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Normal electrocardiogram values of healthy children

Sağlıklı çocukların normal elektrokardiyogram değerleri

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Abstract

Aim: Electrocardiography is an important diagnostic tool in the evaluation of cardiac diseases. Normal electrocardiograms are age-dependent and may also vary due to several factors. Many studies have been performed to establish the normal values for the childhood period. The aim of this study was to determine the normal electrocardiograms values for healthy Turkish children in Aydın.

Material and Methods: All children underwent physical examination by a pediatrician and the electrocardiograms were analyzed by the same pediatrician. In the event of improper or insufficient data, the analyses were repeated. Children with a suspicious electrocardiograms or physical examination were recalled and examined by same pediatric cardiologist in outpatient clinic.

Results: In this study, electrocardiogram records were collected randomly from 1163 children with a sampling rate of 500 Hz. Of the children, 562 were female (47.4%) and 601 were male (52.6%). The total population was divided into ten age groups. Significant differences in normal limits were determined compared with previously published studies.

Conclusion: The observed differences in various electrocardiograms parameters could be related to biologic variability and to some technical details such as precordial electrode placement and visual checking of the records in addition to race.

Keywords: Electrocardiogram, normal limit, Turkish children

Öz

Amaç: Elektrokardiyografi kardiyak hastalıkların değerlendirilmesinde önemli bir tanı aracıdır. Normal elektrokardiyogram yaşa bağımlıdır ve çeşitli etmenlerle değişmektedir. Çocukluk dönemi normal değerlerini belirlemek için bir çok çalışma yapılmıştır. Bu çalışmanın amacı Aydın ilinde sağlıklı Türk çocuklarında normal elektrokardiyogram değerlerini belirlemektir.

Gereç ve Yöntemler: Çalışmada tüm çocukların fizik bakısı çocuk doktoru tarafından yapıldıktan sonra aynı kişi tarafından elektrokardiyogramları çekilerek değerlendirilmiştir. Uygun olmayan verilerin olması durumunda analiz tekrar edilmiştir. Fizik bakıda ya da elektrokardiyogramda şüphe olması durumunda hastaneye çağrılarak çocuk kardiyologu tarafından ayrıntılı inceleme yapılmıştır.

Bulgular: Çalışmada 500 Hz örneklem hızıyla toplam 1 163 olgudan elektrokardiyogram örnekleri alınmıştır. Olguların 562'si kız (%47,4%) iken 601'i erkekti (%-52,6). Tüm çalışma popülasyonu toplam 10 yaş grubuna ayrıldı. Tüm gruplardan elde edilen normal değerlerde daha önce yayınlanmış normal değerlere göre anlamlı farklılıklar görüldü.

Çıkarımlar: Elektrokardiyogram değişkenlerinde gözlenen farklılıklar biyolojik değişkenlik ve ırksal özelliklere ek olarak prekordiyal elektrot yerleştirme, kayıtların görsel kontrolü gibi bazı teknik detaylarla ilişkili olabilir.

Anahtar sözcükler: Elektrokardiyogram, normal değer, Türk çocukları

Introduction

Electrocardiography is an important diagnostic tool for cardiovascular diseases. The normal electrocardiogram (ECG) limits vary in children according to age and sex (1, 2). Only a few parameters were studied in the beginning of the 21st century; however, ECG reached its recent form after the addition of the precordial electrodes (3, 4).

The first comprehensive study for normative ECG measurements was a study by Davignon et al. (1) published in 1980, in which ECGs, digitized at a sampling rate of 333 Hz, from 2141 white healthy children aged 0 to 16 years were recorded and normal limits were presented as percentile charts. In the following years, Macfarlane et al. (5) presented the normal limits of children with a sampling

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rate of 500 Hz and demonstrated that the 98th percentile of normal amplitudes could be up to 46% higher than published by Davignon et al. (1).

In our country, Semizel et al. (6) investigated the effect of age and sex on ECG limits among 2241 healthy Turkish children in Bursa. Olgun et al. (7) presented the normal ECG values of 1530 children aged 6–16 years living in Erzurum, a city in eastern Turkey with moderate altitude and found no significant effect of altitude on ECG measurements compared with a study by Rijnbeek et al. (8) performed in Rotterdam.

In this study, we aimed to establish the normal pediatric ECG limits of healthy Turkish children aged 0 to 16 years in Aydın, with a low altitude similar to Rotterdam.

Material and Methods

This study was conducted in Aydın to determine the normal ECG values in healthy Turkish children aged 0 days to 16 years. Healthy infants aged 0–3 days were selected from the maternity hospital, and infants aged 3–28 days were collected from the healthy child outpatient clinic. Children aged 1 month to 3 years were collected from the public health outpatient clinic among children referred for vaccination. All outpatient clinics, kindergartens, preliminary schools and high schools' names were recorded. The clinics, kindergarten/schools and the classes of these schools were determined by drawing lots. Children with previously known systemic and cardiovascular abnormalities were excluded from the study. The total population was divided into ten age groups (0–7 days, 7–30 days, 1–3 months, 3–6 months, 6–12 months, 1–3 years, 3–5 years, 5–8 years, 8–12 years, and 12–16 years). All parents and all children (aged 12 or older) gave their written informed consent. The study was approved by the local ethics committee (2006/00138). In this study the rules of the Helsinki Declaration have been complied with. All parents (including all age groups) and all children (aged 12 or older) gave their written informed consent to the study.

Physical examinations of all children were performed and demographic data were noted. All ECGs were saved as ten-second data. Before the electrode placement, gentle application of alcohol was performed to the skin to reduce the impedance. Limb lead placement with Ag/AgCl electrodes was performed according to the standards. The six precordial electrodes were placed according to the following procedure. Leads V1 and V2 were located on opposite sides close to the sternum in the fourth intercostal space, V4 was placed on the left midclavicular line in the fifth intercostal space. Next, lead V6 was located on the midaxillary line. V3 was moved to V3R position, and V5 was moved to V7 position. To prevent variability of electrode placement and methodology, the same pediatrician performed all ECG recordings.

In this study, the ECGs were recorded using a Cardioline Elan CP/I (Italy) with computer-based software, and a Cardioline Cube (serial number: 1304) system with a sampling rate of 500/Hz according to the recommendation of the American Heart Association (AHA). The ECGs were analyzed by the same pediatrician and in the event of improper or insufficient data, the recording was repeated. Children with a suspicious ECG or physical examination were recalled and examined by the same pediatric cardiologist in the outpatient clinic.

Statistical analysis

Statistical analysis was performed using the SPSS version 18.0 for Windows software package. Values of $p<0.05$ were considered significant. Descriptive analysis was performed on all groups. The 2nd and the 98th percentiles of the measurement distribution were taken as the lower limit and the upper limit of normal, respectively. Zero amplitude values indicating absent Q, R or S waves were excluded from the statistical analysis as in previously performed studies. Student's t test was performed for the comparison of both sexes. For the analysis of categorical variables, Pearson's and Fisher's exact tests were performed. For the comparison of numeric variables between the groups, the normality was tested using the Kolmogorov-Smirnov test. The Mann-Whitney U test was used for the final comparisons because it was determined that the groups were not distributed normally.

