THE VECTORCARDIOGRAM IN NORMAL CHILDREN*

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Received November 25, 1963

The evolution of the vectorcardiogram obtained with the Frank lead system (Frank, 1956) from normal infants was reported in a previous publication (Namin *et al.*, 1964). It was based on a study of 216 vectorcardiograms on 107 infants. To establish a baseline for the vectorcardiographic recognition of ventricular overwork patterns in children, the vectorcardiograms of a group of normal older children were analysed.

SUBJECTS AND METHODS

Eighty-four vectorcardiograms were obtained in as many normal children ranging in age from 2 to 12 years. Most children were admitted to the Cook County Children's Hospital for various surgical conditions and almost all were ambulatory. Cardiovascular disease was ruled out by physical examination, conventional electrocardiography, and chest radiography. The children were divided into two groups: Group I, 36 children from 2 to 5 years; Group II, 48 children from 6 to 12 years.

All tracings were taken with the subject recumbent. The 5 chest electrodes of the Frank lead system were arranged at the level of the fifth intercostal space at the sternal margin. The H electrode was placed on the back of the neck. The recording system consisted of a Sanborn Viso-Scope model 185 which received its input from a Sanborn vector amplifier with an external Frank lead selector box. The vector trace was photographed with a Fairchild camera using type 42 Polaroid film. The three standard projections were recorded on each subject. The trace consisted of a series of time dashes with blunt leading ends produced at intervals of 2.5 milliseconds. A 1 mV input standardization produced equal deflections along the vertical and horizontal co-ordinate axes of the grid on the oscilloscope screen.

The reference frames used in this study are shown in Fig. 1. The right sagittal projection used in this report facilitates comparison between the Frank system and the cube system of vectorcardiography (Grishman and Scherlis, 1952) in which the right sagittal projection is commonly used. The right sagittal view was an alternate choice of the Committee on Electrocardiography of the American Heart Association (American Heart Association, 1954), and when used along with the other views in the set of reference frames in this report, avoids discrepancy of trigonometric sign (Helm, 1956).

The following qualitative and quantitative parameters were analysed:

- (1) Directions of the initial and terminal 0.005-second (5-millisecond) vectors and the mean QRS axis ($\hat{A}$ QRS).
- (2) Directions and magnitudes of the 0.02-second, 0.04-second, maximum QRS vectors, and of the maximum T vectors.
- (3) Direction of inscription (rotation) of the QRS loop.
- (4) Amplitudes of the maximal projections of the QRS loop along the vertical (Y), horizontal (X), and sagittal (Z) axes.
- (5) QRS duration.

* This study was supported by a research grant from the Chicago Heart Association.

FIG. 1.—Reference frames used in this study.

When the manner of inscription of the loop varied considerably with respiration at least two representative tracings of the horizontal projection were obtained. The tracing that showed the returning limb farthest anterior was chosen for analysis.

As in the previous report (Namin *et al.*, 1964), the notation followed in naming parts of the loop conformed with that in conventional electrocardiography in which the wave is represented by a capital letter and the lead by a subscript. Thus for the vertical or Y lead, the magnitude of the projections of the maximum

(6) Direction and magnitude of the S-T vector.

In any plane in which any of the mean instantaneous vectors was obscured by an overlapping portion of the tracing, the direction of that vector was derived from readings of the same vector in the other two planes using the formula,

$$\frac{\tan \alpha}{\tan \beta} = \tan \gamma,$$

where α represents the smallest angle between the vector in the frontal plane and the horizontal co-ordinate axis of the reference frame for the frontal projection; β , the smallest angle between the vector in the sagittal plane and the horizontal co-ordinate axis of the right sagittal reference frame; and γ , the smallest angle between the vector in the horizontal plane and the horizontal co-ordinate axis of the respective reference frame. The quadrant location of the derived vector can be determined from its location in the two other planes.

FIG. 2.—Method of measuring the amplitude of the maximum projections along the orthogonal axes. See text.

initial upward (negative) deflection, the maximum downward (positive) deflection, and the maximum terminal upward (negative) deflection on the vertical axis was obtained for Q_y , R_y , and S_y , respectively (Fig. 2). R_z and S_z were the maximum anterior and posterior projections, respectively, along the sagittal (Z) axis. The magnitude of Q_x was the maximum initial rightward (negative) projection, that of R_x the maximum leftward (positive) projection, and that of S_x [the maximum terminal rightward (negative) projection along the horizontal (X) axis.

