Normal ECG Limits for Asian Infants and Children

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Abstract

Normal ECG limits are age-dependent, particularly in infants and children, and diagnostic ECG criteria are dependent on the availability of normal limits. As part of an ongoing study, we have evaluated selected ECG amplitudes and time intervals in a cohort of 1,166 healthy Chinese infants and children from Shanghai, China. We observe notable increases of QRS and QT intervals with age, a notable trend toward decreased R and increased S amplitudes in V2, and that T wave transition occurs at age 12 and that it occurs slightly earlier for males. We observe no notable gender differences in ECG parameters at age less than 12 years old, but that evolution differences begin to be manifested after age 8 years. The normal ECG limits in Asian infants and children are also compared with available data from North American infants and children.

1. Introduction

ECG interpretation requires knowledge of normal limits, which in infants and children are strongly age-dependent. Diagnostic ECG criteria are dependent on the availability of appropriate normal limits. Normal standards have been published for Caucasian children [1-5] but no normal ECG limits are available for Asian children. As a part of an ongoing study, we have evaluated selected ECG amplitudes and time intervals for healthy Chinese infants and children with age ranging from 1 hour to 17 years. Our objective was to study trends in ECG waveform changes by age and gender and to establish tentative normal ECG standards. .

2. Materials and methods

2.1. Study population

The ECGs from newborns and infants were recorded in the Shanghai Children's Medical Center, and the ECGs of older children were recorded during school physical examinations in a number of elementary and high schools. Subjects with known history of cardiovascular or congenital heart disease or other abnormal conditions were excluded. Demographic data collected included age, gender, body weight, and height. A total of 1,347 subjects were included in data analysis at the time that this manuscript was completed. The study subjects were stratified by age into 8 groups (Table 1).

Table 1. The composition of the study population by age and gender.

Age Group	Female	Male	Total
0-24h	47	42	89
1d-7d	50	49	99
1w-3y	41	40	81
3y-5y	80	86	166
5y-8y	128	150	278
8y-12y	91	82	173
12y-16y	157	129	286
16y-17y	58	117	175
Total	652	695	1,347

2.2. ECG recording

Standard 12-lead ECGs were recorded using Philips Pagewriter XLi electrocardiographs at a sampling rate of 500sps and with a frequency response range of 0.05-150Hz. ECGs were analyzed using Philips 12-lead algorithm (PH09)[6]. ECG waveform measurements from the program used for the study included global PR interval, QRS duration, and the Bazett's corrected QT interval (QTc). Amplitude measurements of R, S, and T waves in quasiorthogonal leads V2, V5 and aVF were also studied. In addition, vectorcardiographic data synthesized from the 12-lead scalar ECG was also analyzed, including the initial, maximum, and terminal vector magnitudes and orientation angles of the maximum vector in the horizontal (x-z) plane.

2.3. Data analysis

ECG measurements were retrieved from the Philips standard measurement matrix in electronic form, and analyzed using a commercially available software package, S-plus [7]. Exploratory data analysis was performed to study the distribution by age and gender. The student t-test was applied to test for significance of difference by gender in the various age groups. The one-way ANOVA F statistic was applied to compare the variances of selected ECG and VCG variables.

Table 2. Mean values and standard deviations (± S.D) of the global PR, QRS, and QTc intervals by age and gender.

Age Group	PR (ms)		QRS duration (ms)		QTc (ms)	
	F	M	F	M	F	M
0-24h	128 ± 41	120 ± 26	58 ± 6	60 ± 7	417 ± 31	415 ± 43
1-7d	112 ± 16	108 ± 17	58 ± 5	58 ± 6	417 ± 31	425 ± 30
1w-3y	119 ± 23	120 ± 15	69 ± 7	76 ± 8	429 ± 23	425 ± 18
3–5y	127 ± 12	131 ± 15	74 ± 5	76 ± 6	431 ± 18	430 ± 16
5-8y	132 ± 15	132 ± 15	76 ± 7	80 ± 7	433 ± 20	431 ± 21
8-12y	138 ± 21	137 ± 15	79 ± 6	81 ± 7	439 ± 18	440 ± 20
12-16y	147 ± 20	143 ± 19	84 ± 8	90 ± 9	441 ± 17	436 ± 20
16-17y	150 ± 18	151 ± 20	84 ± 7	93 ± 8	436 ± 17	428 ± 24

3. Results

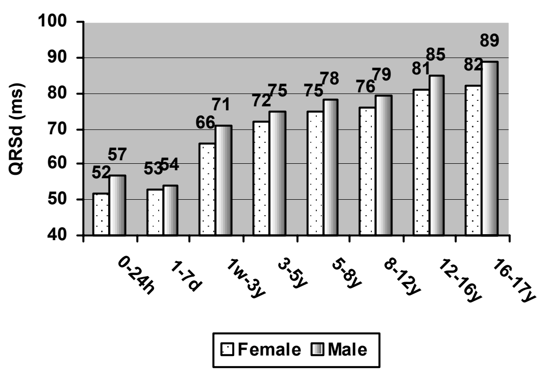

Figure 1. Mean QRS duration in lead V2 by age and gender. The increasing trend with age is statistically significant. The gender difference is not statistically significant until age > 8 years.

