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Does the electrocardiogram grow with an adolescent?: a 3-year follow-up study

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ORIGINAL ARTICLE / PRACA ORYGINALNA

Does the electrocardiogram grow with an adolescent?: a 3-year follow-up study

Czy wraz z nastolatkiem rośnie jego elektrokardiogram?

— badanie na podstawie 3-letniej obserwacji

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Abstract

Introduction. Human heart's growth and development are followed by gradual changes on the electrocardiogram. The study was conducted to analyse changes in the resting electrocardiogram of 10-year-olds in relation to their somatic growth.

Material and methods. 120 students (62 male) aged 10.8 (± 0.49) years were examined. The study consisted of a resting electrocardiogram and anthropometric measurements repeated in a 3-year interval. Statistical analysis of changes in electrocardiographic parameters (PR, QRS, QTc, QRS axis, wave amplitudes) and corresponding changes in height, weight, and body mass index (BMI) was conducted.

Results. Through time, a substantial elongation of PR ($p < 0.001$), ORS ($p < 0.001$), and QT ($p < 0.001$) lengths was observed while the QRS axis and corrected QT time remained stable ($p = 0.320$ and 0.857 respectively). In girls PR elongation correlated with an increase in BMI ($r = 0.33$). Right axis deviation corresponded with height gain in boys ($r = 0.45$). R and S amplitudes in limb leads did not change significantly except for lead I. There was a considerable decline in R and S wave voltages in precordial leads in adolescent girls that corresponded with weight and BMI increase. In boys, the increase in BMI was related to greater R waves in left precordial leads.

Conclusions. Adolescent growth has an influence on some electrocardiographic variables. There are significant differences between boys' and girls' electrocardiograms regarding QRS amplitudes.
Key words: child development, adolescent, cardiology, physiology

Introduction

Human growth and development are two inseparable processes on the way towards adulthood. Despite being commonly associated with the musculoskeletal system, they take place simultaneously in all parts of the body, including the circulatory system. As the body grows, the left ventricular mass (LVM) increases to provide satisfactory cardiac output with lower resting heart rate (HR). As a consequence, important changes on the electrocardiogram (ECG) appear, including elongation of the mean RR interval and all its components (PR, QRS, QT) in various proportions, gradual left heart axis deviation, and changes in wave amplitudes.

A human's individual growth curve is not linear in nature. Its shape in the first years of life is strongly dependent on genetic and environmental factors that can change it significantly [1]. The majority of pubescent children experience a growth spurt, which is a phase of intense somatic metamorphosis and subsequent physiological adaptations triggered by a rapid increase in GnRH secretion [2]. Both sexes undergo a series of transitions in a specific order. The intense growth phase in males begins approximately 2 years later than in females, is usually longer, and brings greater effects. The human heart's growth has also been proven to be sex-dependent [3] as well as related to fat-free body mass [4]. These observations, however, have not been attributed to variations in ECG. Similarly to many other diagnostic tools, paediatric ECG has its age-dependent reference values [5, 6], however, wide normal ranges of the parameters are a source of doubt for health practitioners assessing the lengths and durations of distinct waveforms. This study was conducted to investigate the effect of growth on individual changes in resting ECG of healthy adolescents in 3-year observation.

Methods

The study was conducted as a part of a yearly program SOPKARD-Junior [7], which is aimed at the primary prevention of non-communicable diseases. It was originally addressed to 5th grade students (10–11 years of age) in September 2016 and repeated after 3 years, in September 2019. The program included all children studying in the town of Sopot (about 36

000 inhabitants) provided that written consent was given by their parents. In September 2016 164 students participated in the program, 131 of which were present again during the second edition (79.9%). 120 students with correct ECG recordings obtained in both editions were included in the study. We excluded 11 participants: 6 participants for heart rhythm disturbances on one of the recordings and 5 for school absence on the day of examination. None of the subjects had signs of a substantial heart defect or cardiomyopathy on transthoracic echocardiography. On the examination day the students' height and weight were measured and standard 12-lead, 10-second electrocardiograms were recorded. We used the Mortara Eli 280 instrument at the chart speed of 25 mm/s and the standard calibration of 10 mm/mV. All tests for each year were performed by one physician. The technical quality of each recording was assessed straight away. In case it was not satisfactory, the ECG was repeated. All files were converted to digital format. Measurements of heart rate, PR, QRS, and QT were taken automatically and visually checked. In case the automatically taken measurement differed by ≥ 20 ms from the manually taken, it was replaced. Subsequently, R and S wave amplitudes were measured in each lead after magnifying the image by 200%. We used a digital measuring tool from Adobe Acrobat Reader DC software. The peak wave amplitude and the isoelectric line were indicated manually by the same investigator. For the R and S amplitudes, we took the mean of the two corresponding measurements (from the 1st and the 2nd QRS complex). The study conception was approved by the local Independent Bioethics Committee for Scientific Research.

