The Kinetocardiogram

III. The Distribution of Forces Over the Anterior Chest

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The distribution of the various motions of the anterior chest wall during the cardiac cycle has been studied, with particular reference to their magnitude in normal subjects. A few recordings of the posterior chest wall motions are included. Analysis of the type of distribution and localization of certain motions suggest their origin in terms of response of the chest wall to cardiac forces.

In preceding communications, a simple method of recording precordial movements was presented, as well as an analysis of the three types of patterns found in normal young adults. The present report presents an analysis of the distribution of various motions and magnitude of force over the entire anterior chest wall.

Method

The method of recording the movements over the chest, and estimating their magnitude, has been presented previously. Records for this study were obtained from approximately 20 normal type I adult males. The amplitudes of the various movements have been estimated in 12 of these individuals. A few observations which have been made on both the anterior and posterior surfaces of the chest with the subject either lying on his right side or sitting. The motion of the posterior chest wall was studied in a few subjects, with the subject lying prone. Records were obtained from the right parasternal region in all intercostal spaces and designated as KV₁, first, second, and third intercostal spaces, etc.; whereas tracings for the left parasternal space were designated as KV₂, first, second, third, fourth, and fifth intercostal spaces; while records from the midclavicular line on the right side of the chest were designated as KV₃R in the first, second, third, etc., intercostal spaces. Records obtained halfway between the left midclavicular line (KV₄) and the parasternal regions (KV₂) were designated as KV₃, second, third, etc., intercostal spaces; and the comparable portion of the right side of the chest were designated as KV₄R, first, second, third, etc., intercostal spaces. Records from the anterior axillary lines are designated KV₁ and KV₂R, with the intercostal space, and, similarly, the midaxillary line is designated as KV₅ (left chest) and KV₆R (right chest). Records were also obtained in the subclavicular region in the midclavicular line. All intercostal spaces were not explored in every subject; however, in the majority of subjects records were made from all areas.

Results

Patterns from the Right Side of the Chest. Figure 1 is presented to furnish a guide to nomenclature which has been previously discussed. Figure 2 contains records obtained from KV₃R in the fifth intercostal space and in KV₄R in the second intercostal space. Note that the record lacks much of the detail of those obtained from the left anterior precordium. There are two significant features that should be pointed out: (1) There is a pronounced inward movement (I₂–E₁) immediately before and during the early part of rapid ejection (as determined by the carotid upstroke). (2) The outward movement during systole (E₁–E₂), which parallels the IJ upstroke of the displacement ballistocardiogram, is especially prominent. The peak of the movement (E₂) in records from the right upper chest usually precedes the J peak in the ballistocardiogram .01 to .02 second, while it usually follows the J peak in KV₃R records, and in records from the left upper chest. Most of the records from the right anterior chest are similar in this general type pattern. The initial inward motion associated with ejection (I₂–E₁), how-

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ever, is most pronounced in the region paralleling the lower portion of the sternum, and becomes much smaller in the upper chest, while the reverse is true with the outward motion (E₁-E₂) that parallels the IJ upstroke. (In figure 2 note that the diastolic movements are not prominent in any of these records obtained from the right side of the chest.)

Pattern of Records from the Left Anterior Side of the Chest. Figure 3 contains records from the left anterior chest at KV₁ in the third intercostal space. In contrast to the movements on the right side of the chest the outward systolic movement (E₁-E₂), which parallels the IJK wave in the ballistocardiograph, is small or absent. Conversely, the diastolic waves have become more prominent, especially the outward movement (D₁-D₂) which parallels the MN upstroke in the ballistocardiogram. The inward motion during early ejection (I₁-E₁ on the right and I₁-E₁ on the left) is similar in magnitude to that noted on the right chest, and is deepest in the lower parasternal area, and almost absent in the upper chest. Records from the lateral subclavicular area on both sides of the chest (fig. 4) resemble a mixed arterial and venous pulse tracing. It is probable that the pattern is, therefore, a transmitted pulse from the subclavian vessels. Thus records from the left chest have more prominent diastolic movements, while the records from the right chest have more prominent systolic movements.

