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Sex- and Age-Related Differences in Electrocardiographic Parameters of Healthy Black Adolescents in Ido/ Osi Local Government Area, Ekiti State, Nigeria

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Abstract

Background: Age, sex and racial factors may influence the variations in electrocardiographic (ECG) values in children.

Objective: To describe the sex and age-related differences in ECG variables of apparently healthy black adolescents.

Methods: This cross-sectional study involved 1,194 participants aged 10 to 19 years from selected secondary schools in the Ido-Osi LGA of Ekiti State, Nigeria. A standard resting 12-lead ECG was recorded with the Zoncare ZQ 1203-G ECG machine and interpreted manually. The differences in mean values of ECG variables between males and females were analysed.

Results: The subjects comprised 530 (48.8%) males and 664 (55.6%) females. The overall mean (SD) age was 14.3 ±2.0 with no significant difference in the mean age or frequency of the two sexes. The mean ECG heart rate and QTc were significantly higher in females than in males ($p < 0.001$ and $p = 0.002$, respectively). The amplitudes of P, Q, R, S, and T waves ($p <0.001$) and the sum of S waves in right precordial leads (RPL) and R waves in left precordial leads (LPL) were also higher in males than in females ($p < 0.001$). The occurrence of sinus tachycardia, notched R and S waves and persistent juvenile T wave pattern was more frequent in females, while J point elevation, J waves and q waves occurred more in males.

Conclusion: Sex - and age - related differences exist in ECG variables of black adolescents. The use of sex - and age - specific reference standards for the interpretation of ECG in black adolescents should be considered.

Keywords:* *Adolescence, Cardiac rhythm, Heart rate, Nigeria, T wave, QRS duration.

Introduction

The electrocardiogram (ECG) is a widely used diagnostic tool in clinical practice, and its interpretation is best done in context. Age, sex, and race influence variations in electrocardiographic values and abnormalities. [1-3] The basic principles of interpretation of the ECG in children are similar to those in adults. Still, the anatomic and physiologic changes which occur progressively between birth and adolescence result in some differences from the normal adult pattern and vary with age. [4, 5] Progressive modifications in QRS duration, QRS voltages, T-wave orientation, and conduction intervals have been documented, with individual variability in the pace and degree of these changes. Studies have reported increases in PR, QRS, and QT intervals with age, and a notable trend towards decreased R amplitudes and increased S amplitudes in V2. [6-8]

From birth to early adulthood, the ECG features undergo changes reflecting cardiac growth and maturation. The cardiac axis slowly shifts as the left ventricle grows and begins to dominate the right ventricle. The atria also grow and change orientation. As the left ventricle enlarges, its electrical contribution to the QRS complex predominates, leading to increased left-sided voltages and decreased right-sided voltages. Concurrently, QRS duration, PR interval, and P wave duration, all increase slowly because the electrical impulses take longer to transverse larger atria, ventricles and conduction pathways. Also, the changes in cardiac axes shift leftward with age due to the increasing ventricular mass and change in atrial orientation. [9, 10]

Adolescents are aged 10-19 years. [11, 12] During adolescence, young people undergo rapid changes in body structure and physiologic, psychologic, and social functioning. [11] Changes have been observed in the ECG during adolescence, and major differences have been noted between the ECGs of adolescents, other children, and adults. [13, 14] Studies have also shown that sex differences in various ECG parameters become apparent during adolescence. [15,16]

During the first decade of life, the quantitative ECG parameters in females and males are remarkably similar regarding resting heart rate, PR interval, QRS duration, QRS voltages, T wave amplitude, T axis, ST segment QRST – angle, QT interval and the frequency of normal U waves. [16] Beginning in adolescence, the resting heart rate is faster in females than males; the QT interval and the QTc interval become significantly longer in females than males due to acceleration of ventricular repolarisation by testosterone. QRS amplitude and QRS duration become larger in males than in females because of the effects of male hormones and the associated increase in cardiac mass and left ventricular wall thickness. QRS duration has been consistently longer in boys across all age groups. [6, 17 - 23]

Several studies have demonstrated sex-related differences in the ECGs of healthy subjects. Females were reported to have higher heart rates, shorter PR and QRS intervals, lower ECG voltages, longer QT intervals, more prevalent ST segment changes, and a higher frequency of sinus arrhythmia. Males often displayed early repolarisation patterns more frequently than females. [1, 13, 19 - 23]
Tabansi *et al.* [24] also reported significantly higher heart rate and QTc in adolescent females, higher QRS voltages, T wave amplitude, and R/S ratio in the precordial leads in males, but no differences in P wave duration, PR interval, and QRS duration between males and females in the Niger Delta region of Nigeria. In a study of children aged 5–15 years in Kano, Northern Nigeria, Aliyu and Ibrahim observed no difference in P-wave duration, higher heart rate in females, higher PR intervals, QRS voltages, T-wave amplitude, and QRS duration in males. Ogunlade [25] carefully analysed the patterns of ECG in male and female young adults, and features that could be used to delineate male and female

patterns were selected as criteria for the formulation of a simple scoring system called Ogunlade Sex Determination Electrocardiographic Score (OSDES). The scoring system was evaluated and found to have a reasonable degree of sensitivity and specificity of 95.99 per cent and 92.63 per cent for males and 92.63 per cent and 95.99 per cent for females. [26]

Recently, Siergersma *et al.* [27] accurately classified sex based on ECG features using deep neural networks (DNN). A DNN was trained to classify sex based on 131,673 normal ECGs and successfully distinguished female from male ECGs. The ventricular rate was the strongest mediating ECG variable in males, while the maximum amplitude of the ST segment was strongest in females. Compared to Caucasian and Asian adolescents, Black adolescents exhibit a higher prevalence of anterior T-wave inversions, early repolarisation patterns and higher precordial voltages, which are frequently benign and physiologic in this group but may be interpreted as pathological in other populations if ethnic-specific norms are not considered. [19, 20, 28-32] Caucasian adolescents tend to have fewer repolarisation variants and lower QRS voltages. In contrast, Asian adolescents have been reported to demonstrate shorter QT intervals and a lower incidence of early repolarisation patterns. [33, 34] Sex-related QT interval differences (longer in females than males) are consistent across ethnic groups but may present at different ages of onset. [22] Despite the widespread use of the electrocardiogram in clinical practice, its interpretation is reliant on reference standards derived largely from non-African populations. [29, 35] Given the known ethnic variations in ECG patterns, this creates a risk of inaccurate classifications of findings in this group.

Despite these observations, age and sex stratified normative data for healthy Black adolescents are limited, emphasising the need for this study to identify existing sex and age-related differences in ECG variables of black adolescents. The study aimed to identify and describe sex- and age-related differences in electrocardiographic parameters among healthy Nigerian adolescents. By characterising these variations, the study seeks to contribute to the development of population-specific ECG reference values for more accurate interpretation in clinical and screening settings.

Methods

Study design and setting

A descriptive, cross-sectional study was conducted among adolescents attending 12 public secondary schools in Ido-Osi LGA, Ekiti State, Southwest Nigeria, over a period of nine months, providing a representative sample of apparently healthy Black adolescents from diverse socio-economic backgrounds.

