Vibrations of Low Frequency over the Precordium

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A method for taking tracings which represent actual movements of the precordium (displacement curves) or records which show waves proportional to the velocity of movement of the chest wall (velocity curves) is described. The equipment employed is readily available, and the method is easy to use. The displacement curves are nearly identical with cardiograms taken with a good optical setup, and they may have diagnostic value. The velocity curves are more closely related to the functional status of the myocardium. The clinical significance of these tracings, especially the former, is pointed out.

Vibrations of many different kinds are produced by mechanical activity of the heart, and these may be transmitted through the chest wall and be detected by inspection, palpation, auscultation or by more elaborate instrumental methods. The heart sounds, murmurs and other auscultatory findings heard with the stethoscope are due to vibrations within the audible range (average frequency, 20 to 30 cycles per second or more), and much information relative to structural defects or functional disorders of the heart is, of course, obtained from these phenomena. Few physicians realize that these audible vibrations are usually insignificant in amplitude compared with those of low frequency. The latter may be seen and felt, but they are not heard on auscultation, and comparatively little attention has been paid to them. It is true that the apex beat or point of maximal impulse (PMI) is often referred to in a cursory fashion, but rarely is the character of the low frequency pulsations that cause it studied in any detail, and vibrations that may be seen or felt elsewhere over the precordium are often completely neglected.

Instruments for recording vibrations over the precordium have been available for many years in the form of tambours connected with levers arranged to write on smoked paper, and records (apex cardiograms) taken with such equipment may still be found in some text books of physiology. The poor frequency response and great mechanical lag inherent in such apparatus make these tracings nearly valueless, but optical methods developed by Frank, Frank and Hess, and refined by Wiggers make it possible to record vibrations occurring over the precordium or elsewhere with a high degree of accuracy. Weitz, using the optical method of Frank with a somewhat different pickup device, recorded vibrations from the cardiac apex in normal subjects and in patients with different types of heart disease and claimed that alterations in the tracings characteristic of cardiac enlargement and of various types of valve lesions were present. Crehore, using an ingenious optical method employing interference bands, recorded the apex beat in a number of subjects and concluded that these records should “be of use not only for research work but also for clinical purposes.”

Suggestions that apex cardiograms may represent a record of intraventricular pressures have been denied by Wiggers, who states that “the apex beat represents only the varying pressure of the cardiac apex on the thoracic tissue; and this is solely governed by the shifting of the heart’s position and its degree of filling.” In the last edition of his book, Circulation in Health and Disease, Wiggers...
implies but does not clearly state that apex cardiograms, even those taken with adequate technics, are not likely to be of much clinical value. One wonders if this pronouncement may not have discouraged further work in this field. In 1933 Dressler published a book on the pulsations of the chest wall in which basic anatomic considerations, experimental studies on animals and a vast clinical experience were woven together to produce a volume of incomparable value to any physician interested in precordial vibrations of low frequency. It is unfortunate that much of the material in this book is unknown to most physicians, since careful inspection and palpation, guided by interest and experience, will, as Dressler points out, help tremendously in the diagnosis of many heart lesions.

Kountz, Smith, Gilson and co-workers have published several papers within the last 10 years relating to the use of the cathode ray oscillograph and associated equipment for the study of the heart sounds and vibrations in the subaudible range appearing over the precordium. Many interesting and important matters are brought out in these papers, but the work might be critized because the frequency response of the apparatus was not adequate to record vibrations having a frequency much below 5 cycles per second. Furthermore, the dynamic microphone employed gave tracings which record the velocity of movement of the precordium and not its displacement, and these records are not, therefore, comparable to cardiograms taken with optical methods, since the latter are usually true displacement curves.

In an excellent discussion, The Graphic Registration of the Normal Heart Sounds, Rappaport and Sprague clearly point out problems involved in the registration of audible vibrations as well as those below the audible range and emphasize that the amplitude of the latter may be very much greater than the former. Using a crystal microphone for recording the pulse wave, described by Miller and White, Rappaport and Sprague have taken tracings, which they call "linear" phonocardiograms, in which vibrations of low frequency dominate. These records probably represent with fair accuracy displacements of the chest wall beneath the pickup employed and, if the microphone arrangement were suitably coupled to a direct current amplifier, tracings closely resembling those obtained with a well designed optical setup should be recorded. It should be pointed out that the equipment under discussion was not designed to record static pressure changes within the tubing leading to the crystal, and its response to slow displacements of the chest wall might not be very accurate.

