Historical review of clinical electrocardiographic lead systems and proposed lead systems

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AN HISTORICAL REVIEW OF CLINICAL
ELECTROCARDIOGRAPHIC LEAD SYSTEMS
AND PROPOSED LEAD SYSTEMS

by

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CHAPTER I

INTRODUCTION

In the most general sense the goal of electrocardiography can be said to be the solution of two closely related problems concerning the electrical activity of the heart. The first of these problems is the measurement, via external electrodes located on the body surface, of electrical potentials which accurately characterize the electrical activity of the heart. The second problem is to relate the potentials thus measured to the physiological mechanisms by which they are produced and ultimately to gain insight into the pathological conditions and their location within the heart by which these potentials might be altered.

Several properties of the human heart and of the human body have combined to make the problem of accurately measuring cardiac potential at the body surface an extremely difficult, if not, as believed by many investigators, an impossible assignment. Among these properties are irregularity and individual variability in the size and shape of the human torso, individual variation in the anatomic position of the heart, variability in the position of the electrical center of the heart throughout the cardiac cycle, and inhomogeneities in the conducting medium inter-
posed between the heart and the body surface.

Through the years a large number of electrocardiographic lead systems have been designed which attempt to increase the efficiency of retrieval of the information available in the cardiac electrical activity and to minimize the errors introduced by the physical properties of the heart and of the human body as mentioned in the preceding paragraph.

It is the purpose of this paper to review a number of these lead systems and to discuss their importance, either actual or potential, in clinical electrocardiography.
CHAPTER II

STANDARD 12-LEAD ELECTROCARDIOGRAPHY

The "conventional" clinical electrocardiogram is based on a system of twelve leads which were devised incorporating a number of inaccurate assumptions which introduce certain errors and distortions of various significance into the tracings obtained. These twelve leads are essentially of three types; three standard limb leads, three augmented unipolar limb leads, and six unipolar precordial leads. In the sections to follow these leads will first be discussed separately and finally the combination of these leads and their impact on clinical electrocardiography will be reviewed.

I. THE STANDARD LIMB LEADS

Einthoven\(^1\), in 1913, introduced a system of bipolar leads for the purpose of measuring the "manifest cardiac vector." The system consists of three leads with electrodes placed on the right arm, left arm, and left leg. For lead I the positive electrode is placed on the left arm and the negative electrode is placed on the right arm. In lead II the positive electrode is on the left leg and the negative electrode is on the right arm. Lead III has the positive electrode on the left leg and the left arm electrode is
negative.

In designing this system Einthoven was forced to make three assumptions which he realized at the time to be only approximations of the truth, but which he accepted in the interests of convenience and simplicity, in the absence of satisfactory alternatives, and in the belief that the errors introduced would be small and would not greatly diminish the validity of the information obtained. These assumptions are: (1) that the heart could be represented as a fixed, point-like electrical generator, that is a dipole, (2) that the body could be represented as an infinite, spherical, homogeneous volume conductor with the heart at its center, and (3) that the extremity electrodes were sufficiently distant from the heart to be considered electrically equidistant, if not actually anatomically equidistant, from the heart. Since the introduction of the standard limb leads these assumptions have been the subject of a great deal of controversy and of countless investigations as to their validity and as to the magnitude of the errors involved.

Perhaps the most hotly contested of these three hypotheses is that the heart can be represented as a fixed dipole. Frank\(^2\) states the problem as follows:

Given a three-dimensional conducting medium with an insulating boundary (the human body) and a time-varying potential distribution over the boundary (P, QRS,
and T waves), determine the characteristics of internal electrical generators that could have produced this potential distribution.

From the problem thus stated and from a knowledge of fundamental potential theory it can be seen that an answer is obviously possible, but that an unique answer is just as obviously impossible, since it is known that potential distributions on the boundary do not specify unambiguously internal generators that produced the potential distributions. Therefore, in electrocardiography, an equivalent generator that by definition produces exactly the same body-surface potentials as the actual heart generator can be deduced from body-surface potential measurements, but there is an infinite number of different equivalent generators that could produce the same results. Frank concluded from this that the dipole hypothesis thus represents a generator that could have produced the observed surface potentials, but is an artificial concept and does not actually exist.

More specifically, Taccardi\textsuperscript{3} plotted isopotential maps on the body surface of a series of normal subjects. He found patterns that could not be ascribed to a single dipole generator, that is multipolar patterns, for periods of 20 to 35 msec, during QRS. For the remainder of the QRS duration a dipolar distribution was found.