A statistical comparison of each electrocardiographic variable was performed as follows:

— for males and females in the 2016 study;

— for males and females in the 2019 study;

— for corresponding scores in both electrocardiograms (2016 and 2019).

Finally, the analysis of correlations between changes in anthropometric parameters [height, weight, body mass index (BMI)] and changes in electrocardiographic variables throughout the follow-up period was performed.

The statistical analysis was made in TIBCO Software Inc. (2017). Statistica, version 13. We used the Shapiro-Wilk test to determine the normal distribution of data. Because most of the variables were not normally distributed, the Mann-Whitney *U* test was used for comparative analysis of groups, and the Wilcoxon test was used for dependent samples. Spearman coefficients were calculated as determinants of correlations between variables.

Results

A total of 120 adolescents were examined, 62 (51.6%) of which were male. The mean age was 10.8 (0.49) years in 2016 and 13.8 (0.49) years in 2019 and was the same for both sexes. Average values of height, weight, and BMI were presented in Table 1. Height gain in 3-year time was greater in boys' respect for girls ($p < 0.001$).

Table 1. The main characteristics of the study population during the two visits. The data were presented as mean (SD)

	Total		Boys		Girls	
	2016	2019	2016	2019	2016	2019
Age [years]	10.8 (0.49)	13.8 (0.49)	10.8 (0.49)	13.8 (0.49)	10.8 (0.49)	13.7 (0.50)
Height [cm]	147.9 (8.0)	165.9 (8.7)*	148.1 (8.2)	168.3 (9.9)	147.6 (7.9)	163.5(6.4)
Weight [kg]	39.7 (9.8)	56.4 (12.3)	40.0 (10.2)	57.5 (13.7)	39.4 (9.5)	55.2 (10.5)
BMI [kg/m^2]	18.0 (3.1)	20.4 (3.5)	18.0 (8.0)	20.2 (8.0)	17.9 (3.0)	20.6 (3.3)
HR [bpm]	81 (12.5)	74 (11.7)	79 (11.0)	76 (13.0)	84 (13.6)	72 (9.9)
SBP [mm Hg]	109 (8.9)	115 (9.1)	108 (8.8)	116 (8.3)	110 (9.1)	114 (9.8)
DBP [mm Hg]	65 (7.4)*	67 (7.9)	64 (7.2)	67 (8.4)	66 (7.5)	66 (7.4)

*A significant difference between boys and girls; BMI — body mass index; DBP — diastolic blood pressure; HR — heart rate; SBP — systolic blood pressure; SD — standard deviation

For each of the ECG variables, at least 94% of the scores were within the 2–98 percentile range in accordance with Rijnbeek's tables. There were no significant differences between sexes in terms of the PR interval, QRS axis, QRS duration, QT, and QTc time neither in 2016, nor 2019 ($p > 0.05$). The PR ($p < 0.001$), QRS ($p < 0.001$) and QT ($p < 0.001$) durations changed significantly in three years time, while the QRS axis and QTc remained stable ($p = 0.320$ and 0.857 respectively). There were high positive correlation ratios between PR ($r = 0.76$), QRS duration ($r = 0.78$), and QRS axis ($r = 0.90$) measured in the 3-year interval. Correlations between QT and QTc measurements at the two visits were also statistically significant however of lower strength ($r = 0.52$ and $r = 0.54$ respectively) (Table 2).

