Editorial

Examination of the Validity of the Concept of Vectorcardiography

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Full recognition must be given to the pioneers who have made what is known as vectorcardiography possible, and who have added a most useful tool to the armamentarium of the cardiologist, but it is pertinent to ask whether this newer method of recording the electrical activity of the heart has kept its early promise. Before one can attempt to answer this question it is necessary to ask another two, namely whether vectorcardiographers themselves agree that this is the case, and whether they agree among themselves upon the best way of recording vectorcardiograms.

There certainly is unanimity among them that vectorcardiography is valuable, but they are not able to agree on the best electrode placements—and one obtains as many variations of the recordings as there are systems of electrode placement. Much work has been done and much time has been spent in attempting to correlate these variations mathematically, and even to equate them with the purely synthetic vectorcardiogram constructed graphically from the scalar electrocardiographic leads of the Einthoven system. A most complex terminology concerning lead vectors, vector images, lead field concepts, and so on, has arisen, which is confusing to the uninitiated and deters many a clinician from taking up this most rewarding method of investigation.

The reason for the existence of these various electrode placements is that several different theories have been propounded for siting the electrodes in a particular way. Without, for the moment, considering their individual merits, it must be obvious that these cannot all be correct. Moreover, there is no positive and logical proof which is the correct one—or whether indeed any one of them is correct. In fact no proof is possible. If such proof existed, then all other theories and electrode placements would naturally fall away, and there would remain only a single system. This, however, is not the case, and one must conclude that various vectorcardiographers have a preference for a certain theory, without being able to prove its validity to the others, or to convince them of its particular merit.

It appears that all existing systems are without exception based on assumptions and theories and not on proven facts. Some theories are based on a model of the heart in a model thorax, but this again is tantamount to making assumptions that this will faithfully reproduce the actual potentials of the living skin surface—which it does not do. Others assume that a centrally placed heart lies within a homogeneous tissue envelope inside a symmetrical thorax, and examples could be multiplied.

The concept of vectorcardiography and all the various systems developed depend upon two unproven key assumptions: firstly, that all the instantaneous potentials produced by the heart can at all times of the cycle be represented by a single cardiac vector resulting from the activity of an assumed single equivalent dipole; and secondly, that the body can be regarded as having the shape of a tetrahedron, a triangle, a parallelogram, or a cube, for the purposes of selecting the electrode placement. By strict scientific standards both these assumptions are untenable. If the concept of the single equivalent dipole is not valid, one has to ask oneself: What do these loops which can be produced on an oscilloscope actually represent, if they are not "vector loops" described by hypothetical equivalent cardiac vectors?

It will be necessary to revert to fundamentals. If the horizontal plates of a cathode ray tube are connected to a variable voltage source, and the vertical plates are connected to another variable voltage source, then when both voltages are at zero, the electron beam or spot on the fluorescent screen will occupy the exact centre of the screen, i.e. the intersection of the horizontal or vertical axes. If one voltage alone is increased and varied in any way,

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the spot will describe a straight line—horizontal or vertical, as the case may be. If both voltages are simultaneously and arbitrarily varied, then the spot will describe a loop, a Lissajou figure, which at any instant indicates the relation of these 2 voltages to one another. This is all it does, and to ascribe anything else to this loop is scientifically unwarranted.

Referring to Fig. 1, the upper trace represents a varying voltage and the lower trace another varying voltage. Both were produced and varied purely electrically and they are not electrocardiographic traces of a patient, though they happen to have this general shape. One of these voltages was applied to the horizontal pair of oscilloscope plates and the other to the vertical pair. A loop resulted as seen in Fig. 2, resembling what one is accustomed to call a “vector loop”. This figure, however, proves nothing more than that varying voltages were simultaneously applied to the horizontal and vertical plates.

![Fig. 1](image1.png)

**Fig. 1.** Simultaneous tracings of 2 voltages whose amplitudes were individually and arbitrarily varied with respect to time.

