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Assesment of normal ECG percentiles and cardiac rhythm problems through 12-lead ECG screening in school-age children

Ercan Yilmaz[a], Ozlem Elkiran[b,*], Damla Ince[b], Cemsit Karakurt[b], Zeynep Yamancan Yilmaz[c], Saim Yologlu[d]

[a] *Inonu University, Faculty of Medicine, Department of Obstetrics and Gynecology, Malatya, Türkiye*
[b] *Inonu University, Faculty of Medicine, Department of Pediatric Cardiology, Malatya, Türkiye*
[c] *Inonu University, Faculty of Medicine, Department of Pediatrics, Malatya, Türkiye*
[d] *Inonu University, Faculty of Medicine, Department of Biostatistics, Malatya, Türkiye*

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Abstract

Aim: Electrocardiography (ECG) is an important non-invasive examination tool used for the diagnosis of cardiovascular diseases and rhythm problems for nearly hundred years. Although, many studies have been conducted showing the significant effect of age and gender on electrocardiographic traces, the data on normal reference values of pediatric ECG and the relationship between abnormal ECG recordings and heart disease are insufficient in the current literature. The aim of this study was to evaluate the standard percentile values of ECG measurement and the prevalence of cardiac disorders in school children aged 6-18 in our region.

Materials and Methods: 2154 students who were randomly selected from eight elementary, secondary and high schools in Malatya city center were included in the study and informed consent form was taken from their families. Using MAC 2000 (GE Healthcare, Milwaukee, USA) device capable of taking digital ECG record, ECG records with standard 12 derivations were taken for all participating children. ECG records of all children were examined by the same pediatric cardiologists. Using 24 hour Holter ECG and echocardiography, advanced evaluation was performed for the children with problems detected in ECG records.

Results: Pathology was detected in the ECG of 110 out of a total of 2154 children whose ECG records were examined. Average age of 2044 children without detected conduction and rhythm disorder was 11.4±2.8 and 56.8% (n=1149) were female. These eleven parameters were compared to the other studies in literature. Mean QTc interval was detected below 440 milliseconds in all age groups (6-9, 9-13, 13-18). Mean heart rate per minute was found higher in all age groups in our study compared to other studies. Thus mean QTc interval was found lower than the other studies although QT distance was similar.

Conclusion: Data of this study is important for the detection of normal ECG percentiles and the prevalence of rhythm problems in children and would guide other future studies on this subject.

Introduction

Rhythm and conduction disorders are problems which are less common in children compared to adults. To be able to interpret the electrocardiographic anomalies correctly, prevalence of rhythm and conduction disorders should be determined correctly with larger study groups [1]. Although there are some epidemiological studies on this subject, only a few of them have been done in children. Moreover, only a few of these data have been reported from our country. Sudden cardiac death in children is quite devastating and tragic for family members and the whole society. Thus ECG screening has become a widely accepted approach for cardiovascular disease recently even in asymptomatic children. But strategies on the performance of the screening are still controversial [2-6]. Screening of all young population is among these strategies [7]. Performance and interpretation of 12 lead ECG screening are recommended in different age groups [8-13]. Our aim in this study was to evaluate the prevalence of asymptomatic rhythm and conduction disorders in school children aged 6-18 in our region and to determine their standard ECG

*Corresponding author:
Email address: ozlemelkiran@yahoo.com (Ozlem Elkiran)

percentile values and characteristics.