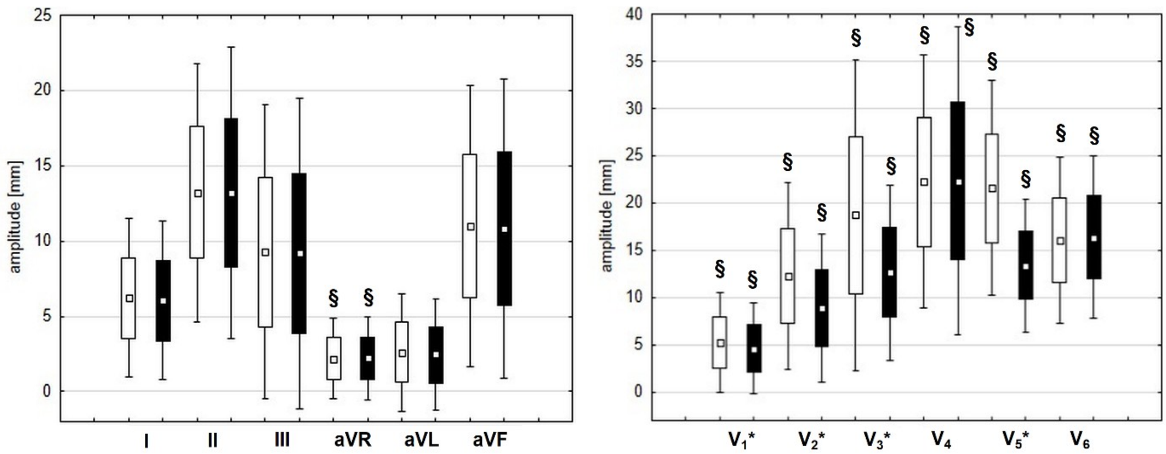
Table 2. Interval measurements were taken at both visits

Variable	2016 M (SD)	2019 M (SD)	R-value
PR [ms]*	134 (16.2)	141 (17.7)	0.76
QRS [ms]*	87 (9.0)	93 (8.6)	0.78
QRS [ms]*	87 (9.0)	93 (8.6)	0.78

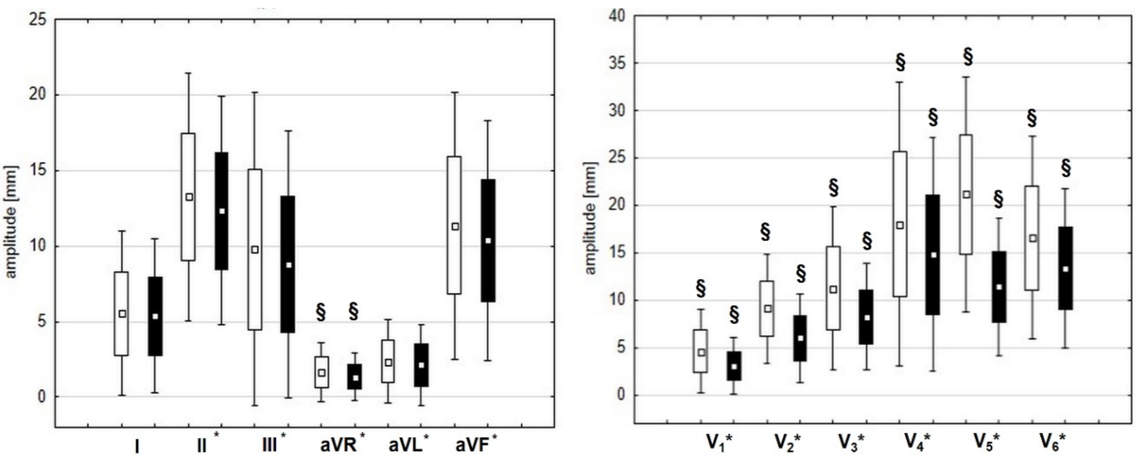
QRS [ms]*	87 (9.0)	93 (8.6)	0.78
QT [ms]*	354 (22.8)	370 (25.9)	0.52
QTc [ms]	410 (22.0)	409 (22.0)	0.54

*A substantial difference between the 2016 and 2019 measurements ($p < 0.05$); r — the Spearman correlation coefficient for both measurements

