The Kinetocardiogram

II. The Normal Configuration and Amplitude

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An analysis of the patterns and amplitudes of the precordial movements is presented. Normal young adult subjects had three types of patterns. Type I occurred in 78 per cent, type II in 14 per cent, and type III in 8 per cent of the subjects studied. The variations of the kinetocardiogram from apex cardiograms and pneumocardiograms are discussed.

In a preceding communication, a method of recording chest-wall movements and the general configuration of the normal pattern was described. The purpose of this paper is to present a more detailed analysis of the normal kinetocardiogram.

Methods

The procedure for recording the precordial movements was described in the previous publication. Records were taken from KV1 through KV4 and KV1R. (KV1R is in the same location as KV2, except for being located on the anterior right side of the chest.) KV1, KV3, etc., are used to denote kinetocardiograms taken from areas similar to conventional electrocardiograph chest leads. Records from KV4 are not included in this analysis; however, they are almost identical in pattern to KV3, but much smaller in amplitude and lacking some detail.

Sixty-four male subjects whose ages ranged from 20 to 30 years were studied. A careful history and a general cardiovascular examination was made on each subject. The magnitude of certain movements from each chest position was estimated by comparing the amplitude to that produced by a calibrated sine wave generator (described in more detail in the previous communication).

Nomenclature

Ideally, functional nomenclature should be introduced in which the symbols used would indicate the underlying mechanism responsible for the various movements. However, some method is necessary to refer the reader to specific movements, and, as the genesis of all the waves is not known, a system has been adapted that refers to times in the cardiac cycle the waves occur, instead of to their origin. Both the peaks and the valleys of waves have been named, to avoid the confusion that is now present in the ballistocardiographic literature. (Some authors refer to the J wave as indicating the entire headward movement which follows the footward I wave, while others refer to the J wave as the headward and footward movement that occurs above a central base line.) The letters employed are the initials of the times in the cardiac cycle the movements occur, while the subnumerals refer to the various points during that period. Odd numerals have been applied to the valleys, while even numerals have been applied to the peaks. Therefore, an odd subnumber to an even subnumber (i.e., E2-E3) indicates an outward movement, while an even subnumber to an odd (i.e., E1-E2) indicates an inward movement.

Figure 1 is a drawing of KV1 and KV4, with all points labeled. A1 and A2 are points occurring during auricular systole, or between the onset of the P wave in the electrocardiogram and the onset of the Q wave.

I1, I2, I3, and I4 are points that occur during the phase of isometric contraction. Actually, this time period includes the phase of protosystole, as discussed in the previous communication, or from the onset of QRS of the electrocardiogram to the onset of carotid ejection. The sharp outward movement I1-I2 always occurs after the onset of the QRS complex, and is present in records obtained during heart block and auricular fibrillation, indicating that this outward movement is the result of ventricular activity and, therefore, should not be included in the auricular period. The point I4 usually occurs before, but may occasionally be simultaneous with, the onset of carotid ejection. Therefore, this point was included with isometric contraction. As points I3 and I4 are not present in the right side of the chest (KV1R, KV2), I3 is, therefore, the last point before ejection, even though I3 is on the right
CHEST

EKG

H-S

CAROTID

KV_1

A_2

I_2

E_2

E_4

D_2

KV_4

A_2

I_2

E_2

E_4

A_1

I_1

E_1

I_4

D_2

D_3

Fig. 1. The nomenclature for the kinetocardiograms is represented in a schematic drawing of records taken from KV_1 on the right side of the chest and KV_4 on the left side of the chest. The nomenclature is based upon a modified division of the cardiac cycle. All points between the onset of the P wave and the QRS complex in the electrocardiogram are assumed to be due to auricular contraction, and the latter A is used to indicate the points occurring in this period. Although the isometric contraction phase technically begins with the onset of the first heart sound and ends with the beginning of ejection, the phase of protocontraction, as discussed in the preceding communication, is included in this period. The motions which begin after the onset of the QRS in the electrocardiogram are presumed to be ventricular in origin, since they occur in patients with auricular fibrillation and in complete heart block. The letter I is used to indicate this isometric contraction period. The letter E is used to indicate the period during chest occurs after I_2 on the left chest, E_n, E_o, E_s, and E_r are used to indicate the points occurring during ejection systole, while the point E is used to indicate the period as late as the second heart sound; however, since it is probably the terminal point of ejection, it is labeled as part of this phase. D_n, D_o, and D_r are used to indicate the points occurring during diastole. Diastole was not separated into isometric relaxation and rapid filling, since the waves do not lend themselves to this separation. D_n-D_o begins in early or midisometric relaxation and often ends during rapid filling. D_r is not a constant point, and is present only when D_n-D_o is large; however, it occurs sufficiently often to warrant designating it by a symbol. All waves will be referred to as A_n-A_o, I_n-I_o, I_r-I_s, etc., to indicate the movement between two points.