Foulger and associates have studied precordial vibrations of subaudible frequencies in man and several species of animals primarily from the standpoint of the changes in their intensity or frequency, or both, induced by various physiologic variables (such as exercise) or by toxic agents. In a subject with a normal heart, exercise increases the average frequency of vibrations in the subaudible range, and anoxia or other deleterious agents lowers these frequencies. These frequencies are below the usual normal range in most patients with serious heart disease in the resting state, and effects of exercise in such individuals suggest that estimation of the low frequency spectrum may give important information about the functional capacity of the myocardium.

Mannheimer has recorded precordial vibrations over a wide range of frequencies by using multiple amplifiers and recorders, and more recently Dunn and Rahm have carried out studies along similar lines. The latter emphasized the complexity of the waves that represent vibrations arising in the heart, the great amplitude of low frequency vibrations as compared with those in the audible range, and pointed out that visual study of records, taken with full knowledge and appreciation of the frequency response of the equipment employed, is of basic importance in work of this kind. They mention the importance of some sort of method for analyzing these records of vibrations and discuss some of the difficulties involved. Burger and Koopman have made mathematical analyses of vibration records from normal subjects, thus obtaining data which give the approximate frequency spectrum of the heart sounds in the subaudible as well as in the higher frequency range.
range. These studies are similar in some respects to those carried out by Foulger and associates.

It is clear that many workers have been interested in vibrations of low frequency over the precordium, but there has been little continuity between the various studies and not a great deal of clinical value has come from them. This somewhat surprising situation is understandable if one remembers that the registration of the vibrations in question has involved the use of more or less complicated apparatus not usually readily available for clinical use, that the proper use of such equipment demands special training and experience, and finally, that different investigators have been interested in and have recorded tracings representing these phenomena for different reasons. Thus, Foulger and his associates have developed methods and apparatus primarily to estimate the range of frequencies that are most prominent in subjects of different types under varying conditions, while the majority of others have been more concerned with the form of vibration records and what they may mean in terms of normal or abnormal structure or function of the heart. Both of these approaches may be important, but for somewhat different reasons.

It is the purpose of this paper to describe a method for the accurate registration of vibrations in the subaudible range using equipment that is readily available and simple to use. Several records taken on subjects with normal hearts and different types of heart disease are presented, and the possible value of the tracings in this relatively unexplored field is discussed.

**Method**

An instrument designed primarily for studies in a somewhat different field has been found to perform very well as the basic unit in a setup to record vibrations of low frequency over the precordium. This is the electromanometer designed and built by the Sanborn Company of Cambridge, Massachusetts. Since this device employs an oscillating circuit with a balanced bridge arrangement having a transducer of capacity type in one arm of the bridge, its output is proportional to pressures transmitted to one plate of the condenser from any desired external source. If the system of tubing leading to the transducer does not leak, the instrument will measure constant as well as variable pressures. In other words, if the tube connected to the transducer is attached to a small endpiece resting snugly on the precordium, vibrations of the chest wall, including those of the lowest frequencies, will be faithfully registered by a suitable recording device connected to the output of the electromanometer. The manometer usually supplied for measurement of arterial or venous pressures is not sensitive enough for the purpose at hand, but a more sensitive transducer may be obtained which will avoid this difficulty.

A simultaneous electrocardiogram is very helpful in timing, and we have found it convenient to use a

![Fig. 1. View of all equipment used to take vibration records. The Sanborn Electromanometer is at the left, and the Tri-Beam Electrocardiograph we have used to record the tracings with a simultaneous electrocardiogram is on the right. The yoke arrangement supporting the endpiece which rests on the chest wall is shown in front of the manometer.](http://circ.ahajournals.org/)

Sanborn Tri-Beam electrocardiograph to record the vibration record and the accompanying electrocardiogram. Figure 1 shows all of the equipment used to take the tracings.