Despite the fact that the dipole hypothesis is
almost universally considered inaccurate, it is also generally accepted that within the framework of clinical electrocardiography it does represent a good first order approximation. Indeed, Frank⁴ provided sound theoretical evidence that the theory is a sufficient model of actual conditions to provide useful clinical information without gross distortion.

As regards Einthoven's second assumption, Katz⁵ states that the human body as a volume conductor is finite rather than infinite. It is neither spherical nor homogeneous. And furthermore, the heart is located eccentrically and close to the surface.

A large body of information concerning the conductive properties of the various tissues surrounding the heart has also been presented over the years. Linder and Katz⁶ in a series of experiments involving the insertion of insulating materials between the heart and the surrounding tissues demonstrated that the posterior muscle mass is the best electrical conductor, followed by the diaphragm and its adjacent viscera, and then by the superior mediastinum. The anterior chest wall they found to be a relatively poor conductor and the lungs act as almost complete insulators. They state that the electrocardiogram is not a summation of events occurring in all parts of the heart, but is primarily a summation of events occurring in those regions
which are in contact with the better electrical conductors. Other regions play a less important role. Thus the regions which will have the greatest effect on the distant electrical field and hence on the electrocardiogram will be those in contact with the posterior paravertebral muscle mass (the base of the left ventricle and the posterior aspect of the left atrium) and those in contact with the diaphragm (the caudad regions of the right atrium, right ventricle, and left ventricle). The anterior surfaces of the right atrium, right ventricle, and left ventricle, in contact with the anterior chest wall over the precordium, will have a lesser importance, while the rest of the heart shielded from the body by the lungs will have an unimportant role, especially in the upper lateral portions of the heart where the lung is so thick that for practical purposes it shields completely these parts of the heart from the chest wall.

In designing a system of leads for the purpose of measuring cardiac vectors it is essential that all leads involved measure potentials on the same scale, which is to say that all electrodes must equidistant electrically from the source of the electrical field. Realizing the difficulty of placing three mutually perpendicular leads on the body equidistant from the heart equivalent generator, Einthoven made use of a characteristic property of electrical fields
that the intensity of the field diminishes algebraically with increasing distance from its center. It has been shown that when an electrode is about 15 cm. from the heart increasing this distance has little effect on the measured potential. Thus in making the assumption that electrodes placed on the limbs are electrically equidistant from the heart Einthoven is again technically inaccurate but the error introduced is so trivial that for clinical electrocardiographic purposes the assumption is a valid approximation.

II. THE AUGMENTED UNIPOLAR LIMB LEADS

The remaining two components of the standard 12-lead system are unipolar leads as differentiated from the standard limb leads which are bipolar leads. A unipolar lead may be defined as one which measures the potential difference between a variable point and a fixed point in which the potential variations of the fixed point are equivalent to those of a region of the force field wherein current density is negligible in comparison to its variation at the variable point.

Many years after Einthoven introduced the standard limb leads, Wilson and his associates introduced the unipolar limb leads. In these leads the variable or positive electrodes are each attached to a limb. The fixed or
negative electrode is attached by three wires to all three limbs. The negative electrode is thus the summation of the three standard limb leads. Assuming the validity of Einthoven's postulates and the accuracy of the Einthoven, and according to Einthoven's law which states that the magnitude of the deflection of lead II (where lead II by convention has a reversed polarity), then the central terminal of Wilson (which as pointed out above is the summation of the limb leads) will have a zero potential throughout the cardiac cycle.

The unipolar limb leads and the Wilson central-terminal utilize the same electrode positions as those employed for the standard limb leads and thus, as would be expected, they are subject to the same errors and distortions as were discussed above for the standard limb leads. Two additional aspects of this system of leads (and also of the precordial leads, as will be pointed out in a later section) which incorporate the theoretical basis for their application and the rationale behind their introduction have been subject to detailed scrutiny.