Materials and Methods

The study was conducted in the city of Malatya in 2018. Total population of children in the age group of 6-18 in the city of Malatya was 190.000. Power analysis representing the universe was conducted statistically. In the power analysis, required minimum sampling size to predict with 3% deviation rate and 95% confidence interval was determined as 1650 individuals. The study was started after taking the necessary permissions from Malatya Directorate of National Education and detected school managements. 2154 students who were randomly selected from eight elementary, secondary and high schools in Malatya city center were included in the study and informed consent form was taken from their families. Cardiac rhythm disorder survey form to be filled in together by the parents and children was distributed among the children in the classes under the supervision of the teacher. After distributing, each question in the survey was explained in detail to the students in the class (for example how does 'chest pain' take place?). The aim, advantages and the severity of the research were explained to the teachers and the students. A contact number was provided to answer the questions of the parents on the survey. Detailed information was provided to the contacting parents on the subjects they asked about. The surveys given to a total of 3500 students were collected through school visits on the third and fifth days. 2154 (61.5%) students who filled in the survey form were included in the study. Based on the information acquired through this survey, children followed up due to cardiac disease and had cardiac surgery (n=2) and were previously diagnosed with rhythm and conduction disorder (n=1) were excluded from the study. Also the participants detected to have cardiac arrhythmia at the end of the study (n=110) were not included in ECG percentile determination phase.

Study phase was formed by three examination stages as

- ECG scanning.
- Repeated ECG and Electrocardiographic assessment.
- The examination included three stages including 24 hour Holter ECG and exercise test in selected cases.

For all participating children, using a system capable of digital ECG recording, paper speed for standard ECG records with 12 derivations was taken as 25 mm/sec. MAC 2000 (GE Healthcare, Milwaukee, USA) capable of ECG recording at 16000 samples/sec, ECG analysis frequency sampling at 1000 samples/sec and pace sensation at 75000 sampling was used. ECG records of all children were examined by the same pediatric cardiologists. ECG records were examined both digitally and by eye. 110 children detected to have ECG anomaly in their records were invited to Turgut Özal Medical Center Pediatric Cardiology Clinic. Echocardiography and -if required- 24 hour holter ECG examination and exercise test were performed on these children by the same pediatric cardiologist. Written consent was taken from all participating children and their parents using Volunteering informed consent form.

Table 1. Echocardiography results of the children with detected anomaly in ECG.

Echocardiographic findings	Number of patients (n)	Percent (%)
Patent foramen ovale	5	11.1
Physiological mitral insufficiency	2	4.4
Bicuspid aortic valve	1	2.2
Secundum ASD	2	4.4
VSD with tricuspid pouch	1	2.2
Normal Echocardiographic results	34	75.7
Total	45	100

Table 2. Pediatric conduction and rhythm disorders detected through ECG and 24 hour holter ECG.

ECG findings	Number of patients (n)	Percent (%)
1st degree AV block	5	4.6
Ventricular extra systole (VES)	2	1.8
Incomplete right branch block	2	1.8
J point elevation	3	2.7
Sinus tachycardia	9	8.2
Sinus arrhythmia	86	78.2
Sinus pause	1	0.9
Ectopic atrial rhythm	1	0.9
Borderline long QT	1	0.9
Total	110	100

All procedures performed in this study are in accordance with the ethical standards of the institutional and/or national research committee and the 1964 Helsinki Declaration and its later amendments or comparable to the ethical standards. This study was approved by the local ethical committee (reference: 21.11.2017/25-9). This study was supported by the scientific research projects unit of İnönü University.

Statistical analysis

Statistical analysis was performed using SPSS (Statistical package for the social science) version 17.0 package program. Categorical variables were provided in number and percentage. P value <0.05 was regarded as statistically significant. Consent of İnönü University Scientific Research and Publication Ethics Committee was taken for the study. Written consent form was taken from the families for the study.

Results

Pathology was detected in the ECG of 110 out of a total of 2154 children whose ECG records were examined. At the end of evaluation, average age of 2044 children without detected conduction and rhythm disorder was 11.4±2.8 and 56.8% (n=1149) were female. Height and weight measurements were performed for the children. 4.4% (n=90) of the children were under 3 percentile and 5.6% (n=114)

Table 3. Percentile distributions of ECG data based on gender in school-age children.