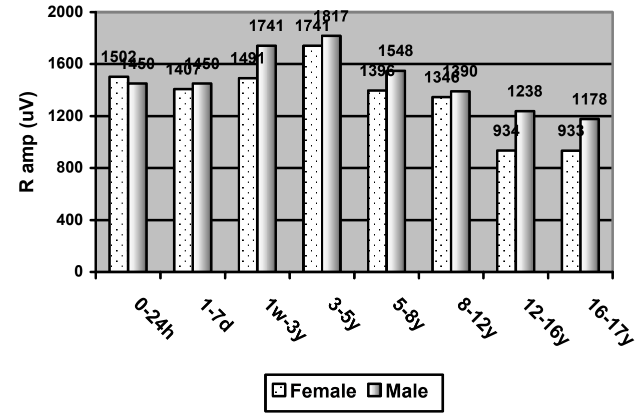

Figure 2. Distribution of mean R amplitude in V2 by age and gender. There is a statistically significant age trend for both girls and boys. The gender difference is not significant until age > 12 years.

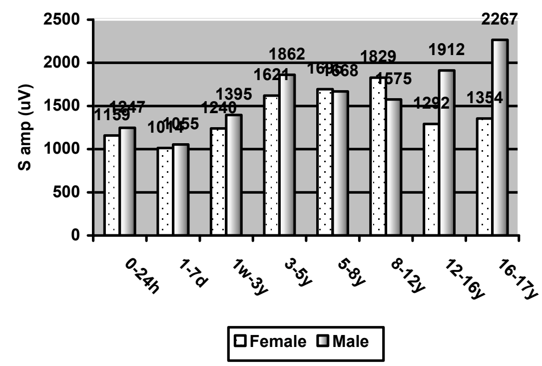

Figure 3. Mean S wave amplitude in Lead V2 by age. The trend with age is statistically significant in both girls and boys. The gender difference is not significant until age > 12 years.

The mean values and standard deviations of the global PR, QRS, QTc intervals by age and gender (Table 2) show an increasing trend by age for PR interval and QRS duration. QTc mean values do not show a significant trend with age. As shown in Fig.1, there is a notable increase in QRS duration in V2 by age ($p < 0.0001$). Minor, non-significant gender differences were noted.

Waveform amplitude measurements of R, S, and T in Lead V2 are also compared and tested as shown in Figs. 2-4. The R amplitude distribution increases with age until age 5 years old, and decreases with age in both girls and boys. The one-way ANOVA test confirms the trending of R amplitude is significant in both girls and boys ($p<0.0001$). The difference between girls and boys is not significant until age reaches 12 ($p<0.001$) as shown in Fig.2.

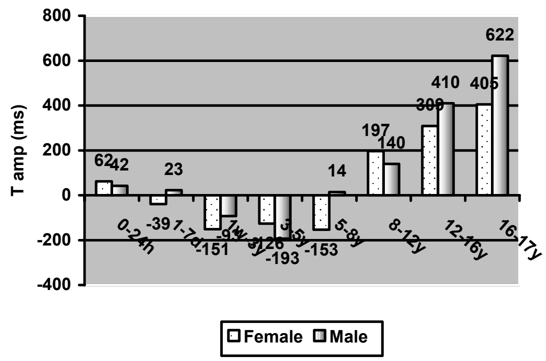

Figure 4. The mean TV2 amplitude by age and gender T wave transition zone is at V2 (TV2 becomes positive) after age 8 years in the majority of both boys and girls. The T wave amplitudes in boys become clearly larger (more positive) than in girls in the older two age groups.

Table 3. Distribution of mean maximum QRS vector magnitude and the horizontal plane azimuth angle (0° left, anterior 0° to 180°, posterior negative 0° to -180°) by age and gender.

Age Group	Magnitude		Angle	
	F	M	F	M
0-24h	1,252 ±359	1,252 ± 363	71 ± 68	101 ± 86
1d-7d	1,267±286	1,371 ± 504	65±66	77 ± 74
1w-3y	1,679±373	1,758 ± 355	9 ± 169	13 ± 140
3y-5y	1,513± 374	1,570 ± 339	12 ± 19	12 ± 21
5y-8y	1,568± 333	1,625 ±372	1 ± 25	0 ± 29
8y-12y	1,817±479	1,855 ±448	-7 ± 26	-2 ± 15
12y-16y	1,415±362	1,786 ±469	-12 ± 28	-12 ± 25
16y-17y	1,417± 342	1,804 ± 523	-13 ± 28	-19 ± 28
One-way ANOVA	P<0.0001	P<0.0001	P<0.0001	P<0.0001

The age trend in S amplitudes in V2 (not shown) was significant in both girls and boys ($p<0.0001$ for both). The gender difference became significant at age 12 years ($p<0.001$). The high S amplitude at age 12-16 years and 16-17 years can be explained by the increasing dominance of the left ventricular mass. As shown in Figure 4, it should be pointed out that the transition of the T wave occurs at age of 5 and it occurs slightly earlier in males. In summary, we observe no notable gender differences in ECG parameters at age less than 8 years old, and that age evolution differences manifest themselves after age 8 years. Gender differences in children 8 years old and above involve complex mechanisms from the evolution of both cardiac and extra-cardiac factors.