The first of these assumptions is that the central-terminal contributes a zero potential throughout the cardiac cycle. Hill states that on the basis of the characteristics of the "surface zero" measured by external electrodes and the "intrinsic zero" measured at the surface of the
heart equivalent generator and as a result of the characteristics of the conducting medium imposed between the two it is impossible to find a point or even any combination of points on the body that will give a true zero potential, or that will give the same potential throughout the cardiac cycle. In support of this view Bayley states that the Wilson central-terminal is no more than a method of approximating the potential of the mid-point of the equivalent cardiac dipole. He measured the potential of the central-terminal with respect to a grid-lead central terminal and found that the potential varies considerably from subject to subject and averaged 0.32 mv in a small group of normal male subjects. Frank measured the central-terminal potential on a normal human subject and found an amplitude of 0.79 mv.

However, although it was conclusively demonstrated that the central-terminal did not remain at zero potential throughout the cardiac cycle, it was also demonstrated by Dolgin, Grau, And Katz that its fluctuation from zero was less than at any single point on the body surface. Thus, the Wilson central-terminal has gained almost universal acceptance as a useful approximation of an "indifferent" or "zero potential" electrode.

The second assumption made with respect to unipolar limb leads and to unipolar leads in general is that their
introduction would provide information not obtainable from the bipolar limb leads and they would be greatly influenced by that region of the heart in closest proximity to the exploring electrode.

Since the unipolar limb leads use the same electrode locations as the standard limb leads they must measure the same electrical forces as the standard limb leads do. The differences in contour observed simply reflect the fact that the axes on which the unipolar leads are measured are oriented differently. In short, both the standard limb leads and the unipolar limb leads contain exactly the same information and neither type has superiority from either a clinical or theoretical point of view.

The concept that the unipolar leads would measure directly the electrical activity of those regions of the heart in closest proximity to the exploring electrode has also been extensively examined and found to be inaccurate. This idea will be discussed in greater detail in association with the precordial leads.

III. THE PRECORDIAL LEADS

The third type of lead utilized in the clinical electrocardiogram is the unipolar precordial lead. Six such leads are generally recorded and are labelled V1 through V6. As in the unipolar limb leads the negative or indifferent
electrode is the Wilson central-terminal. The positive or exploring electrodes are located at six specific sites across the anterior chest wall as follows:

V1........Fourth interspace, to right of sternum
V2........Fourth interspace, to left of sternum
V3........Midway between V2 and V4 positions
V4........Fifth interspace in mid-clavicular line
V5........Lateral to V4 in anterior axillary line
V6........Lateral to V5 in midaxillary line

The introduction of the precordial leads into electrocardiography owes largely to contributions by Wilson in two areas. The first, of course was the design of the central-terminal. The second contribution stemmed from his observation that if one electrode was placed directly over the heart and the other at a remote site little difference was recorded in the pattern as the location of the remote electrode was varied. He reasoned from this that the potential variation observed was due almost entirely to that measured by the precordial electrode and that the reason for this imbalance was the relative proximity of the electrode to the heart. It then seemed logical to assume that the electrode preferentially measured the electrical activity of that portion of the heart directly underlying it.

On the basis of this assumption Wilson\(^1\)\(^2\) introduced the precordial lead system that is still in use today. The first three precordial leads were presumed to selectively measure the activity of the right ventricle, while the last three were believed to measure that of the left ventricle. The
acceptance of this theory led to the so-called "unipolar method" of interpretation which was held to be accurate for several years after its emergence.

This hypothesis has been tested extensively and subsequently was shown to be false. Among others, Frank\(^\text{13}\) demonstrated that local effects measured in the precordial leads accounted for only about 5% of the QRS complex in normal subjects. Simonson et al\(^\text{14}\) confirmed this and in addition showed that this proportion remained small in abnormal situations as well. Further evidence against the theory of "local effect" is the fact (to be dealt with in greater detail in a later section) that various orthogonal lead systems have been found to contain all the information available in a standard 12-lead electrocardiogram which would not be the case if the precordial leads were indeed influenced by specific regions of myocardium.

Despite the fact that the "unipolar method" has proven to be invalid, the precordial leads have been of considerable benefit to the practicing physician. Both the standard limb leads and the unipolar limb leads measure the cardiac vectors only as projections on the frontal plane, but provide no information as regards the anterior-posterior projection of the vectors. Since the negative electrode is for all practical purposes at zero potential the axes of the precordial leads can be shown to be extending
along an imaginary line between the electrical center of the heart to the location on the chest of the exploring electrode. By measuring the projections of the cardiac vectors along the axes of the six precordial leads an estimate as to their orientation in the anterior-posterior direction can be made.