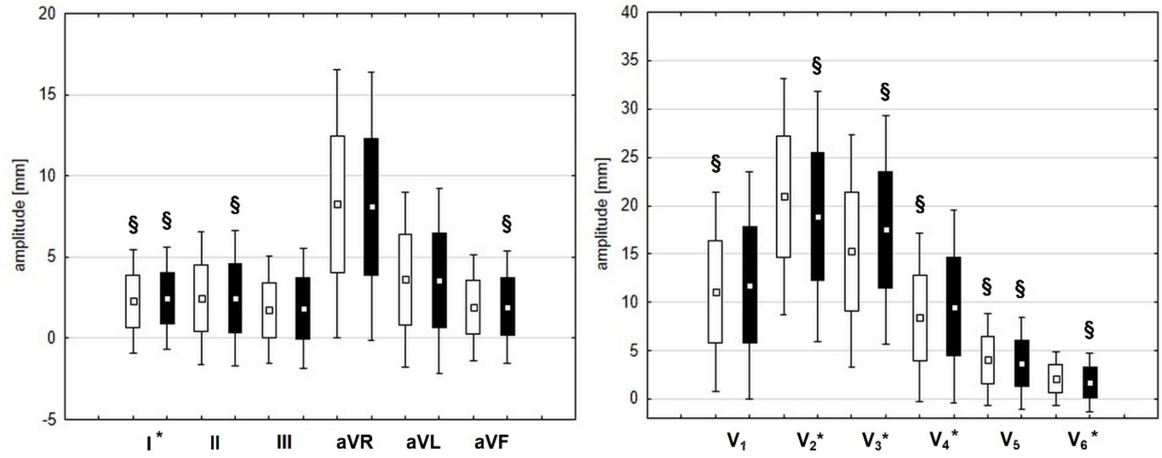
In contrast to interval lengths, the QRS morphology was sex-dependent (Figure 1). At both visits, the R voltages in lead aVR and precordial leads were significantly greater in boys' ECGs. There was a significant decline in R voltages through the follow-up period, regarding all leads except lead I in girls and some of the precordial leads in boys. As for the S waves, their amplitudes decreased in girls' ECGs in all leads except lead I, whereas, in boys a decline in leads V1 and V6 and an increase in lead I, V3 and V4 were observed. Substantial correlations between measurements taken in 2016 and 2019 were reported for both sexes.



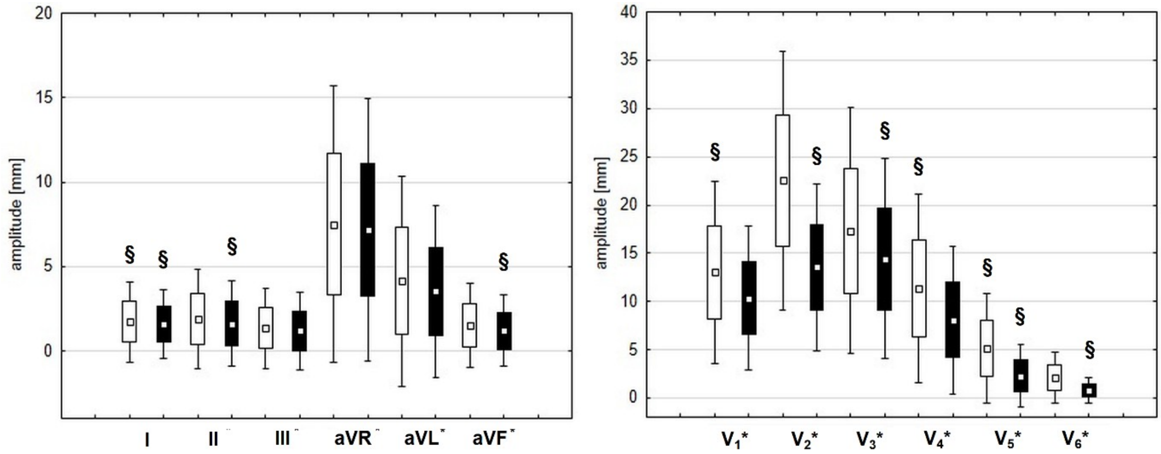
A.



B.



C.



D.

Figure 1. Box-plots illustrating R and S wave amplitudes in distinct leads for boys and girls separately; **A.** R waves — boys; **B.** R waves — girls; **C.** S waves — boys; **D.** S waves — girls; White bars represent the measurements from 2016 and the black ones — from 2019. *Substantial difference between 2016 and 2019 measurements; §Substantial difference between boys and girls in terms of a distinct variable

No significant correlations between changes in height and interval lengths were observed. Heart rate both in 2016 and 2019 was independent of anthropometric parameters. The same referred to heart rate change in relation to somatic growth. Neither PR and QRS lengths nor their changes in 3 years were related to students' somatic growth. In male students, we observed a moderate positive correlation (r = 0.45) of QRS axis deviation towards the right with height change (Figure 2). QT elongation in boys corresponded negatively with BMI increase, but the coefficient was low (r = –0.26). No significant correlations were observed after QT correction (QTc).