Ethical considerations

Approval to carry out this study was obtained from the Research and Ethics Committee of the Federal Teaching Hospital, Ido-Ekiti (ERC/2016/11/02/SBA) and the State Ministry of Education. Written informed consent was also obtained from parents/guardians and assent from adolescents.

Study participants

The participants were 1,194 apparently healthy adolescents aged 10–19 years, recruited from selected secondary schools. They were considered healthy based on medical history, physical examination, and absence of known cardiovascular or systemic diseases.

Inclusion criteria required participants to be of Black African descent, free of known cardiovascular or systemic illness, and not on medications that affect cardiac function.

Exclusion criteria included acute or chronic illness, use of medications with cardiovascular effects, musculoskeletal or chest wall deformities, signs and symptoms suggestive of cardiac disease, blood pressure >95th percentile for age, sex and height using the blood pressure tables in the Fourth Report on the Diagnosis, Evaluation, Treatment of High Blood Pressure in Children and Adolescents [36] and values greater than 120/80 mmHg for children older than 12 years using the American Academy of Pediatrics 2017 Clinical Practice Guidelines. [37] Other exclusion criteria included underweight/obesity (CDC BMI criteria) and substance use (smoking, alcohol, drugs).

Variables

The primary outcome variables were ECG parameters, including heart rate (HR), cardiac rhythm, P wave duration and amplitude, PR interval, QRS duration, QRS axis, QRS-T amplitudes in precordial and limb leads, corrected QT (QTc) intervals, and morphologic ECG variants (J-waves, J point elevations, notched waves, T-wave inversions). Independent variables included age and sex.

Quantitative variables were ECG measurements analysed as continuous data.

Data sources and measurement

A structured research proforma captured demographic and health information. Anthropometric measurements (height, weight) were obtained using standard equipment and procedures. A thorough physical examination was performed for all participants. Standard 12-lead resting ECGs were recorded for participants in a supine position, according to the American Heart Association specification [38], using a 3-channel portable electrocardiograph, Zoncare™ ZQ 1203G, with a frequency range of 1-150 Hz.

The ECG measurements were interpreted and read manually using an ECG ruler and digital ECG calliper. Visual inspection and interpretation were performed using a magnifying glass (x10). The P, Q, R, S, and T wave amplitudes per lead of 12 leads were measured in millivolts. The duration of the waves, intervals and segments, namely P wave duration, QRS duration, T wave duration, PR interval, RR interval, and QT interval, were determined from lead II and measured in milliseconds. QTc was calculated using the Bazett formula. $QTc = QT/\sqrt{RR}$. [39] In general, when manual measurements are taken, ECG durations, including QRS duration, are measured where the wave is most visible and accurately measurable. Several studies have reported measuring QRS duration in lead II, V1, V5, or V6. [5-7] However, studies using computer-generated analysis have ECG wave durations measured in all leads. The values for the P-wave, T-wave, and QRS axes were the only computer-generated values recorded in this study. The ECG measurements were interpreted and read manually using an ECG ruler and digital ECG calliper. Visual inspection and interpretation were performed using a magnifying glass (x10). Two of the researchers read and reported each of the electrocardiograms. A third researcher reviewed the ECG reports again for quality control in cases of discrepancy.

Bias

Selection bias was minimised through random selection of schools and participants. Measurement bias was reduced by standardising data collection and calibration of instruments. There was a standardised ECG recording procedure, with at least two recordings per participant and blinded interpretation by at least two independent researchers.

Sample size determination

Sample size was estimated using standard epidemiological formulae for cross-sectional studies, ensuring adequate power and allowing for non-response. [40, 41] A total of 1194 students were recruited. These were grouped into three age groups: 10-13 years, 14-16 years, and 17-19 years, representing early, middle, and late adolescence, with no significant difference in the number of males and females across age groups. The calculated sample was selected using a multistage sampling technique across schools, classes and arms of classes.

Data analysis

Data analysis was conducted using SPSS version 25.0. The mean, standard deviation, 2^{nd} and 98^{th} percentile values of ECG variables were determined. Comparison of categorical variables between groups was performed using the Chi-Square test and Fisher's Exact test. Differences in mean values of ECG parameters between males and females were compared using the Student's t-test for normally distributed variables and the Mann-Whitney U test (U) for non-normally distributed variables. Statistical significance was expressed as p-value < 0.05 at 95% confidence interval.

Results

Descriptive data

The cohort comprised 530 (44.4%) males and 664 (55.6%) females, giving a male-to-female ratio of 1:1.3. The mean (±SD) age of the participants was 14.3±2.0 years. The majority (48.8%) of participants were aged 14–16 years, and there were more females in each of the age groups. The overall mean (±SD) weight was 45.0±8.8 kg; 44±9.6 kg for males and 46±8.1 kg for females (range 25 to 78 kg). The overall mean (±SD) of height was 154.8±9.8 cm; 154.7±11.7 cm for males and 154.9±8.0 cm for females (range 128.3 to 182.0 cm), while the overall mean (±SD) BMI was 18.7±2.1 kg/m^2; 18.1±1.7 kg/m^2 for the males and 19.1±2.2 kg/m^2 for the females, with a range of 14.7 to 30.0 kg/m^2. The difference in height, weight and BMI of male and female participants was statistically significant.

Rhythms

The predominant rhythm observed was sinus rhythm, accounting for 56.1%, 66.2%, and 71.9% in the adolescent age groups 10-13 years, 14-16 years, and 17-19 years, respectively. Sinus arrhythmia was observed in 25.4%, 21.3%, and 18.9% of adolescents aged 10-13 years, 14-16 years, and 17-19 years, respectively. Sinus tachycardia was more commonly observed in females across all age groups.

Table I shows the mean values of heart rate, QRS axis, P wave duration, PR interval, QRS duration, and QTc of males and females across the adolescent age groups.

Table I: Lead Independent Indices of the Participants ((Heart Rate, Pwd, PRI, QRS duration, and QTc)

		Male		Female		p value
Variable	**Age (years)**	**Mean± SD**	**(2nd – 98th)**	**Mean ± SD**	**(2nd – 98th)**	
HR(bpm)	10 – 13	83 ± 13	(60 –108)	92 ±12	(72 – 120)	<0.001
	14 – 16	81 ± 13	(60 – 114)	86 ±12	(60 – 114)	<0.001
	17 – 18	79 ± 12	(58 – 107)	823±13	(60 – 114)	0.047
Pwd (ms)	10 – 13	90±10	(80–100)	90±10	(70–120)	0.79
	14 – 16	90±10	(80–120)	90±10	(60–100)	0.031
	17 – 18	90±10	(80–120)	90±10	(80–120)	0.498
PRI (ms)	10 – 13	150±20	(120–180)	150±20	(120–200)	0.21
	14 – 16	150±20	(120–200)	150±20	(120–200)	0.321
	17 – 18	160±20	(120–200)	160±10	(120–200)	0.295
QRS axis	10 – 13	53 ± 22	(4 – 94)	55 ± 20	(2 – 87)	0.229
	14 – 16	55 ± 19	(7-93.76)	53 ± 18	(7 –81)	0.576
	17 – 18	54 ± 20	(13 – 89)	52 ± 19	(14 – 88)	0.464
QTc (ms)	10 – 13	416±22	(370–460)	420±23	(380–460)	0.067
	14 – 16	415±20	(370–450)	420±20	(370–450)	0.002
	17 – 18	407±21	(360–440)	420±21	(370–460)	<0.001
QRSd (ms)	10 – 13	70±10	(60–100)	70±10	(50–100)	0.459
	14 – 16	70±10	(60–100)	70±10	(60–100)	0.306
	17 – 18	70±10	(60–100)	70±10	(40–100)	0.689

2nd – 98th percentile (lower to upper limit of normal): SD – Standard deviation: Test of statistical significance – t test. HR- Heart rate. Pwd- P wave duration. PRI- PR interval. QTc- Corrected QT interval. QRS duration.

