J. ELECTROCARDIOLOGY 17 (3), 1984, 313-318

The Circular Reference System Revisited

In 1913 Einthoven, Fahr and de Waart introduced the equilateral triangle for the determination of cardiac vectors in the plane known as frontal from the bipolar limb leads[1]. In their concept, the human body is considered as an infinite homogeneous volume conductor with its geometrical center as the origin of the cardiac dipole. Although such an approximation is far from real, it nevertheless has been proven to be one of the most useful concepts in clinical electrocardiology.

During the seventy years since that triangle concept was first proposed, numerous systems or methods have been developed based upon the same concept, for the same purpose and from the same leads, as well as from the unipolar limb leads[2-31]. Why is the search never ending? Because each author believed that his system was better than those already existing. Some may indeed appear more practical than others. But as a rule, the choice is largely a matter of personal preference. Some methods use too few vectorial directions for meaningful clinical application, especially during evolutional changes. Most systems were developed for greater accuracy. Almost always this aspect of the new system was presented at length. Unfortunately, accurate results were and are not attainable due to the limitations of the concept upon which a system was or is derived, regardless of laborious and/or time-consuming efforts. The current editorial will focus exclusively on cardiac vectorial orientation which requires more attention than vectorial magnitude in clinical ECG interpretation. Besides, magnitudes, whether high or low, can usually be ascertained by inspection of the leads, and their changes are quite easily noted in serial tracings.

One way to estimate the degree of inaccuracy of the equilateral triangle is by means of a comparative study with the scalene triangle of Burger and van Milaan[32]. Their concept permits the thoracic configuration and heterogeneously conductive thoracic tissues within the left ventricular region to determine a stationary dipole as the source of cardiac electrical activity. This approach therefore represents a considerable improvement in a biophysical sense over the concept advanced by Einthoven and associates. In a carefully designed human model, coefficients were experimentally determined for the construction of the scalene triangle. Cardiac vectors determined with the scalene triangle can be used to measure the deviations of the vector determined with the equilateral triangle from the true vector. However, the sides of the scalene triangle are lead vectors of unequal strength in the image space and cannot be used in the way the lead axes are conventionally used. To simplify the comparison, both triangles were transformed into respective curves on a specially constructed diagram[33]. This diagram gives simultaneously the Burger and the Einthoven directions for any cardiac vector recorded in limb leads I and III. Most importantly, the diagram reveals that only two directions can be accurately determined with the equilateral triangle, namely at +6° and at -77°. All other vectorial directions deviate variably up to some 30 degrees to the left or to the right.

The original scalene triangle probably is accurate for most individuals. Its accuracy, however, will be diminished when the cardiac vectorial origin moves to a new location[34]. This occurs, for example, while determining the portion of the QRS vectorial direction caused by W-P-W syndrome or right bundle branch block. The triangle also cannot be applied to other species without modification[35]. In addition, it is unable to deal adequately with a moving dipole or with non-dipolar components, aspects which may well be present in cardiac patients[36].

The value of Einthoven's concept lies in its ease of clinical application, not in its physical exactness. Why spend time to exactly determine these directions which deviate in varying degrees anyway? And by chance, a freely estimated direction may be even closer to the reality. What is really useful in clinical medicine is the consistency of a cardiac vectorial direction determination and not the method itself. The goal is to achieve uniform interpretation among the medical community and in the literature.

The common denominator of the equilateral triangle and of all subsequent corresponding systems is the utilization of the lead axis principle. As a result, none are capable of indicating cardiac vectorial directions directly. To obtain vectorial directions, additional manipulations are required which include the measurement of the height or depth of the waves, the calculation of the enclosed areas, the utilization of a ruler to draw lines, or other means. During bedside visits