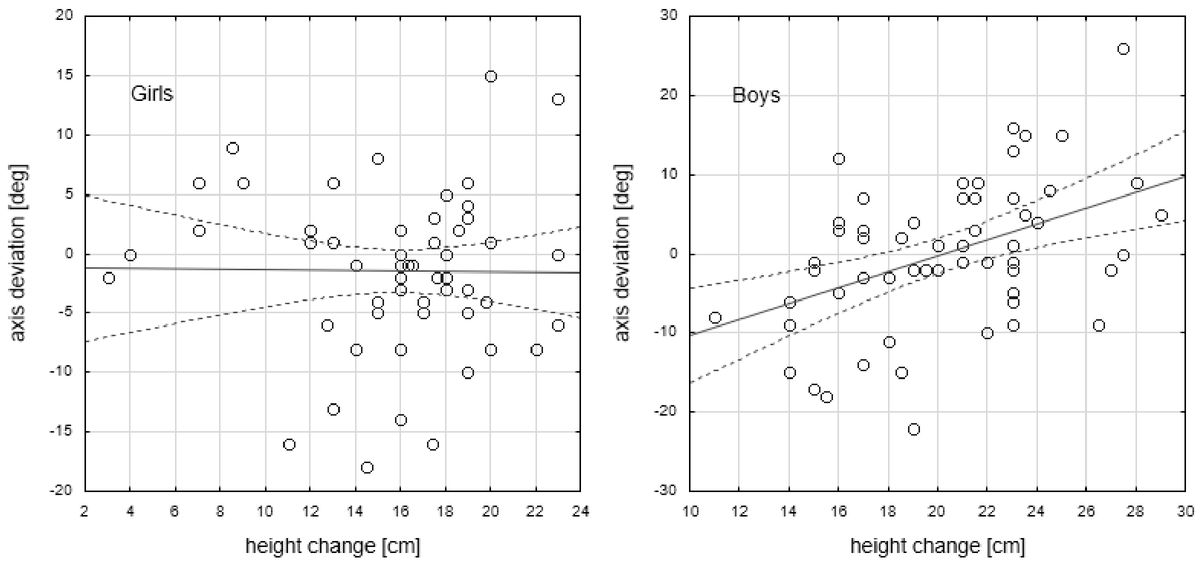


Figure 2. A scatter chart showing the relationship between the change of the QRS axis and height. A positive correlation (r = 0.45) is only present in boys

The analysis of correlations between wave amplitudes and indices of somatic growth revealed important discrepancies between sexes (Table 3). In boys, height gain had no substantial impact on R and S voltages, while weight gain correlated with higher R (r = 0.27) and S (r = 0.47) voltages in lead I, and higher R voltages in lead V_6 (r = 0.31). Similarly, increase in BMI during the follow-up period was associated with an increase in R amplitudes in lead I (r = 0.36) and V_6 (r = 0.38), as well as S amplitudes in lead I (r = 0.38) and aVR (r = 0.40). In girls, height gain correlated with a decline in S amplitudes in lead I (r = 0.35) and aVR (r = 0.32), while an increase in BMI was associated with R voltage gain in lead I (r = 0.28).

Table 3. The Spearman distribution of R and S amplitudes in relation to height, weight, and BMI for boys and girls separately. Significant correlation ratios were marked in bold

	Boys						**Girls**					
	R waves			**S waves**			**R waves**			**S waves**		
	Height	Weight	BMI	Height	Weight	BMI	Height	Weight	BMI	Height	Weight	BMI
I	–0.15	**0.27**	**0.37**	0.03	**0.47**	**0.51**	0.08	0.26	**0.28**	**0.35**	0.07	0.00
II	0.06	0.21	0.23	–0.10	–0.03	0.00	0.23	0.11	0.06	–0.08	–0.16	–0.1

												3
III	0.21	0.07	–0.01	0.12	–0.18	–0.19	0.13	–0.11	–0.13	–0.07	–0.02	–0.02
aVR	0.04	0.16	0.12	-0.21	0.17	**0.40**	0.08	–0.06	–0.07	**0.32**	0.17	0.10
aVL	–0.16	0.10	0.20	0.22	0.11	0.18	0.11	0.00	0.05	–0.07	–0.25	–0.18
aVF	0.13	0.14	0.10	0.07	–0.21	–0.24	0.15	0.02	–0.01	0.00	0.04	–0.04
V_1	–0.05	–0.14	–0.18	0.04	–0.09	–0.14	–0.23	–0.11	0.03	–0.07	–0.14	–0.09
V_2	–0.10	–0.09	–0.08	0.10	0.04	0.10	–0.20	**–0.46**	**–0.41**	–0.11	**–0.31**	**–0.30**
V_3	–0.24	–0.21	–0.19	0.19	0.09	0.10	**–0.30**	**–0.28**	–0.20	–0.04	**–0.29**	**–0.33**
V_4	–0.09	–0.05	–0.02	0.21	0.12	0.12	**–0.36**	**–0.28**	–0.18	0.03	**–0.35**	**–0.46**
V_5	0.04	0.23	0.25	0.16	0.10	0.12	**–0.31**	0.09	0.21	0.17	**–0.30**	**–0.39**
V_6	0.24	**0.31**	**0.38**	0.00	0.08	0.16	–0.07	0.11	0.13	0.17	**–0.34**	**–0.3**

BMI — body mass index

Importantly, in girls, there were negative correlations between indices of growth and changes in wave amplitudes regarding leads V_2–V_6. The Spearman coefficients for the aforementioned analysis were collected in Table 3.