Heart rate

The mean heart rate for males decreased from 83 beats per minute (bpm) in the 10-13 age group to 81 bpm in the 14-16 age group and 79 bpm in the 17-19 age group. A similar trend was observed among females, with heart rate decreasing from 92 bpm to 86 bpm, then to 82 bpm across the age groups. The mean heart rate was higher in females than in males in all age groups, with statistical significance.

QRS axis

The QRS axis ranged between 0 and 90 degrees across all age groups. The mean values were not more than 55 degrees in both sexes. There was a decline in the values for females as the age increased.

P wave duration

The mean P wave duration was 90 ms. There were no differences in the mean values of P wave duration across age groups or between males and females.

PR interval

The mean values of PR value ranged from 150 to 160 msecs, with a 2nd percentile of 120 msecs and a 98th percentile of 200 msecs. The values were higher in the older age group (160 msecs), but no difference was observed between males and females.

QRS duration

The mean QRS duration was 70 msecs, with the 98th percentile (upper limit) at 100 msecs across all age groups and in both sexes.

QTc

The mean QTc values were 416 msecs, 415 msecs, and 407 msecs in males across the age groups and 420 msecs across the age groups in females, with a 98th percentile value of 460 msecs. The females had a longer mean QTc than males (Figure 1). This observed difference was statistically significant in older age groups (14–16 and 17–19 years).

ECG waves

The details of age- and sex-stratified ECG wave amplitudes in all leads are shown in tables II-IV.

The mean values of P wave amplitude in lead II were 0.1mV in males and 0.08 mV in females. The 98th percentile values were 0.25 mV in males and 0.20 mV in females. The values were higher in males in most of the leads in the older age groups (14 – 16 years and 17 – 19 years). The difference in P-wave amplitudes between males and females was statistically significant, especially in the precordial leads, in the older age groups ($p < 0.001$), as shown in Table II.

The details of the Q wave depth in all leads are shown in Table III. Zero deflection, indicating an absent Q wave, was excluded from the statistical analysis of the data. Q waves were not observed in V1 across all age groups, and in V2 in the 17-19 years age group. The highest mean Q-wave depth was recorded in the left precordial leads, with mean values of 0.18 mV in males and 0.12 mV in females, and 98th percentile values of 0.5 mV in males and 0.3 mV in females.

The Q wave depth was higher in boys in most of the leads. The difference in Q wave depth between males and females was significant in the left precordial leads (LPL). Q waves were more frequently observed in males across most of the leads. The difference in the frequency of Q-wave appearance between males and females was significant in the LPL and a few other leads. The details of the R wave amplitudes in all the leads are presented in Table IV. The mean values in V5 were as high as 2.8mV in males and 1.73 mV in females. In all age groups, males had higher R-wave amplitudes in the precordial leads. The difference in values of R wave amplitudes between male and female adolescents was statistically significant in the precordial leads across all adolescent age groups ($p < 0.001$).

Table II: Values of P wave amplitudes of participants by sex and age groups (in millivolts)

		Age (years)					
		10 – 13		14 – 16		17 – 19	
	Sex	Mean ± SD	(2^{nd} – 98^{th})	Mean ± SD	(2^{nd} – 98^{th})	Mean ± SD	Median (2^{nd} – 98^{th})
I	Male	0.1± 0.02	0.05 – 0.15	0.1 ± 0.01	0.05–0.13*	0.09 ± 0.02	0.05 – 0.1
	Female	0.1 ± 0.02	0.05 – 0.19	0.09 ± 0.02	0.05 – 0.12	0.09 ± 0.03	0.05 – 0.2
II	Male	0.14 ± 0.05	0.05 – 0.22	0.14 ± 0.05	0.06 – 0.22	0.15 ± 0.05	0.05 – 0.25
	Female	0.14 ± 0.04	0.05 – 0.22	0.13 ± 0.04	0.05 – 0.2	0.14 ± 0.04	0.05 – 0.2
III	Male	0.09 ± 0.04	0.05 – 0.2	0.1 ± 0.04	0.05 – 0.2*	0.1 ± 0.04	0.05 – 0.25
	Female	0.09 ± 0.04	0.03 – 0.2)	0.08 ± 0.03	0.03 – 0.18	0.09 ± 0.04	0.02 – 0.2
aVR	Male	0.11 ± 0.03	0.05 – 0.2	0.11 ± 0.03	0.1 – 0.2*	0.11 ± 0.02	0.05 – 0.16
	Female	0.11 ± 0.02	0.05 – 0.18	0.1 ± 0.02	0.05 – 0.18	0.11 ± 0.02	0.05 – 0.15)
aVL	Male	0.07 ± 0.03	0.02 – 0.10	0.07 ± 0.03	0.03 – 0.1*	0.06 ± 0.02	0.01 – 0.1
	Female	0.06 ± 0.03	0.02 – 0.10	0.06 ± 0.03	0.01 – 0.1	0.06 ± 0.03	0.02 – 0.14
aVF	Male	0.11 ± 0.05	0.05 – 0.20	0.11 ± 0.05	0.04 – 0.2*	0.12 ± 0.5	0.03 – 0.2
	Female	0.11 ± 0.04	0.05 – 0.20	0.1 ± 0.04	0.02 – 0.2	0.11 ± 0.4	0.03 – 0.2
V1	Male	0.12 ± 0.04	0.05 – 0.2*	0.12 ± 0.04	0.09 – 0.2*	0.12 ± 0.4	0.03 – 0.2*
	Female	0.09 ± 0.03	0.05 – 0.2	0.08 ± 0.03	0.04 – 0.2	0.08 ± 0.2	0.04 – 0.1
V2	Male	0.11 ± 0.03	(0.5 – 2.0)	0.11 ± 0.04	0.05 – 0.2*	0.12 ± 0.4	0.05 – 0.2*
	Female	0.11 ± 0.03	(0.5 – 2.0)	0.09 ± 0.03	0.05 – 0.12	0.09 ± 0.2	0.05 – 0.1
V3	Male	0.1 ± 0.03	(0.5 – 2.0)	0.11 ± 0.04	0.05 – 0.2*	0.11 ± 0.3	0.06 – 0.2*
	Female	0.1 ± 0.03	(0.5 – 2.0)	0.09 ± 0.02	0.05 – 0.12	0.1 ± 0.3	0.05 – 0.2
V4	Male	0.11 ± 0.03	(0.5 – 2.0)	0.11 ± 0.04	0.05 – 0.2*	0.1 ± 0.3	0.05 – 0.2*
	Female	0.11± 0.03	(0.5 – 2.0)	0.09 ± 0.02	0.05 – 0.12	0.09 ± 0.2	0.03 – 0.1
V5	Male	0.11 ± 0.03	(0.5 – 2.0)	0.11 ± 0.03	0.05 – 0.2*	0.1 ± 0.3	0.05 – 0.2*
	Female	0.1 ± 0.03	(0.5 – 2.0)	0.09 ± 0.03	0.05 – 0.1	0.09 ± 0.2	0.02 – 0.12
V6	Male	0.1 ± 0.02	(0.5 – 2.0)*	0.10 ± 0.03	0.05 – 0.2*	0.1 ± 0.2	0.05 – 0.2*
	Female	0.09 ± 0.02	(0.5 – 1.8)	0.08 ± 0.03	0.05 – 0.1	0.09 ± 0.2	0.02 – 0.1