	Heart rate (pulse/min)	PR interval (ms)	QRS time (ms)	QT interval (ms)	QTc interval (ms)	P axis (degree)	QRS axis (degree)	T axis (degree)
Female (n=1149)								
3p	69	100	62	304	360	33	47.5	28
10p	76	110	66	320	380	40	56	36
25p	83	112	70	334	390	43	60	41
50p	93	120	74	350	400	46	63	44
75p	104	130	80	360	420	50	65.5	48
90p	116	140	84	370	426	61	71	51
97p	125	150	90	380	432	70	78	58
Male (n=895)								
3p	63	100	65	310	370	32	45	32
10p	71	110	69	322	380	40	56	38
25p	79	110	74	340	380	42	60	42
50p	89	120	80	354	400	46	63	45
75p	100	130	86	360	418	51	66	48
90p	110	140	92	370	425	62	72	54
97p	121	150	98	380	432	72	80	62
Total (n=2044)								
3p	65	100	63	306	365	33	46	30
10p	74	110	67	321	380	40	56	37
25p	80	111	72	336	386	43	60	41
50p	81	120	80	352	400	46	63	44
75p	102	130	85	360	419	50	66	48
90p	113	140	87	370	426	61	71	52
97p	123	150	91	380	432	71	79	60

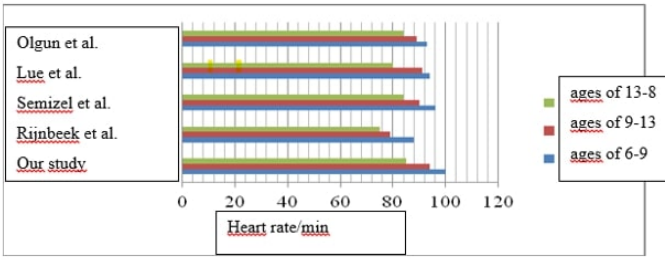

Figure 1. Comprasion of median heart rate values found in our study with other studies.

were at 97 percentile and above based on height evaluation. Based on body weight evaluation, 3.7% (n=75) of the children were under 3 percentile and 7.2% (n=147) were at 97 percentile and above. Out of 89 children admitted to health institution with tachycardia complaint, 38 (42.7%) were male and 51 (57.3%) were female. Sinus arrhythmia in 10 children and first degree atrioventricular (AV) block in 2 children and right branch block and ventricular extrasystole (VES) in one child were the problems detected in the ECG of 89 children. Atrial septal defect (ASD) and physiological mitral valv prolapse (MVP) in one child, MVP and trace mitral valve insufficiency (MI) were detected in two children in echocardiographic examinations and these children were clinically followed-up after providing the required suggestions. 24 Holter ECG monitorization of these children detected first degree AV block in two children and VES in one child. Cardiac drug usage rate was detected as 0.1% (n=3). While one of these children was using enalapril due to operated atrioventricular septal defect (AVSD), mitral cleft, subaortic membrane, trace-first degree MI and trace AI, two was using benzathine penicillin due to rheumatic heart disease. 35.4% (n=724) of the children participating in the study stated that they sometimes had dizziness. 10.2% of the participants experiencing dizzines (n=74) stated that they felt dizzy even while resting. Among these 724 children, echocardiographic examinations was performed on 15 children with pathology in ECG. MVP and trace MI were detected in two of these children while patent foramen ovale (PFO) was detected in one. Children with dizziness considered to lack a cardiac cause were transferred to otorhinolaryngology and pediatric neurology. Three of these children were diagnosed with Benign Paroxysmal Vertigo and one with migraine. As a result, cardiac-related dizziness was not considered in these children. 12.1% of the participants (n=248) thought that their hearts were beating slowly. Based on their ECGs, three of these children had bradycardia considering the normal values for their ages. 24 hour Holter ECG monitorization was performed for these children. It was interpreted as normal sinus rhythm and normal heart rate for the age. Patients were followed up. 227 of the children (11.1%) thought that they might have cardiac arrhythmia. 68 of these children were male (30%) and 159 were female (70%). Three of these cases