Discussion

The study proved that the physiological elongation of ECG intervals is independent from height, weight, and BMI change in early adolescents. Additionally, it showed that there is no significant difference between adolescent boys' and girls' ECGs in terms of PQ, QRS, and QT durations. An interesting part of the analysis is the observations regarding R and S wave amplitudes. Not only were they higher in boys' respect for girls, but also the decline in R and S voltages correlated with somatic growth in pubescent girls. This finding is probably due to breast development in the female subject throughout the follow-up period.

Our results are consistent with previous studies where a significant sex-dependent variation of interval lengths was not observed [5, 8–11]. In Rijnbeek's study [6] the QRS duration was longer in adolescent boys than in girls, with median values and upper limits (98 pc) differing by 3–5 ms. In our study a similar difference regarding the mean values was not statistically significant, which might be the result of a smaller sample number. As for the QTc, upper limits are higher for adolescent girls by about 10 ms [6, 8, 10], however, the differences reported in cross-sectional studies are not always remarkable. A significant difference in QTc in children aged 13–18 was observed by Lue [8], in contrast to Rijnbeek's study [6]. We did not detect a significant change in QTc over time, which is consistent with previous reports.

Even though, electrocardiography has a limited role in screening for structural heart disease, high QRS amplitudes in precordial leads are commonly being associated with ventricular hypertrophy. Noticeably, left ventricular mass (LVM) is not the only predictor of R and S voltage; other factors include the heart's distance from the chest wall [12], the composition of tissues surrounding the heart, and their inhomogeneities [13–15]. Importantly, an increase in LVM in children was proven to be confluent with somatic growth and related to sex, aerobic fitness, and family history of cardiovascular disease [3, 4]. Thus, in a healthy population, boys have greater LVM at any age and undergo an additional considerable increase during adolescence, while in females LVM increases more steadily [16]. Normal values of R and S wave amplitudes are, therefore, sex-dependent [6, 8, 10], which was additionally confirmed in our study. The discrepancy in R waves in left precordial leads was observed by Rijnbeek [6] from the 1st month of life onwards, and appeared in the other leads in early adolescence, while Lue [8] reported significant differences between males and females starting from the age of 9. Similarly, in our study R waves in boys and girls differed significantly at both visits. Apart from greater LMV increase in boys, the difference may be attributed to breast development, which normally takes place at the age of 10–14. These two phenomena can explain opposite coefficient signs in correlations (positive in boys, negative in girls) between changes of wave amplitudes in precordial leads and an increase in BMI and weight.

To our knowledge, height gain has not been evaluated in terms of electrocardiographic variables in previous studies. In the present analysis, height was not an independent predictor for any of the analyzed parameters except for QRS axis in boys. Right axis deviation following a rapid growth can be explained by the vertical orientation of the heart in the elongated chest. Noticeably, in girls, whose growth is more steady, such a relationship did not occur. A low degree of correlation of height gain with some of the R and S waves was secondary to a positive relationship between changes in height and weight throughout the observation period.

Another factor declared to influence the shape of the electrocardiogram is body stature. In our study population the change in body weight and BMI was not only due to linear growth but in some cases a sign of developing obesity. In fact, 10 students (6 boys and 4 girls), were placed above the 95th percentile for BMI at the age of 14 with 8 of them not being obese 3 years before. The effect of excess weight on ECG was discussed in several studies regarding both adults [17, 18] and children [11, 19]. Simple obesity is not related to pathological left axis deviation as is commonly thought but to low QRS voltage [17]. Additionally, in their cross-sectional study on obese and normal-weight adolescents, Sun and colleagues observed positive correlations of the PR interval and QRS duration with BMI [19]. The effect of obesity on QTc prolongation is debatable [20, 21]. As in the case of Sun's study [19], we observed no relationship between BMI increase and QT.