RESULTS

It was possible to divide the patterns from the 64 subjects studied into three separate types. The divisions, initially, were made entirely on the appearance of patterns; however, on careful study there are significant differences in these groups as to amplitude and distribution of certain movements. Thus it now appears that there are definite criteria for the divisions as described, which, in addition, may be of physiologic importance.

Type I

Configuration. The most common pattern found was designated as type I, and occurred in 50 of the 64 subjects, or in 78 per cent, and resembles the general pattern described in the first communication. All of the details will not be repeated here, but certain important features should be emphasized. Figure 2 is a labeled record of KV_ros and KV_4 in type I pattern. Approximately 0.02 second after the onset of the QRS complex, there begins an outward movement (I_1-I_2), most pronounced in KV_ros and KV_4; however, it may appear as far lefward as in KV_4. A sharp inward movement occurs in KV_4 (I_2-I_3), and sometimes is noted ejection, while the movements during diastole are indicated by the letter D. Note that the odd subnumerals are all located on the valleys, while the even subnumerals are all located on the peaks of the various movements. Note also that the point I_2 in KV_4 on the right side of the chest occurs approximately at the same time as I_2 on the left side of the chest, since I_2 was the next definable point after I_1 on the right side of the chest. Thus the motion I_1-I_2 is absent on the right side of the chest.
as far rightward as KV₂. This inward motion (I₁–I₂) is then followed by a prominent outward movement (I₂–I₄) in KV₄, corresponding clinically to the apical thrust. This outward motion (I₂–I₄) begins 0.02 second to 0.05 second before the onset of carotid ejection, and is 0.06 to 0.11 second after the beginning of the QRS in the electrocardiogram, with an average of 0.08 second. The movement (I₂–I₄) is most pronounced over the apex but is present to a lesser degree often as far rightward as KV₂, but never in KV₁. Simultaneously with the I₂–I₄

(Data from 14 subjects were not included, since records were obtained before the calibration procedure was being employed.) The range and standard deviations are wide, indicating a marked variability in amplitude among the normal subjects.

In general, the individuals with thick chests had smaller amplitudes. The outward movement during isometric systole, which correlated with the apical thrust (I₃–I₄), has the greatest amplitude in KV₄ position, averaging 25 microns. Since similar small outward move-

in KV₄, or very shortly after it, the right chest (KV₃R and KV₃) begins moving inward (I₂–E₁). It is important to point out that the beginning of this inward motion (I₂–E₁) of the right chest begins as much as 0.06 second before the carotid upstroke, and is, therefore, not primarily related to the ejection process. Figure 3A is a drawing of the relationships of KV₁ to KV₄ during protosystole and isometric contraction in type I subjects.

Amplitude. The amplitude of the principal movements were measured. Table 1 includes the mean of the amplitudes, range, and standard deviations computed for 36 type I subjects.
The record of the apparent movement of the right precordium, apparently noted in KV type I and II subjects, occurs in a general outward motion occurring during isometric contraction. This characteristic is apparently not an artifact, since all type II records were repeated a week later and found to be identical to the original pattern. The movements during the isometric period of diastole tend to be small in amplitude. The record in the KV I position is not too different from KV I noted in other type I subjects. (C) A composite diagram of KV I and KV II from a type III subject. Note that in KV I, the outward movement I-I₂ is prominent, being absent in the KV III position. The E₂-D₁ movement, or the inward movement which occurs in early isometric relaxation, is most pronounced in KV II and very small in KV III, while the converse is true for the E₃-E₄ movement, occurring in late systole. Note the large diastolic movements in both KV II and KV III records in type III. (D) Represents superimposed records from type I, type II, and type III from the KV I position. Note that type I records which occur in the majority of subjects, or 78 per cent, apparently appears to be a mixture of both type II and type III records.