Results

The study population consisted of 1305 healthy children aged 0 days to 16 years. A total of 142 electrocardiograms were excluded [insufficient or noisy records (n=120), ectopic atrial rhythm (n=7), premature ventricular contraction (n=5), atrial premature contraction (n=2), congenital heart disease (n=2)]. The remaining 1163 EGCs were included in the study. The distribution of the study population is presented in Table 1.

In this study, all of the ECGs were analyzed on the computer due to usually improperly suited p waves during routine practice. Improperly suited points as determined by the computer were called as inaccurate measurements. These inaccurate data were re-measured manually using the caliper of the Cardioline Cube program (Table 2). Manual and automatic measurements of P wave duration, P wave amplitude, P axis, and PR interval in DII derivation were compared and statistical significance was found (Table 3).

Table 1. The distribution of the study population by age and sex

Age	Female	Male	Total
0–7 d	39	50	89
7–30 d	32	71	103
1–3 m	42	47	89
3–6 m	42	49	91
6–12 m	47	48	95
1–3 y	52	51	103
3–5 y	46	53	99
5–8 y	80	84	164
8–12 y	73	49	122
12–16 y	109	99	208
Total	562	601	1163

Table 2. The distribution of the patients with a manually remeasured P wave

Age group	Total (% in the group)	Female	Male
0–7 d	25 (28.1)	7	18
7–30 d	22 (21.4)	8	14
1–3 m	37 (41.6)	14	23
3–6 m	26 (28.6)	9	17
6–12 m	18 (18.9)	9	9
1–3 y	26 (25.2)	11	15
3–5 y	2 (2.0)	1	1
5–8 y	3 (1.8)	3	–
8–12 y	5 (4.1)	5	–
12–16 y	6 (2.9)	–	6
Total	170 (14.6)	67	103

Table 3. Comparison of manual and automatic measurements of P wave

	Manual	Automatic	p
P duration (ms)	70.05	80.26	<0.001
PR interval (ms)	91.62	109.91	<0.001
P ax (°)	47.95	46.71	0.339
P amplitude (DII-mV)	0.09	0.12	<0.01

Tables 4–9 show normal limits of the clinically most relevant parameters. The median values are given together with the 98th percentiles as the upper limits of normal. The 2nd percentiles, as the lower limits of normal, are also supplemented for precordial leads where they are clinically relevant. Normal limits are presented for all cases (upper row), and for girls (middle row) and boys (lower row). To indicate sex differences, statistically significant values are visualized by bold percentiles.

Table 4 shows the normal limits for the lead-independent ECG measurements. When the median values were compared, whereas heart rate and QRS axis decreased with age, P duration, PR interval, and QRS duration increased. Heart rate reached the upper limit in the 7–30 d group. After this period, the upper limit of the heart rate continuously decreased and was slightly higher in girls than boys from the age of 8 years onward (8–12 y p=0.003, 12–16 y p<0.001).

In our study, the lowest values for PR intervals were detected in the 1–3 m group, and after that, values gradually increased, especially in boys. The median QRS axis was directed to the right in the first four weeks of life showing right ventricle dominance and changed to the left lower quadrant after the first month. The mean QRS duration substantially increased with age. The QTc interval remained relatively constant over the years with an upper limit of 441 milliseconds (ms) in girls and 442 ms in boys, and a lower limit of 368 ms in girls and 358 ms in boys.

In Table 5, P-wave amplitude is given for leads II and V1. In all groups, the median values in lead II did not exceed 0.30 mV. The Q-wave amplitude is presented for clinically important leads in Table 6. The highest Q-wave amplitude values were detected between 6 months and 3 years. After this period, the amplitude values gradually decreased.

The normal limits of the amplitude of the R and S waves are shown in Table 7 and 8, respectively. R wave amplitudes decreased with age in the right precordial leads associated with an increase in the left precordial leads. R wave amplitudes reached the highest upper limits in the 8–12 y group. In all precordial leads, R wave amplitudes were significantly higher in boys than in girls in the 8–12 y group. S wave amplitudes decreased until the end of the first month in the right precordial leads and after that, they gradually increased with age. In the adolescent period, among all precordial leads, S wave amplitudes were significantly higher in boys.

In Table 9, the R/S ratio was presented in the precordial leads. Although there was a decrease in the right precordial leads, an increase was observed in the left precordial leads with age. The upper and lower limits of the ratio spread in a large band. In some age groups, the upper limit of normal could not be calculated because of the absent S waves in more than 2% of the ECGs.

Discussion

The normal electrocardiogram limits vary in children from birth to the adolescent period. For that reason, the evaluation of the pediatric ECG should be age-dependent

Table 4. The normal limits for the lead-independent ECG measurements for all cases (upper row), for girls (middle row), and for boys (lower row): median (2nd percentile/98th percentile)

