Normal Frank Vectorcardiogram in Infancy and Childhood*

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Vectorcardiography as an added diagnostic method is of value in the study of congenital heart disease. With the development of the corrected orthogonal lead systems, the Frank system is the most frequently used because of its theoretical soundness and ease of application (Frank, 1956).

Though several reports have dealt with the description of the normal Frank vectorcardiogram (Pipberger, 1958; Seiden, 1957; Bristow, 1961; Forkner, Hugenholtz, and Levine, 1961; McCall, Wallace, and Estes, 1962; Gunther and Graf, 1965), few have been concerned with infancy and childhood (Hugenholtz and Liebman, 1962; Namin *et al.*, 1964), hence the need for additional normal data.

Several authors have studied the evolution of the vectorcardiogram in infancy and childhood, as recorded with different lead systems (Namin *et al.*, 1964; Rosen and Gardberg, 1957; Rothfeld *et al.*, 1960; Wachtel *et al.*, 1960; Calleja, Barker, and Kissane, 1961; Elek *et al.*, 1953); in their reports emphasis was placed mainly on the shift in the direction and rotation of the QRS loop and the T vector in the horizontal plane, but detailed information regarding the changes in the planar and spatial magnitude was lacking. Also, to our knowledge, the normal evolution of the spatial QRS-T angle in infancy has not previously been described.

It is the aim of this paper (1) to present in detail the qualitative and quantitative aspects of the vectorcardiogram as recorded with the Frank lead system in 175 normal infants and children, and (2) to

demonstrate the evolutionary changes of depolarization and repolarization from the age of 1 day to 15 years of age.

SUBJECTS AND METHODS

The study comprised 175 subjects varying in age from 1 day to 15 years, admitted to the Hospital for Sick Children, Toronto, Canada. All were considered free of cardio-pulmonary disease on the basis of a careful physical examination and normal chest radiographs and normal electrocardiograms.

They were divided into three groups according to age:

Group I—29 infants under 2 months of age,

Group II—46 infants from 2 to 11 months,

Group III—100 children from 1 to 15 years.

All vectorcardiograms were recorded with the Frank lead system. The chest electrodes were placed in the fourth intercostal space. In children over 2 years of age the records were taken in a sitting position. The tracings were recorded by single exposure and on running paper to identify the zero "E" point. The Electronics for Medicine DR 8 vectorcardiograph was used to record all tracings.

The exposures were made at various amplifications using a 1 mV standard calibration signal. The vector loop was interrupted 400 times a second. In all tracings the direction of inscription is indicated by the pointed thin end of the time dash.

The frontal, horizontal, and left sagittal plane projections were recorded and analysed for the angular direction and magnitude of the instantaneous 0.01, 0.02, 0.03, 0.04, 0.05 sec. QRS vectors, the maximum QRS vectors, and the half area QRS vectors. The 0.06 sec. QRS vector was measured in 30 patients in Group III in both the horizontal and sagittal plane.

The direction and magnitude of the maximum T vector and the planar half area QRS-T angle were determined in all cases. The spatial QRS-T angle was calculated using Helm trigonometric tables (Helm and Fowler, 1953). The P vector was studied in 30 subjects in Group III after increasing the amplification of the loop.

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The spatial magnitude of the first 0.01, 0.02 sec. QRS vectors and the maximum QRS vectors were computed using the formula:

$$\text{Spatial vector magnitude} = \sqrt{\frac{m^2 + n^2 + o^2}{1.41}}$$

where m =projection of vector on horizontal plane; n =projection of vector on left sagittal plane; o =projection of vector on frontal plane.

The sum of the magnitude of the maximum rightward vector in both the frontal and horizontal plane was measured, rather than the maximum spatial rightward vector as done by Hugenholtz and Gamboa (1964).

RESULTS

The mean values with one-standard deviation of the angular direction and magnitude of the different instantaneous timed vectors are tabulated according to planar projection in Tables I, II, III.

