INFLUENCE OF AGE, SEX, AND BODY HABITUS ON THE MEAN QRS ELECTRICAL AXIS IN CHILDHOOD AND ADOLESCENCE

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The "mean QRS electrical axis" has been defined by Ziegler (1951) as the average direction in which the excitatory process spreads throughout the ventricular myocardium. This mean axis or vector in the frontal plane may be calculated from the standard limb leads and used as an index of cardiac abnormality. In biometrics the term "deviation" is usually used to indicate the departure of a measurement from an established normal value. Thus in electrocardiography right or left axis deviation denotes departure of the electrical forces from the normal toward one or other side of the body. Accurate interpretation of such deviation is dependent upon well-established normal standards, and several authorities (Johnston, 1961; Ezra, 1961; Milnor, 1962) have indicated that those values currently available for older children and adolescents are inadequate. Most previous studies have contained insufficient numbers to permit statistical analysis (Lincoln and Nicolson, 1928; Hafkesbring, Drawe, and Ashman, 1937; Epstein, 1948; Gros, Gordon, and Miller, 1951; Yu, Joos, and Katsampes, 1951; Veasy and Adams, 1952; Sodi-Pallares *et al.*, 1958a), and many have contained relatively few cases in later childhood and adolescence. Ziegler (1951) considered that his own data on the mean QRS axis merely acted as a "satisfactory nucleus for further study and revision."

This investigation, which is part of a larger study of electrocardiograms in normal children and adolescents (Walker and Rose, 1961; Walker and Wershing, in preparation) was thus designed to test statistically the hypotheses of previous writers and to present normal standards related to age, sex, and body habitus from an adequate number of subjects between the ages of 6 months and 20 years.

SUBJECTS AND METHODS

The records of 2082 patients who attended the Denver Rheumatic Fever Diagnostic Service during the years 1957 to 1961 were reviewed. Despite the special nature of this clinic, a complete history was taken and a thorough physical examination performed, each patient being examined by two or more experienced paediatric cardiologists on the medical centre faculty. Laboratory studies included urine examination, hæmatocrit, white blood cell count, differential count, sedimentation rate (Wintrobe), C-reactive protein, and serum mucoprotein tyrosine. A 14-lead electrocardiogram (standard 12 leads plus V3R and V7) was recorded on a standard direct writing Cambridge instrument at 25 mm./sec. paper speed, with a calibration of 1 mV=10 mm. The majority of the earlier patients had either cardiac fluoroscopy or routine radiograms with barium swallow. More recently, if the history was negative and the murmur typically innocent, this examination was omitted in order to avoid unnecessary radiation. As a result of the evaluation of the 2082 case records, 1199 patients were excluded for one of the following reasons: the history or presence of recent illness (as evidenced by physical findings, raised sedimentation rate, white blood count, or abnormalities in the urine), diagnosis or suspicion of rheumatic fever (past or present), the diagnosis of congenital or acquired organic heart disease or the suspicion of such abnormality. The remaining 883 patients were thus regarded as being normal and were included in this study.

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The Q, R, and S deflections of each of the six standard limb leads were measured and the algebraic sum calculated. The electrical axis was then determined by plotting these values on the triaxial reference system of Carter, Richter, and Greene (1919). The unipolar limb lead axes were added, thus forming a hexaxial system for the purpose of checking the accuracy of the plotting in all cases (Grant, 1957).

The body habitus may be expressed in terms of the ratio of weight to height, and as the latter is a linear measurement it is more accurate to cube its value for this purpose and divide by 1000 (Bardeen, 1920). The ratio of weight to height cubed was calculated for each subject in the study and used for evaluating the relation between body build and the mean QRS electrical axis.

RESULTS

The values of the mean QRS electrical axis for the 883 patients (393 female and 490 male) ranged from -60° to $+134^\circ$, the greatest number of cases falling in the 65° to 85° range. The distribution around the total mean axis of 66.95° was seen to form a bell-shaped curve with the slight skew, typical of most population studies, being in the direction of left axis. Of the cases 97 per cent (860/883) had axes that fell into the range of 0° to 105° . The exceptions included six cases with axes between 105° and 120° and one with an axis of 134° : at the other end of the scale there were four cases with axes between 0° and -15° , eight between -15° and -30° , three between -30° and -45° , and one with a -60° axis. Although axes of less than -30° are usually considered abnormal, unbiased sampling for statistical study necessitates the inclusion of these clinically normal subjects.

