The Frank Vectorcardiogram in Normal Men

Norms Derived from Visual and Manual Measurement of 300 Records

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Broad clinical application of vectorcardiography has been limited by the lack of a single, widely accepted recording system and the paucity of firmly established diagnostic norms. Most clinical reports and texts, therefore, have used the vectorcardiogram primarily for vivid pictorial display of typical abnormalities. A recent co-operative study, in which interpretation of the vectorcardiogram by the qualitative techniques now available was compared with the 12-lead electrocardiogram, showed no advantage for the vectorcardiogram (Simonson and Tuna, 1966). Furthermore, in recent years, evidence that the vectorcardiogram of most abnormal and many normal subjects includes a measurable "non-dipolar" component, and that there are insoluble problems in achieving complete orthogonality, has made it likely that the search for a better system of recording will be fruitless (Briller and Okada, 1965). Therefore, many centres have decided to select a reasonably orthogonal, clinically practical recording system, and develop essentially empirical quantitative criteria for its interpretation. The Frank lead system is now widely used in the U.S.A. for this purpose.

Empirical norms for this system, essential for its broad clinical application, have been slow in appearing. The wealth of information concerning magnitude, spatial angle, and rate of change in potential obtainable from vectocardiograms has led to a diversity of approaches to quantitative analysis, some of which are so complex as to be clinically impractical. A recent extensive report by Draper *et al.* (1964) has finally supplied carefully analysed data on a large group of normal subjects that may serve as a standard of reference. These data, however, were obtained by the direct analysis of x, y, and z lead information, without utilizing the loops constructed from them. These leads were converted

into digital information which was then studied by multidimensional analysis in a computer. Such a system is not available to most clinical services which must depend on the visual inspection of x, y, and z leads, or the loops constructed from them, as a basis for interpretation.

The purpose of this study was to analyse the vectorcardiograms of 300 normal subjects by visual inspection and manual measurements, in order to establish the range of normal by this technique for certain clinically important parameters, and, further, to compare these results with the previously published computer analysis. Furthermore, since clinical interpretation of the standard 12-lead electrocardiogram has led to the description of differences between young adults and the aged, who were not separated in the report of Draper *et al.*, a comparison of all measurements was made between three age-groups.

SUBJECTS AND METHODS

Three hundred normal men from the Bronx Veterans Hospital were selected. All were admitted for reasons other than cardiovascular disease. Selection of cases was based on a complete history, physical examination, and laboratory data. If there was any suggestive history of angina, hypertension, or cardiac disorder, the patient was disqualified. All patients had a normal 12-lead electrocardiogram and chest x-ray film.

The Frank orthogonal lead system was used, with the subject in the supine position and the chest electrodes placed in the fourth intercostal space as recommended (Frank, 1956; Langner *et al.*, 1958). The Electronics for Medicine multichannel recorder with attached automatic timing circuit was used to record and photograph the loops. The timing circuit permitted exclusion of P and T loops when so desired. Standardization of the loop on the oscilloscope screen was performed for each subject. One millivolt was made to produce a 5 cm. deflection. A photograph of the loop in the frontal,

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transverse, and left sagittal plane was obtained. For better delineation of early forces, a fourfold amplification of the isolated QRS loop was also photographed. This amplification was so standardized that 0.5 mV was equal to 10 cm. All angular measurements were defined according to the standard system used by Helm (1956).