Measurement	0–7 d	7–30 d	1–3 m	3–6 m	6–12 m	1–3 y	3–5 y	5–8 y	8–12 y	12–16 y
Heart rate	131 (100/166)	142 (110/176)	143 (105/188)	135 (101/165)	131 (106/166)	124 (92/171)	104 (76/138)[a]	101 (79/131)	91 (65/119)[b]	88 (57/129)[c]
(beat per	130 (98/166)	142 (114/197)	142 (106/187)	136 (109/165)	131 (111/151)	123 (89/177)	106 (83/138)	103 (78/133)	94 (71/123)	93 (59/134)
minute)	131 (100/168)	143 (102/175)	143 (101/191)	134 (99/166)	131 (95/166)	125 (92/171)	101 (72/143)	100 (77/129)	86 (59/117)	82 (54/110)
P ax (°)	47 (0/79)	52 (12/77)	47 (0/71)	48 (0/71)	46 (0/66)	46 (0/70)	43 (0/67)	48 (0/73)	44 (0/69)	48 (3/76)
	49 (0/85)	51 (0/81)	45 (0/69)	48 (0/69)	46 (0/64)	45 (0/72)	44 (0/70)	49 (12/75)	45 (0/74)	50 (4/77)
	46 (0/78)	52 (28/77)	49 (4/73)	48 (0/72)	46 (0/74)	46 (1/65)	42 (0/66)	47 (0/71)	42 (0/66)	47 (0/74)
P duration	62 (46/84)	60 (40/86)a	63 (40/91)	64 (46/83)	69 (46/91)	76 (56/96)	84 (66/98)	87 (66/103)[a]	91 (72/108)	97 (76/116)[a]
(ms)	61 (44/82)	64 (40/88)	61 (44/79)	63 (46/88)	67 (46/97)	76 (56/96)	84 (54/98)	86 (64/102)	91 (70/108)	96 (73/114)
	63 (46/85)	59 (41/83)	64 (40/91)	65 (46/82)	71 (40/91)	77 (48/98)	85 (67/100)	89 (65/106)	92 (72/112)	99 (78/116)
PR interval	88 (63/113)	89 (66/120)	89 (69/119)	92 (72/119)	98 (72/128)[a]	102 (72/146)	109 (84/140)	115 (90/151)[a]	122 (94/163)*	130 (100/181)
(ms)	89 (61/116)	92 (73/121)	89 (76/133)	92 (67/144)	96 (72/118)	102 (65/147)	110 (84/156)	112 (89/151)	119 (92/151)	129 (100/184)
	87 (64/106)	88 (66/116)	90 (67/116)	91 (73/112)	101 (72/128)	102 (72/146)	107 (82/140)	118 (89/161)	125 (94/204)	132 (98/170)
QRS ax (°)	140 (76/199)[b]	131 (81/186)*	78 (-43/169)	61 (2/140)	54 (-11/125)	62 (-37/230)	52 (-28/107)	59 (-15/97)	56 (-11/96)a	56 (-16/106)
	132 (46/178)	122 (61/172)	80 (26/127)	63 (-11/164)	58 (-2/129)	62 (-83/231)	52 (-53/109)	62 (-13/97)	60 (-5/99)	57 (-12/111)
	147 (92/214)	135 (85/187)	76 (-49/193)	59 (5/136)	50 (-15/125)	63 (-37/230)	53 (-26/93)	56 (-42/96)	49 (-16/97)	55 (-30/106)
QRS duration	78 (61/90)	76 (56/88)	78 (50/92)	82 (66/92)	85 (66/97)	86 (66/102)	91 (76/106)b	88 (76/100)	87 (78/108)[b]	91 (80/112)[c]
(ms)	78 (62/88)	75 (48/86)	78 (50/90)	81 (64/92)	85 (64/92)	84 (58/100)	89 (76/100)	87 (72/99)	86 (76/100)	87 (78/102)
	78 (56/92)	76 (56/89)	78 (50/92)	82 (66/94)	85 (66/106)	87 (70/102)	93 (78/112)	89 (77/105)	90 (78/116)	95 (82/114)
QTc interval	412 (388/432)	411 (383/428)	412 (372/430)	414 (383/432)	416 (386/432)	412 (381/437)	407 (386/431)[b]	409 (379/433)	410 (375/441)	405 (367/433)[a]
(ms)d	412 (390/431)	411 (379/428)	412 (380/429)	417 (397/437)	417 (400/429)	412 (381/441)	411 (382/431)	409 (378/433)	408 (375/441)	407 (368/433)
	412 (379/436)	411 (385/429)	412 (372/431)	412 (380/431)	416 (381/435)	412 (373/436)	404 (388/427)	409 (378/435)	413 (359/442)	402 (358/436)
T ax (°)	24 (0/90)	27 (0/88)	24 (0/56)	25 (0/47)	25 (0/75)	30 (0/64)	31 (0/54)	34 (0/58)b	36 (0/62)	45 (17/59)[a]
	25 (0/90)	28 (0/90)	21 (0/58)	26 (0/50)	25 (0/74)	30 (0/70)	30 (0/54)	30 (0/64)	35 (0/65)	43 (17/62)
	22 (0/90)	26 (0/79)	27 (0/56)	24 (0/45)	26 (0/90)	31 (0/61)	31 (0/58)	37 (6/57)	37 (0/60)	47 (12/59)

[a]p<0.05; [b]p<0.01; cp<0.001; d: QTc interval according to the Bazett formula $\left(QTc = \frac{\text{QT duration (measured) (s)}}{\sqrt{\text{RR duration (s)}}}\right)$

Table 5. P wave amplitudes for all cases (upper row), for girls (middle row), and for boys (lower row): median (98th percentile)

Lead	0–7 d	7–30 d	1–3 m	3–6 m	6–12 m	1–3 y	3–5 y	5–8 y	8–12 y	12–16 y
DII	0.10 (0.17)	0.10 (0.19)	0.09 (0.18)	0.10 (0.17)	0.11 (0.21)	0.12 (0.19)	0.13 (0.20)	0.14 (0.22)	0.14 (0.24)	0.14 (0.25)
	0.10 (0.17)	0.11 (0.16)	0.09 (0.18)	0.11 (0.19)	0.11 (0.22)	0.12 (0.19)	0.13 (0.22)	0.14 (0.21)	0.14 (0.22)	0.15 (0.27)
	0.09 (0.17)	0.10 (0.19)	0.09 (0.18)	0.10 (0.17)	0.11 (0.21)	0.12 (0.21)	0.12 (0.19)	0.14 (0.24)	0.14 (0.27)	0.14 (0.25)
V1	0.08 (0.17)	0.07 (0.22)	0.05 (0.14)	0.06 (0.11)	0.07 (0.14)	0.07 (0.14)	0.08 (0.13)	0.08 (0.15)	0.08 (0.13)	0.07 (0.13)[a]
	0.08 (0.16)	0.07 (0.22)	0.05 (0.08)	0.05 (0.10)	0.06 (0.12)	0.07 (0.14)	0.08 (0.17)	0.08 (0.15)	0.08 (0.18)	0.07 (0.14)
	0.08 (0.17)	0.07 (0.22)	0.05 (0.15)	0.06 (0.11)	0.07 (0.16)	0.07 (0.15)	0.07 (0.11)	0.07 (0.15)	0.08 (0.13)	0.08 (0.14)

[a]$p<0.05$

(2–4). Therefore, we aimed to establish the normal pediatric ECG limits of healthy Turkish children in Aydin.

Another factor that affects ECG values is the ECG's characteristics. Although in the first half of the 20th century ECGs were measured manually in restricted parameters, after the 1970s the values were transferred to a computer- based system (3, 4, 9). In Garson's study (10) published in 1987, marked differences were observed between the measurements of analog and digital electrocardiograms. Frequently, in the evaluation of the pediatric ECGs, normative ECG measurements of Davignon et al. (1) study are used. In Davignon's study, the ECGs were digitized at a sampling rate of 333 Hz; however, in the following years, Macfarlane et al. (5) presented the normal limits of children with a sampling rate of 500 Hz. Macfarlane et al. (5) emphasized that the normal limits should be renewed because of their 98th percentile of normal amplitudes up to 46% higher than published by Davignon et al. (1). The American Heart Association recommends a minimum sampling rate of 500 Hz because of the effect of high frequency electrocardiogram, especially in little children (11).

Another factor that affects the values is electrode placement. In our study, all ECGs were collected by the same pediatrician with maximum care to electrode placement. Before the placement, gentle abrasion with alcohol was performed to the skin to reduce the impedance. To minimize mistakes at the stage of electrode placement, there are suggestions offering a standardized procedure of locating ECG chest electrode positions (12–15). Also, gentle application to the skin is suggested by Olson et al. (16) in order to reduce the impedance, especially in low frequencies.

For the comparison of both sexes, Student's t-test was performed in all age groups. Values of Rijnbeek et al. (8) were used, especially for the differences of race. In addition, our results were compared with the two studies from our country to reflect the differences caused by sampling diversity and biologic variability. In all the included studies, the sampling rates of the electrocardiograms were correct according to the recommendations of the AHA.

In the first month, the QRS axis was over +90° in our study, similar to Rotterdam and Bursa studies, and the value gradually decreased after first month (6, 8). For the first month, the results were like the results of European Society of Cardiology's values of the neonatology period derived from 668 neonates (17). The closest values to our study were from Davignon et al. (1). They reported the QRS axis values of about 135° in the first seven days, decreasing to 60° in 3–6 months, and stablity around these values onwards, similar to our study with QRS axis values of 140° in the first seven days and 61° in children between 3 and 6 months (1).