Consistent with the observations of Liebman [2], the maximum QRS vector anterior orientation in infants and younger children rotates gradually counterclockwise and reaches average orientation to the left at age 5 to 8 years, and then becomes posterior in older children and adolescents, as shown in Table 3.

4. Normal limits for Asian children in comparison with North American and European children

Comparing the normal ECG limits for Asian children with those in North America [1] and recently published data from European children [5], it is noted that the age trends in the ECG waveform are similar in Asian, North American and European children (Figure 5-6).

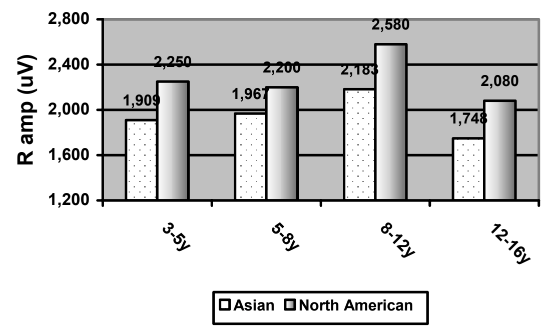

Figure 5. Mean R amplitudes in V5 for Asian and North American children in matched age groups.

However, some of the amplitude distributions by age are notably different, for the mean R amplitude in V5 (RV5), as shown in Figure 5. RV5 amplitudes in North American children in all age groups are considerably higher than in Chinese children. The RV2 amplitudes for Asian children are higher than for European children (Figure 6). As expected from the differences in RV5 and RV2 amplitudes, the SV2 amplitudes for Asian children are smaller than those of the European or American children (not shown). The comparison of the available demographic data for the Chinese and North American adolescents at age group 12 to 15 years (Table 4) reveals, unexpectedly, that the body weight and height of the Asian children studied is substantially higher then their North-American counterparts.

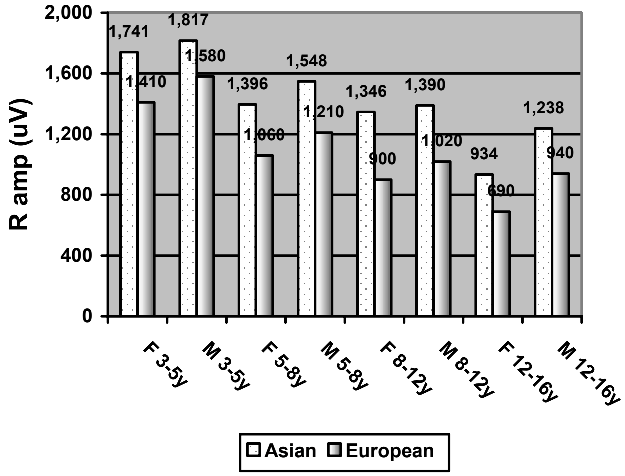

Figure 6. Mean values of R amplitude in V2 for Asian children are compared with European children in age- and gender-matched groups.

Table 4. Body Weight and Height of Asian and North American Adolescents (12-15years).

	Weight (kg)	S. D.	Height (cm)	S. D.
ShangHai (2003)	49.7	10	160	7.8
Montreal (1970's)	31.1	7.7	135	9.6
t-test	P < .01		P < .01	

5. Discussion and conclusion

It should be noted that the sample size in the present study in age range 1 week to 3 years is too small to permit finer stratification by age, and the normal limits in this group need to be interpreted with caution.

Several factors could contribute to the observed differences in ECG wave amplitudes. The differences in recording devices, such as sampling rate and frequency response can impact the waveform amplitudes. Rijnbeek et al. ruled out the sampling rate when comparing rates down to 333Hz used in the Montreal study but did not address the issue of frequency response. Electrode placement is another technical factor that may introduce voltage differences. Variation in electrode placement from patient to patient is a known problem, and this variation can be significantly higher from country to country. Aside from the technical factors, amplitude differences in normal limits may be associated with the demographic differences, particularly in body weight. Lifestyles have changed substantially and the there has been a significant trend towards being overweight, including for children, during the 30 year period since the study of Davignon et al. [1]. The normal limits in North American infants and children may need to be re-evaluated, also the demographic differences observed in the present study need to be verified.

In conclusion, gender differences in ECG parameters become significant in Chinese adolescents at age 12 years old and older. Complex mechanism causing the gender differences involves changes both in cardiac and extra-cardiac factors [8-10]. Our study data suggest that demographic and racial factors may play a critical role in influencing normal ECG standards. Older normal limits established in racially homogeneous populations may no longer be applicable to current pediatric practice.

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