chest wall itself has very little effect on the movements recorded,

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* The peak of the KL upstroke, as recorded by the direct displacement method, and discussed in a separate communication, occurs close to the time of the carotid incisura.
other than perhaps altering the amplitude of the record in a given individual. Studies on a cadaver, leaving the chest wall intact, inserting the hand from the abdomen and tapping the chest wall from within (both in the region of the apex and of the sternum) revealed an outward motion (fig. 5) which returned to the baseline with almost no overshooting. The response varies in amplitude with the proximity of the pickup arm to the location of the tapping. By striking the chest wall a very hard blow it was possible to set the chest into vibration at a frequency of about 50 cycles per second, which is well out of the range of motions described in this paper. Thus it appears that the chest wall has very little direct effect on the pattern of the kinetocardiogram.

It seems probable that there are many factors which are responsible for the movements of the chest wall, as recorded. These include: (1) Movements as the result of the impact of the heart against the chest wall; (2) changes in the interthoracic volume as the result of ejec-

![Fig. 5. A record obtained from the chest wall of a cadaver by inserting the hand into the abdomen and tapping on the chest wall from within, in the region of the apex. Note that following the marked outward motion as result of the tap, the curve comes back to the baseline with almost no overshooting, suggesting the chest wall does not actively alter the motions being recorded.](image)

![Fig. 6A and B. Illustrations of abnormal records as obtained from patients with: (A) severe angina pectoris; (B) organic mitral insufficiency. The beginning of systole is designated by the letter “S;” and the beginning of diastole is designated by the letter “D.” Note the marked dissimilarity between these records and those obtained from normal individuals (fig. 2A and B, and fig. 3). In A it is noted that the inward motions associated with systole are much smaller in magnitude than those of diastole, and in some instances could be entirely missed if it were not for the simultaneous heart sounds and carotid pulses obtained. In figure B note the marked outward motion occurring in late systole, and, likewise, a marked dissimilarity between this and records obtained from normal subjects.](image)
tion or filling; (3) phenomena of the impacts of blood in the great vessels; and (4) possible positional and shape changes of the heart. A detailed analysis of these facts will be presented in an additional communication.

Certainly, preliminary observations confirm the opinion of Johnston,\(^1\) and Luisada\(^6\) that totally different records are obtained in organic heart disease. Such records are even more complicated than the normal patterns, and at present the meaning of the various movements is not clear. Figures 6A and B are records obtained from a patient with severe angina pectoris, and a subject with organic mitral insufficiency. The marked difference from the normal pattern emphasizes the possible future value in the procedure in the study of heart disease.

**SUMMARY AND CONCLUSIONS**

1. A method for recording precordial chest movements during the cardiac cycle has been described.

2. The general pattern obtained from normal subjects is pointed out, and the relationship of these movements to the phases of the cardiac cycle and the ballistocardiogram are noted.

3. Different normal young males usually displayed similarity in records taken at corresponding points, but there are striking differences in the same individual in records taken from varying points.

4. The term “kinetocardiogram” (KCG) is introduced to designate circulatory movements as recorded from the chest wall.

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**SUMARIO ESPAÑOL**

Un método sencillo para registrar los movimientos precordiales de frecuencia baja se presenta y se ha denominado Kinetocardiograma para indicar movimientos resultantes del movimiento cardíaco. Los patrones normales precordiales se describen al igual que las relaciones de tiempo al ciclo cardíaco y al ballistocardiograma.

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