Analysis of the QRS loop included the measurement of the angle made by the 0.02 and 0.04 vector in each plane. The timing of these points was obtained by counting dots on the photograph from the onset of QRS; each represented 0.004 sec. Objection to the method of obtaining the instantaneous vector angles by inspection and plotting has been raised by Pipberger (1958). If much superimposition of early forces occurs in the frontal plane it is at times difficult or impossible to identify the initial points of the loop. This rarely presents a problem, however, in all planes. When frontal loop configuration was obscure, it was found possible to inspect for the most lateral point on the transverse plane and to determine the point in time of the QRS loop that this reflected. Because of orthogonality of the system, the most lateral vector, to the right or left, in the transverse plane is identical or nearly so with the lateral projection of the frontal plane. The identification of this point in the frontal plane was consequently easily established, and, by counting back, the exact 0.02 V in the frontal plane could be determined. Further clarification of the timing and position of the initial and terminal forces was obtained by the routine use of a fourfold magnification of the QRS loop with the usually superimposed P and T loops electronically deleted. By the use of these two techniques, definition of the early forces was readily obtained. Typical loops so recorded are shown in Fig. 1.

The maximum QRS vector was defined in all three planes. Both direction (angle) and magnitude (millivolts) were measured. Analysis of the T loop was limited to the estimation of the angle of the mean half-area T vector. Because of the symmetrical nature of the T loop, this could be obtained by inspection.

The QRS-T angle was obtained by measuring the difference between the maximum QRS vector and the half-area T vector in each plane. The angle was then

classified as either positive or negative depending on whether the half-area T vector was clockwise in each plane to the maximum QRS vector (+) or counter-clockwise (-). The terminal QRS forces were analysed only to the extent of determining in which octant in space they occurred. No precise angle measurement was made.

Routine measurement of the duration of the QRS and of the rotation of the QRS loop in each plane was also made. Angular data were prepared in graphic form for ready reference. In addition, the mean, standard deviation, and standard error of the mean were calculated by standard statistical methods for all parameters. The figures listed as range of results list the total range of normal results rather than the 96 per cent range used by Draper *et al.*

RESULTS

The results are shown in Tables I to IV and Fig. 2-7.

DISCUSSION

In Table IV it is seen that simple manual and visual analysis of some of the information in the Frank vectorcardiogram gives results similar to those obtained by more sophisticated computer analysis.

The excellent correlation between the maximum QRS voltage in the two studies is not unexpected, since this quantity should be readily apparent on the photographed vector loop. The apparent discrepancy in average medium voltage in the sagittal plane (1.32 mV in the study of Draper *et al.* and 1.17 in this report) is readily explained in terms of difference in age distribution. The study of Draper *et al.* is heavily weighted in favour of a younger age-group; the maximum voltage in the sagittal plane in our 25-35 age-group is 1.36 mV,

TABLE I
MAXIMUM QRS VOLTAGE (mV) IN EACH AGE-GROUP

	Age-group			Total group
	25-35	36-50	51 and over	
<i>Frontal plane</i>				
Mean	1.64	1.58	1.36	1.54
Range	0.85-2.25	0.6-3.0	0.75-2.25	0.6-3.0
Standard deviation	0.5	0.47	0.36	0.465
Standard error	0.051	0.047	0.04	0.028
<i>Transverse plane</i>				
Mean	1.46	1.39	1.27	1.38
Range	0.75-3.75	0.55-2.78	0.6-2.75	0.55-3.75
Standard deviation	0.46	0.47	0.473	0.447
Standard error	0.048	0.042	0.05	0.025
<i>Sagittal plane</i>				
Mean	1.36	1.14	1.01	1.17
Range	0.4-2.49	0.5-3.1	0.5-2.49	0.4-3.1
Standard deviation	0.404	0.407	0.407	0.429
Standard error	0.041	0.039	0.041	0.024

FIG. 1.—Vectorcardiograph loops recorded with the Frank system. The upper row shows the frontal (F), transverse (T), and sagittal (S) display of the full loop. The lower row shows fourfold magnification of the QRS loop with partial deletion of the P and T loops. The initial and terminal points of the QRS loops are easily demonstrated.

which is similar to their average result. This finding can be considered as evidence of the importance of age in evaluating deviation from normal.