Each of the mean instantaneous vectors was represented by an imaginary line between the E point and the leading end of the time dash denoting the desired instant.

In open loops, i.e. in the presence of an S-T vector, the amplitude of the Q, R, and S deflections and the direction and magnitude of the QRS and T vectors were determined with the origin of the QRS loop as the point of reference. An exception was the terminal 5-millisecond QRS vector for which the terminus of the QRS loop was the reference point.

In determining the mean electrical axis of the QRS loop ($\bar{A} \text{ QRS}$) in any plane, the algebraic sum of the maximum projections in each of the two leads comprising the plane was substituted

into the formula,

$$\tan \alpha = \frac{y}{x},$$

where α is the smallest angle between $\hat{A}$ QRS and the horizontal co-ordinate axis of the reference frame, y is the algebraic sum of the projections along the vertical co-ordinate axis, and x is the algebraic sum of the projections along the horizontal co-ordinate axis.

The maximum QRS and T vectors were measured between the E point and the farthest point on the respective loops. All directions were expressed as positive angles measured in a clockwise fashion from the zero axis.

The figure-of-eight loops in the horizontal plane were classified according to the position of (1) the intersection of the returning limb and the midline and (2) the crossing of the figure-of-eight with respect to the E point (Fig. 3). Type I had both intersections anterior to the E point. In type II, the returning limb intersected the midline posterior to the E point. In type IIA, the crossing of the figure-of-eight was also posterior to the E point and proximally located. In types IIB and IIC, the crossing of the figure-of-eight was distally located, being anterior to the E point in the former and posterior in the latter.

RESULTS

QRS and T Vectors. The mean direction of the mean instantaneous vectors, the maximum QRS vector, $\hat{A}$ QRS and the maximum T vectors along with the other calculated statistical data are shown in Table I. Those vectorcardiographic features that did not show normal distribution are plotted in Fig. 4, 5, and 6. The 0.02-second vectors in the horizontal plane are also plotted (Fig. 4), though their direction had a normal distribution.

Both the initial and terminal 5-millisecond vectors were widely scattered but were mostly oriented in the right upper and lower quadrants. These vectors were more closely grouped in the sagittal projection and still more closely in the horizontal plane. All the initial 5-millisecond vectors were

FIG. 3.—Schematic representation of the different types of figure-of-eight loops in the horizontal projection. See text.

TABLE I
DIRECTION OF INSTANTANEOUS QRS VECTORS, MAXIMUM QRS VECTOR, $\hat{A}$ QRS, AND MAXIMUM T VECTOR*

	Frontal					Horizontal				
	No.	Mean	S.D.	S.E.	Range	No.	Mean	S.D.	S.E.	Range
Group I										
In 5-msec. . .	35	Wide scatter				35	122.1	16.4	2.8	88-154
0.02-sec. . .	35	34.5	12.5	2.1	345-53	36	38.0	24.9	4.1	350-109
Max. QRS . .	36	36.4	12.0	2.0	15-59	See Fig. 6A				
$\hat{A}$ QRS . .	36	37.1	15.6	2.6	3-59	36	354.3	23.0	3.8	297-36
0.04-sec. . .	36	Wide scatter				See Fig. 4A				
Max. T . .	36	41.1	10.0	1.7	0-57	36	340.7	20.0	3.3	295-22
Group II										
In 5-msec. . .	47	Wide scatter				47	114.0	37.5	4.0	40-149
0.02-sec. . .	46	41.0	22.2	3.3	12-99	47	38.1	24.2	3.5	351-103
Max. QRS . .	48	39.0	13.5	1.9	24-72	See Fig. 6B				
$\hat{A}$ QRS . .	48	39.1	12.2	1.8	8-75	48	349.6	16.3	2.4	286-21
0.04-sec. . .	46	Wide scatter				See Fig. 4B				
Max. T . .	48	42.4	13.5	1.9	0-74	48	340.4	20.8	3.0	295-22

* All measurements are in angular degrees.

SD=standard deviation; SE=standard error; In 5-msec.=initial 5-millisecond QRS vector; Max. QRS=maximum QRS vector; Max. T=maximum T vector.