Records Obtained with the Patient Lying on the Right Side and in the Sitting Positions. Although the records obtained with the patient lying on the right side are somewhat poor in quality, because the patient is usually unable to remain sufficiently quiet, there are several significant features. The anterior records with
patient lying on the right side are, in general, similar to the records obtained with the patient supine, although they are altered somewhat in amplitude. Motions of the posterior chest during protosystole and early isometric contraction, however, were opposite in direction to those obtained on the anterior chest (fig. 5). The records from the comparable positions in the sitting position, the record from KV₂ was identical to that obtained supine. The records directly opposite on the posterior chest revealed the same observations as obtained with the subject lying on the right side (fig. 6).

**Records with the Patient Prone.** A surprising finding was that with the patient prone, the records obtained from the posterior region in exactly the same position are completely altered from those of the posterior chest with the patient lying on the right side or sitting (fig. 5). The records resemble those made from the anterior chest in type II subjects. It is possible that the effect of gravity and the inability of the anterior chest wall to move with that posture produce the altered response, and the records become incomparable with the movements on the anterior surface of the chest supine.

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![Fig. 2. Records from KV₃R in the fifth intercostal space and KV₃R in the second intercostal space. Note that the outward movement E₁-E₂, which parallels the IJ wave of the ballistocardiogram, is much more prominent in the upper right anterior chest wall than in the lower right chest. The inward motion, which begins just before carotid ejection, is more pronounced in the inferior region of the right anterior chest than in the upper portions of the anterior chest. In both records, the movements occurring during diastole are relatively small in amplitude.](image-url)
Amplitude of Response. The most significant aspect of this study was the distribution of the forces in regard to the amplitude of the various movements. Figure 7 contains the mean amplitude of the outward motion (I1–I4) associated with the apical thrust, plotted in the various positions on the chest wall. Note that the force is maximal in the region of the point of maximal impulse and KV₃, and diminishes circumferentially in all directions, being absent over most of the right chest and on the upper left anterior chest. This movement is thus a localized movement to the region of the palpable apex thrust.

Figure 8 represents the mean amplitudes of the inward motion associated with ejection (I4–E₀). Although the initial inward movement recorded from the right side of the chest is probably not related to ejection, the total inward movements, I₁–E₁ on the right and I₁–E₂ on the left, were measured. Note that the greatest magnitude of motion is noted in the lower parasternal area. This inward motion is symmetric in magnitude, being similar over the right and left chest, with a decrease in amplitude the further laterally the records are taken. Also, it is of note that this inward motion is very small or absent in the upper chest, and, occasionally, an outward motion may be detected.

Figure 9 is the representation of the mean amplitude of the wave (E₁–E₂) which parallels the IJ upstroke on the ballistocardiogram. The maximal amplitude is distributed over the right anterior chest, and extends down into the KV₄₀ and KV₄₁ areas in the fourth and fifth intercostal spaces. The area of maximal outward motion is noted in KV₄₀ in the second intercostal space (fig. 9). This outward motion E₁–E₂ is also fairly marked in the right parasternal area in the fourth, third, and second intercostal spaces. Only very small E₁–E₂ motions are noted over the left anterior chest and, when occurring, are of greater amplitude.
in the upper portion of the chest in the region of the second intercostal space. The outward motion \((E_3-E_4)\), which begins with or just before the phase of protodiastole, is equally distributed over the lower left and right chest relaxation, is most prominent in the left lower parasternal region (fig. 11). This motion is somewhat localized, with an average amplitude of approximately 50 to 70 microns in the left parasternal region, falling off fairly rapidly to 25 microns in \(K_{V_1}\) and around 19 microns in \(K_{V_5}\). Although \(D_1-D_2\) is present both in the right chest and in the left chest, the localiza-

![Fig. 5. Composite figure of records obtained in the \(K_{V_1}\) position with the subject supine, from the posterior aspect of the left chest with the subject lying on the right side, and from the posterior aspect of the left chest with the subject prone. It was possible to superimpose these records, since they were of approximately the same cycle length. The movements from the posterior chest (with the patient lying on the right side), which occur during the isometric contraction period and the isometric diastolic period, were of opposite directions to the movements from the anterior chest (supine). Note that the record from approximately the same position on the posterior aspect of the chest is entirely changed when the patient is prone. However, the movements during the isometric contraction period are still opposite in direction to those noted on the anterior surface, while the marked outward movement \((D_1-D_2)\) in diastole is now in the same direction as that obtained supine.](image)

in the parasternal regions, as is the distribution of the inward movement \((E_3-D_1)\) that parallels the LM downstroke of the ballistocardiogram (fig. 10).