Occasionally, a subject will have one movement which is exaggerated in amplitude. Eight subjects with type I pattern were noted to have a very prominent outward movement (D₁-D₂), beginning in isometric relaxation and paralleling the MN upstroke of the displacement ballistocardiogram. This movement (D₁-D₂) may be much greater than the movements associated with the systolic portion of the cardiac cycle. Figure 5 is a record from a subject in which this movement (D₁-D₂) was

**Figure 3.** A, B, C, and D are composite diagrams of the features in the various types. (A) A diagram of the pattern obtained from the KV I position and KV III position in type I subjects. Note the marked inward movement during isometric contraction (I₁-I₂) is present in KV III, during which time the record in KV I continues to go outward. (B) A diagram of KV II and from KV III in a type II subject superimposed. Note the apparent absence in KV III of the I₁-I₂ movement with apparent fusion of I₁-I₂ with I₁-I₃ in KV II resulting in a slow general outward motion occurring during isometric contraction. This characteristic is apparently not an artifact, since all type II records were repeated a week later and found to be identical to the original pattern. The movements during the isometric period of diastole tend to be small in amplitude. The record in the KV I position is not too different from KV I noted in other type I subjects. (C) A composite diagram of KV I and KV III from a type III subject. Note that in KV I, the outward movement I₁-I₂ is prominent, being absent in the KV III position. The E₂-D₁ movement, or the inward movement which occurs in early isometric relaxation, is most pronounced in KV II and very small in KV III, while the converse is true for the E₃-E₄ movement, occurring in late systole. Note the large diastolic movements in both KV II and KV III records in type III. (D) Represents superimposed records from type I, type II, and type III from the KV I position. Note that type I records which occur in the majority of subjects, or 78 per cent, apparently appears to be a mixture of both type II and type III records.

**Table 1.—The Mean Amplitudes, Range of Values in Microns, and Standard Deviations of the Various Movements in Type I Subjects**

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<th>Type</th>
<th>No. of Obs.</th>
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<th>E₃-E₅</th>
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which parallels the IJK waves of the ballistocardiogram, is most marked in the KV I area and much smaller over the left precordium.
especially prominent. The movement (D₁-D₂) could not only be felt clinically but, on inspection, it was noted that the entire left chest moved outward. The force producing this movement (D₁-D₂) apparently is greatest in magnitude in KV₂; however, it it not as localized as the apex thrust, being distributed over the entire left anterior chest (table 1). A diastolic thrust has been previously described to be associated with pericardial scarring, if associated with systolic retraction of

the sternum, absence of apical impulse, and sudden emptying of the cervicle veins.² No pathologic causes for this large outward movement (D₁-D₂) in isometric diastole could be found in any of these eight subjects. It is possible that the last part of this movement is augmented somewhat by the filling of the heart.

Type II

Configuration. Type II patterns occurred in nine (14 per cent) of the subjects studied. The chief variations from type I are noted during the period of isometric contraction. Figure 6B is a record from a subject with type II pattern, with the other two types included for contrast. In these subjects, the most significant feature is the apparent absence of the sharp inward movement (I₂-I₃) which occurred at the time of the first heart sound in type I subjects. The initial outward movement (I₁-I₂) that begins shortly after the onset of the QRS of the electrocardiogram is apparently fused with the outward movement (I₁-I₂) of the apical thrust. Often notchings are noted where the two outward forces are superimposed; the notch occurring at the usual time when the movement of the apical thrust begins. Occasionally, sub-

![Fig. 4. A is a kinetocardiogram obtained from the KV₁ position in a subject with an easily palpable apex thrust. Note the marked outward movement I₁-I₂. B illustrates the record obtained from the KV₄ position in a subject who had no palpable apex thrust; note the same movement (I₁-I₂) is present but is below the diastolic base line and, therefore, would not be expected to be palpable.]