**: p-value <0.05: 2^{nd} – 98^{th} percentile (lower to upper limit of normal): SD – Standard deviation*

The details of the S-wave depth in all leads are shown in Table V, with mean values of 1.8 mV in males and 1.2 mV in females in V2. The S wave depth was significantly higher in males than in females in the precordial leads ($p < 0.001$) in all adolescent age groups.

The mean values of the summation of S wave in RPL, and R wave in LPL of participants were 4.3 mV in males and 2.6 mV in females (in the older age group). The values were significantly higher in males in all age groups, as shown in Table VI. The values increased with age among males but decreased with age among females.

The details of T-wave amplitude in all leads are shown in Table VII, with mean values of 0.5 mV in males and 0.3 mV in females (in the older age group). The amplitude of the T wave was significantly higher in males than in females ($p < 0.001$) in both limb and precordial leads across all adolescent age groups, except in lead aVL, where the difference was significant only in the 14-16 years age group.

Other morphologic ECG features

Inverted T waves were seen in V1 only, V1-V2, V1-V3, V1-V4, and V1-V5 in different participants.

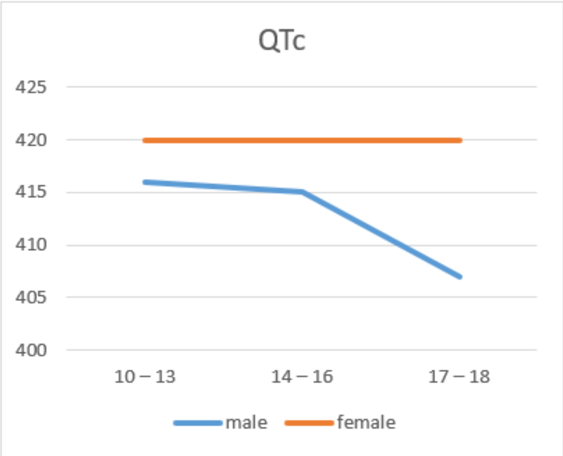

Figure 1a: Mean QTc is longer in females with same value across all age groups. Values in males are lower in the older adolescent age groups.

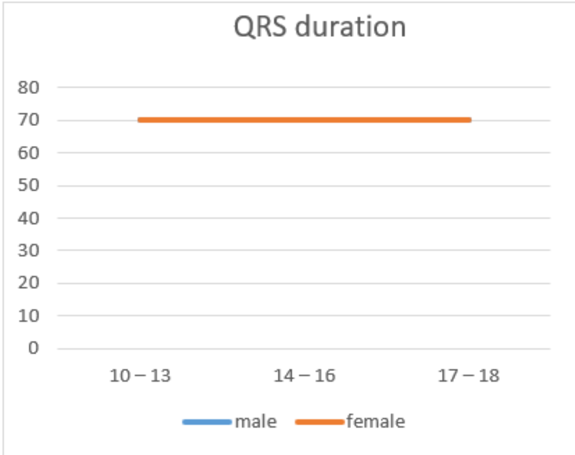

Figure 1b: Mean QRS duration is the same in male and female and across all adolescent age groups.

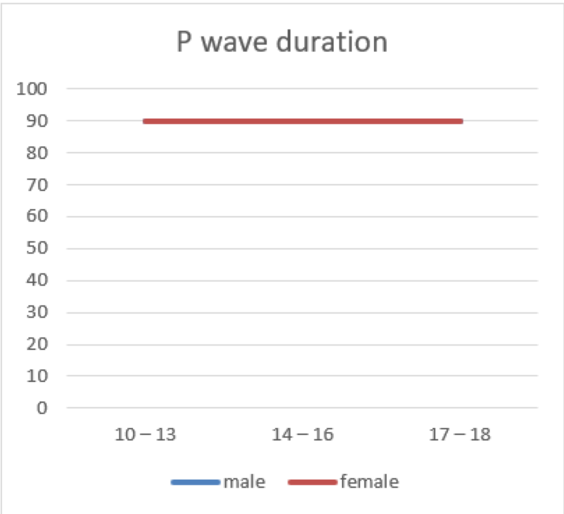

Figure 1c: No difference in mean P wave duration between male and female adolescents and across the adolescent age groups.

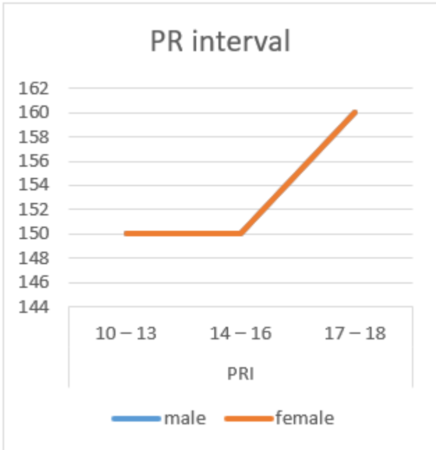

Figure 1d: Mean PR interval is same in both sexes and higher in older adolescent age groups.

The presence of inverted T waves in V1 had the highest frequency across all age groups, followed by V1-V3. Inverted T waves in V1 were seen in 478 (72%) females and 340 males (64%), being less common in older adolescents. J waves were observed more often in males (66; 12.5%) than in females (37; 5.6%). The notched R waves were seen in 14 (2.6%) males and 25 (3.8%) females, while notched S waves were observed in 12 (2.3%) males and 25 (3.8%) females. In the older age group (17-19 years), J point elevation occurred more frequently in males in the older age group. Sinus tachycardia, notched R and S waves and persistent juvenile T wave pattern were more frequent in females, while J point elevation, J waves and q waves occurred more frequently in males.