Frontal Plane (Table I). In Group I the direction of the instantaneous QRS vectors was widely distributed. The initial and terminal vectorial forces were orientated rightward, superiorly, or inferiorly. The major part of the loop, as well as the maximum vector, was displaced to the right.

In Groups II and III the 0.02, 0.03 sec. and maximum QRS vectors were orientated leftward and inferiorly, with a narrow scatter. The planar QRS-T angle was wider in Group I than in Groups II and III.

Horizontal Plane (Table II). The evolution of the electrical forces was best delineated in the horizontal plane. The morphology of the QRS loop

was variable at different age-groups (Fig. 1). The initial 0.05 sec. vector was orientated anteriorly, either to the right or left, but the 0.02 sec. vector was orientated mainly to the left and anteriorly. In Group I the 0.04 sec. vector was directed to the right and posteriorly with a small scatter, while in Groups II and III the same parameter showed a wider range of variation.

The maximum QRS vector in Group I was directed mainly to the right with a wide scatter, then it shifted to the left and anteriorly in Group II, while in Group III it had a bimodal distribution but directed mainly to the left and posteriorly. The terminal vectors were directed rightward and posteriorly in all age-groups.

The inscription of the QRS loop was variable in Group I, being clockwise in 40 per cent, figure-of-eight configuration in 42 per cent, and counterclockwise in 18 per cent.

In Group II only one subject, 3 months of age, had a clockwise inscription of the horizontal loop. In Group III all subjects showed counterclockwise inscription. In 5 per cent the loop exhibited terminal crossings which varied with respirations.

Left Sagittal Plane (Table III). The 0.01, 0.02 sec. vectors were directed anteriorly but either superiorly or inferiorly. The maximum QRS vector in Groups I and II was directed anteriorly and inferiorly, and in Group III posteriorly with a wide scatter. The terminal vectors were directed posteriorly, either superiorly or inferiorly. Counterclockwise inscription of the QRS loop was noted in all age-groups.

TABLE I
FRONTAL PLANE

Instantaneous timed QRS vectors	Group I	Group II	Group III
0.01 sec. { Direction	Wide scatter	Wide scatter	Wide scatter
{ Magnitude	0.36 (0.18)*	0.32 (0.19)	0.21 (0.12)
0.02 sec. { Direction	Wide scatter	21 (35)	40.5 (25)
{ Magnitude	0.68 (0.47)	0.85 (0.35)	0.65 (0.28)
0.03 sec. { Direction	100.8	66.2 (36)	46.8 (13)
{ Magnitude	0.83 (0.4)	1.1 (0.45)	1.1 (0.45)
{ Direction	Wide scatter	155 (40)	Clockwise 75 (37)
0.04 sec. { Magnitude	0.53 (0.35)	0.56 (0.35)	Counterclockwise 40 (35)
{ Direction	—	—	0.9 (0.5)
0.05 sec. { Magnitude	—	—	Wide scatter
{ Direction	85 (48)	46.7 (16)	45 (10)
Max. { Magnitude	1.2 (0.35)	1.45 (0.4)	1.6 (0.48)
Planar half area			
QRS-T angle	53 (45)	30 (22)	14 (13)
Inscription of QRS loop			
Clockwise	26	41	59
Counterclockwise	—	2	31
Figure-of-eight	3	3	10

* Figures in parentheses are one-standard deviations.