In preliminary tests the tubing attached to the transducer was filled with distilled water, but this makes the entire system very sensitive to external vibrations, and fluid conduction was soon given up and air conduction employed exclusively. Tests have been carried out by means of suitable electric and acoustic circuits which show that a pressure change produced at the endpiece is transmitted to the transducer with a delay of approximately 0.005 second. This lag between acoustic and electrical records is too small to be important, at least for any studies we are doing at the present time. Air conduction probably causes some attenuation of pressure changes of high frequency, but again this is unimportant, since vibrations in the audible range are not primarily under investigation.

A few additional words must be said about the
endpiece and the manner in which it is secured to the precordium. A medium sized endpiece of the Bowles type with the diaphragm removed has been used exclusively. This must be supported so that it rests firmly on the chest wall and makes an airtight connection. This is essential, since leakage anywhere in the air space between the transducer and the endpiece will seriously disturb the response at low frequencies. To accomplish this, the endpiece is held by a support attached to a circular lead yoke, which is, in turn, fastened at the desired place on the chest by rubber straps placed around the thorax. (See fig. 2.) The lead yoke is covered with leather, but it can be bent in any desired fashion so that the endpiece will rest squarely and snugly on the chest wall.

![Fig. 2. Close-up view of the circular lead yoke which holds the endpiece. See text.](image)

It must be noted that this method of supporting the endpiece is advantageous, since the effects of respiratory movements are minimized, and it gives records which represent vibrations occurring in rather sharply circumscribed areas. It should be mentioned, however, that, if the entire precordium moves with the motion of the underlying heart, the yoke as a whole will also move, and the record obtained may not be a very true picture of actual displacements beneath the endpiece. Studies with other types of equipment, that cannot be described here, make it clear that vibrations closely resembling ballistocardiograms exist, not only over the precordium but over the entire chest, and one reason for the use of the device described above is to minimize these transverse ballistic effects.

It should be clear from the foregoing that the tracings obtained depict outward or inward movements of the chest wall beneath the endpiece and are true displacement curves. They should closely resemble cardiograms taken with a properly arranged optical setup. In our tracings, an upward deflection represents an outward movement of the chest wall beneath the endpiece. For reasons that will be discussed later, it is desirable to record tracings that reflect the velocity of movements of the chest wall as well as the actual displacements, and this is easily accomplished by the use of a differentiating circuit supplied by the Sanborn Company. When this circuit is plugged in, a velocity curve rather than the displacement curve is recorded. Both types of tracings have been taken in all subjects we have studied.

Respiratory movements, by altering the location of the heart with respect to the chest wall, and for other reasons, alter the form of the vibration records considerably. This is particularly true of the displacement curves, and for this reason all of these were taken during suspended respiration. This practice was not generally followed when velocity curves were being taken and explains some of the variations between complexes seen in our records.

**Results and Discussion**

Figures 3 and 4 are reproductions of records taken on different subjects. In all of them the vibration record is above and the electrocardiogram below. The former is labelled to indicate whether it is a displacement or velocity curve, and the sensitivity (scale setting on the electromanometer) used is also given. In many cases records were taken at two different speeds of the recording paper; 25 and 75 mm. per second. All tracings were taken at

**Figure 3.** See facing page.

**Fig. 3A.** Vibration records and simultaneous electrocardiogram (lead II) taken at the apex with the patient lying partially on his left side. The subject here was a man of 67 years with arteriosclerotic heart disease with no cardiac enlargement or signs of congestive failure. Moderate dyspnea on exertion was his only symptom. The heart sounds were faint, and barely audible extra sounds in early and late diastole were present. In these records and in the rest of those seen in figures 3 and 4, the vibration curves are labeled to indicate whether they are displacement or velocity curves, and the sensitivity at which they were taken (scale setting on the electromanometer) is given. Thus D-40 means displacement curve taken at sensitivity of scale 40 and V-10 means velocity curve taken at four times the sensitivity, i.e. scale 10. All records were taken at the apex unless labeled otherwise.

**B.** Records taken on an 18 year old male with a normal heart. The apex beat was not visible and barely palpable. The heart sounds were somewhat faint, and an inconstant third heart sound was heard. Lead II simultaneously.