The outward motion \((D_1-D_2)\) which parallels the MN upstroke in the ballistocardiogram, and which occurs during the phase of isometric

![Fig. 6. Record of the anterior \(K_{V_2}\) and opposite position, posteriorly, obtained from a subject in the sitting position. Note again, as in figure 5, that the movements on the posterior aspect of the chest are, in general, opposite in direction to those on the anterior side. It is important that the movement \((D_1-D_2)\) beginning in isometric diastole is opposite in direction on the posterior side to that on the anterior side, suggesting that at this time the entire heart is moving anteriorly, pulling the posterior aspect of the chest inward.](image)

![Discussion](image)

The distribution of the various movements studied gives some evidence of the underlying
mechanisms involved. Thus a movement localized over the heart suggests that the impact of the heart on the chest wall is responsible. A bilateral distribution of a movement suggests other factors are involved, rather than the local action of the heart. Therefore, the movements can be divided into several categories.

Produced by the impact of the apex against the chest wall. Evidence will be presented later that this is probably the result of the heart rotating to the right, thrusting the apex outward and producing the apex beat. Clinically,

The localization of this movement to the region of the apex offers evidence that the outward movement is produced by the thrusting or the impact of the apex against the anterior chest wall.

The amplitude of some of the smaller movements, especially those occurring during proto-systolic and early isometric contraction (I₁-I₂)/(I₂-I₃), were not measured and, therefore, the distribution of magnitude will not be discussed.

Movements as the Result of the Impact of the Heart on the Chest Wall. The marked localization of the outward movement just preceding ejection (I₃-I₄) (fig. 7) suggests that this is produced by the impact of the apex against the chest wall. Evidence will be presented later that this is probably the result of the heart rotating to the right, thrusting the apex outward and producing the apex beat. Clinically,

Fig. 7. Diagram of the distribution of the magnitude of the force I₃-I₄ (the apical thrust) over the anterior chest. Note that the outward movement is greatest in amplitude over the apical region of the heart, diminishing circumferentially in all directions and being almost absent over the right anterior chest. The localization of this movement to the region of the apex offers evidence that the outward movement (I₃-I₄) is produced by the thrusting or the impact of the apex against the anterior chest wall.

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Fig. 8. Magnitude of the inward motion during rapid ejection (I₄-E₁ on the left chest and I₄-E₁ on the right chest) is represented. Note that the area of maximal inward motion occurs in the lower parasternal regions, diminishing on both sides and in the upper anterior chest. There is a small inward motion occurring elsewhere over the chest below 30 microns in magnitude. It is important to point out that this motion is bilaterally symmetric in magnitude, although the inward motion begins slightly earlier on the right side of the chest than that on the left chest. The symmetric aspects of this motion suggest that this is possibly the result of: (1) change in intrathoracic pressure as a result of a shift of blood with ejection; (2) a shift of blood from the lower to the upper aspects of the chest; (3) the movement of the entire heart, posteriorly, pulling inward the anterior surface of the chest.
the entire heart is striking the anterior chest wall. The occurrence of the inward movement, as recorded from the posterior chest wall (fig. 6), simultaneous with the D1-D2 outward movement from anterior chest wall, also adds