Age and Sex. The mean values of the QRS axis and the standard deviations were calculated for each age and sex from 1 to 20 years. When subject to the *t* test (Bancroft, 1957), no significant difference was found between the two sexes at any age, so they were combined in the following age-groups for further analysis—6 months up to 2 years, 2 to 4, 4 to 6, 6 to 8, 8 to 11, 11 to 13, 13 to 16, and 16 to 20 years. The relation between the mean axis and age is shown in Fig. 1 and Table I. A leftward trend in infancy is observed in the 6-month to 2-year age-group. However, the results also indicate that there is a rightward trend from 2 to 8 years, a further leftward trend from 8 to 13 years, and another rightward trend after 13 years of age. The axis differences between these age-groups were also subjected to the *t* test. Between the 6-month to 2-year group and the 6 to 8-year group, the difference was significant ($p = < 0.02$). The leftward trend between the 6 to 8 year and the 11 to 13-year groups was of borderline significance ($p = < 0.05$). The rightward trend during adolescence was not confirmed statistically ($p = < 0.2$), probably due to the smaller number of patients in the 16 to 20-year age-group. These trends in means and standard deviations of the composite groups are depicted in Fig. 2. It is evident in both Fig. 1 and 2 that the rightward extremes of axis distribution remain relatively constant, whereas the leftward extremes vary considerably with age.

TABLE I
RELATION BETWEEN AGE AND SEX AND MEAN QRS AXIS

Age (years)	Male subjects			Female subjects			Total			Significance of difference
	No. of cases	Mean	S.D.	No. of cases	Mean	S.D.	No. of cases	Mean	S.D.	
6/12-2	9	54.9°	± 35.1	8	54.4°	± 33.3	17	54.6°	± 34.0	$0.02 > p < 0.01$
2-4	45	68.6°	± 17.0	36	69.0°	± 23.4	81	68.8°	± 19.9	
4-6	80	64.0°	± 24.8	65	72.5°	± 19.5	145	67.8°	± 22.9	
6-8	85	70.3°	± 21.7	70	69.8°	± 22.9	155	70.0°	± 22.2	$0.05 > p < 0.02$
8-11	86	64.6°	± 29.0	76	65.4°	± 27.0	162	65.0°	± 28.0	
11-13	65	64.0°	± 28.0	60	63.6°	± 26.9	125	63.8°	± 27.3	
13-16	87	67.4°	± 22.4	53	64.9°	± 25.1	140	67.1°	± 23.8	$0.2 > p < 0.1$
16-20	28	68.4°	± 26.9	24	69.9°	± 20.5	52	69.1°	± 23.9

FIG. 1.—Mean QRS axis and standard deviations according to age-groups and sex.

On the one hand, the percentage of cases with a mean axis of $+90^\circ$ or more changes little from one age-group to another (range -3.3% to $+3.5\%$ from the average of 15.8%). On the other hand, the percentage of cases with a mean axis of $+30^\circ$ or less shows considerable variation between the age-groups (range -7.4% to $+24.1\%$ from the average of 11.1%). This indicates that the changes in mean values noted with age are caused mainly by variation in the incidence of cases falling toward the leftward end of the scale.

FIG. 2.—Trends in mean QRS axis throughout childhood and adolescence.

Body Habitus. The electrical axis and the body build were then correlated for each patient. The latter, expressed as the ratio of weight/height³, constitutes the ordinate and the mean QRS axis constitutes the abscissa. Separate scattergrams (Fig. 3) were prepared for each group, in order to take into account the normal variation of the mean weight/height³ ratio with age, especially in the younger children. A line was drawn to indicate the mean ratio and the mean axis for each group, dividing each diagram into quadrants for better demonstration of correlations, and a regression line was superimposed. Coefficients of correlation were determined for each group to test the significance of the relation between these entities (Bancroft, 1957).