![Fig. 5. A record obtained from an individual in which the diastolic movement (D₁-D₂) is prominent. The arrow points to the movement. In this subject a diastolic outward motion could be detected clinically over the anterior chest by both palpation and inspection. An exaggeration of this movement occurred in approximately eight of the type I subjects. Apparently the exaggeration of this movement is only a physiologic variation in the normal type pattern.]

jects will have the outward apical thrust motion (I₁-I₄) in KV₄ occurring at the same time as in type I, but still lack the preceding inward motion. Figure 3B is a schematic drawing of KV₂ and KV₄ superimposed to show these relationships. Thus there occurs a well-marked outward movement (I₁-I₄) during protodiastole and isometric contraction, going above the diastolic baseline, and followed by a slow inward movement (I₄-E₄) with ejection. Records from KV₁ in type II are similar to those obtained in KV₁ of type I, while records from KV₂ and KV₃ do not have the transition-like quality noted in type I, but resemble KV₄ in pattern and in magnitude (fig. 7 and table 2).
Fig. 6. (A) A record obtained in a type I subject from the KV₄ position. (B) An example of a record from the KV₄ position in a type II subject. Note the apparent absence of the sharp inward movement in type II records which occurs during isometric contraction; instead, there is a slow outward movement preceding ejection. The movements occurring during diastole also tend to be small in type II subjects. The ballistocardiogram in this subject has an apparent absence or an inverted GH upstroke. (C) A record obtained from the KV₄ position of a type III subject. Note the prominent diastolic movements which occur in type III subjects. The diastolic portion of the ballistocardiogram are also especially prominent in these individuals; however, some subjects in type I also have equally prominent diastolic movements.

Fig. 7. Records from the KV₁, KV₂, KV₃, and KV₄ positions from both type I and type II individuals. Note that in type I subjects there is a transition from KV₁ to KV₄, while in type II the same type pattern is noted over the entire anterior precordium. The records KV₁ and KV₄ in the type II illustrations appear smaller in amplitude than KV₂ and KV₄ records because of difference in sensitivity setting of the recording galvanometer.
Although type II has a well-defined outward movement occurring in protodiastolic isometric contraction, none of these subjects had a palpable apex thrust. This is possibly explained by the fact that the outward movement is over the entire precordium, and not localized in one area, as is the outward movement (I₁-I₄) in type I. Although there is no apical thrust, per se, the observer may note an outward movement of the entire precordium. The outward movement (E₄-E₅) was small in all type II subjects, as was the following inward movement (E₄-D₁). Frequently, only a small notch- ing occurred at this time. However, the outward movement (D₁-D₂), which parallels the MN upstroke in the ballistocardiogram, was prominent.

Of the nine type II subjects, one gave a past history compatible with rheumatic fever at the age of 6; however, he has had no recurrences, nor is there any detectable heart damage present at this time. There were no murmurs present in any of the subjects. Seven subjects had thin chests, while two subjects had thick chests and were much heavier in stature. All nine subjects in type II had electrocardiograms with a vertical QRS axis; however, some subjects in type I also had a vertical QRS axis. The precordial electrocardiographic leads, in general, had a prominent R in V₁, V₂, and V₃.
and sometimes showed transitions of the QRS in V₄. In addition to the alteration in the pattern during isometric systole in type II subjects, the displacement ballistocardiograms had absent or, at most, very small GH upstrokes (fig. 6B).

**Amplitude.** The total outward movement during isometric contraction (I₁–I₄) was of equal amplitude in KV₂, KV₃, and KV₄ (table 2). The difference in amplitude of this outward movement in type I and type II records was significant. The occurrence of an outward movement (I₁–I₄) during this time in KV₁ is important to note.

Thus the force producing the outward movement of the apical thrust apparently is fused with the outward movement, beginning shortly after the onset of the QRS complex. This force is apparently distributed equally to KV₂ and KV₄ positions, since the amplitudes are similar (table 2).