The normal limits for the QRS duration are similar to the Bursa study in all age groups and to the Rotterdam study in the 8–16 y group (6, 8). The values are also similar to the results Macfarlane et al. (5), of approximately 86 ms in the 13–14 years age group. In this age group, our limits were substantially higher than those reported by Davignon et al. (1). This difference may be due to the anatomic differences changing over the years in the adolescent group.

The QTc interval is important in patients referring to pediatric cardiology

Table 6. Q wave amplitudes for all cases (upper row), for girls (middle row), and for boys (lower row): median (98th percentile)

Lead	0–7 d	7–30 d	1–3 m	3–6 m	6–12 m	1–3 y	3–5 y	5–8 y	8–12 y	12–16 y
DII	0.12 (0.35)	0.11 (0.23)	0.15 (0.35)	0.16 (0.38)	0.17 (0.43)	0.18 (0.50)	0.14 (0.31)	0.13 (0.35)	0.11 (0.35)	0.10 (0.25)
	0.11 (0.26)	0.10 (0.22)	0.15 (0.33)	0.15 (0.44)	0.17 (0.47)	0.16 (0.49)	0.15 (0.31)	0.13 (0.34)	0.12 (0.35)	0.09 (0.22)
	0.13 (0.35)	0.11 (0.25)	0.16 (0.40)	0.17 (0.36)	0.18 (0.42)	0.19 (0.59)	0.13 (0.32)	0.13 (0.38)	0.10 (0.31)	0.11 (0.27)
DIII	0.15 (0.31)	0.14 (0.28)	0.19 (0.37)	0.22 (0.47)	0.25 (0.58)[a]	0.20 (0.50)	0.19 (0.42)	0.17 (0.39)	0.15 (0.42)	0.13 (0.32)
	0.15 (0.31)	0.14 (0.27)	0.18 (0.37)	0.22 (0.45)	0.21 (0.35)	0.17 (0.52)	0.19 (0.32)	0.16 (0.39)	0.15 (0.44)	0.13 (0.34)
	0.16 (0.31)	0.14 (0.30)	0.20 (0.37)	0.22 (0.48)	0.29 (0.58)	0.22 (0.45)	0.18 (0.42)	0.18 (0.45)	0.16 (0.40)	0.12 (0.31)
aVF	0.13 (0.30)	0.12 (0.26)	0.16 (0.36)	0.17 (0.36)	0.18 (0.42)	0.18 (0.52)	0.15 (0.31)	0.14 (0.36)	0.12 (0.34)	0.10 (0.27)
	0.13 (0.37)	0.11 (0.24)	0.15 (0.36)	0.15 (0.37)	0.16 (0.45)	0.17 (0.56)	0.16 (0.32)	0.14 (0.31)	0.12 (0.35)	0.10 (0.28)
	0.13 (0.26)	0.12 (0.31)	0.16 (0.38)	0.18 (0.35)	0.20 (0.39)	0.18 (0.39)	0.14 (0.28)	0.14 (0.37)	0.11 (0.31)	0.10 (0.27)
V_6	0.09 (0.32)	0.09 (0.20)	0.15 (0.33)[a]	0.16 (0.38)	0.17 (0.38)	0.17 (0.44)	0.15 (0.31)	0.15 (0.30)	0.13 (0.33)	0.12 (0.26)[b]
	0.09 (0.21)	0.09 (0.21)	0.14 (0.29)	0.14 (0.41)	0.17 (0.37)	0.16 (0.40)	0.14 (0.31)	0.15 (0.30)	0.12 (0.31)	0.09 (0.24)
	0.09 (0.55)	0.09 (0.19)	0.17 (0.36)	0.17 (0.38)	0.16 (0.41)	0.19 (0.62)	0.17 (0.32)	0.15 (0.31)	0.13 (0.37)	0.14 (0.29)
V_7	0.10 (0.28)	0.10 (0.22)	0.14 (0.30)	0.16 (0.34)[a]	0.17 (0.39)	0.16 (0.40)	0.14 (0.28)	0.13 (0.27)	0.12 (0.36)	0.11 (0.24)[b]
	0.10 (0.34)	0.10 (0.22)	0.13 (0.29)	0.14 (0.37)	0.17 (0.36)	0.15 (0.37)	0.14 (0.29)	0.13 (0.27)	0.11 (0.28)	0.09 (0.23)
	0.09 (0.24)	0.10 (0.24)	0.15 (0.31)	0.17 (0.34)	0.17 (0.40)	0.17 (0.48)	0.15 (0.27)	0.13 (0.27)	0.13 (0.40)	0.12 (0.27)

[a]p<0.05; [b]p<0.001

outpatient clinics, especially for syncope and arrhythmia (18). In the evaluation of the QT interval, several methods such as the Bazett formula, and Ashman and Hull formula are used (19–21). The most commonly used method is the Bazett formula (22), predicting normal QTc values below 440 ms among children aged between 1 and 15 years (19). Although median QTc values were lower than in the Bursa study, we found median limits similar to the Rotterdam study and to healthy Nigerian children (23). The upper limits of the QTc interval were lower than in the Rotterdam and Bursa studies, but in all age groups because the upper limits were below 440 ms, which is the commonly used criteria for prolongation (6, 8).

Values of P wave amplitude greater than 0.25–0.30 mV are accepted as right atrial hypertrophy. In our study, the upper limit of normal P-wave amplitude is 0.20 mV in the 0–8–years age group, and 0.27 mV in the 8–16–years age group in lead II, while substantially lower limits were found in V1, like in the Rotterdam study (8). The upper limit of normal P wave duration was found to be similar to the other studies in children aged older than 8 years. However, in the younger children, P wave duration was significantly lower in our study compared with the other studies. In automatic measurements of the electrocardiogram, we detected the incorrect marking of the P wave end point. Although no problem was observed in the QRS complex and T wave, in particular in 41% of the patients below three years of age, incorrect marking of the P wave end point was determined in the automatic measurement of the ECG. In our study, all the measurements were checked on the computer using the program's caliper system. In the other groups, the incorrect value ratio was 4.1%. In all those patients, the measurements were repeated using the caliper system and the program's ruler. For this reason, automatic measurements and interpretations including P wave should

Table 7. R wave amplitudes (mV) for all cases (upper row), for girls (middle row), and for boys (lower row): median (98th percentile)