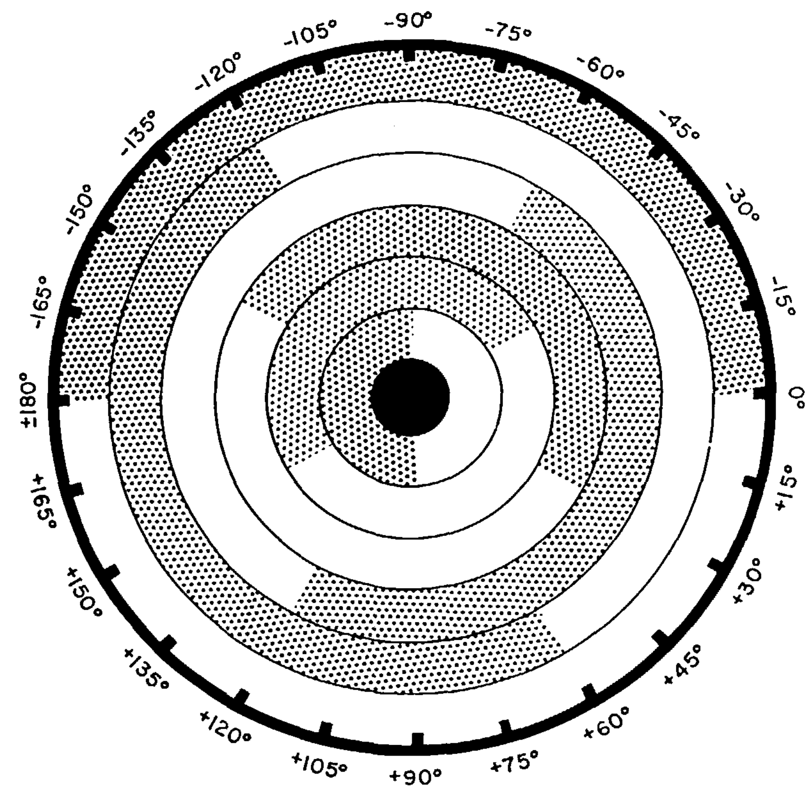

Fig. 1. The Circular Reference System from the Limb Leads*. Lead circles from the center toward the periphery represent leads I, II, III, aVR, aVL, aVF. Each lead circle consists of one positive semicircle (white), one negative semicircle (dotted) and two boundary lines (where the two semicircles meet). See text for instructions.

*The Bowen Co. (1800 Chapman Ave., Rockville, MD 20852, U.S.A.) supplies both circular reference systems, one from limb leads and one from precordial leads, in color, both printed on one pocket-sized plastic chart, priced at $3.00.

and especially in emergency situations, such additional manipulations have not been shown to be practical.

An ideal system would be one which shows directly, without any manipulation, the cardiac vectorial directions in the RLF (frontal) plane clinically sufficient in number and uniform in distribution, and provides identical results among all interpreters.

In fact, such a system has been constructed by utilization of the lead circle principle, *not* the lead axis principle. It was proposed as early as 1952 but drew relatively little attention (Fig. 1)[37,38]. Each lead circle provides four cardiac vectorial directions: one at each boundary between the positive and negative semicircles, one within the positive semicircle and one within the negative semicircle. By itself a lead circle is seemingly useless. In a concentric arrangement of all six limb lead circles around a center, however, the system provides a total of twenty four cardiac vectorial directions spaced equally 15 degrees apart in the RLF plane. Directions obtained without any iso-electric or equiphasic deflection are considered to be 15 degrees apart from the next direction on either side for uniformity (see example below). The circles, arranged from the center toward the periphery, are those of leads I, II, III, aVR, aVL and aVF respectively. Because this is the sequence in which the leads are recorded and read, the system gives the impression of vectorial directions originating from the center. (However, lead circles can be concentrically arranged in any sequence. Recently a new circular reference system has been proposed for the lead sequence of I, -aVR, II, aVF, III and -aVL[39]. Such a sequence, with inverted aVR and aVL leads, displays in a conceptually familiar format important diagnostic information ordinarily overlooked when these leads are used with the current polarity in a conventional sequence. It is particularly easy to use with computer-processed ECGs.) The white area, established by white semicircles, indicates where positive deflections are recorded in these leads, whereas the dotted area indicates the negative deflections. The boundary line between the white and dotted semicircles of a lead indicates no deflection (isoelectric P, T, U waves, ST segments, or equiphasic QRS complexes). Thus each vectorial direction correlates with the polarities of that vector recorded in the six limb leads. Screening the polarities of a given deflection in these leads is actually equivalent to determining the resultant polarities of the algebraic sum of the components and visualizing the mean direction of the corresponding cardiac vector with the aid of this system.