The results suggest a possible correlation between axis and body build in the 6-month to 2-year, the 11 to 13-year, and the 13 to 16-year age-groups. In general the coefficients of correlation indicate poor interrelation between these factors in early childhood, with the possible exception of the first group in which the figure was relatively high (coefficient of correlation = -0.204). The *p* value, however, was only 0.4 due to the small number of cases. It is probable that a larger series of children between the ages of 6 months and 2 years would show a significant correlation. In the 11 to 13 and 13 to 16-year age-groups, however, highly significant correlation was found (coefficients of correlation were -0.24 and -0.365 respectively, and the *p* values were 0.007 and 0.00006). The fact that the periods at which the correlation is most significant correspond to the ages of rapid longitudinal growth strongly suggests that the rightward trends are due to the more vertical position of the heart during such periods of growth.

FIG. 3.—Relation between height/weight ratios and mean QRS axis.

DISCUSSION

While the mean QRS axis remains relatively unchanged throughout normal adult life (Simonson, 1958), review of earlier publications reveals a lack of agreement concerning some of the changes that occur during childhood and adolescence.

As early as 1917, Krumbhaar and Jenks noted that "preponderance of the right ventricle is uniformly present at birth and the early weeks of infancy, and gradually disappears in the second or third month." There is general agreement that the mean axis reflects this dominance of the right ventricle at birth with quoted mean values ranging from 108° to 138° (Hafkesbring *et al.*, 1937; Ziegler, 1951; Gros *et al.*, 1951; Furman and Halloran, 1951; Michaëlsson, 1959). Krumbhaar and Jenks (1917) further observed that by the sixth month the infant's electrocardiogram had become practically the same as that of the adult, and Coleman (1962) found that the greatest leftward change occurred during the first six months. Burnett and Taylor (1936) observed a similar trend, noting that the number of "right axis deviations" decreased considerably during the 4 to 6-month period, and Mannheimer (1940) observed this throughout the whole of the first year of life. These observations coincide well with the anatomical findings of Emery and Mithal (1961) in which the left ventricle was noted to exceed the right in weight by 4 weeks of age and to grow more rapidly for the first 3 months at least. The cases in the present study did not fall in the early infancy age-group, but it is notable that at no time in childhood or adolescence was there a greater tendency to a leftward axis than in the 6-month to 2-year group—a finding in accordance with the aforementioned reports.

In contrast with the agreement of investigators regarding the findings in the first year of life, differences in normal values appear in the reports of studies on older children. Hafkesbring *et al.* (1937) found that the electrical axis tended to deviate more to the right from the age of 1 to 5 years and postulated that this was due to the increase in the length of the chest and the resulting vertical position of the heart. In 1938, Ashman explained the slight rightward rotation of the electrical axis from the age of 3 years to puberty on a similar basis. Ziegler (1951) noted a slight rightward trend in the mean axis from 1 year to 8 years (62° to 69°).

In contrast, Grant (1958) stated that the mean QRS axis rotated from the nearly horizontal rightward position to a slightly leftward position in infancy, becoming more leftward (parallel to lead II) in later childhood. Sodi-Pallares and Calder (1956) found a gradual leftward trend from 1 year to 12 years (80° to 50°), while Beheydt, Cloetens, and De Mey (1959), noted a slight leftward trend from 6 to 16 years (66° to 62.6°).

Almost all investigators, with the exception of Beheydt, seem to agree that there is a slight but measurable rightward movement of the mean QRS axis during adolescence (Hafkesbring *et al.*, 1937; Ziegler, 1951; Grant, 1958; Sodi-Pallares *et al.*, 1958b). While most of these authors support their impressions with figures for mean and standard deviations of the mean axis, none record having subjected their trends to statistical scrutiny, comparing ages or age-groups throughout childhood and adolescence.

The present study provides statistical evidence to support the contention that the general trend in axis is leftward during childhood but reveals significant secondary rightward trends in early childhood and again in early adolescence. The true and constant adult pattern does not seem to develop until some time after 20 years of age and cannot be regarded as established at 6 to 9 months as suggested by Krumbhaar and Jenks (1917).

A new range of values for normal subjects has been established in this study. Although the figure of 90° has been widely accepted in the past as representing the upper limit of normal (Nadas, 1957) it was noted in this investigation that a fairly consistent percentage of each age-group (15%) had axes over 90° . Neglect of this fact might lead to the overdiagnosis of right ventricular hypertrophy, especially in older children. Likewise, although several authors have noted the rarity of "horizontal hearts" (Gros *et al.*, 1951; Yu *et al.*, 1951), this study supported the finding of "left axis deviation" in normal children by Burnett and Taylor (1936) in that 8.7 per cent of the patients had axes leftwards of $+30^\circ$ and 1.8 per cent had axes leftward of 0° . This extends the currently accepted limit of normal (Sodi-Pallares *et al.*, 1958b) and again indicates the risk of error in relying

on axis alone as an index of abnormality. The overall mean QRS axis in this study was 66.95° , as compared to values of 61.33° found by Hafkesbring *et al.* (1937) and 56.6° by Perry (1931). These differences may reflect the larger number of adolescents in this study.