Lead	0–7 d	7–30 d	1–3 m	3–6 m	6–12 m	1–3 y	3–5 y	5–8 y	8–12 y	12–16 y
DI	0.16 (0.40)	0.16 (0.36)	0.36 (0.93)	0.55 (1.10)	0.59 (1.11)[b]	0.52 (1.01)	0.57 (1.14)	0.53 (1.08)[b]	0.62 (1.44)[b]	0.61 (1.26)
	0.17 (0.46)	0.15 (0.36)	0.34 (0.76)	0.56 (1.08)	0.51 (0.96)	0.52 (1.02)	0.54 (1.04)	0.48 (1.06)	0.56 (0.97)	0.57 (1.29)
	0.15 (0.37)	0.16 (0.37)	0.38 (1.01)	0.55 (1.22)	0.66 (1.24)	0.51 (1.01)	0.59 (1.20)	0.58 (1.10)	0.71 (1.68)	0.64 (1.26)
DII	0.33 (0.76)	0.39 (0.90)	0.64 (1.28)	0.72 (1.41)	0.76 (1.55)	0.75 (1.43)	0.90 (1.67)	0.98 (1.88)	1.11 (1.95)	1.10 (1.89)
	0.34 (0.70)	0.39 (0.71)	0.69 (1.26)	0.71 (1.29)	0.76 (1.78)	0.74 (1.50)	0.91 (1.67)	0.93 (1.93)	1.14 (1.95)	1.05 (1.88)
	0.31 (0.87)	0.39 (0.91)	0.60 (1.36)	0.73 (1.54)	0.76 (1.35)	0.75 (1.39)	0.88 (2.15)	1.02 (1.93)	1.06 (2.20)	1.15 (2.10)
DIII	0.51 (1.01)	0.49 (1.06)	0.47 (0.93)[a]	0.34 (1.03)	0.30 (0.88)	0.38 (1.16)	0.41 (1.17)	0.58 (1.55)	0.62 (1.60)[a]	0.60 (1.53)
	0.52 (1.01)	0.52 (0.98)	0.54 (0.93)	0.33 (1.03)	0.29 (0.87)	0.34 (1.21)	0.42 (1.13)	0.59 (1.62)	0.70 (1.60)	0.56 (1.74)
	0.51 (1.05)	0.48 (1.07)	0.41 (0.94)	0.35 (1.04)	0.32 (1.10)	0.42 (1.16)	0.40 (1.38)	0.58 (1.62)	0.51 (1.94)	0.63 (1.53)
aVR	0.18 (0.60)	0.14 (0.47)	0.16 (0.49)	0.15 (0.36)	0.16 (0.40)	0.15 (0.47)	0.12 (0.34)	0.11 (0.32)b	0.10 (0.35)[a]	0.10 (0.40)
	0.16 (0.58)	0.12 (0.35)	0.15 (0.41)	0.14 (0.42)	0.16 (0.28)	0.14 (0.31)	0.11 (0.30)	0.12 (0.41)	0.09 (0.25)	0.10 (0.40)
	0.19 (0.66)	0.15 (0.58)	0.17 (0.61)	0.16 (0.36)	0.16 (0.43)	0.17 (0.48)	0.12 (0.41)	0.09 (0.25)	0.11 (0.41)	0.11 (0.42)
aVL	0.14 (0.32)	0.13 (0.36)	0.20 (0.52)	0.33 (0.93)	0.37 (0.82)[b]	0.28 (0.63)	0.27 (0.72)	0.23 (0.60)a	0.26 (0.86)[b]	0.24 (0.88)
	0.14 (0.35)	0.12 (0.34)	0.19 (0.48)	0.34 (0.93)	0.31 (0.80)	0.28 (0.64)	0.26 (0.63)	0.20 (0.56)	0.22 (0.68)	0.22 (0.69)
	0.14 (0.29)	0.13 (0.40)	0.22 (0.59)	0.32 (0.96)	0.42 (0.82)	0.28 (0.63)	0.28 (0.81)	0.26 (0.72)	0.31 (1.14)	0.26 (1.28)
aVF	0.41 (0.89)	0.43 (0.91)	0.55 (1.07)a	0.50 (1.14)	0.50 (1.21)	0.54 (1.26)	0.66 (1.29)	0.77 (1.62)	0.85 (1.72)[a]	0.84 (1.74)
	0.43 (0.92)	0.44 (0.81)	0.60 (1.13)	0.49 (1.22)	0.51 (1.39)	0.53 (1.31)	0.68 (1.29)	0.76 (1.63)	0.91 (1.71)	0.80 (1.79)
	0.39 (0.89)	0.43 (0.94)	0.50 (1.06)	0.51 (1.13)	0.49 (1.20)	0.56 (1.25)	0.65 (1.76)	0.78 (1.72)	0.75 (1.90)	0.88 (1.76)
V_{3R}	0.80 (1.71)	0.61 (1.39)	0.50 (1.14)	0.51 (1.28)	0.44 (1.16)	0.44 (1.23)	0.36 (1.00)[b]	0.32 (0.70)	0.26 (0.66)	0.27 (0.70)[c]
	0.81 (1.83)	0.61 (1.13)	0.46 (0.98)	0.51 (1.32)	0.42 (1.04)	0.39 (0.74)	0.31 (0.68)	0.31 (0.67)	0.25 (0.61)	0.23 (0.50)
	0.78 (1.67)	0.61 (1.45)	0.54 (1.14)	0.51 (1.19)	0.47 (1.37)	0.48 (1.27)	0.41 (1.11)	0.34 (0.83)	0.28 (0.74)	0.32 (0.82)
V_1	0.80 (1.73)	0.86 (1.65)	0.69 (1.39)	0.80 (1.57)	0.73 (1.65)	0.72 (1.72)	0.55 (1.12)	0.48 (0.94)	0.37 (1.00)	0.36 (0.88)[c]
	0.84 (1.93)	0.86 (1.92)	0.67 (1.45)	0.81 (1.57)	0.68 (1.36)	0.68 (1.89)	0.50 (1.02)	0.48 (0.98)	0.36 (1.04)	0.30 (0.69)
	0.77 (1.68)	0.86 (1.65)	0.71 (1.37)	0.79 (1.57)	0.78 (1.92)	0.77 (1.73)	0.58 (1.48)	0.48 (0.92)	0.39 (0.97)	0.43 (1.02)
V_2	0.87 (1.68)	0.96 (1.93)	1.12 (1.86)	1.43 (2.40)	1.43 (2.37)	1.37 (2.77)	1.18 (2.02)a	1.01 (1.88)	0.80 (1.81)[a]	0.66 (1.55)[c]
	0.93 (2.02)	0.93 (1.73)	1.08 (1.79)	1.39 (2.39)	1.35 (2.40)	1.29 (3.00)	1.07 (1.78)	0.98 (1.87)	0.73 (1.90)	0.51 (1.10)
	0.81 (1.55)	0.98 (1.96)	1.15 (1.94)	1.47 (2.43)	1.50 (2.37)	1.45 (2.79)	1.27 (2.19)	1.05 (1.93)	0.89 (1.81)	0.82 (2.06)
V_4	0.86 (1.86)	0.87 (1.62)	1.29 (2.10)	1.42 (2.29)	1.36 (3.03)	1.31 (2.48)	1.52 (3.28)	1.69 (2.98)	1.70 (3.59)	1.60 (3.37)[c]
	0.92 (1.82)	0.91 (1.60)	1.28 (2.04)	1.42 (2.19)	1.48 (3.05)	1.23 (2.77)	1.50 (3.28)	1.59 (2.95)	1.69 (3.50)	1.28 (2.49)
	0.81 (2.01)	0.84 (1.76)	1.30 (2.19)	1.43 (2.34)	1.25 (3.03)	1.39 (2.48)	1.55 (3.31)	1.79 (3.52)	1.73 (4.41)	1.96 (3.67)
V_6	0.29 (0.71)	0.32 (0.75)	0.62 (1.36)	0.71 (1.22)	0.67 (1.50)	0.70 (1.49)	0.82 (1.75)	0.99 (1.82)	1.13 (2.10)	1.09 (2.05)[c]
	0.31 (0.68)	0.33 (0.76)	0.62 (1.23)	0.73 (1.33)	0.69 (1.52)	0.72 (1.63)	0.78 (1.55)	0.94 (1.81)	1.17 (2.04)	0.99 (1.95)
	0.27 (0.80)	0.32 (0.80)	0.63 (1.42)	0.69 (1.20)	0.66 (1.46)	0.69 (1.50)	0.86 (1.82)	1.03 (2.03)	1.08 (2.49)	1.20 (2.44)
V_7	0.19 (0.48)	0.22 (0.48)	0.42 (0.86)	0.50 (0.86)	0.52 (1.33)	0.50 (1.04)	0.65 (1.30)	0.77 (1.39)	0.89 (1.49)	0.86 (1.56)[a]
	0.21 (0.50)	0.23 (0.46)	0.43 (0.81)	0.50 (0.85)	0.54 (1.33)	0.50 (1.13)	0.67 (1.30)	0.73 (1.40)	0.91 (1.49)	0.81 (1.51)
	0.17 (0.42)	0.22 (0.55)	0.42 (1.03)	0.49 (0.91)	0.51 (1.37)	0.50 (1.01)	0.64 (1.40)	0.80 (1.48)	0.87 (1.80)	0.91 (1.79)