TABLE II
HORIZONTAL PLANE

Instantaneous timed QRS vectors	Group I	Group II	Group III
0.01 sec. {Direction	93 (25)*	96.5 (21)	100.7 (27)
{Magnitude	0.57 (0.17)	0.56 (0.2)	0.29 (0.11)
0.02 sec. {Direction	63.5 (31)	58.5 (18.5)	50 (28)
{Magnitude	0.96 (0.35)	1.13 (0.3)	0.57 (0.25)
0.03 sec. {Direction	Wide scatter	356 (80)	4 (16)
{Magnitude	0.75 (0.5)	0.83 (0.4)	0.96 (0.3)
0.04 sec. {Direction	242 (23)	233 (48)	320 (35)
{Magnitude	0.72 (0.2)	0.80 (0.2)	0.96 (0.44)
0.05 sec. {Direction	†242 (20.5)	‡240 (25)	271 (39)
{Magnitude	0.52 (0.25)	0.5 (0.2)	0.5 (0.2)
0.06 sec. {Direction	—	—	§249 (20)
{Magnitude	—	—	0.45 (0.2)
Max. {Direction	Wide scatter	27 (49)	352 (36)
{Magnitude	1.26 (0.28)	1.36 (0.6)	1.3 (0.45)
Planar half area			
QRS-T angle	86 (43)	67 (35)	22 (17)
Inscription of QRS loop			
Clockwise	9	1	—
Counterclockwise	10	38	100
Figure-of-eight	10	7	—

* Figures in parentheses are one-standard deviations.

† 17 determinations.

‡ 40 determinations.

§ 30 determinations.

TABLE III
LEFT SAGITTAL PLANE

Instantaneous timed QRS vectors	Group I	Group II	Group III
0.01 sec. {Direction	199 (20.5)*	196 (17)	176 (27)
{Magnitude	0.57 (0.18)	0.58 (0.17)	0.29 (0.11)
0.02 sec. {Direction	159 (21)	162 (20.5)	141 (26.8)
{Magnitude	0.88 (0.3)	1.03 (0.3)	0.56 (0.2)
0.03 sec. {Direction	71.7 (55)	90.1 (31)	90.8 (20)
{Magnitude	0.92 (0.55)	1.04 (0.3)	0.94 (0.26)
0.04 sec. {Direction	7 (39)	25 (30)	51.6 (31)
{Magnitude	0.62 (0.27)	0.82 (0.35)	0.94 (0.4)
0.05 sec. {Direction	—	346 (23)	7 (32)
{Magnitude	—	0.44 (0.25)	0.6 (0.3)
0.06 sec. {Direction	—	—	346.5 (30)
{Magnitude	—	—	0.45 (0.2)
Max. {Direction	121.5 (50)	113 (47)	78 (30)
{Magnitude	1.23 (0.42)	1.3 (0.35)	1.3 (0.15)
Planar half area			
QRS-T angle	67 (15)	63 (26)	26 (22)
Inscription of QRS loop			
Clockwise	—	—	—
Counterclockwise	27	45	100
Figure-of-eight	2	1	—

* Figures in parentheses are one-standard deviations.

The Half Area QRS Vector, T Vector; Spatial QRS-T Angle. In studying the evolution of depolarization and repolarization events, it was necessary to divide Group III into two subgroups: IIIa (1 to 5 years), IIIb (6 to 15 years), as significant statistical differences were found between them.

The angular direction of the half area QRS and T vectors with $2 \pm$ SD are shown in a scattergram (Fig. 2, 3, 4).

In Group I the half area vector was directed to the right, anteriorly and inferiorly with a large scatter,

then it shifted to the left and anteriorly in Group II, and to the left and posteriorly in older children. The frontal projection of the T vector was leftward and inferiorly in all age-groups.

In the horizontal and sagittal plane projection there was a significant statistical difference ($p < 0.01$) in the orientation of the T vector between Groups IIIa and b (Fig. 3 and 4), but no significant difference was found between Groups I and II.

The horizontal projection showed a gradual anterior shift of the mean T vector with age: Groups

FIG. 1.—Representative vector loops in the horizontal plane of normal subjects at different age-groups. (A) Figure-of-eight configuration; (B) clockwise inscription of QRS loop; (C) counterclockwise inscription of QRS loop: notice the prominence of maximum rightward vector; (D) counterclockwise QRS loop with marked anterior displacement of the loop; (E) notice terminal delay in the loop indicated by overcrowding of the time dots; (F and G) variants of QRS loop in older children.