In order to use the circular reference system, one first looks at the tracing of the successive limb leads I, II, III, aVR, aVL and aVF, to determine the polarity of a given deflection; i.e., whether the QRS complex is positive, negative or equiphasic. Then, starting with the innermost circle for lead I (the white semicircle being positive, dotted negative, and boundary lines being equiphasic) and progressing outwards to leads II, III, aVR, aVL and aVF, one proceeds to match the semicircles with the polarities of the QRS complex previously obtained from the tracing. For example, if its polarities in the successive limb leads are pos., pos., pos., neg., equiphasic, pos., then referring to the circular reference system gives a direction of +60°. If the polarities are pos., pos., pos., neg., pos., pos., this gives a direction of approximately +45°. (Since this direction is obtained without an equiphasic complex, one may proceed further for a closer estimation. If the QRS complex is equally positive in III and aVL, the direction is kept as determined. If III is more positive than aVL, the direction will be +52.5° which is midway between +45° and +60°. If III is less positive than aVL, the direction will be +37.5°, midway between +45° and +30°. Leads III and aVL are chosen because the +/- boundary lines of these lead circles are at an equal distance of 15° from either side of +45°. For other directions determined from positive and negative polarities alone, without equiphasic or isoelectric deflections, the two proper leads for comparison can be selected in the same manner. This procedure increases the total number of vectorial directions in the RLF plane to forty-eight, separated only by 7.5° throughout.) With some practice one can visualize the white and dotted areas in the system (referred to previously) and their boundary lines in the six lead circles at almost the same time, and the mean vectorial direction can be determined at a glance from the polarities of the corresponding leads.

There are clinical cases in which the determination of vectorial directions other than the mean are essential, for example, in bundle branch block, myocardial infarction, or W-P-W syndrome. In such cases we should subdivide the QRS complex into two portions. In bundle branch block, there is a narrow portion corresponding to the initial fast part of the QRS loop, and a wide portion corresponding to the slow terminal vector loop. The QRS vectorial direction determined from the second portion indicates the direction of excitation of the blocked ventricle[40]. In myocardial infarction the first portion corresponds to the direction of the site of the infarct, and in the W-P-W syndrome it (delta wave) corresponds to the direction of the ventricular pre-excitation[41,42].

When using this system in a clinical routine, one should compare one's results with those obtained by others so that differences may not occur. Very rarely the QRS loop is so broad that one may encounter equiphasic QRS complexes in two leads of the same tracing. For example, if this occurs in leads III and aVL, one is not sure whether the direction is +30° or +60°. In such a case the +45° direction should be agreed upon for the sake of uniformity. (With the hexaxial reference system a discrepency near 30 degrees may result between the direction calculated from bipolar limb leads and unipolar limb leads.) Incidentally, a vectorial direction may not be determined when the tracing is improperly mounted, such as when a lead is upside down or two leads are interchanged. For those few who do not use any aid but estimate vectorial directions by inspection, this system is also recommended to attain uniform results with others, to be more at ease with multiple vectorial directions and perhaps also to be more confident with very rare and unusual directions.

Not long after this system had been developed, its usage was extended to include precordial leads to allow the spatial vectorial interpretation of the 12-lead standard ECG advocated by Grant and Estes[43,44]. Unfortunately, the circular reference system from the six precordial leads did not prove its full validity for vectorial interpretation[45]. However, any investigator may use the circular reference system with the twelve derived leads based upon a biophysically founded spatial lead system and thus avoid the limitations imposed by classical precordial leads. Such derived leads from the Frank system are used in the polarcardiography of Dower and associates[46,47]. On the other hand, one may wish to derive the leads by a simple resolution from a little known spatial lead system[48,49,50]. Its improved biophysical features over the Frank lead system may or may not prove to be more useful clinically, but it certainly is more practical because it needs fewer electrodes. In either case, the existing two circular reference systems from the standard leads can be employed without modification.

Zang Z. Zao, M.D., F.A.C.C.
Editor-in-Chief
Journal of Electrocardiology
5720 Calle Miramar
La Jolla, California 92037, U.S.A.