[a]p<0.05; [b]p<0.01; [c]p<0.001

Table 8. S wave amplitudes (mV) for all cases (upper row), for girls (middle row), and for boys (lower row): median (98th percentile)

Lead	0–7 d	7–30 d	1–3 m	3–6 m	6–12 m	1–3 y	3–5 y	5–8 y	8–12 y	12–16 y
DI	0.51 (1.02)	0.40 (0.79)	0.28 (0.75)	0.32 (0.81)	0.32 (0.71)	0.27 (0.67)	0.25 (0.72)	0.21 (0.47)	0.21 (0.59)[c]	0.19 (0.51)[b]
	0.51 (1.02)	0.37 (0.66)	0.27 (0.52)	0.34 (0.83)	0.29 (0.84)	0.26 (0.72)	0.24 (0.84)	0.19 (0.46)	0.17 (0.43)	0.16 (0.49)
	0.51 (1.03)	0.41 (0.82)	0.30 (0.87)	0.30 (0.81)	0.35 (0.62)	0.28 (0.67)	0.26 (0.67)	0.23 (0.53)	0.27 (0.79)	0.22 (0.55)
DII	0.24 (0.63)	0.22 (0.61)	0.20 (0.50)	0.20 (0.44)	0.21 (0.48)	0.23 (0.65)b	0.24 (0.53)	0.22 (0.58)	0.21 (0.57)[b]	0.24 (0.62)[c]
	0.23 (0.59)	0.19 (0.33)	0.19 (0.43)	0.19 (0.43)	0.19 (0.44)	0.19 (0.55)	0.22 (0.59)	0.22 (0.58)	0.17 (0.51)	0.19 (0.53)
	0.25 (0.66)	0.24 (0.61)	0.22 (0.53)	0.21 (0.47)	0.23 (0.52)	0.28 (0.67)	0.25 (0.52)	0.22 (0.59)	0.26 (0.65)	0.28 (0.66)
DIII	0.11 (0.46)	0.12 (0.48)	0.14 (0.44)	0.20 (0.81)	0.26 (0.79)	0.21 (0.61)	0.21 (0.60)	0.17 (0.57)	0.16 (0.77)	0.21 (0.92)[b]
	0.13 (0.47)	0.09 (0.41)	0.12 (0.45)	0.23 (0.90)	0.22 (0.68)	0.23 (0.62)	0.22 (0.56)	0.17 (0.56)	0.16 (0.84)	0.15 (0.51)
	0.10 (0.27)	0.14 (0.50)	0.14 (0.41)	0.19 (0.71)	0.30 (0.93)	0.19 (0.47)	0.21 (0.64)	0.18 (0.70)	0.17 (0.71)	0.26 (1.49)
aVR	0.16 (0.49)	0.20 (0.50)	0.43 (0.97)	0.57 (1.01)	0.62 (1.01)[a]	0.62 (1.13)	0.75 (1.46)	0.76 (1.32)	0.87 (1.59)	0.85 (1.45)
	0.17 (0.49)	0.19 (0.37)	0.43 (0.84)	0.57 (0.99)	0.57 (1.01)	0.62 (1.18)	0.74 (1.26)	0.74 (1.35)	0.86 (1.28)	0.83 (1.46)
	0.15 (0.47)	0.20 (0.55)	0.43 (0.98)	0.56 (1.05)	0.66 (1.03)	0.63 (1.13)	0.76 (1.48)	0.78 (1.27)	0.90 (1.69)	0.87 (1.46)
aVL	0.52 (1.02)	0.44 (0.89)	0.34 (0.75)	0.35 (0.86)	0.36 (0.77)	0.32 (0.68)	0.31 (0.81)	0.34 (0.91)	0.32 (0.96)	0.30 (0.78)
	0.53 (1.03)	0.44 (0.82)	0.35 (0.62)	0.38 (0.98)	0.35 (0.74)	0.31 (0.67)	0.32 (0.90)	0.35 (0.95)	0.33 (0.82)	0.28 (0.81)
	0.51 (0.89)	0.45 (0.96)	0.33 (0.88)	0.32 (0.67)	0.37 (0.77)	0.32 (0.72)	0.30 (0.77)	0.33 (0.93)	0.30 (1.07)	0.32 (0.78)
aVF	0.14 (0.40)	0.15 (0.40)	0.14 (0.33)	0.16 (0.47)[a]	0.16 (0.56)	0.18 (0.48)[a]	0.19 (0.48)	0.18 (0.49)	0.17 (0.44)	0.20 (0.54)[c]
	0.15 (0.33)	0.12 (0.28)	0.13 (0.31)	0.19 (0.53)	0.15 (0.52)	0.15 (0.45)	0.19 (0.45)	0.18 (0.51)	0.15 (0.56)	0.14 (0.44)
	0.14 (0.42)	0.16 (0.46)	0.14 (0.33)	0.14 (0.33)	0.17 (0.61)	0.21 (0.49)	0.20 (0.52)	0.18 (0.51)	0.18 (0.39)	0.26 (1.03)
V_{3R}	0.27 (0.93)	0.18 (0.48)	0.22 (0.69)	0.26 (0.81)	0.26 (1.01)	0.39 (1.01)	0.44 (1.26)	0.48 (1.10)	0.54 (1.37)	0.66 (1.44)[c]
	0.31 (0.98)	0.17 (0.37)	0.19 (0.47)	0.26 (1.33)	0.24 (0.89)	0.36 (0.86)	0.42 (1.04)	0.46 (0.89)	0.52 (1.24)	0.59 (1.39)
	0.24 (0.68)	0.19 (0.51)	0.24 (0.71)	0.26 (0.61)	0.28 (1.20)	0.43 (1.47)	0.45 (1.60)	0.50 (1.47)	0.58 (1.44)	0.75 (1.52)
V_1	0.40 (1.15)	0.41 (1.00)	0.40 (1.11)	0.48 (1.19)	0.51 (1.49)	0.72 (1.87)	0.80 (1.85)	0.85 (1.98)[a]	0.94 (1.92)	0.98 (2.23)[b]
	0.44 (1.28)	0.47 (0.81)	0.37 (0.91)	0.51 (1.19)	0.48 (1.12)	0.73 (1.85)	0.83 (1.99)	0.92 (2.06)	0.97 (1.91)	0.89 (1.87)
	0.36 (0.93)	0.39 (1.03)	0.43 (1.17)	0.45 (1.12)	0.54 (2.15)	0.71 (1.88)	0.77 (1.84)	0.79 (1.59)	0.90 (2.52)	1.08 (2.35)
V_2	1.00 (2.22)	0.92 (1.96)	0.82 (1.70)	1.04 (2.06)	1.15 (2.18)	1.37 (2.75)	1.60 (2.94)	1.57 (2.92)[a]	1.64 (3.01)	1.52 (3.75)[c]
	1.09 (1.98)	0.98 (1.70)	0.80 (1.63)	1.04 (2.00)	1.11 (2.28)	1.38 (3.21)	1.59 (2.95)	1.67 (3.15)	1.60 (2.76)	1.20 (2.51)
	0.94 (2.55)	0.89 (2.10)	0.84 (1.77)	1.05 (2.26)	1.19 (2.18)	1.37 (2.48)	1.61 (2.91)	1.48 (2.56)	1.70 (3.52)	1.88 (3.85)
V_4	0.82 (2.09)	0.66 (1.32)	0.63 (1.33)[a]	0.75 (1.67)	0.69 (1.56)	0.77 (2.42)[a]	0.74 (1.89)[a]	0.70 (1.61)[b]	0.63 (1.71)[c]	0.62 (1.56)[c]
	0.74 (1.58)	0.66 (1.52)	0.57 (1.04)	0.73 (1.63)	0.64 (2.21)	0.67 (2.14)	0.64 (1.89)	0.61 (1.52)	0.53 (1.07)	0.45 (1.13)
	0.89 (2.63)	0.66 (1.21)	0.69 (1.33)	0.77 (1.82)	0.73 (1.50)	0.86 (2.45)	0.83 (1.91)	0.78 (1.69)	0.78 (1.97)	0.81 (1.78)
V_6	0.24 (0.65)[a]	0.20 (0.47)	0.21 (0.50)	0.21 (0.69)	0.23 (0.75)[a]	0.22 (0.73)[a]	0.22 (0.53)	0.18 (0.43)	0.18 (0.54)[c]	0.16 (0.44)[c]
	0.19 (0.48)	0.18 (0.44)	0.19 (0.51)	0.22 (0.71)	0.19 (0.48)	0.19 (0.72)	0.21 (0.62)	0.17 (0.46)	0.15 (0.39)	0.13 (0.33)
	0.27 (0.78)	0.21 (0.57)	0.23 (0.49)	0.20 (0.68)	0.26 (1.20)	0.26 (1.02)	0.23 (0.52)	0.18 (0.40)	0.23 (0.58)	0.20 (0.48)
V_7	0.14 (0.41)	0.11 (0.31)	0.12 (0.33)	0.10 (0.35)	0.14 (0.77)[a]	0.16 (0.54)	0.15 (0.42)	0.12 (0.40)	0.11 (0.33)[b]	0.11 (0.29)[c]
	0.13 (0.31)	0.09 (0.19)	0.11 (0.24)	0.10 (0.37)	0.10 (0.35)	0.14 (0.42)	0.15 (0.37)	0.12 (0.41)	0.09 (0.22)	0.08 (0.23)
	0.14 (0.43)	0.12 (0.34)	0.12 (0.34)	0.10 (0.32)	0.18 (1.20)	0.18 (0.62)	0.16 (0.43)	0.12 (0.47)	0.13 (0.34)	0.12 (0.32