IV. CLINICAL APPLICABILITY OF THE 12-LEAD SYSTEM

Since its inception the field of clinical electrocardiography has been highly empirical. Electrocardiographic theories have largely been formulated and discarded on the basis of agreement with or variance from clinical and postmortem observations.

It is well recognized that body surface potentials as representative of the electrical activity of the heart are appreciably distorted. A great many factors are involved in producing this distortion. Among these are factors already mentioned, such as the distributed nature of the electrical forces within the heart itself, inhomogeneities in the conducting medium, inability to determine the electrical center of the heart, and inability to place surface electrodes accurately and uniformly. Other distorting factors include normal variation in torso size and shape, variation in electrical orientation and position of the heart and skin-electrode interface distortion.
In order to devise a method of retrieval of the information provided by the electrical activity of the heart, which is both simple enough to be practical and yet accurate enough to be meaningful, a number of assumptions and approximations have been made. Some of these have been discussed in the preceding paragraphs.

The field of electrocardiography which thus evolved has become, and will continue to be an extremely valuable tool for the practicing physician and provides a great deal of clinically valuable information. However, the information that is obtained is largely qualitative or at best semi-quantitative, and there undoubtedly is a significant amount of information available which at the present time we are unable to make use of.

In order to promote greater efficiency in the retrieval of this information, in order to better investigate the field of cardiac electrophysiology itself, and in order to obviate the errors inherent in the present system, a number of lead systems have been proposed. It is with selected examples of these systems that the remainder of this paper will deal.
CHAPTER III

ORTHOGONAL AND DIFFERENTIAL LEAD SYSTEMS

I. ORTHOGONAL LEAD SYSTEMS

If the assumption that the heart represents a fixed, point-like current generator were valid, the theoretically the electrical potential generated by the cardiac dipole could be completely characterized as to magnitude and direction by three mutually perpendicular leads. A great many so-called orthogonal lead systems have been proposed through the years but, as in the case of the standard limb and precordial leads, the irregular physical characteristics of the human heart and torso have limited their success.

The design and analysis of orthogonal lead systems have been greatly simplified by the introduction of the concept of the "lead vector" by Burger and van Milaan. They based the lead vector on the assumption of a single, fixed dipole. The lead vector is related to the potential difference measured across the terminals of any electrocardiographic lead by the following equation:

\[ V = \hat{M} \cdot \hat{J} \]

where \( V \) is the lead potential, \( \hat{M} \) is the current dipole moment of the heart, \( \hat{J} \) is the lead vector, and \( \hat{M} \cdot \hat{J} \) signifies the dot or scalar product of two vectors.

\( \hat{J} \) is dependent on the size, shape and conductive
characteristics of the torso and on the position of the electrodes. It is, however, unaffected by changes in the magnitude or direction of the dipole. Since in any individual the only variable affecting the lead vector is the electrode position it may be used to estimate the orthogonality of any system of leads. The lead vector is identical to the "image vector" of Frank\textsuperscript{15} and the transfer impedance of Schmitt.\textsuperscript{17}

McFee and Johnston\textsuperscript{18} introduced the concept of the lead field which extended the concept of the lead vector to allow for the more realistic situation of a heart consisting of multipole dipoles. They defined the following theorem:

The open circuit voltage, $v$, produced in any lead is related to the electromotive forces of the heart by the equation:

$$v = e_1i_1 + e_2i_2 + \ldots$$

where the $e$'s are the potential differences of the electromotive force elements, and the $i$'s are the currents passing through the elements when a unit current is introduced into the lead.

The lead field is then defined as the field of current which is produced in the body when a unit current is introduced into the negative electrode of a lead and leaves its positive lead.

Although the lead field is based on the more accurate assumption of multiple cardiac dipoles rather than a single dipole as in the case of the lead vector, it can be
shown that it is an intuitive, non-mathematical approach to the analysis and design of electrocardiographic leads. Both concepts have proved to be extremely valuable tools in the study of lead systems, but if a more exact mathematical analysis of lead structure is desired the description of leads in terms of multiple lead vectors should be employed.