had first degree AV block, five had sinus arrhythmia and one had right branch block. First degree AV block was detected in two of the children who had 24 hour Holter ECG monitorization and they were followed-up. While 36.8% of the children (n=753) stated to have chest pain in any period of their lives, only 8.8% of the participants (n=179) were admitted to any health institution with chest pain complaint. Chest pain had a compressive character in 51.6% (n=389), knife-like character in 25.5% (n=192) and a stinging character in 22.9% (n=172) in children experiencing chest pain. Among the children with chest pain, first degree AV blockage and VES were detected in one child each while sinus arrhythmia was detected in eleven children. 17.7% of the children (n=362) had minimum one syncope or presyncope attack during their lives. 0.1% of these (n=3) stated to experience presyncope after sports and climbing up the stairs. ECG examinations of these children were repeated in our hospital. Echocardiography, 24 hour holter ECG and exercise test of the children were normal. The children were followed-up and were also transferred to pediatric neurology department. Cardiac drug usage rate was detected as 0.1% (n=3). While one of these children was using enalapril due to operated atrioventricular septal defect, mitral insufficiency and trace aortic insufficiency, two were using benzathine penicillin due to rheumatic heart disease. No important pathology was detected in ECG of these children. Echocardiography was performed in all patients (n=45) considered to have major pathology in ECG. Based on this evaluation, major cardiac pathology (Atrial septal defect: 2, Ventricular septal defect: 1) was detected in 3 out of 45 children and minor cardiac pathology (Patent foramen ovale: 5, physiological mitral insufficiency (MI): 2, bicuspid aortic valve: 1) was detected in 8 children (17.3%) (Table 1). Based on ECG and 24 hour holter ECG evaluation, 87 of the children were detected to have sinus arrhythmia, 5 had 1st degree AV block, 2 had rare VES, 2 had incomplete right branch block, 1 had sinus pause, 3 had J point elevation, 1 had ectopic atrial rhythm and 9 had sinus tachycardia (Table 2). Following the repeated ECGs of all five cases with a QTc range measured between 0.44 and 0.46 sec, QTc range was again measured as 0.46 sec in one of the cases (20%). 24 hour holter ECG monitorization and exercise test was performed for all of these five children. ECGs of the mothers, fathers and siblings of all cases were also examined More detail was taken on familial and individual anamneses. 1 case was decided to be followed-up for long QT syndrome based on 24 hour holter ECG, exercise test and genetic tests. Children with no detected conduction disorder after the examinations were categorized according to their genders and age groups (ages of 6-9, 9-14 and 13-18). In addition to the heart rate, PR, QT and QTc interval and QRS time, R/S ratio was calculated in V1, V2 and V6 precordial derivations together with QTc, P, QRS and T axis for the participants. 3-10-25-50-75-90 and 97 percentile data of the cases were acquired through this evaluation (Table 3).

Discussion

Normal standards for age and gender should be known to be able to evaluate electrocardiography in children. ECG screening is made in many countries for this aim. This study is among the limited number of studies made on this subject in Turkey. A survey form was also prepared and evaluated to question cardiac rhythm disorder and additional cardiac symptoms in our study. Data of 2154 children who had ECG were examined within the scope of our study. Data of 110 children with detected pathological ECG were not included in percentile curves. ECG percentiles of 2044 children between the ages of 6-18 evaluated as normal in terms of arrhythmia were taken. The patients and families are worried by chest pains in childhood. Childhood chest pains are rarely caused by a severe organic pathology. But distinctive diagnosis is very important since chest pains forming due to organic pathology may cause mortality. In the study by Alp et al [14], the rate of patients with chest pain was found as 3.40% (n=496) among all patients who were admitted to pediatric cardiology clinic and whose survey data were missing. Cardiac pathology prevalence was reported as 4.2% in patients with chest pain complaint in the study. Chest pain was detected to be due to respiratory causes in 5.4%, digestive system-related causes in 6.2%, psychological causes in 11%, muscoloskeletal system related causes in 26.3% and idiopathic causes in 47%. Prevalence of admittance to pediatric emergency service with chest pain complaint was detected as 0.29% by Allen et al. [15]. The rate of patients with chest pain complaint was found as 0.54% among all patients admitted to Pediatric Cardiology clinic in the studies by Fukushige et al. [16]. A retrospective study made in Kırıkkale area by Şanlı et al. [17] reported the prevalence of admittance with chest pain complaint to pediatric emergency service as 0.5%. Chest pain prevalence was detected as 36.8% based on the anamneses of the children in our study. 51.6% of the children with chest pain described it as compressive, 25.4% as knife-like and 23% as stinging. Prevalence of seeking medical advice for chest pain complaint was found as 8.8% which was found to be significantly higher in our study compared to others. The rate of seeking medical advice for chest pain complaint may be high in our study as it was not validated through hospital records. Syncope is a problem degrading the quality of life in childhood [18]. Although it is a rare condition, the morbidity and mortality of syncope emerging due to cardiac causes are high [19]. Previous studies showed that cardiac-related syncope in childhood constituted nearly 10% of all syncopes [20]. 17.7% of the children (n=362) had a story of syncope or presyncope attack in our study. Arrhythmia was not detected in the controls of these children. No particularity was present in their familial stories. ECG, Echocardiography, 24 hour holter ECG and exercise test were detected as normal. The patients considered to have neurological problems were transferred to pediatric neurology department. Suggestions were provided for the children considered to have vasovagal syncope and they were followed up. For pediatric ECG evaluation, the results of the study of Davignon et al. [21] covering 2141 Caucasian children at 333 Hz sampling speed in 1980 are commonly used as standard value ranges. Later, Macfarlane et al. [22] presented normal values within the scope of their studies with devices with a sampling rate of 500 Hz while Rijnbeek et al. [8] presented those with the sam-