FIG. 4

FIG. 4.—Scattergram of the direction and magnitude of the 0.02-second and 0.04-second QRS vectors in the horizontal plane. In this and subsequent figures, the magnitude of the vector is represented by its distance from the centre. A=Group I; B=Group II. See text.

FIG. 5

FIG. 5.—Scattergram of the direction and magnitude of the maximum QRS vector in the right sagittal plane. A=Group I; B=Group II. See text.

FIG. 6

FIG. 6.—Scattergram of the direction and magnitude of the maximum QRS vector in the horizontal plane. A=Group I; B=Group II. See text.

directed anteriorly. All the terminal 5-millisecond vectors were oriented posteriorly. The 0.02-second vectors were narrowly scattered in all projections in both groups. The 0.04-second vectors were widely distributed in the frontal plane but concentrated closely in the sagittal plane, around a mean of 167.0° (S. D. 34.2°) and 158.7° (S. D. 33.8°) in Groups I and II, respectively. In the horizontal plane, the distribution of this 0.04-second vector was markedly skewed to the 240° – 270° sector in both age-groups. Fig. 4A and B show the distribution of the magnitudes and directions of the 0.02 and 0.04-second vectors in the horizontal plane. The percentile distribution and ranges of these measurements are shown in Table II.

In the frontal plane the maximum vectors were closely distributed within the left lower quadrant around a mean of 36.4° for Group I and a mean of 39.0° for Group II, with small standard deviations (Table I). In the sagittal and horizontal planes, there was a tendency to a bimodal distribution (Fig. 5A and B, Fig. 6A and B). This became more apparent if the scattergrams for both groups were superimposed. In contrast, the $\hat{A}$ QRS readings were more closely grouped in all planes with the mean located in the left lower posterior octant in both groups. Fig. 5 and 6 also show the distribution of the magnitude of the maximum vectors and Table II shows their percentile distribution.

Almost all of the T loops were either linear or elliptical. The maximum T vector was normally distributed in all planes with small standard deviations. The mean direction of the maximum T vectors was about the same in both groups. The percentile distribution of the magnitude of the maximum T vectors is presented in Table III.

QRS Amplitudes. The percentile distribution and ranges of the amplitude of the maximal projections of the QRS loop along each of the three orthogonal axes are shown in Table IV. Also shown is the amplitude of the R deflection expressed as a percentage of the sum of the amplitudes of R and S in the same lead. The percentile distribution of the Q_x/R_x ratio expressed as a percentage

TABLE II

MAGNITUDES OF THE 0·02-SECOND, 0·04-SECOND, AND MAXIMUM QRS VECTORS*

	Frontal			Right sagittal			Horizontal		
	0·02	0·04	Max. QRS	0·02	0·04	Max. QRS	0·02	0·04	Max. QRS
<i>Group I</i>									
Min.	0·20	0·15	1·40	0·45	0·15	0·93	0·40	0·20	0·80
10th P	0·52	0·19	1·47	0·56	0·36	1·04	0·58	0·41	1·10
90th P	1·49	1·09	2·58	1·29	1·29	1·83	1·29	1·28	2·22
Max.	1·95	2·25	3·15	1·35	1·90	2·00	1·50	1·90	3·00
<i>Group II</i>									
Min.	0·30	0·15	1·00	0·25	0·20	0·70	0·35	0·20	0·87
10th P	0·46	0·23	1·32	0·38	0·38	0·98	0·53	0·42	1·10
90th P	1·98	1·31	2·76	1·09	1·45	2·12	1·59	1·37	2·16
Max.	2·30	2·80	3·40	1·50	2·10	2·70	1·80	2·55	2·90

* All measurements are in millivolts.

Max. QRS=maximum QRS vector; Min.=minimum voltage; P=percentile; Max.=maximum voltage.

TABLE III

MAGNITUDE OF THE MAXIMUM T VECTOR*

	Min.	10th P	50th P	90th P	Max.
<i>Group I</i>					
Frontal	0·15	0·27	0·48	0·74	0·90
Rt. sagittal	0·20	0·25	0·37	0·58	0·80
Horizontal	0·20	0·32	0·45	0·58	0·80
<i>Group II</i>					
Frontal	0·15	0·32	0·47	0·79	0·90
Rt. sagittal	0·20	0·26	0·41	0·62	0·75
Horizontal	0·15	0·23	0·38	0·57	0·80

* In millivolts.