Lead vectors have been found to be extremely sensitive in both magnitude and direction to changes in dipole location. However, by forming compound or network leads a greater uniformity of the lead vector has been achieved. Thus a lead need not be limited to the measurement of the difference in potential between two points. Rather a lead might be redefined as a pair of terminals connected directly or through resistors to any number of points. The relative weighting of the contributions of each of the points can be fixed by variation in the resistors interposed between each of the points and the two terminals. Leads thus weighted are electrically rather than anatomically orthogonal and have a relatively uniform lead vector for a wide distribution of dipole locations. The horizontal (X) and sagittal (Z) leads of such "corrected" orthogonal lead systems consist of compound leads. Body configuration is such that a lead formed by an electrode on the head or neck and an electrode on the left leg serves as a satisfactory vertical (Y) lead.
An ideal orthogonal lead system would meet the following criteria\textsuperscript{20}: (1) It would accurately extract three spatially orthogonal components of the equivalent generator. (2) It would obtain identical outputs from a single dipole regardless of the dipole within the medium. (3) If current sources of higher singularity such as quadrupoles of octopoles are present, the output would respond to the dipole only.

A number of lead systems have been designed including those of Frank\textsuperscript{21}, McFee and Parungao\textsuperscript{22}, Schmitt and Simonson\textsuperscript{17}, Barber and Fischmann\textsuperscript{23}, Brody and Arzbaecher\textsuperscript{24}, and Helm\textsuperscript{25}, among many others. A number of investigators have analyzed and compared several of these leads as to their physical characteristics and accuracy. According to Frank\textsuperscript{21} a practical vectorcardiographic lead system must represent an optimum compromise among many conflicting factors, such as soundness of theoretical basis, accuracy, vulnerability to dipole location, ease and speed of application, reproducibility, signal-to-noise ratio, and cost. He estimates that utilizing the basic assumptions of a fixed equivalent dipole and of a homogeneous conducting medium, the information obtained will be accurate to ±15 percent. For the purposes of this review it suffices to say that several of the proposed lead systems are sufficiently accurate for clinical electrocardiographic application. The use of orthogonal
leads in clinical electrocardiography will be discussed in a later section.

II. DIFFERENTIAL LEAD SYSTEMS

As noted previously, the unipolar limb leads and the precordial leads were originally introduced into clinical electrocardiography on the assumption that they represented semi-direct rather than remote leads, and that, therefore, they were influenced primarily by the region of the myocardium directly subjacent to them. While this concept has generally been discarded the quest for lead systems which would measure the "local effect" of various heart regions has gone on.

Fischmann and Barber\textsuperscript{26} studied a homogeneous heart-torso model consisting of six electrically isolated areas. They developed "aimed" electrocardiographic leads which they felt responded selectively to each of the defined electrically active areas while being insensitive to the other regions.

In 1959, Schmitt\textsuperscript{27} introduced the term "differential lead" to describe an array of electrodes intended to accentuate certain aspects of activity in the heart to the exclusion of others. He attempted to utilize the concept of transfer impedance to develop leads whose transfer impedance vector would concentrate at a certain region or plane of the myocardium and thus would focus at that point for diagnostic
evaluation. The ideal differential lead would produce transferimpedance vectors which would cancel out at all portions of the heart other than that region focussed upon.

Sinbel utilized a human torso model to design differential lead systems by transfer impedance characteristics. She observed that different orthogonalized lead systems might have very similar transfer impedances in one projection but would differ significantly in other projections. By combining certain of these systems subtractions would result in the cancellation of the similar impedances leaving significant residues from specific cardiac regions. She then described differential leads which would focus on the anterior wall of the heart and on the right, inferior, anterior wall of the heart. She pointed out that by combination of various orthogonalized lead systems differential leads focussing at any desired cardiac region could be obtained.

She emphasized, however, that the method does not permit actual focussing, but instead permits selective cancellation which alternates other regions much more strongly than the desired region. Thus, it is more a masking than a focussing process. Small residual transfer impedance vectors will always be found at all heart locations. The system does, however, differentially measure a significant "local effect".
While a great deal of information is potentially available in the differential, the complexity of both the design of the lead and of its analysis greatly inhibit its clinical usefulness at the present time. Furthermore, a great deal more work as to design and standardization of specific differential leads remains to be done before they assume their rightful importance in clinical electrocardiography.

III. CLINICAL APPLICATION OF ORTHOGONAL LEADS

The standard 12-lead electrocardiogram has been almost universally accepted in the past. However, in recent years more and more attention has been paid to various orthogonalized lead systems and many investigators now feel that the standard 12-lead system should be rejected in favor of a three-lead orthogonal system. Some of the reasons for this preference will be discussed below.