Acknowledgement: I wish to thank Eugene Lepeschkin, M.D., on the occasion of his seventieth birthday, for his valuable assistance.

REFERENCES

1. Eithoven, W, Fahr, G and de Waart, A: Ueber die Richtung und manifeste Groesse der Potentialschwankungen im menschlichen Herzen und ueber den Einfluss der Herzlage auf die Form des Elektrokardiogramms. Pfluegers Arch f d ges Physiol 150:275, 1913. English translation. Am Heart J 40:163, 1950
2. Lewis, T: Observations upon ventricular hypertrophy, with special reference to preponderance of one or another chamber. Heart 5:367, 1914
3. White, P D and Rock, A V: Electrocardiographic evidence of abnormal ventricular preponderance and of auricular hypertrophy. Am J Med Sc 156:17, 1918
4. Carter, E P, Richter, C P and Greene, C H: A graphic application of the principle of the equilateral triangle for determining the direction of the electrical axis of the heart in the human electrocardiogram. Bull Johns Hopkins Hosp 30:162, 1919
5. Dieuaide, F R: The determination and significance of the electrical axis of the human heart. Arch Int Med 27:558, 1921
6. Wilson, F N, Macleod, A G, Barker, P S and Johnston, F G: The determination and the significance of the areas of the ventricular deflections of the electrocardiogram. Am Heart J 10:46, 1934
7. Bayley, R H: On certain applications of modern electrocardiographic theory to the interpretation of electrocardiograms which indicate myocardial disease. Am Heart J 26:769, 1943
8. Ashman, R and Byer, E: The normal human ventricular gradient. I. Factors which affect its direction and its relation to the mean QRS axis. Am Heart J 25:16, 1943. II. Factors which affect its manifest area and its relationship to the manifest area of the QRS complex. Am Heart J 25:36, 1943
9. Sodi Pallares, D, Cuellar, A and Cabrera, E: Sistema de seis ejes con aplicación al vector AvT las hipertrofias ventriculares. Arch Inst Cardiol México 14:142, 1945
10. Luisada, A A: Heart — A Physiologic and Clinical Study of Cardiovascular Diseases. Williams & Wilkins, Baltimore, 1948, p 119
11. Herrmann, G R: Diseases of the Heart and Arteries. 4th Ed. The C V Mosby Company, St Louis, 1952, p 136
12. Goldberger, E: Unipolar Lead Electrocardiography and Vectorcardiography, 3rd Ed. Lea & Febiger, Philadelphia, 1953, p 438
13. Wood, P: Diseases of the Heart and Circulation, 2nd Ed. Eyre & Spottiswoods, London, 1957, p 89
14. Keuskamp, D H G: A simple device for measuring time intervals in the electrocardiogram and for determining the electrical axis of the QRS complex. Am Heart J 57:389, 1959
15. Massie, E and Walsh, T J: Clinical Vectorcardiography and Electrocardiography. The Year Book Publishers, Chicago, 1960, p 19
16. Burch, G E and Winsor, T: A Primer of Electrocardiography, 5th Ed. Lea & Febiger, Philadelphia, 1966, p 275
17. Okamoto, N, Kaneko, K, Simonson, E and Schmitt, O H: Reliability of individual frontal plane axis determination. Circulation 44:213, 1971
18. Wong, P C Y and Lee, T Y: Revised lead equations for frontal plane electrocardiology. J Electrocardiol 5:25, 1972
19. Laiken, S, Laiken, N, O'Rourke, R A and Karliner, J S: A rapid method for frontal plane axis determination in scalar electrocardiograms. Am Heart J 85:620, 1973
20. Yang, S S, Maranhao, V and Goldberg, H: A nomogram for the mean QRS axis in the frontal plane (Annotation). J Electrocardiol 6:51, 1973
21. Lee, T Y: Optimization of frontal plane electrocardiographic lead data in the 30° hexaxial system. J Electrocardiol 6:31, 1973
22. Arbeit, S R, Rubin I L and Gross, H: Differential Diagnosis of the Electrocardiogram. 2nd Ed. F A Davis, Philadelphia, 1975, p 6
23. Lyon, L J: Basic Electrocardiography Handbook. Van Nostrand Reinhold Company, New York, 1977, p 9
24. Dubin, S and Staib, J: Numerical calculation of the mean electrical axis of electrocardiographic deflections (annotation). J Electrocardiol 10:77, 1977
25. Criteria Committee, New York Heart Association, Inc: Nomenclature and Criteria for Diagnosis of the Heart and Great Vessels. Little Brown and Company, Boston, 1979, p 308
26. Blake, T M: The Practice of Electrocardiography. Hans Huber Publishers, Bern, 1980, p 22
27. Hakki, A H, Anderson, G J, Iskandrian, A S and Segal, B L: A simple method to determine the electrocardiographic frontal plane axis (Method). J Electrocardiol 15:285, 1982
28. Ikeda, N, Yamagami, J, Morohoshi, Y, Miyahara, H and Sato, T: An optimal method for calculation of the frontal plane vector from the data of the standard and unipolar limb leads (Method). J Electrocardiol 16:403, 1983