Discussion

This study demonstrates some age- and sex-related differences in ECG parameters among healthy Nigerian adolescents. In this study, the recorded decline in the mean heart rate with age in both sexes is similar to the findings in adolescents in Port Harcourt, southern Nigeria, where the mean ECG heart rate also decreased with age. [24] Studies among Caucasian children also reported similar findings, with the mean heart rate decreasing with age. [8,17, 42, 43]

Table III: Values of Q wave Depth of Participants by Sex and Age Groups (in millivolts)

		Age group (years)					
		10 – 13		14 – 16		17 – 19	
Lead	Sex	Mean ± SD	(2nd – 98th)	Mean ± SD	(2nd – 98th)	Mean ± SD	(2nd – 98th)
I	Male	0.1 ± 0.06	0.02 – 0.32	0.12 ± 0.07	0.02 – 0.3*	0.09 ± 0.05	0.02 – 0.25*
	Female	0.1 ± 0.07	0.02 – 0.4	0.08 ± 0.06	0.02 – 0.3	0.07 ± 0.04	0.02 – 0.24
II	Male	0.1 ± 0.05	0.02 – 0.2	0.1 ± 0.06	0.02 – 0.25*	0.09 ± 0.06	0.03 – 0.25
	Female	0.08 ± 0.04	0.02 – 0.20	0.08 ± 0.05	0.02- 0.2	0.08 ± 0.06	0.02 – 0.20
III	Male	0.16 ± 0.1	0.03 – 0.4*	0.15 ± 0.1	0.05 – 0.55	0,1 ± 0.05	0.05 – 0.4
	Female	0.12 ± 0.08	0.03 – 0.4	0.13 ± 0.09	0.05 – 0.4	0.12 ± 0.07	0.05 – 0.4
aVR	Male	0.39 ± 0.49	0.0 – 1.4	0.38 ± 0.47	0.0 – 1.33	0.44 ± 0.51	0.0 – 1.38
	Female	0.37 ± 0.46	0.0 – 1.47	0.42 ± 0.46	0.0 - 1.3	0.41 ± 0.43	0.0 – 1.1
aVL	Male	0.13 ± 0.09	0.03 – 0.46	0.13 ± 0.07	0.02 – 0.25*	0.12 ± 0.09	0.02 – 0.54*
	Female	0.12 ± 0.09	0.02 – 0.4	0.11 ± 0.06	0.02 – 0.3	0.08 ± 0.04	0.03 – 0.2
aVF	Male	0.12 ± 0.06	0.02 – 0.29*	0.09 ± 0.06	0.1 – 0.1	0.09 ± 0.04	0.02 – 0.1
	Female	0.09 ± 0.05	0.02 – 0.25	0.09 ± 0.05	0.03 – 0.21	0.09 ± 0.06	0.02 – 0.1
V1	Male	0.0 ± 0.0	0.0 – 0.0	0.0 ± 0.0	0.0 – 0.0	0.0 ± 0.0	0.0 – 0.0
	Female	0.0 ±0.0	0.0 – 0.0	0.0 ± 0.0	0.0 – 0.0	0.0 ± 0.0	0.0 - 0.0
V2	Male	0.05 ± 0.0	0.0 – 0.0	0.1 ± 0.0	0.03 –0.1	0.0 ± 0.0	0.0 – 0.0
	Female	0.0 ± 0.0	0.0 – 0.0	0.0 ± 0.0	0.0 -0.0	0.0 ± 0.0	0.0 – 0.0
V3	Male	0.16 ± 0.14	0.02 – 0.1	0.11 ± 0.07	0.04 – 0.5	0.12 ± 0.1	0.05 – 0.1
	Female	0.09 ± 0.03	0.05 – 0.1	0.05 ± 0.0	0.05 – 0.05	0.05 ± 0.0	0.05 – 0.5
V4	Male	0.15 ± 0.10	0.04 – 0.4*	0.17 ± 0.12	0.04 – 0.5*	0.17 ± 0.12	0.05 – 0.4*
	Female	0.1 ± 0.06	0.02 – 0.26	0.07 ± 0.03	0.02 – 0.1	0.09 ± 0.05	0.05– 0.2
V5	Male	0.17 ± 0.11	0.05 – 0.4*	0.18 ± 0.11	0.05 – 0.46*	0.15 ± 0.11	0.04 – 0.5*
	Female	0.11 ± 0.07	0.02 – 0.3	0.08 ± 0.05	0.02 – 0.2	0.08 ± 0.03	0.02 – 0.3
V6	Male	0.17 ± 0.11	0.03 – 0.4*	0.18 ± 0.11	0.03 – 0.4*	0.14 ± 0.08	0.05 – 0.3*
	Female	0.12 ± 0.07	0.02 – 0.3	0.09 ± 0.06	0.02 - 0.23	0.09 ± 0.06	0.02- 0.2

*: p value <0.05: 2nd – 98th percentile (lower to upper limit of normal): SD – Standard deviation

This decrease in heart rate with increasing age is attributable to increased autonomic nervous system (vagal) activity, which is thought to possibly relate to an increase in stroke volume with age (probably due to increasing left ventricular dominance), such that at a lower heart rate, the cardiac output is still maintained.[1] In the present study, a higher mean heart rate was observed among the females, in concordance with previous reports. [1, 7, 13, 15, 18, 19, 24] Vagal influence on heart rate has been reported to be lower in adolescent females, which may explain the higher heart rates observed in them.[44]

In the present study, sinus rhythm was the predominant cardiac rhythm in the different adolescent age groups. While Aliyu and Ibrahim reported sinus rhythm in over three-quarters of the children studied, the present study identified additional rhythms of junctional rhythm and wandering atrial pacemaker reflecting broader ECG variability in apparently healthy adolescents. The prevalence of sinus arrhythmia in the present study was higher in the younger age group. This contrasts with the report of Tutar *et al.* [45] who documented it in 53 per cent of Turkish children aged 7 to 18 years, with the highest incidence in the older adolescents. The increased prevalence of sinus arrhythmia in the older age group is attributed to lower heart rates in older children compared to younger children. This is due to a relatively lower sympathetic nervous system tone at the SA node of the older children, which causes variation in the P–P interval.[5]

Table IV: Values of R wave Amplitudes of Participants by Sex and Age Groups (in millivolts)