FIG. 2.—Scattergram of the direction of the half-area QRS and T vectors with $2 \pm$ SD in the frontal plane. Group I (<2 months) is represented in the central circle. Groups II, IIIa, and IIIb are represented successively in the surrounding circles. The direction of the T vector in Groups I and II is represented in one circle.

HORIZONTAL PLANE
175 Normal Children

FIG. 3.—Scattergram of the direction of the half-area QRS and T vectors in the horizontal plane.

LEFT SAGITTAL PLANE
175 Normal Children

FIG. 4.—Scattergram of the direction of the half-area QRS and T vectors in the left sagittal plane.

TABLE IV
SPATIAL QRS-T ANGLE

	Group I < 2 months	II 2-11 months	IIIa 1-5 years	IIIb 6-15 years	Adults*
Spatial QRS-T angle	71 (29)†	59 (18)	27 (13)	25 (15)	56 (20)

* Three reported series (Ball and Pipberger, 1958; Bristow, 1961; Libretti and Zanchetti, 1960) of adults over 20 years totalling 148 subjects.

† Figures in parentheses are one-standard deviations.

TABLE V
MAGNITUDE OF VECTORS

QRS vectors	Group I	Group II	Group III
Spatial 0.01 sec.	0.79 (0.25)*	0.76 (0.2)	0.15 (0.1)
Spatial 0.02 sec.	1.23 (0.4)	1.5 (0.45)	0.75 (0.2)
Maximum spatial	1.78 (0.45)	1.98 (0.4)	1.7 (0.35)
Maximum rightward vector†	1.8 (0.6)	1.3 (0.7)	0.55 (0.35)

* Figures in parentheses are one-standard deviations.

† The sum of the magnitude of the maximum rightward vector in both the frontal and horizontal plane.

I + II $320^\circ \pm 15^\circ$ and Group IIIb $354^\circ \pm 23^\circ$. The left sagittal projection showed a similar anterior shift. Groups I and II $42^\circ \pm 26^\circ$, Group IIIa $59^\circ \pm 22^\circ$ and Group IIIb $73^\circ \pm 26^\circ$.

The spatial QRS-T angle was wide in Groups I and II and narrowed down in Group III (Table IV). Sometime between adolescence and adult life, as the half area and T vectors begin to diverge again, the spatial QRS-T angle widens to values noted in Group II.

QRS Duration. The mean QRS duration in Group I was 0.054 ± 0.012 , in Group II 0.062 ± 0.011 , and in Group III 0.07 ± 0.015 .

P Vector. The orientation of P vector was studied in 30 patients in Group III. It was directed leftward, inferiorly, either anteriorly or posteriorly.

Magnitude. The mean values of the spatial magnitude of the 0.01, 0.02 sec. and maximum QRS vectors and the sum of the maximal right vector in the frontal and horizontal plane are shown in Table V.

DISCUSSION

Comparing our results with those reported by Hugenholtz and Liebman (1962) and Namin and D'Cruz (1964), we have found close similarity, indicating that the Frank lead system may reasonably be applied to the paediatric age-group.

In this study it was found that the magnitude of the rightward terminal forces showed progressive

reduction with growth. On the other hand, the magnitude of the initial and maximum QRS vectors increased, reaching peak mean values between 2 and 11 months; then decreased again above 1 year of age to values closely similar to those reported by Hugenholtz and Liebman (1962). The increased magnitude of the early vectorial forces at this age could be due to proximity effects and to the relatively thin chest wall.

Quantitative analysis of the spatial QRS-T angle showed that the mean value in infants under 2 months of age (Group I) was much wider than in Group II. This could be explained best by the existing right ventricular hypertrophy at this age, which has been well documented by several investigators (Keen, 1955; Patten, 1930; de la Cruz *et al.*, 1960). With growth the spatial QRS-T angle narrows as the half area QRS vector shifts leftward and posteriorly, bringing the spatial QRS and T vector approximately parallel to each other. With increasing age, sometime between adolescence and adulthood, the QRS-T angle widens again to the reported values for normal adults as the half area vector shifts more posteriorly, while the T vector tends to rotate anteriorly.