The good correlation between the angular measurements at 0.02 and 0.04 sec. from the onset

of QRS is especially important in that it implies that the identification of these points can be made on the loops by means of loop magnification and cross comparison, as was done in this study. The points selected for measurement in this study were those

TABLE II
OCTANT DISTRIBUTION OF TERMINAL QRS VECTORS IN EACH AGE-GROUP

	Age-group			Total group
	25-35	36-50	51 and over	
Right superior posterior (%)	36.5	36.8	19.3	30.7
Right superior anterior (%)	2.1	0	0	0
Right inferior posterior (%)	34.4	31.2	30.1	31.9
Right inferior anterior (%)	0	0	0	0
Total per cent (right)	73	68	49.4	63.5
Left superior posterior (%)	8.6	11.7	10.7	10.3
Left superior anterior (%)	0	0	1.2	0.4
Left inferior posterior (%)	17.2	20.3	38.7	25.4
Left inferior anterior (%)	1.2	0	0	0
Total per cent (left)	27	32	50.6	36.5

TABLE III
QRS LOOP ROTATION IN FRONTAL PLANE
IN EACH AGE-GROUP

Age-group	Clockwise	Counter-clockwise	Figure-of-eight
25-35 (104 subjects)	54.8%	17.3%	27.9%
36-50 (100 subjects)	50.0%	11.8%	38.2%
51 and over (96 subjects)	41.5%	15.9%	42.6%
Total Group (300 subjects)	48.8%	15.0	36.2%

All normal subjects have counterclockwise loops in the transverse and sagittal plane.

considered most useful in the clinical differentiation of hypertrophy, infarction, and bundle-branch block from the normal; routine measurement of all possible instantaneous angles would make the procedure clinically impractical. Furthermore, statistical analysis of the distribution of 0.02 vectors in the frontal plane was not done because the wide observed range of variation was considered to make statistical data meaningless. Much of the observed difference between the two series can be explained by differences in age distribution. Thus, at 0.02 sec., the 11° difference between the two series in both the transverse and sagittal planes is reduced to 6° when our younger and more comparable age-group is used. Similarly, the 10° difference noted at 0.04 sec. in the sagittal plane is reduced to 6° when our younger subjects are used in the comparison.

Norms for magnitude of QRS voltage at these

points in time were not presented in this report as the magnitude alone, dissociated from the angle of the vector at each point in time, has little value. To be meaningful, it would be necessary to establish norms for QRS magnitude for each angle evaluated with the normal range, in each plane, at each of the points in time. This would require the analysis of tens of thousands of normal records to reach statistical significance.

As an alternative, one could establish angle-magnitude criteria to separate normal and various clinical and/or necropsy confirmed abnormalities, at what prove to be diagnostically critical points. Such analysis is in progress in our department at present.

The data presented do not include the mean vector in each plane, as its determination involves a tedious integration. Instead the orientation of the maximum QRS vector is recorded. Previous work has

TABLE IV
COMPARISON OF PRESENT RESULTS WITH COMPUTER STUDY OF DRAPER *ET AL.*

	Maximum QRS voltage			Mean QRS angle or Maximum QRS angle		
	Frontal	Transverse	Sagittal	Frontal	Transverse	Sagittal
Draper <i>et al.</i>	1.57 mV	1.39 mV	1.32 mV	44°	323°	53°
Present study	± .42	± .36	± .45	± 23	± 25	± 27
	1.54 mV	1.38 mV	1.17 mV	38°	334°	47°
	± .46	± .44	± .42	± 19	± 40	± 37
	0.02 QRS angle			0.04 QRS angle		
	Transverse		Sagittal	Frontal	Transverse	Sagittal
Draper <i>et al.</i>	81°		180°	40°	343°	72°
Present study	± 26		± 25	± 16	± 25	± 27
	70°		169°	41°	338°	62°
	± 30		± 28	± 19	± 27	± 26
	Mean T vector or 1/2 area T vector			QRS-T angle		
	Frontal	Transverse	Sagittal	Frontal	Transverse	Sagittal
Draper <i>et al.</i>	33°	52°	152°	+ 12°	+ 97°	+ 89°
Present study	± 24	± 18	± 21	+ 2°	+ 72°	+ 86°
	40°	41°	133°			
	± 18	± 19	± 26			