		Age group (years)					
		10 – 13		**14 – 16**		**17 – 19**	
Lead	**Sex**	**Mean ± SD**	**(2nd – 98th)**	**Mean ± SD**	**(2nd – 98th)**	**Mean ± SD**	**(2nd – 98th)**
I	Male	0.85 ± 0.25	0.3 – 1.45*	0.54 ± 0.3	0.32 – 1.52*	0.5 ± 0.27	0.3 – 1.4
	Female	0.8 ± 0.31	0.3 – 1.75	0.75 ± 0.28	0.25 – 1.45	0.73 ± 0.2	0.4 -1.1
II	Male	1.38 ± 0.41	0.54 – 2.39	1.37 ± 0.36	0.7 – 2.25*	1.4 ± 0.4	0.5 – 2.27
	Female	1.32 ± 0.41	0.4 – 2.3	1.29 ± 0.37	0.7 – 2.3	1.27 ± 0.38	0.55 – 2.15
III	Male	0.76 ± 0.42	0.12 – 1.8	0.72 ± 0.4	0.2 – 1.82	0.74 ± 0.47	0.1 – 1.9
	Female	0.75 ± 0.44	0.1 – 1.95	0.71 ± 0.39	0.1 – 1.6	0.68 ± 0.42	0.1 – 1.68
aVR	Male	0.16 ± 0.11	0.05 – 0.5*	0.19 ± 0.19	0.05 – 1.0	0.14 ± 0.09	0.03 – 0.4
	Female	0.17 ± 0.22	0.02 – 1.1	0.18 ± 0.24	0.05 – 1.2	0.15 ± 0.11	0.05 – 0.5
aVL	Male	0.35 ± 0.2	0.1 – 0.9*	0.35 ± 0.23	0.05 – 0.9	0.31 ± 0.18	0.05 – 0.74
	Female	0.34 ± 0.27	0.05 – 1.26	0.32 ± 0.24	0.05 -1.05	0.3 ± 0.16	0.1 – 0.6
aVF	Male	1.05 ± 0.42	0.3 – 2.0	1.01 ± 0.4	0.1 – 1.9	1.05 ± 0.42	0.3 – 2.0
	Female	1.0 ± 0.46	0.1 – 2.05	0.99 ± 0.39	0.25- 1.82	0.96 ± 0.42	0.2 – 1.9
V1	Male	0.64 ± 0.27	0.2 – 1.4*	0.63 ± 0.32	0.19 – 1.5*	0.51 ± 0.25	0.05 – 1.2*
	Female	0.42 ± 0.25	0.1 – 1.1	0.32 ± 0.18	0.05 – 0.8	3.2 ± 0.14	0.05 – 0.65
V2	Male	1.55 ± 0.57	0.7 – 2.79*	1.45 ± 0.55	0.53 – 2.8*	1.28 ± 0.52	0.4 – 3.2*
	Female	1.17 ± 0.5	0.4 – 2.7	0.94 ± 0.42	0.3 – 2.05	0.9 ± 0.35	0.1 – 1.8
V3	Male	2.02 ± 0.75	0.8 – 4.0*	2.01 ± 0.88	0.7 – 4.22*	1.85 ± 0.71	0.5 – 3.2*
	Female	1.64 ± 0.61	0.63 – 3.0	1.43 ± 0.54	0.6 – 2.72	1.28 ± 0.43	0.45 – 2.6
V4	Male	2.63 ± 0.85	1.0 – 4.4*	2.77 ± 0.95	0.9 – 5.2*	2.92 ± 0.9	1.0 – 4.7*
	Female	2.12 ± 0.65	0.98 – 3.72	1.81 ± 0.54	0.9 – 3.3	1.75 ± 0.52	0.6 – 3.0
V5	Male	2.71 ± 0.73	1.5 – 4.8*	2.83 ± 0.9	1.2 – 5.6*	2.78 ± 0.79	1.0 – 4.6*
	Female	2.13 ± 0.65	1.05 – 3.65	1.73 ± 0.48	1.0 – 2.91	1.65 ± 0.33	0.95 – 2.44
V6	Male	2.29 ± 0.56	1.31 – 3.6*	2.23 ± 0.69	1.01 – 4.0*	2.18 ± 0.65	0.9 – 4.2*
	Female	1.86 ± 0.6	0.94 – 3.1	1.49 ± 0.41	0.8 – 2.6	1.47 ± 0.34	0.9 – 2.4

**: p value <0.05: 2nd – 98th percentile (lower to upper limit of normal): SD – Standard deviation*

However, in the present study, the prevalence of sinus arrhythmia was less common among the older adolescents, in contrast to Turkish children and Nigerian children based in Kano metropolis, where the prevalence of sinus arrhythmia increased with age. [7, 45] This may be related to the difference in sample size and age range studied. The older adolescents (17 – 19 years) had a lower number of participants. Sinus tachycardia was more common in females, possibly influenced by anxiety during the recording and heightened adrenaline surge, especially since the procedure required them to undress.

In the present study, the mean QRS axis was less than 90 degrees, with higher values observed in younger females. This could be possibly due to the rotation of the axis from right to left as a result of increasing electrical preponderance of the left ventricle compared to the right ventricle as children grow. [33] Similar observations were also documented in other studies. [7, 13, 16, 24] However, values appeared to increase with age in males, but the reason for this is unclear. In older participants, the QRS axis was higher in males than in females.

Table V: Values of S wave Depth of Participants by Sex and Age Groups (in millivolts)

		Age (years)					
		10 – 13		**14 – 16**		**17 – 19**	
Lead	**Sex**	**Mean ± SD**	**(2^{nd} – 98^{th})**	**Mean ± SD**	**(2^{nd} – 98^{th})**	**Mean ± SD**	**(2^{nd} – 98^{th})**
I	Male	0.19 ± 0.13	0.05 – 0.62	0.2 ± 0.14	0.05 – 0.6	0.2 ± 0.12	0.05 – 0.45
	Female	0.2 ± 0.12	0.05 – 0.55	0.17 ± 0.12	0.02 – 0.5	0.19 ± 0.12	0.03 – 0.5
II	Male	0.25 ± 0.15	0.05 – 0.61*	0.23 ± 0.13	0.05 – 0.6*	0.26 ± 0.13	0.05 – 0.6
	Female	0.19 ± 0.11	0.05 – 0.5	0.17 ± 0.11	0.03 – 0.45	0.24 ± 0.17	0.05 – 0.5
III	Male	0.23 ± 0.14	0.05 – 0.6	0.23 ± 0.17	0.05 – 0.7	0.28 ± 0.16	0.05 – 0.8*
	Female	0.29 ± 0.27	0.05 – 1.63	0.21 ± 0.18	0.05 – 0.85	0.22 ± 0.18	0.03 – 0.6
aVR	Male	1.16 ± 0.22	0.7 – 1.69*	1.1 ± 0.28	0.24 – 1.6*	1.14 ± 0.31	0.55 – 1.6
	Female	1.04 ± 0.37	0.1 – 1.9	1.05 ± 0.31	0.15 – 1.71	1.04 ± 0.23	0.7 -1.7
aVL	Male	0.32 ± 0.21	0.05 – 0.85	0.32 ± 0.21	0.0 – 1.34	0.31 ± 0.18	0.05 – 0.73
	Female	0.32 ± 0.23	0.05 – 1.0	0.28 ± 0.2	0.05 – 0.84	0.29 ± 0.27	0.05 – 1.5
aVF	Male	0.23 ± 0.14	0.05 – 0.66*	0.22 ± 0.15	0.05 – 0.76*	0.25 ± 0.13	0.03 – 0.65*
	Female	0.19 ± 0.17	0.05 – 1.0	0.19 ± 0.18	0.05 – 1.0	0.19 ± 0.16	0.05 – 1.0
V1	Male	1.31 ± 0.5	0.4 – 2.4*	1.44 ± 0.6	0.36 – 2.8*	1.52 ± 0.65	0.5 – 3.4*
	Female	1.05 ± 0.51	0.16 – 2.25	0.93 ± 0.38	0.4 – 1.8	0.97 ± 0.37	0.3 – 1.7
V2	Male	1.56 ± 0.76	0.2 – 2.9*	1.76 ± 0.74	0.4 – 3.29*	1.88 ± 0.86	0.58 – 4.6*
	Female	1.19 ± 0.62	0.2 – 2.8	1.07 ± 0.47	0.2 – 2.4	1.22 ± 0.42	0.4 – 2.2
V3	Male	1.21 ± 0.61	0.2 – 2.4*	1.25 ± 0.6	0.2 – 2.64*	1.36 ± 0.66	0.44 – 2.8*
	Female	0.89 ± 0.49	0.2 – 2.2	0.73 ± 0.38	0.1 – 1.67	0.87 ± 0.38	0.3 – 1.8
V4	Male	0.93 ± 0.53	0.2 – 2.2*	0.92 ± 0.45	0.1 – 2.0*	0.94 ± 0.56	0.2 – 2.44*
	Female	0.67 ± 0.41	0.13 – 1.8	0.53 ± 0.30	0.1 – 1.3	0.65 ± 0.36	0.2 – 1.6
V5	Male	0.61 ± 0.42	0.1 – 1.8*	0.59 ± 0.36	0.1 – 1.6*	0.56 ± 0.41	0.09 – 2.0*
	Female	0.45 ± 0.3	0.1 – 1.5	0.36 ± 0.31	0.1 – 1.0	0.43 ± 0.33	0.05 – 1.3
V6	Male	0.39 ± 0.3	0.1 – 1.5*	0.33 ± 0.23	0.05 – 1.0*	0.3 ± 0.2	0.1 – 0.9
	Female	0.31 ± 0.27	0.05 – 1.4	0.19 ± 0.16	0.05 – 0.5	0.31 ± 0.22	0.05 – 1.0