29. SWEETWOOD, H M: Clinical Electrocardiography for Nurses. Aspen Systems Corporation, Rockville, 1983, p 6
30. MARRIOTT, H J L: Practical Electrocardiography, 7th Ed. Williams & Wilkins, Baltimore, 1983, p 32
31. WARTAK, J: ECG aximeter (Method). J Electrocardiol 17:193, 1984
32. BURGER, H C AND VAN MILAAN, L B: Heart vector and leads. Part I Brit Heart J 8:157, 1946. Part II Brit Heart J 9:154, 1947. Part III Brit Heart J 10:229, 1948
33. ZAO, Z Z: A geometric study of the relationship between limb leads and cardiac vectors in the frontal plane. Am Heart J 59:249, 1960
34. ZAO, Z Z: Burger triangle as a method for correcting inaccuracies of Einthoven triangle. Science 122:375, 1955
35. ZAO, Z Z: An experimental study of Burger triangles constructed from toad hearts in situ. Circ Res 4:211, 1956
36. ZAO, Z Z: Beitrag zum Burgerschen Dreieckschema. Ztschr f Kreislaufforschg 44:593, 1955
37. ZAO, Z Z AND LARANJA, F S: Um método simples para determinação da direção dos vetôres cardiacos no plano frontal. Arq Brasil Cardiol 5:82, 1952
38. ZAO, Z Z: The circular reference system (Letter to the Editor). Am J Cardiol 11:130, 1963
39. ZAO, Z Z: Directional sequence of the limb leads and the lead circle (Editorial). J Electrocardiol 12:437, 1979
40. ZAO, Z Z, HERRMANN, G R AND HEJTMANCIK, M R: A study of cardiac vectors in the frontal plane. Am Heart J 56:65, 1958
41. ZAO, Z Z, HERRMANN, G R AND HEJTMANCIK, M R: A further study of cardiac vectors in the frontal plane. Am Heart J 57:66, 1959
42. ZAO, Z Z, HERRMANN, G R AND HEJTMANCIK, M R: A vector study of the delta wave in "non-delayed" conduction. Am Heart J 56:920, 1958
43. GRANT, R P: Clinical Electrocardiography. McGraw-Hill Book Company, New York, 1957
44. ZAO, Z Z, HERRMANN, G R AND HEJTMANCIK, M R: Spatial vector electrocardiography. Method and average normal vector of P, QRS and T in space. Am Heart J 56:195, 1958
45. ZAO, Z Z: Horizontal plane electrocardiographic vectors. A study in conjunction with frontal projections. Cardiologia 45:333, 1964
46. DOWER, G E: A lead synthesizer for the Frank system to simulate the standard 12-lead electrocardiogram. J Electrocardiol 1:101, 1968
47. DOWER, G E AND MACHADO, H B: XYZ data interpreted by a 12-lead computer program using the derived electrocardiogram. J Electrocardiol 12:249, 1979
48. ZAO, Z Z: Resolution of orthogonal leads for spatial vector electrocardiography (Annotation). J Electrocardiol 3:91, 1970
49. ZAO, Z Z: Vector loops from normal children recorded with a new spatial lead system. J Electrocardiol 2:63, 1969
50. ZAO, Z Z: Major VCG systems proposed in the USA (Editorial). J Electrocardiol 4:179, 1971