CLINICAL PROGRESS

The Clinical Value of Vectorcardiography

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SOME WORKERS, with great enthusiasm about the clinical value of vectorcardiograms, may, after reading this article, believe it should be classified under some heading other than Clinical Progress, but the writer hopes that the discussion will at least point out clearly the relationship between ordinary electrocardiograms and vectorcardiograms and some of the problems relating to the registration of the latter. If these matters are clearly understood, much of the uncertainty regarding the clinical value of vectorcardiograms, expressed by some, as well as the overenthusiasm relative to their diagnostic value displayed by others should disappear.

In the simplest possible terms, vectorcardiograms are only a different technique for displaying electrical information contained in two electrocardiograms of the conventional type. The idea is not new, since Einthoven, Fahr, and deWaart\(^1\) in 1913 suggested the use of vectorcardiographic representation of the standard leads, and Mann\(^2\) in 1920 actually constructed from these leads figures that he called monocardiograms. These loops were very similar to vectorcardiograms recorded today in the frontal plane, but his work stimulated little interest and was largely ignored. In 1938 Schellong,\(^3\) in Germany, and Wilson and Johnston,\(^4\) in this country, almost simultaneously described techniques for recording electrocardiographic information as vector figures using the cathode-ray oscillograph and the name vectorcardiogram was suggested as a suitable term for these records. Since electrodes on the extremities were used for all of this early work, vectorcardiograms in the frontal plane only were recorded.

The cathode-ray oscillograph is essentially a special type of vacuum tube shaped like an Erlenmeyer flask with a suitable filament or heater emitting large numbers of electrons in the small end or neck of the tube. These electrons are concentrated into a small beam by properly placed, positively charged, focusing electrodes and further accelerated by other positively charged electrodes so the highly concentrated and rapidly moving beam of electrons passes from the small neck of the tube and strikes the inside surface of the larger circular base of the tube near its center. This inner surface is coated with special materials that emit visible radiation, usually blue or green, as a result of the bombardment with electrons. Thus, if the electron beam is in its normal position, at the central axis of the tube, it will cause a brilliant blue or greenish spot to appear at the center of the base of the tube. If the tube is to function as a recording instrument, two sets of deflecting plates (or in some tubes coils of insulated wire to create a magnetic field) must be mounted centrally beyond the electrodes that accelerate the electrons. These plates are at right angles to each other, one set, the vertical plates, being placed above and below the centrally located electron beam and the horizontal plates on each side of the beam. Voltages impressed on the horizontal plates cause the electron beam to be deflected to the right or left, thus causing the spot of light on the face of the tube to move from its central position to the right or left. Similarly, voltages on the vertical plates cause the spot

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Circulation, Volume XXIII, February 1961
to move either up or down from the central position. Figure 1 illustrates these matters.

The cathode-ray oscillograph is not a very sensitive recording device, and if the instrument is to be employed to record the small voltages involved in the electrocardiogram, these voltages must be stepped up with suitable electronic amplifiers, providing voltage amplification of 50,000 or more. If this is done and amplified lead I is connected to the horizontal plates, with the polarity arranged so an upward deflection in this lead causes the spot to move to the observer’s right, and amplified lead Vₚ (or aVₚ), with proper sensitivity, is connected to the vertical plates, so an upward deflection in this lead causes the spot to move downward from the central position, a series of closed loops that represent the vectorcardiogram in the frontal plane will be traced by the bright spot on the face of the tube. These figures are easily photographed if a camera is set up in front of the tube and the shutter is opened for a single heart beat.

It should be clear that a vectorcardiogram obtained by the use of the cathode-ray oscillograph will contain no information not previously available, since it is derived by the combination of two leads (for example, I and Vₚ), which are commonly recorded as ordinary (scalar) electrocardiograms. Furthermore, although the cathode-ray technic provides an elegant and “automatic” method of obtaining vectorcardiograms, the records would be no different from those constructed from ordinary leads by methods similar to those described by Mann.

Since the deflecting plates in the cathode-ray tube are located at right angles to each other and voltages impressed on either the horizontal or vertical plates cause the electron beam to move in a strictly horizontal or vertical direction, it seems logical, when one wishes to record a vectorcardiogram in the frontal plane, to employ leads or lead systems that provide the best possible transverse and vertical components of cardiac voltages. Similarly, for a vectorcardiogram in the horizontal plane one should employ leads that give transverse and sagittal components of cardiac e.m.f.s. are desirable. From the above, it will be observed that only three leads, each giving the transverse, vertical, and sagittal components of heart voltages in pure form, are needed to record satisfactory vectorcardiograms.