**C.** Records taken on a 28 year old male physician with a normal heart. This individual had a thick chest wall, and no apex beat was visible or palpable. Heart sounds normal. Lead I simultaneously.
D. Records taken on a 23 year old male medical student with a normal heart. Lead II simultaneously.

E. Records taken from a point inside the apex on a 44 year old man with constrictive pericarditis. A diastolic heave was present over much of the precordium, and a distinct sound in early diastole was audible at both apex and base. Auricular fibrillation was present. Lead I simultaneously.

F. Records taken at the apex (A) and at a point near the left sternal edge at a higher level (I.A.) on a 47 year old man with rheumatic heart disease. Mitral and tricuspid lesions were present. Marked systolic pulses in the neck veins and persistence of peripheral edema and hepatomegaly in spite of treatment made the diagnosis of tricuspid disease quite certain here. Lead I simultaneously.
Fig. 4A. Records taken on a man of 38 years with hypertensive heart disease. The heart was enlarged and a double impulse was easily felt at the apex. The first sound at the apex was very faint, and extra sounds in both early and late diastole were audible. It is clear from the displacement curves that the second component of the double apex impulse that could be felt was due to a prominent outthrust in early diastole. Lead I simultaneously.

B. Records taken on a 34 year old man with chronic nephritis and hypertension. Cardiac enlargement was present. Although the displacement curves taken at the apex show large waves of low frequency in both early and late diastole, only an extra sound in presystole was heard. Lead I simultaneously.

C. Records taken on a 63 year old man about two months after anterior myocardial infarction.
the apex unless otherwise noted. A brief statement about the subjects from which each of these records were taken, including important physical findings, is included in the legends describing the figures. This material will not be repeated in the text, except in a few instances, in order that important points may be emphasized.

Because of the simple form of the displacement curve, the tracings shown in figure 3A were selected for discussion first. The records in this figure were obtained from a man of 67 years with arteriosclerotic heart disease. At the time they were taken no cardiac enlargement or signs of congestive failure were present, but careful auscultation at the apex with the patient on his left side revealed faint extra sounds in early and late diastole and indistinct heart sounds. Within six months he suffered a serious cardiac breakdown requiring vigorous treatment. The displacement curve consists primarily of three upward waves (representing out-thrusts of the chest wall). Small waves are seen in presystole and early diastole, and a larger one with a rather gradual ascent and more abrupt descent occupies systole. Except possibly for the wave in presystole, the three major waves here are of too low frequency to be audible, and they completely dominate the record. Vibrations corresponding to the first and second sounds are present on the ascending and descending limbs of the major wave in systole, but they appear as scarcely visible ripples or undulations.

The middle and lower sets of tracings in this figure show velocity curves taken from the same point on the precordium (apex) at four and ten times the sensitivity of the displacement curve. As one would expect, these records show vibrations corresponding to the easily audible components (first and second sounds) quite clearly. Since a differentiating circuit was employed to obtain the velocity curve, it must be the derivative of the displacement record. Inspection, in this instance where the vibration records are of relatively simple form, shows that this is true.

It is clear that in the displacement curve taken from this patient with serious myocardial disease, vibrations in the subaudible range are dominant. This appears to be generally true. (See figs. 4A, B, C, D). It may be of importance that this tracing showed the characteristics mentioned some months before heart failure appeared and when there were few clinical findings pointing to serious heart disease. Of considerable interest is the fact that low frequency vibrations corresponding in time to barely audible early and late diastolic extra sounds are clearly seen in both displacement and velocity curves. It is well known by anyone experienced in the technic of taking ordinary phonocardiograms that low pitched sounds like diastolic gallop or third heart sounds may be easily recorded even though they are scarcely audible. It appears that these phenomena are due to events which produce vibrations primarily in the subaudible range, since, in our experience and that of others, prominent vibrations of low frequency are regularly found to occur in early or late diastole.

The heart was of borderline size, and a distinct extra sound in presystole was audible at the apex. Lead I simultaneously.

D. Records taken on a man of 61 years with arteriosclerotic and rheumatic heart disease. The heart was enlarged, the heart sounds were faint and an inconstant early diastolic extra sound was present. Early congestive failure was present at the time this record was taken, and he died a few weeks later. Lead I simultaneously.