pling rate of 1200 Hz. Due to the high frequency ECG values of sampling rate in young children, American Heart Association (AHA) recommends devices with a minimum sampling rate of 500 Hz. A device with a sampling rate of 1000 Hz samples/sec was used in our study.

Heart rate

The data of our study showed the decrease in mean heart rate with increasing age as in the studies by Semizel et al. [2], Rijnbeek et al. [10] Lue et al. [22], Yoshinaga et al. [23] and Kolawole et al. [24]. On the other hand, median heart rate was found higher in our study (Graphic-1). Heart rate decreasing with age was lower in females compared to males. This condition may be related to the more excited character of the females in older age group compared to the males during ECG. Values similar to adult heart rate were detected in adolescence with increasing age.

PR interval

As in the studies by Rijnbeek et al. [10], Semizel et al. [2], Lue et al. [22], Yoshinaga et al. [23], Olgun et al. [4], Kolawole et al. [24] and Uygur et al. [3], PR interval increases with age. Although PR interval was detected higher in females compared to males in 13-18 age group (adolescence), no statistical difference was found. ($p<0.005$) PR interval was found higher than the studies by Olgun et al. [4], Semizel et al. [2] and Rijnbeek et al. [10] and lower than the study by Lue et al. [22] in our study.

QRS time

QRS time was detected to increase with increasing age in our study as other studies in literature. Mean QRS time of male participants was found higher than female participants in all age groups. Similar to the study by Olgun et al. [4], shorter QRS times compared to the studies by Semizel et al. [2], Rijnbeek et al. [10], Lue et al. [22], Uygur et al. [3] were detected in all three age groups in our study.

QT interval

QT distance was detected as 340 ms in males and as 336 ms in females aged 6-9 while mean QT distance in the age range of 9-13 was detected as 348 ms in males and 346 ms in females and mean QT distance between in the age range of 13-18 was detected as 357 ms in males and as 358 ms in females in our study. Our study supports the study by Lue et al. [22].

QTc interval

QTc value is expected to be lower than 440 ms in 1-15 age range [25]. While 98 percentile value (upper value) of QTc calculation made with Bazzet formula was expected to be 440 ms, this limit was found as 450 ms in the studies by Rijnbeek et al. [10] and Semizel et al. [2] and QTc interval was detected as 433 ms in female and male participants in our study as in the study by Uygur et al [3].

QRS axis

Mean QRS axis was detected as 62° in our study. Mean QRS axis was detected as 58° by Semizel et al. [8], as 67° by Lue et al. [22], 58° by Rijnbeek et al. [10] and 56° by Uygur et al. [3] A significant difference was not found when this result of our study was compared to other studies in literature ($p<0.05$).