By all odds, the biggest technical difficulty in vectorcardiography today is the lack of agreement concerning leads or lead systems that should be employed for their registration; until decisions, which are generally accepted, are made on this important point, standardization of technic as has been attained with ordinary (scalar) electrocardiograms will be impossible.

Circulation, Volume XXIII, February 1941
As mentioned earlier, the vectorcardiograms in the frontal plane taken in 1938 by Wilson and Johnston were obtained by using lead I for the transverse (x) and V_F for the vertical (y) component (fig. 1). In the light of current knowledge, it is clear that these records were not very accurate, primarily because lead I does not give pure representation of the transverse components of cardiac voltages. Duchosal and Sulzer a few years later began to record vectorcardiograms not only in the frontal but in the transverse and sagittal planes as well, and constructed wire models from these figures that depict fairly well the size, shape, and relationship of the loops that represent the P waves, the QRS complexes, and the T waves. Although the rectangular lead system chosen by Duchosal seemed a reasonable and good one at the time, studies in recent years indicate that this arrangement, as well as the closely related cube system used extensively by Grishman and Scherlis and many others in this country in recent years, do not provide good transverse, vertical, or sagittal components of voltages arising in the heart. If the excellence and accuracy of vectorcardiograms are judged on the basis of how good are the orthogonal leads that one employs to obtain them, it must be conceded that vectorcardiograms taken with the cube and related systems are not very satisfactory. This situation has done little to dampen the enthusiasm of some vectorcardiographers who have claimed that their vectorcardiograms are better than ordinary scalar electrocardiograms for the diagnosis of bundle-branch block, ventricular hypertrophy, and other cardiac conditions. Claims of this kind deny the long years of clinical and experimental experience that underlie proper interpretation of ordinary electrocardiograms and are largely nonsense, in the opinion of the writer. Vectorcardiographers should always remember that the vectorcardiograms they record always represent the combination (by the magic of the cathode-ray tube) of two leads from each of which ordinary electrocardiograms may be taken, and further that there can be no essential information in the vector figures that may not be gleaned from a study of these two electrocardiograms. Few of the vectorcardiographers who extoll the value of their vector records would brag about the excellence of electrocardiograms taken with the same leads. Most physicians are "suckers" for complicated and fancy equipment, and the writer suspects that much of the current popularity of vectorcardiography arises from the glamorous apparatus, rather than from any well-founded conviction that vectorcardiography represents a truly new approach to electrocardiographic diagnosis.

Burch and associates and others have taken many vectorcardiograms in the frontal, transverse, and sagittal planes, using the equilateral tetrahedron as the basis of their lead system. This arrangement employs lead I for the transverse (x) component, V_F (or aV_F) for the vertical, (y), component, and a point in the back (V_B) behind the heart, and the central terminal as the sagittal (z) component. Of these three leads, only V_F(y) is a good orthogonal lead, and V_B, the sagittal lead, is especially poor. Again, if one believes (with the writer) that vectorcardiograms are only accurate if good orthogonal leads are used to record them, it must be concluded that vector figures taken with the equilateral tetrahedron system are not good records, and conclusions drawn from them (like those from the cube system) must be taken with a large "grain of salt."

This discussion brings up an obvious question. Are there any good and practical systems for obtaining orthogonal leads that may be used to record accurate vectorcardiograms? The answer to this question is a qualified yes. Schmitt and Simonson and Frank have carried out extensive studies on torso models of human subjects and from these investigations have been able to design lead systems that provide orthogonal leads giving far better and purer representations of the transverse (x) and sagittal (Z) components of the cardiac voltages than in any of previously described arrangements. A good vertical component (y) is easy to obtain compared with the other two, and most workers will agree that V_F (or aV_F)
or a lead obtained by electrodes on the left leg and around the neck are quite acceptable. The systems suggested by Schmitt and Simonson and by Frank are both based on experiments in which hearts of normal size and usual location were assumed and the electrode locations and size of resistances in the associated averaging networks were chosen in accord with experimental results in this average "normal" subject. One may therefore properly question the accuracy of these orthogonal leads in patients with considerable cardiac enlargement or an unusually placed heart.

Burger and van Milaan laid the foundations for a great deal of important work on electrocardiographic leads when they described the concept of the lead vector in 1946. Burger more recently has suggested the use of relatively simple lead systems for the orthogonal \((x, y, z)\) leads by employing coefficients that may be used to correct the error inherent in these leads and make them essentially orthogonal. Unfortunately, the magnitude of these coefficients should vary in different patients with variations in the size and position of the heart, just as should the ideal positions for electrodes and the character of the resistance networks in the systems of Frank and Schmitt mentioned above.