It has been suggested by Hafkesbring *et al.* (1937), Ashman (1938), and Mannheimer (1940) that the variation of axis with age may be due to changes in the relative growth of the chest and its contents, resulting in a more or less vertical position of the heart. Grant (1958) in comparing electrical axes with anatomical axes of the heart found that the anatomical position of the heart may account for relatively minor variations in the direction of the mean QRS vector (up to 30°) but that it is rarely the cause of the greater axis deviations often seen. Guntheroth, Ovenfors, and Ikkos (1961), however, found no significant correlation between the electrical and anatomical axes in the frontal plane. Behey *et al.* (1959) compared axes with height and found no significant correlation. Despite the many studies reviewed no large series could be found in which the electrical axes in children and adolescents were correlated with age in relation to body build. Such a correlation in this study has in fact shown a relation between the periods of rapid longitudinal growth (early childhood and adolescence) and the rightward trend of the axis. At the same time, the overall leftward trend continues, suggesting that anatomical dominance of the left over the right ventricle also plays a significant part in determining the mean values. Along with age, anatomical position (body habitus), and the balance in ventricular mass, other factors such as variation in electrical conduction may influence the mean axis and account for the wide range of normal values and the trends seen during the age period studied.

Little attention has been paid to the influence of sex on the direction of the electrical axis. Hafkesbring *et al.* (1937) observed differences in the axes of boys and girls throughout childhood but did not determine whether or not these were significant. On the other hand, Simonson *et al.* (1960) in comparing the electrocardiograms of men and women found no significant sex differentiation in the QRS axis although they did see significant differences in voltage in the præcordial leads. This study supports Simonson's findings in both respects. No significant difference in the mean axis was observed while differences in præcordial voltage between the sexes were significant (Walker and Rose, 1961).

Some normal children have hearts that are rotated around their longitudinal axis with the apex displaced to the left and backwards. Electrocardiograms of such children give a typical "S1, S2, S3 pattern" or a "figure of eight loop"; that is, the standard limb leads have biphasic QRS complexes with deep S waves in leads I, II, and III. It is difficult to plot a true mean QRS axis from the standard electrocardiogram in such cases, and the values may range from -60° to -120° . Attempts to plot these axes are frequently misleading. While in adults this S1, S2, S3 pattern is found mainly in cases with right ventricular hypertrophy, in this series it was observed in five apparently normal subjects ranging in age from 3 to 14 years.

The fact that most practitioners and pædiatricians do not have the expensive apparatus required for vector loop electrocardiography does not deprive them of the value of the mean axis as an aid to accurate interpretation of the electrocardiogram. Triaxial and hexaxial diagrams are readily available (Perry, 1931) and, with values for the normal range established, the physician can add greatly to electrocardiographic interpretation by easily and rapidly plotting mean QRS axis from the standard limb leads.

SUMMARY

The electrocardiograms of 883 normal children between the ages of 6 months and 20 years were studied and the mean QRS axes were calculated. The average QRS axis for all age-groups was 66.95° . The range of values found (-60° to $+134^\circ$) was considerably wider than that usually accepted as normal. A consistent percentage (15.8%) of subjects in each age-group had axes greater than 90° and in the total group 1.8 per cent had axes of less than 0° . A set of means and standard deviations for each age-group has been prepared.

Variations in these values are apparent with age, but no significant difference in the mean axis was noted between the sexes at any one age or for any age-group.

Attempts have been made to correlate the trends in axis with body build. Such correlation was statistically significant only during age periods of rapid longitudinal growth. The overall leftward trend throughout childhood was confirmed.

Because of the wide range of normal values, it is evident that cardiac abnormalities cannot be diagnosed on the basis of axis alone, but the mean QRS axis may be a valuable adjunct to diagnosis when combined with study of the præcordial leads.

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