E. Displacement curves taken on a 31 year old woman with high grade mitral stenosis, both from the apex (A) and from a site along the left sternal edge at a higher level (I.A.). Note the prominent upward vibration in presystole seen in the tracing taken in the latter location. Lead I simultaneously.

F. Displacement curves taken on a man of 22 years with aortic insufficiency of rheumatic origin. These records show that a very large systolic out-thrust followed by one in early diastole of nearly equal size was present, since they were taken at low sensitivities. Variation between the relative size of the systolic and early diastolic waves in different records is probably due to the fact that they were taken at different periods of the respiratory cycle. Lead I simultaneously.
in subjects in whom these extra sounds in diastole are heard. (See figs. 4A, B and C.) Low frequency vibrations in diastole lacking in higher frequency components and therefore entirely inaudible are often seen in curves taken on normal subjects. These vibrations with or without audible components may appear in exaggerated form in tracings obtained from patients with serious myocardial disease, and a study of them should help to make clear some of the factors responsible for diastolic gallop rhythms.

The tracings taken on normal subjects shown in figures 3B, C and D vary widely in appearance but also have several things in common. While vibrations of very low frequencies are prominent in the displacement curves, oscillations corresponding to at least the major waves of the heart sounds are easily seen, and the velocity curves are not unlike ordinary sound tracings. Small vibrations in early or late diastole are seen in these normal records, and our experience so far indicates that generally speaking the subaudible vibrations both in systole and diastole are smaller compared with oscillations of higher frequency than is true in records from patients with serious myocardial disease. If this is correct, one would expect the velocity curves in patients in the latter group to be relatively smaller, compared to the displacement curves, than is the case in normal subjects. We have the impression that this is true, but further data and a satisfactory method of comparing the amplitudes of displacement and velocity curves will be needed before a positive statement on this matter can be made. It should be mentioned, however, that these concepts are in complete agreement with the ideas of Foulger and co-workers.15

Referring again to figures 3B, C and D, it is obvious that the apex impulse is not a simple out-thrust lasting throughout systole in all normal subjects. While this is roughly true in the individuals from whom the first two sets of records were obtained, figure 3D makes it clear that, except for a quick outward movement in early systole, the opposite was true in the third normal subject. These variations, even in normal subjects, may be understood if one remembers the previously quoted statement by Wiggers7 that "the apex beat represents only the varying pressure of the cardiac apex on the thoracic tissue; and this is solely governed by the shifting of the heart's position and its degree of filling." This explanation applies to vibrations of low frequency due to cardiac activity appearing at any point on the precordium and not to apex cardiograms alone. With this in mind, one realizes how many factors existing in the normal subjects, such as basic orientation of the heart with respect to the chest wall and effects of respiration and body position on this relationship, enter to make these vibrations vary tremendously in this group. Dressler8 points out many of the factors that may produce systolic out-thrusts or the reverse in subjects with normal hearts.

With full realization that relatively little is known about these vibration records even in patients without heart disease, it seems worth while to present a few examples of tracings taken on patients who have structural diseases which alter in a qualitative fashion the filling of the heart as a whole or lead to striking changes in the systolic or diastolic pulsations originating in one or more of its chambers. Thus, in figure 3E, vibration records taken from a patient with constrictive pericarditis are reproduced. In this patient a distinct out-thrust in diastole was visible over much of the precordium, and a fairly loud extra sound in early diastole was audible over this entire region. The displacement curves indicate the presence of an outward movement in diastole, and these waves have peculiar flat tops distinctly different from those obtained from any other subject to date. The significance of these flat topped waves becomes clear if one remembers that dense fibrous tissue surrounding the heart will prevent filling and dilatation of the ventricles beyond a certain point in diastole after which these chambers will remain engorged and relatively immobile. Electro-kymograms taken on patients with constrictive pericarditis have recently been reported by McKusick23 to show diastolic waves of very similar outline.