Our study has some limitations. First of all, we used different precordial electrodes than the authors of ECG percentile charts. We found the standard V_1–V_6 set more appropriate for our study population than the one including V_{3R} and V_7 electrodes instead of V_5. Secondly, QRS amplitudes measurements in the present study were not made from, so-called, mean beats, applied by previous researchers. Even though the method differed, our measurements did not diverge substantially from Rijnbeek's normal limits [6]. Additionally, the use of nonparametric statistics might have limited accuracy of our estimations. Finally, we did not take daily physical activity into consideration in our analysis regarding QRS voltage, which might be subject to further evaluation. Repetition of the analysis in another 3 years' time could also give better insight into the subject.

In conclusion, sex and body stature are considerable determinants of electrocardiographic variables in early adolescents, predominantly regarding QRS amplitudes. We suggest using sex-dependent reference values for ECG evaluation in this group. In paediatric patients with no underlying heart defect, the process of their somatic growth should be taken into consideration when interpreting an ECG.

Conflict of interest

The authors have stated that there are no conflicts of interest in connection with this article.

Written informed consent was obtained from legal guardians of the study participants.

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Streszczenie

Wstęp. W wyniku wzrastania i dojrzewania dzieci obserwuje się u nich postępujące zmiany w elektrokardiogramie (EKG). Celem badania była ocena zmian w spoczynkowym EKG u 10-latków oraz ich zależności od tempa wzrostu somatycznego.

Materiał i metody. W grupie 120 uczniów (62 chłopców) w wieku 10,8 (± 0,49) lat wykonano spoczynkowe EKG oraz pomiary antropometryczne w odstępie 3 lat. Przeprowadzono analizę statystyczną zmian parametrów elektrokardiograficznych (PR, QRS, QTc, oś zespołów QRS, amplitudy załamków) w zależności od zmiany wzrostu, masy ciała i wskaźnika masy ciała (BMI) badanych.

Wyniki. W czasie obserwacji zaobserwowano istotne statystycznie wydłużenie PR (p < 0,001), ORS (p < 0,001) i QT (p < 0,001) bez istotnych zmian osi zespołów QRS i QTc (odpowiednio: p = 0,320 i 0,857). Wydłużenie odstępu PR u dziewcząt korelowało ze wzrostem BMI (r = 0,33), natomiast u chłopców odchylenie osi QRS w prawo korelowało z przyrostem wysokości ciała. Woltaże załamków R i S w odprowadzeniach kończynowych z wyłączeniem I nie zmieniły się istotnie w czasie obserwacji. W odprowadzeniach

przedsercowych zaobserwowano spadek woltaży załamków, który u dziewcząt korelował z przyrostem masy ciała i BMI. U chłopców wzrost woltaży załamków R i S w odprowadzeniach przedsercowych lewokomorowych korelował z przyrostem BMI.

Wnioski. Proces wzrastania nastolatków ma wpływ na niektóre parametry elektrokardiograficzne. Elektrokardiogramy chłopców i dziewcząt różnią się głównie pod względem amplitud zespołów QRS.

Słowa kluczowe: dorastanie, nastolatek, kardiologia, fizjologia

References

1. Ulijaszek SJ. The international growth standard for children and adolescents project: environmental influences on preadolescent and adolescent growth in weight and height. Food Nutr Bull. 2006; 27(4 Suppl Growth Standard): S279–S294, doi: 10.1177/15648265060274S510, indexed in Pubmed: 17361663.
2. Bogin B, Varea C, Hermanussen M, et al. Human life course biology: A centennial perspective of scholarship on the human pattern of physical growth and its place in human biocultural evolution. Am J Phys Anthropol. 2018; 165(4): 834–854, doi: 10.1002/ajpa.23357, indexed in Pubmed: 29574837.
3. Schieken RM, Schwartz PF, Goble MM. Tracking of left ventricular mass in children: race and sex comparisons: the MCV Twin Study. Medical College of Virginia. Circulation. 1998; 97(19): 1901–1906, doi: 10.1161/01.cir.97.19.1901, indexed in Pubmed: 9609082.
4. Janz KF, Dawson JD, Mahoney LT. Predicting heart growth during puberty: The Muscatine Study. Pediatrics. 2000; 105(5): E63, doi: 10.1542/peds.105.5.e63, indexed in Pubmed: 10799627.
5. Davignon A, Rautaharju P, Boisselle E, et al. Normal ECG standards for infants and children. Pediatric Cardiology. 1980; 1(2): 123–131, doi: 10.1007/bf02083144.
6. Rijnbeek PR, Witsenburg M, Schrama E, et al. New normal limits for the paediatric electrocardiogram. Eur Heart J. 2001; 22(8): 702–711, doi: 10.1053/euhj.2000.2399, indexed in Pubmed: 11286528.
7. Suligowska K, Czarniak P, Krawczyk M, et al. An assessment of health status and health behaviours in adolescents: main points and methods of the SOPKARD-Junior programme. Arch Med Sci. 2018; 14(1): 38–51, doi: 10.5114/aoms.2016.63742, indexed in Pubmed: 29379531.