It seems to the writer that a concept closely related to the lead vector, namely that of the lead field, described by McFee and Johnston, points the way to a simple practical scheme for obtaining good orthogonal leads. As mentioned above, either lead \(V_r\) (or \(aV_r\)) or a bipolar lead with electrodes on the left leg and around the neck provides an entirely satisfactory lead for the vertical component \((y)\) of voltages arising in the heart. This is true because the lead fields associated with these leads could be represented by lines of current flowing uniformly in a vertical direction through the heart. Similarly, leads providing good transverse \((x)\) and sagittal \((z)\) components of cardiac voltages should be associated with uniform lead fields having strictly transverse and sagittal directions. An arrangement consisting of uniformly spaced electrodes (16 or more) mounted on a thin flexible plastic sheet placed over the cardiac area anteriorly and on the posterior chest wall behind the heart should give a uniform, sagittally directed lead field and therefore be a good lead for the sagittal \((z)\) component of cardiac voltages. Each of the electrodes of the grid must be connected through equal, large (1 meg. ohm) resistances to a common terminal, and these terminals, one anterior and one posterior, are the points of connection for the sagittal lead. Reynolds and associates have discussed the technic for a sagittal lead of this kind in detail. A similar multiple electrode arrangement placed on the left and right lateral chest walls at the cardiac level or corrected lead I described by McFee and Johnston should provide a good lead for the transverse \((x)\) components of heart voltages.

It is likely that electrocardiograms or vectorcardiograms taken with the systems of Schmitt or Frank would be much like those obtained by the multiple electrode arrangement outlined above in the majority of patients. It seems to the writer, however, that since the latter system does not depend on fixed positions for electrodes and an accompanying network of resistances tailored to fit an average normal subject, it has some advantages over the systems proposed by Schmitt and by Frank. For example, if a patient is known to have a greatly enlarged heart the only important consideration with the multiple electrode system is to be sure that the grid arrangement is large enough to cover the projected area of the heart for both sagittal and transverse leads. Objections to the use of the grid system because it is complicated and time consuming are not justified by the facts, since it has been satisfactorily used in our laboratory by technicians trained only in the registration of routine electrocardiograms.

A great many studies have been carried out to estimate the comparability and excellence of some of these systems for orthogonal leads, and there seems to be general agreement that the arrangement of Schmitt and Simonson (S.V.E.C.III), the seven-electrode system of Frank, and the multiple electrode grid set-up give similar results and are clearly superior.
to the cube or equilateral tetrahedron systems. Nevertheless, as mentioned earlier, there has been no general agreement on which plan should be accepted, and until this is achieved vectorcardiography will continue to be an empirical and mixed-up science.

An important additional reason for uniform acceptance of good arrangements for orthogonal leads is that leads good for vectorcardiography would also be good for ordinary scalar electrocardiograms and should simplify routine electrocardiographic technic greatly. Thus, it is almost certain that two leads giving complete and accurate representations of the transverse and vertical components of cardiac voltages would provide all the information now recorded in six limb leads. It is also likely that, for many purposes, a good sagittal lead would give the essential data displayed by the six routine chest leads. Thus, in three leads one would find a display of the essential electrical activity of the heart, and these could be used either for ordinary scalar electrocardiograms or for vectorcardiograms, as the physician desired. If it is remembered that a good orthogonal lead rejects voltages in the heart that are not oriented in a certain direction (transverse, vertical, or sagittal) but serves to sum up or average all components of heart voltages in one of these directions, it should be clear that the electrical effects of a small lesion, like an anterior infarct, might be lost in the averaging process, and evidence pointing to a lesion of this kind might not appear in a single sagittal lead. Another way of saying essentially the same thing is that not all of the information to be gleaned from leads taken on the surface of the body can be due to a single equivalent dipole located in the heart. Most well-informed workers on electrophysiology of the heart will agree with this view, and it means that three "perfect" orthogonal leads may have to be supplemented by a few chest leads to pick up small lesions, like anterior infarcts, in some patients. This will be equally true whether scalar electrocardiograms or vectorcardiograms are taken with these perfect orthogonal leads.