Min.=minimum; P=percentile; Max.=maximum.

is also included. The greatest Q_x measured 0·8 millivolt in Group I, which was 43 per cent of the corresponding R_x . In both groups, however, the 90th percentile for the deflection was well below 25 per cent.

Direction of Inscription of the QRS Loop. Table V shows the percentage incidence of the different directions of inscription of the QRS loop. All three loop forms were found in the frontal plane and were mostly narrow. In the sagittal plane, only completely clockwise and figure-of-eight loops were noted. In the horizontal projection, the only patterns were the completely counterclockwise and the figure-of-eight with the returning limb crossing the midline posterior to the E point.

QRS Duration. There was a mean of 0·058 second and a range of 0·050 to 0·80 second for the QRS duration in Group I, a mean of 9·063 second with a range of 0·045 to 0·080 second in Group II.

S-T Vector. A distant S-T vector was noted in the horizontal projection in 3 subjects in Group I (8·3%) and in 3 subjects in Group II (6·3%). In no case did its magnitude exceed 0·2 millivolt. All were directed within the 340° to 10° sector.

TABLE IV

MAGNITUDE OF THE PROJECTIONS OF THE QRS LOOP ALONG THE X, Y, AND Z AXES*

	Y axis				Z axis			X axis				
	Q _y	R _y	S _y	$\frac{R_y+S_y}{R_y} \times 100$	R _z	S _z	$\frac{R_z+S_z}{R_z+S_z} \times 100$	Q _x	$\frac{Q_x}{R_x} \times 100$	R _x	S _x	$\frac{R_x}{R_x+S_x} \times 100$
<i>Group I</i>												
Min. . .	0	0.40	0	53.0	0.35	0.10	26.9	0	0	0.80	0	59.4
10th P	0	0.47	0	67.2	0.39	0.32	32.0	0.02	1.0	1.06	0	72.5
90th P	0.21	1.46	0.39	100.0	1.03	1.38	67.3	0.35	19.5	2.26	0.40	100.0
Max. . .	0.65	1.90	0.63	100.0	1.30	1.90	85.7	0.80	43.3	2.90	0.80	100.0
<i>Group II</i>												
Min. . .	0	0.50	0	56.0	0.20	0.25	22.7	0	0	0.85	0	58.6
10th P	0	0.66	0	69.2	0.32	0.37	27.8	0	0	1.03	0	76.5
90th P	0.18	1.94	0.42	100.0	0.77	1.32	58.8	0.34	20.8	2.12	0.41	100.0
Max. . .	0.38	2.60	0.55	100.0	1.48	1.68	76.1	0.50	27.8	2.80	0.60	100.0

* All measurements are in millivolts. See text.
Min.=minimum; P=percentile; Max.=maximum.

TABLE V

PERCENTAGE INCIDENCE MODES OF INSCRIPTION OF THE QRS LOOP*

	Frontal			Right sagittal			Horizontal					
	CW	Figure-of-eight	CCW	CW	Figure-of-eight	CCW	Figure-of-eight types					
							CW	I	IIA	IIB	IIC	CCW
Group I	44.4	38.9	16.7	86.1	13.8	0	0	0	2.7	11.1	0	86.2
Group II	41.7	45.8	12.5	95.8	4.2	0	0	0	4.2	0	2.1	93.7

* See text and Fig. 3 for the types of figure-of-eight loops in the horizontal plane.
CW=clockwise; CCW=counterclockwise.

DISCUSSION

The test of the practical value of any system of vectorcardiography is in its clinical application. In the analysis of the normal series, there was the usual attempt to lay stress on the parameters that would help to identify the abnormal vectorcardiogram. In children, the principal value of electrical records is in the recognition of cardiac chamber hypertrophy or overwork patterns. Many of the characteristics of the normal vectorcardiogram in this study aid in this differentiation.

The T vectors and most of the planar QRS vectors in the two groups in this study showed a rather narrow range of variation. Although the distribution of the direction of the 0.04-second vectors was very skewed in the horizontal plane, its limits were well defined so that a 0.04-second vector in the right anterior quadrant in these age-groups may be readily recognized as abnormal.