**: p value <0.05: 2^{nd} – 98^{th} percentile (lower to upper limit of normal): SD – Standard deviation*

This is consistent with reports in Nigerian adolescents in Kano and Port Harcourt. [7, 24] In contrast, Semizel *et al.*16, in a study of Turkish adolescents, reported that the mean QRS axis was higher among female participants. Variations in the QRS axis may be due to differences of the ECG machines used across studies and to racial differences in the populations studied. In the present study, the differences in QRS axis noted between males and females were not statistically significant.

The mean P wave duration was the same in all age groups and in both sexes. This is similar to the findings in other children in southern and northern Nigeria [7, 24], but contrasts with reports among Japanese, American, and Dutch children and adolescents [13, 17], where P-wave duration was higher in males. This disparity may be related to racial differences between black and white individuals and differences in the age groups studied. Although females demonstrated lower mean values of P-wave amplitudes than males, the difference in Lead II was not statistically significant, as also observed by

Tabansi *et al.*[24] The P-wave amplitude shows minimal sex-related variation, likely because atrial depolarisation is less dependent on myocardial mass and chamber size than ventricular activity. Studies have shown that atrial dimensions do not significantly influence P-wave morphology and exhibit limited sex-based differences (atrial size differences are minimal). [18, 23, 46]

Table VI: Summation of S wave in RPL and R wave in LPL of participants by sex and age groups (in millivolts)

		Age (years)					
		10 – 13		**14 – 16**		**17 – 19**	
Variable (mm)	**Sex**	**Mean±SD**	**(2nd – 98th)**	**Mean ± SD**	**(2nd – 98th)**	**Mean ± SD**	**(2nd – 98th)**
SV1+ RV5	Male	4.02 ±0.93	3.5 – 6.0*	4..26 ± 1.12	2.0 – 7.04*	4.3 ± 1.07	2.15 – 6.6*
	Female	3.18 ± 0.91	1.8 – 5.3	2.66 ± 0.67	1.67 – 4.26	2.62 ± 0.6	1.25 – 4.04
SV1+ RV6	Male	3.6 ± 0.79	2.06 –5.59*	3.67 ± 0.95	1.8 – 5.62*	3.7 ± 0.93	2.05 – 6.2*
	Female	2.92 ± 0.86	1.6 – 4.8	2.42 ± 0.62	1.4 – 3.95	2.44 ± 0.63	1.2 – 4.05

**: p value <0.05: 2nd – 98th percentile (lower to upper limit of normal): SD – Standard deviation: RPL – (Right precordial lead V1); LPL – (Left precordial lead V5, V6)*

The mean duration of the PR interval increased with age, as observed in previous studies. [7, 8, 17] The difference with increasing age might have been significant if the design of the present study had focused on individual ages rather than age groups that were used. There was no difference in the mean values observed between male and female participants, consistent with the findings in adolescents studied by Tabansi *et al.* 24 in southern Nigeria and by Yoshinaga *et al.* 17 in Japanese children. However, in some other studies, the PR interval was observed to be longer in males than in females. [7, 13] The disparity in results observed across these studies may be accounted for by differences in age group and sample size.

The mean QRS duration was the same across all age groups and in both sexes in the present study. Tabansi *et al.*,[24] in their study of adolescents, also reported no difference in mean values across all age groups and in both sexes. In contrast, Aliyu and Ibrahim[7] had noted that QRS duration was longer in males and increased with age. Afolabi and Omokhodion also reported that QRS increased with age. [6] The mean values were also longer in males than females in the Caucasian studies. [10, 15, 16, 23] The QRS duration is known to increase from birth to puberty. [5, 6] The participants in the present study were adolescents, suggesting that the increase in QRS duration occurring between birth and adolescence does not continue throughout the adolescent years.

The mean QTc in the study was longer in females, and this difference was statistically significant. This has been attributed to the effects of the androgen hormone, which shortens QTc in males and reduces repolarisation reserve in females. [47-49] This finding is consistent with reports from previous studies. [15, 22, 24]. In contrast, Aliyu and Ibrahim[7] observed that QTc values were higher in males, suggesting variability within the local population. Q waves were more frequently observed in males across all age groups. The mean values of Q-wave amplitude were higher in male participants, as observed in Japanese children. [23] In this study, the amplitude of the R wave was significantly higher in males in the precordial leads in all age groups and in almost all the limb leads. The amplitude of the S wave was also higher in males than in females, and the difference was statistically significant. This is similar to reports from earlier studies. [6, 7, 13,] [16, 24, 28]. The higher amplitudes of R and S waves in males may be due to greater cardiac muscle bulk in adolescent males compared with their female counterparts. Breast development has also been postulated as a reason for this difference, due to the damping of electrical activity by the adipose tissue around the breasts, which increases the distance between the recording electrode and the myocardium.[24]

Table VII: Values of T wave amplitudes of participants by sex and age groups (in millivolts)