[a]$p<0.05$; [b]$p<0.01$; [c]$p<0.001$

Table 9. R/S wave amplitude ratio for all cases (upper row), for girls (middle row), and for boys (lower row): median (2nd percentile/98th percentile)

Lead	0–7 d	7–30 d	1–3 m	3–6 m	6–12 m	1–3 y	3–5 y	5–8 y	8–12 y	12–16 y
V_{3R}	4.74	4.28	3.39	2.51	**2.50**	1.50	**1.16**	**0.87**	**0.63**	**0.50**
	(0.80/18.47)	(0.93/11.24)	(0.55/11.20)	(0.65/8.04)	**(0.51/7.53)**	(0.30/5.02)	**(0.25/6.14)**	**(0.21/3.01)**	**(0.11/2.53)**	**(0.09/1.60)**
	4.40	4.24	3.46	2.41	**2.64**	1.57	**1.06**	**0.85**	**0.60**	**0.47**
	(0.61/15.79)	(0.86/8.23)	(0.79/12.02)	(0.50/7.86)	**(0.44/13.13)**	(0.30/11.08)	**(0.25/6.27)**	**(0.18/3.26)**	**(0.09/3.40)**	**(0.09/1.90)**
	4.99	4.29	3.33	2.60	2.37	1.42	**1.25**	**0.88**	**0.67**	**0.54**
	(0.96/22.16)	(1.00/12.90)	(0.27/10.50)	(0.88/8.50)	(0.52/6.91)	(0.22/4.03)	**(0.24/5.98)**	**(0.19/3.84)**	**(0.12/2.93)**	**(0.11/1.70)**
V_1	3.17	2.74	2.82	2.27	**2.13**	1.24	**0.88**	**0.67**	**0.45**	**0.43**
	(0.65/16.10)	(0.70/10.06)[a]	(0.37/7.71)	(0.66/9.69)	**(0.49/10.33)**	(0.26/3.25)[a]	**(0.20/3.92)**	**(0.17/1.95)[a]**	**(0.09/1.29)[a]**	**(0.09/1.45)**
	2.93	2.15	2.76	2.00	**2.07**	1.08	**0.82**	0.60	**0.39**	**0.39**
	(0.56/14.88)	(0.71/4.92)	(0.41/6.75)	(0.67/6.03)	**(0.49/10.15)**	(0.24/2.97)	**(0.20/3.92)**	(0.14/1.68)	**(0.05/0.91)**	**(0.06/1.63)**
	3.36	3.03	2.89	2.49	**2.18**	1.42	**0.93**	**0.74**	**0.53**	**0.47**
	(0.69/18.46)	(0.70/10.45)	(0.33/7.95)	(0.62/11.96)	**(0.46/12.34)**	(0.36/4.90)	**(0.19/3.80)**	**(0.18/2.75)**	**(0.10/2.79)**	**(0.12/1.49)**
V_2	**0.94**	**1.30**	1.56	**1.60**	**1.39**	**1.16**	**0.87**	**0.74**	**0.56**	**0.56**
	(0.41/2.79)[b]	**(0.40/4.95)**	(0.54/3.37)	**(0.69/5.09)**	**(0.61/3.47)**	**(0.29/4.36)**	**(0.26/2.86)**	**(0.22/1.74)**	**(0.15/2.29)**	**(0.12/2.47)**
	0.89	**1.15**	**1.53**	**1.65**	**1.36**	**1.11**	**0.77**	**0.68**	**0.50**	**0.52**
	(0.36/2.74)	**(0.32/3.35)**	**(0.60/3.76)**	**(0.71/6.65)**	**(0.64/2.71)**	**(0.29/5.47)**	**(0.28/2.13)**	**(0.18/1.95)**	**(0.11/1.29)**	**(0.12/2.09)**
	0.97	**1.36**	1.59	**1.56**	**1.42**	**1.20**	**0.96**	**0.79**	**0.65**	**0.61**
	(0.47/2.98)	**(0.45/5.00)**	(0.39/3.22)	**(0.60/3.90)**	**(0.58/3.84)**	**(0.59/4.42)**	**(0.22/6.14)**	**(0.28/1.89)**	**(0.16/3.58)**	**(0.12/4.31)**
V_6	2.15	2.09	3.66	4.57	4.66	5.89	5.88	8.12	9.83	10.23
	(0.20/11.52)	(0.25/7.35)	(0.13/10.37)	(0.13/15.98)	(0.08/24.37)	(0.08/26.70)[b]	(0.09/21.06)	(0.09/33.76)	(0.07/35.26)[a]	(1.77/35.54)
	2.61	2.41	4.09	4.66	4.82	7.79	6.38	8.58	11.47	10.53
	(0.25/12.98)	(0.20/7.35)	(0.11/10.47)	(0.90/18.16)	(0.10/15.78)	(0.08/50.00)	(0.09/27.04)	(0.09/32.64)	(2.71/44.59)	(1.92/33.56)
	1.79	1.96	3.29	4.50	4.50	4.07	5.43	7.69	7.45	9.93
	(0.19/9.22)	(0.39/7.82)	(0.14/8.38)	(0.12/12.03)	(0.08/25.07)	(0.08/13.53)	(0.09/20.32)	(0.10/44.04)	(0.07/32.91)	(0.10/52.21)
V_7	2.34	2.91	5.23	7.05	7.10	6.06	7.23	8.84	11.89	11.41
	(0.20/17.18)	(0.21/11.45)	(0.22/16.54)	(0.40/23.50)	(0.10/29.35)	(0.08/23.20)	(0.08/33.93)	(0.08/30.26)	(1.70/36.90)[a]	(1.98/36.55)
	2.99	3.21	5.40	6.77	8.14	7.28	7.65	9.33	13.59	12.51
	(0.20/18.59)	(0.17/6.16)	(1.25/15.16)	(1.24/18.93)	(0.12/26.89)	(0.08/23.93)	(0.08/31.67)	(0.07/32.23)	(3.56/35.94)	(2.12/40.56)
	1.93	2.80	5.08	7.30	6.04	5.12	6.88	8.41	9.89	10.51
	(0.22/9.75)	(0.26/11.49)	(0.15/17.25)	(0.11/25.07)	(0.09/32.48)	(0.08/19.44)	(0.08/37.04)	(0.31/31.08)	(0.12/39.93)	(1.05/36.34)