The maximum QRS vectors in the three planes do not always represent the same instant in the depolarization process. There can be as many as three different maximum QRS vectors in a spatial loop if these maximum vectors are based on the three planes. In the frontal plane where the QRS loops were long and narrow, the maximum vector was easily determined and its readings were closely grouped. In the sagittal and horizontal planes in which the QRS loops tended to be round or triangular, a number of widely separated points on the loop could represent a maximum vector. Our

data showed a tendency for this vector to have a bimodal distribution in the sagittal and horizontal projections (Fig. 5 and 6). In the study of Bristow (1961) and of Forkner, Hugenholtz, and Levine (1961) in normal adults, a similar distribution was noted in the horizontal projection. In the series of Hugenholtz and Liebman (1962) in normal children aged 7 months to 16 years, the maximum QRS vector showed a considerable standard deviation in the sagittal and horizontal planes (39.2° and 42.9° , respectively). Like the 0.04-second vector, the range of distribution of the maximum QRS vector in our series was sharply delineated, so that a maximum vector in the right anterior quadrant is abnormal.

The half-area QRS vector has been proposed as a close approach to the true mean QRS axis (Pipberger, 1957). Its measurements were shown to fall within a narrow range, the standard deviations being 17° , 20° , and 18° in the frontal, left sagittal, and horizontal projections, respectively, in Bristow's series in adults; and 18.8° , 28.1° , and 32.6° in the same respective planes in the series of Hugenholtz and Liebman (1962) in an age-group comparable to ours. The method of mean axis determination used in this study yielded $\bar{A}$ QRS readings with a distribution that compares favourably with that of the half-area QRS vector readings in the study of Hugenholtz and Liebman (1962). Determination of the half-area vector involves bisecting the QRS loop by a line that passes through the isoelectric point. This may be done by inspection if loop contour favours it. The use of planimetry (Pipberger, 1957) by trial and error (Bristow, 1961) to find the bisecting line (the half-area QRS vector) has been suggested. This is more time consuming than our method of finding the $\bar{A}$ QRS, which entails only linear measurements. However, accuracy in methods that obtain the axis by considering magnitude alone suffer in the presence of grossly deformed QRS complexes or intra-ventricular conduction defects in which a linear relation between QRS time and QRS amplitude may be absent. Abildskov and associates (1958) used a method similar in principle to ours in obtaining the QRS axis in the frontal plane from deflections in the X and Y leads of scalar tracings obtained with the Frank lead system.

In the previous report (Namin *et al.*, 1964), figure-of-eight loops in the horizontal plane were classified according to the position of the crossing of the figure-of-eight in relation to the E point. In the present report, we classified such loops according to whether the returning limb intersected the midline anterior or posterior to the E point (Fig. 3). The latter classification has more merit for it gives information regarding the position of most of the returning limb. In the earlier series in every figure-of-eight loop in the horizontal plane, the crossing of the figure-of-eight had the same position in relation to the E point as the intersection of the returning limb and the midline.

The evolution of the QRS loop with age is best seen in the horizontal plane. In younger age-groups (Namin *et al.*, 1964) the figure-of-eight pattern with the returning limb intersecting the midline anterior to the isoelectric point was noted as late as the 12th to the 18th month of life. The figure-of-eight loops in the present series have returning limbs posterior to the E point (Table V and Fig. 3).

Since the T loops were usually linear or symmetrically elliptical, the maximum T vector and the mean T vector had the same direction.

SUMMARY AND CONCLUSIONS

Eighty-four Frank system vectorcardiograms of normal children aged 2 to 12 years were analysed.

The directions of the initial and terminal 5-millisecond QRS vectors were widely scattered in the frontal plane but were closely grouped in the sagittal and horizontal planes. The directions of the 0.04-second and the maximum vectors did not always follow a normal distribution but were well enough delineated in the horizontal plane to be of diagnostic value. The 0.02-second vector, $\bar{A}$ QRS, and the maximum T vector in all planes were narrowly enough distributed to be clinically significant.

The rotation of the QRS loop in the horizontal plane was mostly counterclockwise, although in a small minority the loop showed a figure-of-eight pattern with the returning limb intersecting the mid-

line posterior to the E point. This parameter, which shows a distinct evolution with age, appears to be of considerable diagnostic value.

The method of mean QRS axis determination used in this study was comparable to the half-area method and was simpler to use in our hands.

We are grateful to Dr. Robert A. Miller, Director, Department of Cardiology, Cook County Children's Hospital, for his critical review of this paper.

We also express appreciation to Mrs. Geneva F. Harris and to Mr. Robert L. Mann who rendered secretarial and technical assistance, respectively.

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