As previously pointed out the standard and unipolar limb leads and to a lesser extent, the precordial leads measure cardiac vector projections only on the frontal plane, thus measuring transverse and vertical components but neglecting the sagittal component of the vector. Also, a system of twelve leads measuring only activity in one plane would contain a great deal of redundant information. A three-lead orthogonalized system would include the sagittal
component of the cardiac vector. And since it consists of three leads measuring only components in three axes redundancy of the recorded information would not be present.

According to Borun\textsuperscript{29} the major potential advantage of using accurate orthogonal leads for recording electrocardiograms is that such leads should minimize distortion and variation to differences in location of the cardiac dipole source or to non-cardiac sources. This, he states, would greatly facilitate the problem of relating the electrocardiographic data to electrical events within the heart and should result in improved discrimination between normal and abnormal subjects. By disregarding non-dipolar elements of the cardiac electrical activity a certain amount of information will be lost. Scher\textsuperscript{30}, however, demonstrated that 95 per cent of the total information available satisfied a three-function system and could be obtained with just three leads. 95 per cent retrieval of information certainly compares favorably to the standard 12-lead system and, indeed, greater retrieval of information cannot be expected from any system available at the present time.

Pipberger\textsuperscript{31} cites two major advantages of three-lead orthogonal systems. First, the diagnostic recognition could be greatly improved. Second, the information content of the electrocardiogram would greatly exceed that of the 12-lead electrocardiogram.
He gives two examples of diagnostic improvement by the use of the orthogonal leads. He analyzed, one year after the insult, 134 cases of well-documented myocardial infarction by both the standard electrocardiogram and by orthogonal leads. By conventional record analysis the diagnosis could be made in 70 percent of the cases, eight percent were questionable, and in 22 percent the tracings were interpreted as showing no evidence of old infarction. Orthogonal records were classified 100 per cent as myocardial infarctions.

He also analyzed orthogonal records of 32 cases of biventricular hypertrophy confirmed by post-mortem examination. Although in the literature this diagnosis can be confirmed in only 25 percent of cases, orthogonal lead analysis provided the correct diagnosis in 94 percent of the cases studied. In addition, significant correlations could also be made between the electrocardiographic data and the left ventricular thickness, total heart weight, and the ratio between left and right ventricular thickness.

He makes the statement that orthogonal analysis is so superior to standard 12-lead analysis that maintaining the 12-lead electrocardiogram can be justified only on the basis of prevailing habits both in teaching and in interpretation.

While there appears to be a great deal of information to support this view a number of practical objections must
first be met. First, agreement must be made on the choice of an orthogonal system which would best approximate the ideal conditions of uniformity and orthogonality. Second, although computer programs have been devised for analysis in all cases with sinus rhythm, programs for analysis of orthogonal leads in cases of arrhythmias are still to be developed. Finally, for adequate interpretation computer analysis would be mandatory and such facilities are not available to the vast majority of practicing physicians.

In conclusion, while three-lead orthogonal electrocardiography has obvious advantages a number of practical considerations insure that the conventional 12-lead electrocardiogram will continue to utilized for some time to come.
CHAPTER IV

SUMMARY AND CONCLUSIONS

Variations in the shape and size of the human torso, variations in the location of the anatomic and electrical center of the heart, inhomogeneities in the conductive properties of the tissue lying between the heart and the body surface, and other factors have necessitated the development of electrocardiographic lead systems which record surface potentials which are only approximations of the actual electrical activity of the heart.

A standard lead system composed of three bipolar limb leads, three unipolar limb leads, and six precordial leads has long been accepted as the basis of clinical electrocardiography. These leads were described individually and the errors which they introduce were discussed.

In order to improve the efficiency of retrieval of information about the cardiac electrical activity a number of lead systems have been introduced which are based on the principle that the cardiac vector could be completely characterized by measuring its projections along the three axes of a Cartesian coordinate system. A review of the theoretical basis and ideal characteristics of these orthogonal leads is presented.

A goal of electrocardiographers through the years has
been the design of lead systems which would measure selectively the electrical activity in localized regions of the myocardium. A review of a number of attempts to realize this goal is discussed.

Finally, a comparison of the clinical usefulness of the standard 12-lead system and three-lead orthogonal system of electrocardiography is discussed. The conclusion is made that although the orthogonal leads are superior to the standard electrocardiogram, practical considerations dictate that the standard 12-lead electrocardiogram will continue to find clinical application in the years to come.
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