[a]p<0.05; [b]p<0.01; [c]In bold percentiles; ratio of S=0 values is below 2%

be reanalyzed in the first three years of life. In the Rotterdam and Erzurum studies, the measurements were reanalyzed visually, and 16% and 12.4% of the cases were excluded, respectively (6–8). All these variations may be due to this technical difference.

The Q wave reflects interventricular septum depolarization, and deeper than expected Q waves (in all age groups deeper than 0.5 mV) in left precordials suggest left ventricular hypertrophy. In all age groups, the upper limit of normal Q wave amplitude in V6 and V7 was lower than 0.5 mV in our study, and these measurements were substantially higher than in the Rotterdam and Bursa studies, but also near to measurements of Davignon et al. (1). When the Rotterdam study recomputed their values with zero values included, the authors found the upper limit to be 0.47 Mv, similar to our results. The Q wave is a negative deflection wave, so like the Rotterdam group, we also believe in exclusion of the zero values to establish valuable statistical results. This exclusion of the zero values is not clear in the Davignon or Bursa studies (1, 6).

R and S wave amplitudes in the precordial leads are used in the diagnosis of ventricular hypertrophy. In right precordials, the upper normal limit of R wave-amplitude in V3R is found to be higher than in the Rotterdam study and lower than in the Bursa study in all age groups (6, 8). In the 7–30 d group, our upper limit of normal was 0.60–0.70 mV, lower than in the Bursa study (6). In the same derivation, S wave amplitude, similar to R wave, was higher than in the Rotterdam group. Compared with the Bursa and Erzurum studies, our results of S wave amplitude were lower (6, 8). All our S wave amplitude values in V2 were lower in the 5–16 years age group compared with the healthy Asian children presented by Sun et al. (24). For left precordial waves, the upper limit of normal R wave-amplitude in V7 was close to the Erzurum study, but lower than in the Bursa and Rotterdam studies. When the upper limit of R wave-amplitude was compared, Davignon et al. (1) reported an upper limit of normal of 4.5 mV, and Rijnbeek et al. (8) reported an upper limit of normal of 3.27 mV in V4 for children aged 3–5 years. Similar to Rijnbeek et al. (8), we found the upper limit of normal in this age group as 3.28 mV. For V7, S- wave amplitude was similar to R-wave amplitude. Recently, Yoshinaga et al. (25) investigated 1st, 7th, and 10th graders from a school-based ECG screening system and showed that the effects of age and sex were different among ECG parameters, and that the criteria for ventricular hypertrophy should be newly determined by age and sex (25).

In the evaluation of ventricular hypertrophy, when the R/S ratio was compared, especially in the right precordial leads, the results were similar to other studies. The R/S ratio gradually decreased in the right precordials and increased in the left precordial leads with age, as expected. In the determination of the ratio, aside from V2, 98th percentile values were recalculated in all precordial leads because of the absent S waves in more than 2% of the ECGs. For this reason, the R/S ratio can be considered reliable and convenient only in V2.

The influence of sex differences on pediatric ECGs has been investigated in many studies and the upper limit of amplitude in boys is found to be higher than in girls in the adolescent period. These differences are greatest in adolescents when the amplitudes of Q, R, and S waves are fairly consistently higher in males in most precordial leads. In the 12–16–year age group, many of these differences are significant (8, 9). Rijnbeek et al. (8) concluded that another reason could be breast development in this period. In LaMonte and Freiman's (26) study, significant changes were observed in ECG measurements after mastectomy. To standardize this diversity, Kligfield et al. (27) recommend the precordial electrode placement under the breast tissue during the adolescent period. Therefore, in our study, the electrodes were placed under the breast tissue but the amplitudes were still higher in boys in the Q, R and S wave-amplitudes. Also, Lue et al. (28) stated that ECG sex difference began to appear at the earliest at ages 6–9 years, and it occurred mostly at ages 9–13 years and 13–18 years, reflecting the anatomic and physiologic consequences of puberty (28). Therefore, other factors may contribute to this difference besides breast tissue.

Conclusion

The difference in our results may be explained by electrode placement and visual checking of the measurements in addition to race. It is recommended that in the evaluation of the studies from other countries and races, the differences should not be easily linked to genetic, biologic, and ethnic factors because of these considerable differences among the studies from our country.

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Ethics Committee Approval: Adnan Menderes University Local Ethics Committee 2006/00138.

Informed Consent: All parents (including all age groups) and all children (aged 12 or older) gave their written informed consent to the study.

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Mali Destek: Yazarlar bu çalışma için mali destek almadıklarını beyan etmişlerdir.

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