QRS VECTORS FRONTAL PLANE

FIG. 2.—Range of direction of QRS vectors and mean QRS vectors of 300 patients in the frontal plane at 0.02 sec. and 0.04 sec. of the QRS, and at the time of the instantaneous QRS vector of greatest magnitude. Because of the wide scatter of results, statistical analysis of the data at 0.02 sec. was not made.

QRS VECTORS TRANSVERSE PLANE

FIG. 3.—Range of direction of QRS vectors and mean QRS vectors of 300 patients in the transverse plane at 0.02 sec. and 0.04 sec. of the QRS, and at the time of the instantaneous QRS vector of greatest magnitude.

QRS VECTORS SAGITTAL PLANE

FIG. 4.—Range of direction of QRS vectors and mean QRS vectors of 300 patients in the sagittal plane at 0.02 and 0.04 sec. of the QRS, and at the time of the instantaneous QRS vector of greatest magnitude.

FIG. 5.—Range of direction of estimated half-area T vectors in all three planes for all three age-groups.

FIG. 6.—Distribution of angles between the instantaneous QRS vector of greatest magnitude and the half-area T vector in each plane and for each age-group. T vectors clockwise to the QRS are indicated as positive; T vectors counterclockwise to the QRS vector are indicated as negative.

shown that this correlates fairly well with the mean vector in the normal subject, though not quite as well as the planimetric determination of the half-area of the loop, which is also impractical for large-scale use (Pipberger, 1957). In abnormal loops, initial and terminal distortion and slowing of the loop frequently produce wide divergence between the mean and both the half-area and maximal vector. In these clearly abnormal loops, the separate analysis of each component is more meaningful than any averaging technique.

Inspection of Table IV shows that because of the symmetrical nature of the frontal and sagittal loops in most normal subjects, the correlation between the measurement by computer of the integrated mean QRS and the measurement of the angle of the point of maximal QRS voltage is good. In the transverse plane, however, there is a wide discrepancy between the two parameters. The average maximum QRS angle is some 11° less posterior than the mean QRS, but this difference again could be explained by age. In the 25–35 age-group reported here, the average maximum QRS angle is 6° posterior to the mean value obtained in the study

of Draper *et al.* The important difference between the two measurements is to be found in the width of the range of normal. Thus, at least in the 96 per cent of normal subjects presented by Draper *et al.*, no mean QRS in the transverse plane is directed rightward and none is directed anterior. Such results are more consonant with projection of the values obtained in the frontal and sagittal planes upon the transverse, than are the data presented here. By our method, some subjects in all age-groups, but especially some older patients, had angles of maximum QRS directed leftward and anterior, and some subjects in all age-groups, but especially younger patients, had angles of maximum QRS vector directed rightward and posterior (Fig. 8). None the less, accepting this systematic difference, objective norms can be established for the maximum vector angle, which do not require computer integration.

In the low voltage and generally symmetrical T loop, visual estimation of the half-area was feasible, and the correlation between these half-area and mean T angles is fairly good (Table IV).

The determination of the QRS–T angle of course

FIG. 7.—Distribution of angles between the instantaneous QRS vector of greatest magnitude and the half-area T vector in all three planes for the total group. Notation conventions are the same as in Fig. 6.