In the foregoing discussion emphasis has been placed on the fact that vectorcardiograms are only a different way of presenting data readily available in ordinary scalar records and that they therefore can represent no basically new approach to electrocardiographic diagnosis. Nevertheless, vectorcardiograms are much more illustrative of electrical events occurring in the heart than are scalar electrocardiograms, and they depict very clearly phase differences between peaks of R waves (for example) that can only be appreciated if the scalar ingredients of the vector figure are recorded simultaneously. These matters have been discussed and are illustrated in an editorial written by the writer several years ago.14

For example, if one examines a normal vectorcardiogram taken in the frontal plane (fig. 2A), it is immediately clear that during excitation of the ventricles (represented by the QRS loop) the average direction of excitation is downward and to the left, close in direction to the anatomic long axis of the heart, and that there is not a great deal of rotation of the instantanous electrical axes during the entire period of activation. Further, one sees the normal relationship between the T loop and the QRS loop. The figure representing the P wave is also seen in most vectorcardiograms but without greater amplification than is ordinarily employed these loops are small and often obscured in the central (zero) spot. The loops representing P waves are not shown in figure 2.

The vectorcardiogram on the same normal subject taken in a transverse or horizontal plane is shown in figure 2B. Here it will be observed that early in excitation of the ventricles the vectors are small and directed anteriorly and slightly to the right corresponding, of course, to the small initial R waves seen in the right precordial leads, but as activation progresses the vectors rotate in a counterclockwise rotation to assume a posterolateral and finally a nearly posterior direction. These later vectors are responsible for the large S in right precordial and the R waves in left precordial leads. It will also be seen that
the vectorcardiogram, again of the same normal subject, in the sagittal plane (fig. 2C) may be similarly interpreted.

There has been considerable confusion about the term "spatial" vectorcardiography. Many workers would say that the writer is a "spatial" vectorcardiographer, since he has presented the data shown in figure 2. This is not strictly true, however, since all this figure shows is the projection of the loops of the true spatial vectorcardiogram on three planes mutually perpendicular to each other. It is true that any two of these three vector figures provide the information necessary to visualize (if one is imaginative) the approximate outline and position of the loops in three-dimensional space, and if one is industrious, as Duchosal, Burch, and associates, and others have been, to construct wire models of the loops as they exist in space. If these models are carefully made, they are of considerable interest and importance, because from them vectorcardiograms in any desired plane may be obtained by projection, and from these vectorcardiograms scalar electrocardiograms may be derived by projection on the line of any desired lead. The stereovectorelectrocardiograph (SVEC) described by Schmitt is a technic for the visualization of the spatial vectorcardiogram and accomplishes the same end as is achieved by the wire models mentioned above. Unfortunately, the cost and complexity of the equipment required limit the usefulness of this instrument.

This discussion should make it clear that the clinical value of vectorcardiograms should depend primarily on the character of the leads employed to record them. Since the deflecting plates in the cathode-ray tube are placed at right angles to each other and movements of the electron beam and therefore the spot of light on the face of the tube can only move in strictly transverse or vertical directions from the center of the tube when voltages are placed across the horizontal and the vertical deflecting plates respectively, it seems essential to the writer that components of cardiac voltages at right angles to each other (i.e., orthog-
onal leads) of the purest possible kind should be selected for the registration of vectorcardiograms. It must be pointed out that vectorcardiograms will be obtained if any two different leads are amplified and impressed on the horizontal and vertical plates of the tube, but these will not be in the frontal, horizontal, or sagittal planes unless good orthogonal leads are chosen. Workers can go on almost indefinitely collecting vectorcardiographic data using poor (not orthogonal) leads and attempting to correlate these with other clinical and postmortem findings. Much activity of this kind has been carried out and unfortunately fortuitous circumstances have occasionally led some individuals to believe that such vector records are more accurate and reliable than are ordinary scalar electrocardiograms.

It must be remembered that satisfactory orthogonal leads have been developed only in recent years to meet the requirements inherent in a good technic for vectorcardiograms and that no one has had much experience with such leads for the registration of ordinary scalar electrocardiograms. It will be difficult for many physicians, including the writer, to drop the time-honored limb leads and the "unipolar" extremity and chest leads in favor of three orthogonal leads, supplemented occasionally by a few chest leads of the type now recorded. Nevertheless, it seems almost certain that the simplicity of a rectangular (orthogonal) reference system and that many other advantages of good orthogonal leads will lead eventually to their general acceptance for routine clinical work. When this time arrives, vectorcardiograms may be recorded if the physician likes the vector method and has the necessary equipment. A few scalar tracings will probably always be necessary for measurement of important intervals in the electrocardiogram, especially the P-R interval, and for diagnosis of arrhythmias. A number of individuals have suggested and have actually recorded vectorcardiograms on slowly moving paper or film, and this does provide a horizontal time axis for the vector records. This technic, however, has the disadvantage of distorting the vectorcardiograms.

References
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Circulation. 1961;23:297-303
doi: 10.1161/01.CIR.23.2.297

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1961 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

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