![Diagram of the distribution of the magnitudes of the outward movement E₁-E₂, which parallels the IJ upstroke of the ballistocardiogram. Note that the greatest magnitude is located in the upper right chest, or in the anatomic direction of the ascending aorta. The localization of the greatest magnitude of this movement to the upper right chest suggests that it is the result of the impact of blood in the aorta. The movement does occur over the left anterior chest but is of small magnitude, being most pronounced in the upper left chest. However, in most individuals this movement usually is absent in the left anterior chest. The distribution of the force to the right lower aspect of the chest is possibly the result of a transmission of the outward movement to the more movable portions of the chest wall or to impacts of blood in the pulmonary artery, while it is modified by the presence of the heart on the left side of the chest.](http://circ.ahajournals.org/)

![Diagram of the inward movement E₄-D₁ is of small magnitude on all portions of the anterior chest; however, the general distribution is somewhat symmetric in character. This suggests that the heart at this time is moving posteriorly in the chest cavity, pulling the anterior chest wall inward.](http://circ.ahajournals.org/)

evidence that this is an impact of the heart on the anterior chest wall.

The occurrence of such a pronounced movement, associated with the relaxation process, is of note. The force producing this movement is apparently directed anteriorly and slightly to the left. In one subject the upper lateral aspect of the right chest moved inward, associated with the large leftward and outward movement over the left precordium.

Movement as the Result of Shift of Blood Volume. The distribution of the inward movement with ejection (fig. 8) suggests that the principal force moving the chest inward is symmetrically distributed, affecting the right as well as the left side of the chest. Anatomically, the lower sternal area is the most movable, being farthest from the relatively more fixed portions of the chest wall (the spine and the clavicular area). It appears that the inward movement (fig. 8) is maximal in the areas of the chest which are more movable. This generalized type of motion is possibly produced by a decrease in pressure in the thoracic cavity as the result of a decrease in the intrathoracic blood volume associated with the ejection process, or a local shift of blood from the lower aspect of the chest to the superior part. An additional possibility is simply that the entire heart is moving posteriorly.

The fact that the right chest begins moving
inward before the left chest, or about the time of the outward movement (I₁-I₄) of the apical thrust, suggests additional factors initiating the inward movement.

Movements Due to Impact of Blood on the Great Vessels. The outward movement (E₁-E₂) which parallels the IJ upstroke of the ballistocardiogram was distributed largely to the right and this hypothesis. The force is also distributed to the right lower lateral aspect of the chest and probably represents the impacts on the pulmonary arteries or merely a transmitted movement. The chest, as has been pointed out, is more movable in the lower aspect and, therefore, E₁-E₂ in KV₃R and KV₄R in the fourth and fifth intercostal spaces would be expected to be of fair magnitude.

The almost complete absence of the movement (E₁-E₂) in the left chest is probably the result of local cardiac forces nullifying the impact phenomena. The distribution of forces upward and slightly to the right is, however, somewhat at variance with the spacial vector of the IJK wave, as determined by a rotating ballistocardiograph table. Scarborough and co-workers found the vector of the IJK wave to point to the left and slightly posteriorly. It is possible that as the force actually begins, it points anteriorly and to the right, then rotates to the left and posteriorly. This would be additional evidence of why there is an apparent absence of this movement over the left anterior chest, and why the movement is more pronounced over the posterior aspect of the chest.

Conclusions

1. A study of the distribution of forces over the chest wall has been made in normal healthy young adults.

2. The motion associated with the apical thrust (I₁-I₄) has a localized distribution of magnitude.

3. The inward motion (I₄-E₁) associated with ejection is maximal in the lower parasternal region, diminishing peripherally, and is symmetric on both right and left sides of the chest.

4. The outward movement (E₁-E₂) that parallels the IJ upstroke in the ballistocardiogram is maximal in the right upper chest, being almost absent over the left anterior chest.

5. The outward movement (D₁-D₂) that parallels the MN upstroke on the ballistocardiogram is directed anteriorly and slightly to the left, and is centered over the cardiac area.
Sumario Español

Se ha estudiado los varios movimientos de la pared torácica anterior durante el ciclo cardíaco, con particular interés en su magnitud en sujetos normales. Algunos trazados de los movimientos de la pared posterior se incluyen. Análisis del tipo de distribución y localización de ciertos movimientos sugiere su origen en términos de respuesta de la pared torácica a las fuerzas cardíacas.

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