It is possible to produce similar voltages and loops as in Fig. 1 and Fig. 2 by picking off skin potentials arbitrarily with four electrodes from almost anywhere on the thorax. Again, nothing more is proved than that varying voltages exist on the skin and that these are not in phase, otherwise the loop would be symmetrical. In a given set of circumstances the variations in voltages and the shapes of the loops will depend entirely on the relative positions of the 2 electrodes that are connected to the horizontal plates and the 2 electrodes that are connected to the vertical plates—and this loop will be different for every difference in electrode placement. Which is the “correct” placement? There is no unanimous view on this. If one wishes to have large open loops one should search out places on the skin between which a large difference of potential exists in a healthy person, and one must adhere to this placement in relation to the bony skeleton, in all future measurements.

The mere appearance of this loop on the screen is no proof that these skin voltages are caused by an equivalent cardiac dipole, or a rotating vector, or a “projection” of such a vector on to a lead axis.

What then is the nature of these varying voltages and how are they caused? The facts are well established. These potentials are the products of irregular and intricately contoured patterns of several positive and several negative electric fields which either erupt separately, or simultaneously sweep across the skin of the front and rear of the thorax—in the general direction from the right shoulder down to the left costal margin and up again over the back, as Taccardi and Marchetti (1965) have well shown, and as many others have verified. These fields merge, separate, and throw out apparently random pseudopodia as they flee across the skin. Sometimes several positive and negative fields intermingle. At other times only a single positive and a single negative pole seem to be present. A particular electrode pair measures the difference of potential which happens to exist between the two electrodes at any instant, and it is obvious that this must be different with every difference in electrode placement, on account of the highly irregular and unpredictable contours of the electric fields.

This is the phenomenon one measures, and this should be distinguished from the idea that one is measuring the “projections of the single equivalent...
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Cardiac vector. Five or six most favoured electrode placements already exist, and new ones appear from time to time. All of them naturally produce different loops, but all of them work as a diagnostic tool, as work they must, provided a sufficient number of empirical correlations has been established.

The only relevant facts, as opposed to theories, in electrophysiology are measurements of surface potential fields on the one hand, and of direct epicardial and myocardial potentials on the other. All these bear out the extreme complexity of the phenomena with which we are dealing. The heart is a multipolar electrical generator. It has been shown that whatever the number of separate electrical poles, the electrical effects cannot be summed vectorially at a distance less than 5 times the radius of the heart (Pozzi, 1961). This locates suitable electrode positions much further out than the body skin itself, by approximately 30-5 cm. (12 in.), and renders any sort of "vectorcardiography" from electrodes placed on the skin nothing more than the roughest approximation. This accounts for the discrepancies, arguments, and debates that are still raging around this subject. If one takes the surface potentials for what they are and not for what one imagines them to be, one can lay the foundations of a new concept in "vectorcardiography"—only one will not be able to call it by that name, because the loop seen on the cathode ray tube screen is not a resultant vector loop.

This change in the real understanding of the nature of the observed phenomenon, however, does not detract from the usefulness of this x-y display as a most valuable diagnostic tool. It is the theories that are vulnerable and not the facts. Nor is this method less valuable if we alter the terminology from "vectorcardiography" to "x-y cardiology". Doing so releases us from the obligation to establish the validity of some very awkward vector theories, and it also describes the phenomenon more objectively without prejudice or conjecture.

The normal heart is so spirally twisted that the "right" ventricle is anterior and the "left" ventricle is posterior and tilted upwards. The heart, moreover, does not lie symmetrically in the chest. There is in fact no rational geometrical or electrical approach to the measurement of the potentials produced by the heart, and no orthogonal, triaxial, hexaxial, tetrahedral, or other system can represent the "planes", if one can use this word, of the actual heart, because it has no orientation to which we can align our measurements.

Much confusion also exists concerning the distinction between "local" and "general" potentials. What does an electrode on the skin actually measure? It measures the local potential difference which exists between it and some other electrode, which can either be placed on another part of the skin or be connected to a "neutral" point.

But this local potential is a function of the general potentials generated by the heart as a whole, as manifested at this particular point. Whereas the electrode might not measure the direct effect of, say, an infarct geometrically underneath it, it does measure or reflect the effect of this infarct on the total potential generated by the heart, as manifested at the particular point of location of this electrode on the skin.