**Type III**

**Configuration.** Five subjects, or 8 per cent, were found to have type III patterns, Figures 6C and 8 illustrate the pattern in type III subjects. The movements in type III subjects varied both during the isometric contraction and relaxation phases of the cardiac cycle. The initial outward movement (I₁–I₄) occurring shortly after the onset of the QRS complex was especially pronounced in KV₁, KV₂, and KV₃, being absent in KV₄ and KV₅. In one subject the magnitude and sharpness was of such a degree as to produce an easily palpable and visible thrust only 2 cm. from the left parasternal line in the fourth intercostal space. The inward movement (I₅–I₆) at the end of the first heart sound is much deeper in KV₄ and KV₅ than in type I, and appears to begin with or shortly after the onset of the outward movement noted in KV₁ and KV₂.

The outward movement (E₁–E₄), that usually occurs just preceding the carotid incisura, begins earlier, and in one subject began shortly after the inward movement (I₅–I₆). E₁–E₄ is significantly increased in amplitude in KV₄ and KV₅, but small in KV₁ and KV₂. Conversely, the inward movement (E₄–D₄) that begins with the carotid incisura is large in amplitude in KV₁ and KV₅, being small in KV₄ and KV₅. The outward movement (D₁–D₂) that begins in isometric relaxation is pronounced from the entire precordium. Figure 3C illustrates KV₁ superimposed on KV₂.

**Table 3.—The Mean Amplitudes, Range of Values in Microns, and Standard Deviations of the Various Movements in Type III Subjects**

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An S₁, S₂, S₃ pattern was noted on the electrocardiogram in all type III subjects; however, a few subjects in other groups had similar electrocardiograph patterns. The displacement ballistocardiogram in type III subjects revealed especially prominent K₁,L,M,N.
sequences (fig. 6C); however, occasionally these waves are just as marked in some subjects in type I as in figure 6A.

Amplitude. Table 3 contains the amplitudes of the various movements for four of the five subjects. The amplitude of the three principal movements during the relaxation period was greater than the corresponding movements in type I, and was found to be of significant differ-

ence when compared mathematically, adding evidence that type III is a true physiologic variant.

Thus type II apparently is formed by an absence of the early isometric contraction inward movement with a fusion of the apical thrust with the early outward movement \( I_1-I_2 \) while type III has an exaggerated early outward movement \( I_1-I_2 \) in KV, with an equally prominent inward movement in KV, and KV. Type I appears to be a mixture of the two opposite variations. Figure 3D has the three types superimposed to illustrate the significant features of each.

**Comment**

The full understanding of the differences between types I, II, and III would require a knowledge of the cause of the various waves, as well as physiologic and anatomic variations not yet available. At the present time, there is no apparent explanation for the variations noted, and a discussion will have to be delayed until a much greater understanding of the records is attained. An hypothesis of the genesis of the various waves will be presented in a subsequent communication. However, it

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Fig. 9. (A) An apex cardiogram obtained by placing a 2 inch funnel connected to a piezoelectric transducer over the apex of the heart. Note that there occurs a marked outward movement during isometric systole (probably the thrust of the apex), which remains above the base line during the greater part of systole, and returns only during early isometric relaxation. This record resembles previously published apex cardiograms. (B) A record obtained with the bellows from the apex of the same individual. The amplitudes of this record are different from A primarily because of the difference in degree of sensitivity of the recording galvanometer. Note that an outward movement occurs at the same time of the apical thrust, as in the apex cardiogram; however, it is followed immediately by a well-marked inward movement during systole. The diastolic movements are also more clearly demarcated in the kinetocardiogram than those of the apex cardiogram. The kinetocardiogram records the absolute movement of the chest wall, while the apex cardiograms record relative movements of the chest wall and tend to vary according to the diameter of the pick-up device employed. The kinetocardiograms are reproducible and constant in the same individual and, as has been pointed out, approximately 78 per cent of subjects have the same general type pattern from comparable positions over the anterior chest wall.
is important at the present time to point out several differences between the records recorded with the bellows and those obtained by other technics.