The displacement curves shown in figure 3F
were taken from a patient with rheumatic heart disease and insufficiency and stenosis of both mitral and tricuspid valves. One of these records was taken at the apex and the second close to the left sternal edge at a higher level. Both of these tracings show upward waves in presystole and more prominent upward waves in systole. Of considerable interest is the fact that these records show a much greater systolic outpulse in the region near the sternum (probably close to the right auricle) than at the apex. Such a finding would be expected with tricuspid insufficiency but may also be due to right ventricular hypertrophy. Records taken near the sternum in a number of patients with uncomplicated mitral lesions (with normal sinus rhythm) all show large upward vibrations of very low frequency in presystole but in none are very large upward waves in systole (as seen in fig. 3F) seen. This is indirect evidence that marked systolic distension of a large right auricle due to tricuspid insufficiency is the cause for the large waves in systole under discussion.

Figure 4E shows displacement curves from a patient with high grade mitral stenosis taken at the apex and from a point close to the left sternal edge at a higher level. The latter show the large upward wave in presystole, referred to above. It seems likely that these waves arise from outward pressure of an enlarged and dilated right ventricle during auricular systole. They have been inconspicuous or entirely absent in a few patients with mitral stenosis who have had auricular fibrillation.

The displacement curves shown in figure 4F were taken from the apex in a young patient with aortic insufficiency of rheumatic etiology. They were recorded using one-fifth to one-tenth of the sensitivity employed during the registration of most of the records shown in figures 3 and 4, and the upward deflections in systole therefore correspond to a very large systolic out-thrust at the apex. The major bifid wave in systole is followed by a prominent upward wave in early diastole. It is unlikely that this marked out-thrust in early diastole is related to diastolic filling in the usual sense; it is probably due to pressure of the apex against the chest wall caused by blood flowing back into the left ventricle through the incompetent aortic valve. Similar waves of varying sizes have been present in most patients with aortic insufficiency that we have studied.

It seems possible for reasons outlined above that tracings depicting the vibrations of low frequency at certain areas over the precordium may have some value in diagnosis. The displacement curves seem to offer most promise from this standpoint. We do not wish to give an overenthusiastic impression of the value of the method we have described or to leave anyone with the idea that the recording of displacement curves or attempts to explain their possible value is a new concept. Weitz in 1917, using the optical setup mentioned earlier, obtained displacement curves that are strikingly similar to ones we have obtained both in normal and abnormal subjects, and in Dressler's book a one will find not only graphic records illustrating pulsations of many different kinds occurring over the precordium but proof that many of these vibrations in the subaudible range may be detected by the physician who is aware of their existence and will look and feel for them. It seems to the writers that many physicians have forgotten the existence of pulsations over the heart that are often visible and palpable but are not audible, and the important role these vibrations should play in the physical examination of the heart. If this paper contributes anything worth while, it may be to recall and to emphasize the importance of earlier work in this field.

Relatively little has been said about the velocity curves and their possible value. Since these records represent the velocity with which pulsations occur (not the actual magnitude or size as is true of displacement curves), one would expect that they may be closely related to the functional status of the myocardium. Thus, in a patient with congestive failure, we may see and feel (and record) large movements over the heart but receive a very definite impression that these phenomena are occurring more slowly than when failure is absent. Evidence derived from displacement curves supporting this view has been mentioned earlier, and we are quite sure, on the basis of work to
date, that velocity curves are small in patients with serious myocardial disease and impaired cardiac function as compared with those from similar subjects in whom function is normal. It seems rather unlikely now that velocity curves will be widely used as a method for estimating the functional status of the heart, but further experience with them and development of technics for using them in a more quantitative fashion may indicate that they are helpful in this field.

**SUMMARY**

1. Apparatus is described with which accurate registration of vibrations of low frequency existing over the precordium (or elsewhere on the body) is easily accomplished.

2. The method is superior to most of those employed in recent years because it employs a basic unit capable of measuring static pressures. Tracings representing actual pulsations over the precordium (displacement curves) are therefore accurate for vibrations of the lowest frequencies.

3. Tracings showing waves proportional to velocity of movement of the chest wall (velocity curves) may be easily recorded by the use of a differentiating circuit.

4. The velocity curves are related to the functional status of the myocardium and may prove to be of value in this connection.

5. The displacement curves are practically identical with cardiograms taken with a properly arranged optical setup and may show qualitative changes, when taken over certain areas of the precordium in cardiac patients, that have diagnostic value.

6. These vibration records, especially the displacement curves, are important clinically, since they represent displacements of the chest wall that may be quite inaudible and yet are often visible or palpable.

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