How do the moving irregular electrical fields on the skin surface with their several positive and negative maxima and minima come into being? They are the consequence of similar fields appearing on the surface of the heart, modified by a certain amount of short-circuiting and by having to reach the surface of the skin by devious conductive pathways. Depolarization effects of the myocardium are initiated in a very complex pattern and arrive at different sites on the epicardium and hence on the surface of the skin at different times. This intricately convoluted picture of the manifestation of the cardiac potentials, as observed on the surface of the skin, is remote from the hypothetical geometric conceptions of equilateral triangles, cardiac dipoles, and equivalent instantaneous vectors.

This explains the impossibility of accurately equating various vectorcardiographic systems with one another and with the standard 12-lead system.

It seems better, therefore, to accept the skin potentials for what they are, decide on a universally acceptable electrode placement system, collect a large number of empirical correlations in health and in cardiac disease, and have an internationally agreed x-y system, similar to the 12-lead system. In doing so, one should avoid new theories and newly "calculated" points, which in all probability will also give rise to criticism from one quarter or another. The simpler the agreed electrode placement the more acceptable it will become. Einthoven's points were chosen purely empirically because it was easy to place feet and hands into salt water baths.

It is possible that only 4 electrodes of normal size, as used for chest leads, may give all the necessary information, and these should be placed within the path of the revolving or erupting electrical fields so as to avoid "averaging" by electrodes placed further away. For this reason, too, large plate electrodes and multiple coupled electrodes, such as have lately been appearing, should also be avoided.

The so-called vectorcardiogram artificially and graphically constructed from the 12-lead electrocardiogram does not enter into this discussion at all,
because it is nothing more than a geometrical re-drawing of the scalar lead potentials in vectorial form. This is the reason for the frequently heard erroneous claim that a vectorcardiogram is merely another method of representing the ordinary scalar cardiogram, and hence is of no additional value. This is not so, because this kind of vectorcardiogram has been constructed and not actually recorded. Once the cardiograph recording paper has been removed from the machine, our collection of electrical facts is at an end, and nothing more can be added to our knowledge by rearranging these facts in different ways. All that remains is the interpretation of what we have. Real x-y cardiography recorded from the living body by specially selected surface leads is far more meaningful than merely reconstructing the scalar leads on paper, as this does provide new information.

The ideal electrode placement for x-y cardiography should be sited on those points on the thorax which, in a healthy body, display the most marked potentials. Such an x-y cardiogram may bear little resemblance to that obtained from reconstructing the 12-lead scalar electrocardiogram or to other existing vector systems, which have been specially designed to approach the 12-lead system construction as closely as possible, but it does not need to do so. Einthoven accepted his potentials for what they were, others later developed post hoc propter hoc theories on the basis of Kirchhoff’s laws. But these laws apply to all electrical networks, be they 3-lead, 4-lead, 5-lead, etc., up to an infinite number of leads. Einthoven’s 3 leads satisfied these laws, but so would any 3 leads taken from anywhere on the body. To adduce this correlation as “Einthoven’s law” and as proof that the heart is electrically equidistant from his 3 electrodes surely is a fallacy. This does not matter, however, as long as no geometrical constructions or deductions are derived from it.

As a result of such and similar errors in logic, we are today presented with theoretical constructions on paper of axes, projections, and vectors which have no bodily existence.

“Vectorcardiography” is rapidly falling into this error and is becoming far more artificially complicated than it need be. Let us accept that it is empirical, and that therefore the simplest and most efficient possible electrode placement is as good as any other, as long as it is made universal. The skin potentials should be measured just as they are at full output and without corrections and from as few points as will give good clear and large recordings. One could then assess the trace for what it is—notthing more than an x-y recording of the skin potentials in health and in disease. A single cardiac clinic could produce sufficient correlations in one year. The argument that 50 years of experience in cardiology would have to be discarded if this were done has no substance. Oscillographic x-y cardiography would be immensely furthered if electrocardiographers were to establish a single universally accepted method of recording which should be as simple as possible, so as to appeal to the widest circle of users, discard unfounded theories, and establish empirical clinical correlations using directly recorded factual information.

REFERENCES