FIG. 8.—Two transverse loops showing the mean QRS directed leftwards and posteriorly; in the loop on left, the maximum QRS is leftward and anterior, and in the loop on the right, the maximum QRS is rightward and posterior.

depends on the QRS and T angles which are measured. Since we did not measure integrated mean QRS and integrated mean T angle in each plane or in space, the data presented do not truly reflect mean QRS-T angles but rather angle of maximum QRS to angle of half-area T. Despite this basic difference, the correlation with the average QRS-T angles determined by Draper *et al.* are fairly good, with the greatest discrepancy, as would be expected, in the transverse plane. When the median rather than mean results are compared, the discrepancy is greater, especially in the transverse and sagittal planes, reflecting the greater variability of maximal rather than mean QRS angle. This somewhat skewed result is also visible in the distribution curve of QRS-T angles shown in Fig. 6. Such objective determinations of maximum QRS angle, half-area T angle, and maximum QRS half-area T angle, can serve equally as well as the true mean for the separation of normal from abnormal. They cannot be used however for calculation of the ventricular gradient.

The results of three smaller previous studies of the normal Frank vectorcardiogram are available for comparison with the present results and the report of Draper *et al.* The study of McCall, Wallace, and Estes (1962) in 100 normal subjects cannot readily be compared as an entirely different system of notation was used. The studies of Forkner, Hugenholtz, and Levine (1961) of 60 subjects under the age of 36 involved only angular measurements of the maximal QRS and T, and the initial instantaneous QRS angles. Correlation with the present results is only fair even with a comparable age-group, possibly reflecting the small size of the sample and the use of the fifth intercostal space for chest electrodes.

The study by Bristow (1961) of 72 normal subjects, again mostly young, did not include instantaneous angles but gave data for maximal QRS magnitude and angle, half-area T angle, and QRS-T angle. Though the magnitudes of maximal QRS were somewhat higher, the angular measurement of maximal QRS, half-area T, and QRS-T angle were quite similar to the present study despite use of the fifth intercostal space and the sitting position. When small differences existed, Bristow's results were more similar to ours than those of Draper *et al.*, presumably because of the greater similarity in method of analysis.

Analysis of terminal forces is more difficult than analysis of initial forces because of differences of QRS duration. Various measurements have been made using a fixed interval from the end of the QRS, or a fixed fraction of the QRS (Draper *et al.*, 1964). Other studies have instead plotted the angle pro-

jected by the last few counts of the QRS loop (Helm, 1956).

The data presented here are similar to the latter but further simplified by limiting the description to whether the terminal forces are anterior or posterior, superior or inferior, leftward or rightward. This seems justified in that the normal subjects may vary widely but that the separation between anterior and posterior provides a clear separation between normal and abnormal and the other directions provide clues as to the nature of the abnormality.

It can, therefore, be concluded that a simple visual and manual method of analysis of photographed vectorial loops (Frank system) can result in quantitatively reproducible measurements which can be applied to the norms here established. These measurements, in general, correlate well with results obtained by computer analysis, and where systematic differences in method result in different data, an understanding of the differences and use of appropriate criteria can make the simple methods workable.

The features measured reflect only a small part of the information potentially available from the loop. The multiple possible comparisons of instantaneous angle, magnitude, rate of change, and comparison between parts of the loop demand computer analysis. The features measured, however, are those that are useful in characterizing many abnormalities, and can serve as a quantitative base upon which further visual interpretation of loop form can be used.

As further objective quantitative separations between normal and various specific abnormalities become available, dependence on purely visual, descriptive interpretation will be further reduced and the accuracy and usefulness of clinical vectorcardiography enhanced.

Accuracy in determining whether a vectorcardiogram is likely to be normal can be further enhanced by the use of age-corrected normals. This is especially apparent in the measurement of maximum voltage in each plane, but inspection of the tables shows lesser differences in many other areas.

SUMMARY

The range of normal of the readily measurable features of the Frank vectorcardiogram were obtained from the study of 300 normal subjects. The results compared closely with previously reported data prepared by computer analysis of Frank x, y, and z leads, when the same parameters were measured. Data based on the range of normal of the angle of maximum QRS vector are presented.

Further classification of the normal adult vectorcardiogram was achieved by separation of the data into three age-groups.

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