The orientation of the various measured parameters in infants under 2 months of age showed a marked wide scatter, except for the 0.04 sec. QRS vector in the horizontal plane, which was directed to the right and posteriorly (SD 23°). In contrast, the same parameter in older children had a wider range of variation.

The half area QRS vector, a useful parameter to

TABLE VI
NORMAL LIMITS FOR SELECTED VECTORCARDIOGRAPHIC PARAMETERS
IN INFANTS AND CHILDREN (FRANK LEAD SYSTEM)

Vector parameter	<2 months		2-11 months		1-15 years	
	Lower limit*	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Frontal half-area QRS vector direction	355°	†175°	9°	134°	26°	76°
Horizontal half-area QRS vector direction	Wide scatter		358°	78°	315°	30°
Magnitude of maximum QRS vector in horizontal plane	0.7°	1.9	0.4	2.5	0.5	2.2
Spatial 0.02 sec. QRS vector magnitude in mV	0.4	2.0	0.6	2.4	0.3	1.0
Maximum spatial magnitude in mV	0.9	2.7	1.1	2.8	1.0	2.4
Maximum rightward vector in mV	1.2	3.0	0	2.7	0	1.2
Direction of inscription of horizontal loop	Clockwise, figure-of-eight, counterclockwise		Figure-of-eight, counterclockwise		Counterclockwise	
T vector in horizontal plane	260	20	260	20	310	28

* Upper limits calculated as the mean plus two standard deviations and lower limits calculated as the mean minus two standard deviations.

† Upper limit of angular values always recorded in a clockwise direction from lower limit values using reference frame described previously (Pipberger, 1958).

measure (Pipberger, 1958; Bristow, 1961; Hugenholtz and Liebman, 1962), followed a Gaussian distribution in Groups II and III, but there was a significant statistical difference ($p < 0.01$) in its orientation in the different age-groups (Fig. 2). In Group II, infants between 2 and 11 months, the mean value of the half area vector in the horizontal plane was 39°, SD 20°, while in Group IIIa (1 to 5 years) it was 358°, SD 17°, and in Group IIIb (6 to 15 years) 349°, SD 21°.

McCall *et al.* (1962) described three patterns of QRS loop in the normal adult vectorcardiogram, according to the direction of the terminal forces. In our study similar patterns were found in addition to the figure-of-eight configuration frequently noted in the horizontal plane in early infancy, with wide open QRS loop in the frontal and sagittal plane. In 18 per cent of the cases there was terminal delay in the QRS loop in all three planes, as indicated by the overcrowding of the time markings. Its electrocardiographic counterpart was the notching of the R wave in the right præcordial leads or "M" shaped QRS complex known as the "crista pattern".

Based on the data in this study, the upper and lower limits of selected vectorcardiographic parameters are summarized in Table VI. In clinical practice, the planar half area QRS vector can be estimated fairly visually, and the trajectory of the loop can be appreciated at a glance.

The spatial magnitude of the maximum leftward and rightward vectors is increased in cases with obstruction of the left and right ventricles, respectively (Hugenholtz and Gamboa, 1964). The spatial magnitude of the 0.02 sec. QRS vector is in-

creased in many cases with combined ventricular hypertrophy. The normal values of the different vectorcardiographic measurements in this study are important in establishing criteria for ventricular hypertrophy in congenital heart disease.

SUMMARY

Qualitative and quantitative analysis of the vectorcardiogram as recorded with the Frank lead system was described in 175 normal subjects varying in age from 1 day to 15 years. The subjects were divided into three groups: Group I, 29 infants under 2 months, Group II, 46 infants from 2 to 11 months, Group III, 100 children from 1 to 15 years.

A significant difference in the orientation and magnitude of successive instantaneous time QRS vectors was found in the different age-groups.

The evolution of the spatial QRS-T angle with ageing was described.

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