P axis

Mean P axis was found 49° in our study. Mean P axis was detected as 42° by Rijnbeek et al. [10] 42° by Lue et al. [22], 47° by Semizel et al. [2] and 47° by Uygur et al. [3] A significant difference was not found when the result of our study was compared to other studies in literature ($p<0.05$).

T axis

Mean T axis was found 44° in our study. Mean T axis was detected as 37° by Lue et al. [22], 40° by Semizel et al. [2] and 39° by Uygur et al. [3] A significant difference was not found when this result was compared to other studies in literature ($p<0.05$).

R/S ratio

R/S ratio was examined in V1, V2 and V6 derivations in our study. Similar results were acquired when R/S ratio in these three derivations was compared to the results of other studies. R/S ratio decreased with age in right precordial derivations (V1, V2) and in V6.

Adolescence and gender

Many previous studies investigated the effect of age and gender on electrocardiogram and Q, R and S wave amplitudes were detected at higher values in males compared to females especially after puberty. Rijnbeek et al. [10] detected changes in ECG values following mastectomy in the study of La Monte and Freiman [26] and claimed that breast development could also be a factor in Q, R and S wave amplitudes in male and female adolescents.

Considering this effect of breast tissue, Kligfield et al. [27] suggested to place precordial electrodes below breast tissue in adolescents. Considering this suggestion, chest electrodes were located under breast tissue while taking ECGs of female adolescents in our study. However, Q, R and S wave amplitudes of male patients in puberty were found to be higher than the female patients. It was considered that the breast tissue is not the only cause of the difference between the genders in this age group and other factors could also have a role here. ECG use may provide the detection of major and minor ECG anomalies in asymptomatic individuals in epidemiological researches. Prevalence of cardiac conduction disorders was screened in addition to the detection of ECG normal values in our study. Incomplete right branch block rate was reported as 0.705% in children by Niwa et al. [1] while incomplete right branch block prevalence was reported as 2.94% in children by Yamakawa et al. [28]. Migliore et al. [29] found the incomplete right branch block prevalence as 0.5% in their study with 2765 participants in the age range of 8-18. Lue et

al. [22] detected right branch block prevalence as 0.32% in their study with 432166 cases in the age range of 6-20. Pelliccia et al. [30] found right branch block prevalence as 1% in their study with 32652 adolescents and young people. Incomplete right branch block prevalence was found 0.09% in our study. This result is similar to the result of the study by Lue et al [22]. 1st degree AV block prevalence was reported as 0.2% in the study by Migliore et al [29], as 0.097% in children in the study by Niwa et al [1] and as 0.04% in the study by Lue et al. [22] 1st degree AV block prevalence was detected as 0.23% in our study. This result supports the study by Migliore et al. [29]. Ventricular extra systole (VES) prevalence in children was reported as 0.11% in the study by Lue at al. [22], as 0.5% by Niwa et al. [1], as 0.2 by Migliore et al. [29] and 0.42 by Olgun et al. [5] VES prevalence was found as 0.09% in our study. This result supports the study by Lue et al. [22]. This result supports the study by Chiu et al. Wolf Parkinson White (WPW) syndrome is a syndrome in which short PR range and delta wave are observed on ECG and also which may cause paroxysmal supraventricular tachycardias Sudden death may also occur rarely. It is the most common tachycardia cause in childhood and adolescence. WPW prevalence in elementary school children was detected as 0.13% by Niwa et al. [1], as 0.08% by Olgun et al. [5] and as 0.2% by Migliore et al. [29] Any data to make us consider WPW syndrome was not seen on the ECGs examined in our study. Relatively small population screened was considered to have a role in this result.

Conclusion

As a result, our study provided a great contribution to literature to detect normal ECG values and percentiles in children and to determine the prevalence of rhythm problems in this age group. Normal ECG values can be achieved in school children by reaching higher numbers with ECG screening projects similar to our study. Protective and treating measures can also be taken through the early detection on structural and electrical pathologies which may cause significant morbidity and sometimes mortality.

Ethics approval

This study was approved by İnönü University Health Sciences Non-Invasive Clinical Research Ethics Committee (reference: 21.11.2017/25-9).

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