		Age (years)					
		10 – 13		**14 – 16**		**17 – 19**	
Lead	**Sex**	**Mean ± SD**	**($2^{nd} – 98^{th}$)**	**Mean ± SD**	**($2^{nd} – 98^{th}$)**	**Mean ± SD**	**($2^{nd} – 98^{th}$)**
I	Male	0.26 ± 0.08	0.1 – 0.41*	0.28 ± 0.08	0.12 – 0.46*	0.26 ± 0.09	0.1 – 0.6*
	Female	0.23 ± 0.07	0.1 – 0.4	0.21 ± 0.06	0.1 – 0.35	0.2 ± 0.08	0.1 – 0.4
II	Male	0.38 ± 0.13	0.2 – 0.7*	0.4 ± 0.12	0.2 – 0.7*	0.4 ± 0.16	0.15 – 0.8*
	Female	0.3 ± 0.12	0.11- 0.55	0.29 ± 0.1	0.1 – 0.55	0.27 ± 0.09	0.1 – 0.45
III	Male	0.15 ± 0.09	0.03 – 0.4*	0.15 ± 0.08	0.02 – 0.36*	0.17 ± 0.09	0.05 –0.45*
	Female	0.11 ± 0.06	0.03 – 0.25	0.11 ± 0.06	0.03 – 0.25	0.1 ± 0.03	0.03 – 0.2
aVR	Male	0.31 ± 0.09	0.15 – 0.5*	0.33 ± 0.09	0.18 – 0.5*	0.33 ± 0.12	0.1 – 0.68*
	Female	0.25 ± 0.07	0.13 – 0.4	0.25 ± 0.08	0.1 – 0.4	0.22 ± 0.09	0.05 – 0.38
aVL	Male	0.09 ± 0.04	0.02 – 0.2	0.11 ± 0.06	0.02 – 0.3*	0.1 ± 0.06	0.02 – 0.32
	Female	0.1 ± 0.06	0.02 – 0.28	0.09 ± 0.04	0.02 – 0.2	0.09 ± 0.04	0.02 – 0.2
aVF	Male	0.25 ± 0.11	0.03 – 0.59*	2.6 ± 1.0	0.1 – 0.5*	0.27 ± 0.13	0.1 – 0.6*
	Female	0.19 ± 0.08	0.05 – 0.38	0.19 ± 0.07	0.1 – 0.35	0.17 ± 0.07	0.03 – 0.3
V1	Male	0.22 ± 0.1	0.1 – 0.5*	0.21 ± 0.11	0.09 – 0.5*	0.18 ± 0.11	0.05 – 0.6*
	Female	0.17 ± 0.07	0.05 – 0.3	0.14 ± 0.06	0.05 – 0.25	0.13 ± 0.06	0.05 – 0.3
V2	Male	0.34 ± 0.17	0.1 – 0.7*	0.41 ± 0.17	0.12 – 0.8*	0.47 ± 0.23	0.12 – 1.0*
	Female	0.28 ± 0.14	0.1 – 0.6	0.26 ± 0.12	0.1 – 0.5	0.26 ± 0.13	0.1 – 0.6
V3	Male	0.39 ± 0.2	0.1 – 1.0*	0.45 ± 0.2	0.2 – 0.92*	0.49 ± 0.25	0.2 – 1.2*
	Female	0.3 ± 0.14	0.1 – 0.6	0.28 ± 0.13	0.1 – 0.52	0.25 ± 0.13	0.05 – 0.6
V4	Male	0.46 ± 0.21	0.1 – 1.0*	0.51 ± 0.22	0.2 – 1.04*	0.58 ± 0.31	0.1 – 1.4*
	Female	0.38 ± 0.19	0.1– 0.85	0.31 ± 0.14	0.1 – 0.6	0.3 ± 0.14	0.1– 0.7
V5	Male	0.49 ± 0.19	0.15 – 0.96*	0.54 ± 0.19	0.19 – 1.0*	0.56 ± 0.29	0.1 – 1.5*
	Female	0.39 ± 0.16	0.2 – 0.8	0.32 ± 0.14	0.1 – 0.6	0.3 ± 0.13	0.1 – 0.6
V6	Male	0.46 ± 0.17	0.2 – 0.85*	0.48 ± 0.18	0.18 – 0.84*	0.48 ± 0.24	0.1 – 1.24*
	Female	0.36 ± 0.14	0.15 – 0.65	0.3 ± 0.12	0.1 – 0.06	0.29 ± 0.12	0.1 – 0.5

**: p value <0.05: 2^{nd} – 98^{th} percentile (lower to upper limit of normal): SD – Standard deviation*

The mean values of the summation of the R wave in LPL and the S wave in RPL were higher in males. It increased with age among males, while it decreased among females, possibly due to the damping effect of breast tissue (in older girls) on the electrical activity of the heart. In Araoye's criteria for left ventricular hypertrophy, designed to improve diagnostic accuracy in black populations, the cut-off value is higher in males.[50] Applying this criterion revealed that male adolescents approached or exceeded the threshold, whereas females rarely met the criterion. This implies that there is a need for sex – specific voltage criteria in the evaluation of ventricular hypertrophy among adolescents.

In this study, J-point elevation was more commonly observed in males in older age groups, but in females of younger age groups. Similarly, in the study of Ogunlade *et al.,*[18] the dominant ECG peculiarity among young adults was early repolarisation, which showed a male preponderance. There was a gradual increase in the amplitude of the T wave on the precordial leads with increasing age, similar to the study in Kano, Nigeria.[7] Amplitudes were also observed to be higher in males, as documented in previous studies. [6, 7, 24, 51]

The frequency of persistence of inverted T wave in V1 to V3 was reduced in the 17-19 years age group and occurred more in females. The persistent juvenile T wave pattern observed in this study is a recognised finding in black adolescents and adults. [52, 53] Similar to the reports by Basu *et al.*, [53] the presence of a juvenile ECG pattern was more common in females but reduced with increasing age.
Sinus tachycardia, notched R and S waves and persistent juvenile T Wave pattern had a higher frequency of occurrence in females. In contrast, J point elevation, Q waves and J waves were more frequently observed in males. In the older age group, J-point elevations were more common in males than in females, as previously reported. [18,53, 54]

The findings of this study reinforce the existence of distinct age- and sex-related variations in ECG parameters among Black adolescents, particularly in QRS voltages, repolarisation patterns, and QT intervals. Male participants demonstrated higher precordial voltages and a greater prevalence of early repolarisation patterns consistent with previous reports in athletic and general Black adolescent populations. [30, 31, 55] However, anterior T-wave inversions were more common in females. These patterns appeared to intensify with advancing age, reflecting the impact of pubertal maturation on cardiac electrophysiology. When compared to the existing data from Caucasian and Asian adolescents, the observed ECG profiles in Black adolescents showed significant differences - particularly in T-wave morphology and higher QRS voltages, which are more prevalent yet physiologically normal in this group. [13, 32, 33] Asian adolescents, by contrast, have been shown to exhibit shorter QT intervals and lower voltage criteria for LVH, [34] while Caucasians generally present with fewer repolarisation variants. [33]

The differences between male and female adolescents in various ECG parameters likely reflect the interplay of anatomic, structural, hormonal, autonomic, and genetic factors. [23] Studies have demonstrated that sex differences exist and range from the effect of gene expression to cardiac physiology.[48] Sex-specific differences in cardiomyocytes and cardiac functions are most prominent after puberty, suggesting that sex hormones play an important role in causing such differences. Sex hormones directly influence various cellular functions and adrenergic regulation. [56, 57] Testosterone accelerates ventricular repolarisation, thus explaining the differences in QT interval. Women exhibit a higher beating rate and slower repolarisation than men. [48, 56] A clear sex difference in left ventricular mass is observed after puberty, and male cardiomyocytes undergo greater hypertrophy than female cardiomyocytes. Therefore, higher QRS voltages and durations in males may result from greater left ventricular mass and wall thickness. At the same time, longer QTc intervals in females could be attributed to hormonal modulation of cardiac repolarisation. [48, 57] The progressive age-related shifts in ECG variables may also reflect normal cardiac maturation. [1, 4, 5]

Limitation of the study

Age-related differences in ECG variables would have been more apparent if a longitudinal study design was used. While participants were screened for health conditions, subclinical cardiovascular abnormalities could not be entirely excluded.

Conclusion

This study has provided detailed sex- and age-stratified electrocardiographic data for Nigerian adolescents. It concluded that there were significant differences between male and female adolescents, some of which were more pronounced in older age groups. These observed sex, age and interethnic differences emphasise the risk of misclassification when applying generalised ECG interpretation criteria across diverse populations. Therefore, the establishment and application of ethnic-, age-, and sex-specific ECG reference values are critical to improving diagnostic precision and avoiding unnecessary exclusion or further testing in healthy Black adolescents.

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