Comparison of the Kinetocardiogram with the Apex Cardiogram and Other Low-frequency Precordial Records

Often the kinetocardiograms obtained from KV₄ position resemble the apex cardiograms previously published.²⁻⁵ However, instead of the three normal types as were noted in this study, only two different forms of records have been noted previously.⁶ One type was somewhat like type I, while the other was different, in that the record goes outward early with the apical thrust and remains outward during all of systole. We have never noted this latter type in normal subjects, with the technics being employed. The chief reason for the variations lies in the fact that the kinetocardiograms are recorded from a fixed point above the chest wall, while the other methods record the relative motion between two points. Any device resting primarily on the chest wall will not record, or will minimize the movement that the entire chest or part of the chest makes, and registers only the relative movements. Thus the recorded motion between the two points on the chest wall will depend on the distance between the points. (If a microphone type of pickup is used against the chest wall, the outside rim will be the limiting point, and the movement of the area included will be the factor determining the type of record.) The records of Johnson and Overy⁴ differ from those obtained by Luisada and Magri,⁵ possibly since the funnel type of endpiece used by Johnson was smaller in diameter than the end of the microphone employed by Luisada. Figure 9 contains a record obtained with a 2 inch funnel at the apex, and a record obtained with the bellows pickup for the KV₄ position. Note the change in detail of that obtained with the funnel, from the kinetocardiogram, which in this instance resembles the conventional apex cardiograms. In the kinetocardiogram, the anterior chest begins inward shortly after the outward movement of the apex thrust, resulting in the inward movement during ejection (I₄–E₁). This is absent in the apex cardiograms. Thus the present method permits the recording of the absolute movement of a specific small point (7 mm. in diameter) on any place over the chest wall. The magnitudes can be easily estimated and the procedure calibrated,¹ and all records are reproducible and constant.

Comparison of Records with the Pneumocardiograms

Records from KV₃R positions, and frequently from KV₁ (fig. 2), resemble the pneumocardiograms previously published by others.⁶ ⁷ Pneumocardiograms have been taken simultaneously with kinetocardiograms and found to differ primarily in time relationships. The inward motion I₄–E₁ in the KV₃R records occurred 0.08 second before the inward movement of the pneumocardiogram. Thus it seems that such a lag would be unlikely if the two records were due to the same events in the chest. Recently, Hamilton and Lombard presented evidence that changes in interthoracic pressure were negligible in producing the pneumocardiograms.⁶ The onset of the inward motion noted in KV₃R and KV₁ precedes ejection too far to indicate that it is related to the pressure changes during ejection. It is possible, however, that although the onset is not related to ejection or to the changes in interthoracic blood volume, the continuation and depth of inward movement is related to these factors. Thus the records obtained from KV₃R and KV₁ are probably not related to pneumocardiograms because of the marked time difference between the two records. Kinetocardiograms from the left precordium are too markedly different from the pneumocardiograms to indicate any primary relationship, and are probably more related to the shape changes, positional movement, and impacts of the heart.

Conclusions

1. Kinetocardiograms and correlating physiological events were obtained on 64 young normal male subjects.
2. A nomenclature has been submitted that is based upon the division of the cardiac cycle.
3. Three types of variations in the precordial movements were noted.
4. Type I occurred in 78 per cent of the subjects and appeared to be a mixture of type II and type III records.

5. Type II occurred in 14 per cent of the subjects and consisted of a prominent outward movement over the entire left precordium, beginning shortly after the onset of the QRS in the electrocardiogram and then moving inward with ejection. The movements during early diastole were small.

6. Type III occurred in 8 per cent of the subjects studied and consisted of an absence of the early outward movement during isometric contraction (I₁-I₂) in the KV4 position with a sharp inward movement I₂-I₃. All diastolic movements are enlarged in type III subjects.

7. Certain differences have been pointed out between the records reported (KCG) and apex cardiograms obtained by other technics and pneumocardiograms.

**Sumario Español**

Se presenta un análisis de los patrones y amplitudes de los movimientos precordiales. Sujetos adultos jóvenes normales mostraron tres tipos de patrones. Tipo I ocurrió en 78 por ciento, tipo II en 14 por ciento y tipo III en 8 por ciento de los sujetos estudiados. Las variaciones del kinetocardiograma del cardiograma del ápice y del pneumocardiograma se discuten.

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