8. Lue HC, Wu MH, Wang JK, et al. Study on ECG in the Adolescent. Pediatr Cardiol. 2018; 39(5): 911–923, doi: 10.1007/s00246-018-1841-8, indexed in Pubmed: 29556784.
9. Dickinson DF. The normal ECG in childhood and adolescence. Heart. 2005; 91(12): 1626–1630, doi: 10.1136/hrt.2004.057307, indexed in Pubmed: 16287757.
10. Semizel E, Oztürk B, Bostan OM, et al. The effect of age and gender on the electrocardiogram in children. Cardiol Young. 2008; 18(1): 26–40, doi: 10.1017/S1047951107001722, indexed in Pubmed: 18093359.
11. Paech C, Anhalt M, Gebauer RA, et al. New normal limits for pediatric ECG in childhood obesity? Influence of childhood obesity on the ECG. Prog Pediatr Cardiol. 2018; 48: 119–123, doi: 10.1016/j.ppedcard.2017.11.002.
12. Hedman K, Patti A, Moneghetti KJ, et al. Impact of the distance from the chest wall to the heart on surface ECG voltage in athletes. BMJ Open Sport Exerc Med. 2020; 6(1): e000696, doi: 10.1136/bmjsem-2019-000696, indexed in Pubmed: 32201618.
13. LaMonte CS, Freiman AH. The electrocardiogram after mastectomy. Circulation. 1965; 32(5): 746–754, doi: 10.1161/01.cir.32.5.746, indexed in Pubmed: 5846397.
14. Kligfield P, Gettes L, Bailey J, et al. Recommendations for the standardization and interpretation of the electrocardiogram. J Am Coll Cardiol. 2007; 49(10): 1109–1127, doi: 10.1016/j.jacc.2007.01.024, indexed in Pubmed: 17349896.
15. Rautaharju PM, Park L, Rautaharju FS, et al. A standardized procedure for locating and documenting ECG chest electrode positions: consideration of the effect of breast tissue on ECG amplitudes in women. J Electrocardiol. 1998; 31(1): 17–29, doi: 10.1016/s0022-0736(98)90003-6, indexed in Pubmed: 9533374.
16. Cain PA, Ahl R, Hedstrom E, et al. Physiological determinants of the variation in left ventricular mass from early adolescence to late adulthood in healthy subjects. Clin Physiol Funct Imaging. 2005; 25(6): 332–339, doi: 10.1111/j.1475-097X.2005.00632.x, indexed in Pubmed: 16268984.
17. Fraley MA, Birchem JA, Senkottaiyan N, et al. Obesity and the electrocardiogram. Obes Rev. 2005; 6(4): 275–281, doi: 10.1111/j.1467-789X.2005.00199.x, indexed in Pubmed: 16246213.
18. Bacharova L, Nikolopoulos N, Zamanis I, et al. A different effect of obesity on ECG in premenopausal and postmenopausal women. J Electrocardiol. 2018; 51(6): 1085–1089, doi: 10.1016/j.jelectrocard.2018.09.013, indexed in Pubmed: 30497735.

19. Sun GZ, Li Y, Zhou XH, et al. Association between obesity and ECG variables in children and adolescents: A cross-sectional study. Exp Ther Med. 2013; 6(6): 1455–1462, doi: 10.3892/etm.2013.1337, indexed in Pubmed: 24255675.
20. Fukushige T, Yoshinaga M, Shimago A, et al. Effect of age and overweight on the QT interval and the prevalence of long QT syndrome in children. Am J Cardiol. 2002; 89(4): 395–398, doi: 10.1016/s0002-9149(01)02259-7, indexed in Pubmed: 11835918.
21. Güven A, Özgen T, Güngör O, et al. Association between the corrected QT interval and carotid artery intima-media thickness in obese children. J Clin Res Pediatr Endocrinol. 2010; 2(1): 21–27, doi: 10.4274/jcrpe.v2i1.21, indexed in Pubmed: 21274332.