Journal of Electrocardiology 63 (2020) 68–74

Contents lists available at ScienceDirect

Journal of Electrocardiology

journal homepage: www.jecgonline.com

Normal limits of the electrocardiogram in Angolans

Mauer A.A. Gonçalves, MD [a,b,c], João Mário Pedro, PhD [c,d], Carina Silva, PhD [e,f], Pedro Magalhães, MD, PhD [b], Miguel Brito, PhD [c,e,*]

[a] Centro de Estudos Avançados em Educação e Formação Médica (CEDUMED), Luanda, Angola
[b] Faculty of Medicine from University Agostinho Neto, Luanda, Angola
[c] Centro de Investigação em Saúde de Angola (CISA), Caxito, Bengo, Angola
[d] EPIUnit, Instituto de Saúde Pública, Universidade do Porto, Portugal
[e] Health and Technology Research Center (H&TRC), Escola Superior de Tecnologia da Saúde de Lisboa, Instituto Politécnico de Lisboa, Portugal
[f] CEAUL - Centro de Estatística e Aplicações, Faculdade de Ciências, Universidade de Lisboa, Portugal

ARTICLE INFO

Available online xxxx

Keywords:
ECG Normal limits
Electrocardiogram
Cardiology
Angola
Heart function tests
Electrodiagnosis

ABSTRACT

Introduction: Studies on the normal electrocardiogram limits in African populations are limited, especially in sub-Saharan Africa. There is no literature describing normal ECG limits in Angolans.
Objectives: The aim of this study is to establish the normal ECG limits for adult Angolans, without established heart disease, stratified by gender and age.
Methods: A cross-sectional study was performed, involving 2179 participants from a population in northern Angola, without established heart disease, aged between 15 and 74 years. A 12-lead ECG and a rhythm strip were recorded for all participants and analysed and processed by the University of Glasgow software and encoded by the Minnesota Code. The normal range of the electrocardiographic parameters were established as the 2nd and 98th percentiles of the measurement distribution per age group and gender. Mann-Whitney and Kruskal-Wallis tests were used for two independent groups and Bonferroni adjustments were used for multiple testing. GAMLSS models were used to obtain the continuous age-dependent percentile curves.
Results: The *normal range of the ECG* differed between men and women: heart rate 49 to 100 bpm vs. 55 to 108 bpm, P wave duration 81 to 130 ms vs. 84 to 130 ms, PR interval 119 to 210 ms vs. 120 to 202 ms, QRS duration 74 to 110 ms vs. 70 to 104 ms, QT interval 324 to 441 ms vs. 314 and 438 ms, P-wave axis − 29 to 85^0 vs. -18 to 81^0, QRS-wave axis − 13 to 85^0 vs. -18^0 and 82^0, T-wave axis 0 to 72^0 vs. -8 to 73^0, Sokolow-Lyon index 2.13 to 6.21 mV vs. 1.60 to 4.87 mV, Cornell index 0.17 to 6.24 mV vs. 0.14 mV to 4.35 mV.
Conclusions: The values described for the electrocardiographic measurements above can act as a reference framework for Angolan adults without established heart disease. Our study suggests that the *normal range* of most ECG parameters vary according to age and sex and the ECG diagnostic criteria must therefore be specific for these demographic measures.
© 2020 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Introduction

The importance of applying the electrocardiogram (ECG) to medicine was established with its first description by the Dutch physiologist Willem Einthoven in 1902. This discovery brought about a great advance and an innovative resource for the study of heart disorder related issues and generated great advantages in terms of costs, diagnostic accessibility in addition to better accuracy and precision [1,2].

The usefulness of the ECG extends beyond clinical situations as its low cost enables its application in epidemiological studies with important prognostic purposes [3].

The first epidemiological studies deploying the ECG as a research tool began in the 1940s with the evaluation of a cohort of cardiovascular epidemiology studies [4]. Several methodological and technological advances have since occurred which offered access to the ECG, which is an important and widely used tool in population studies, with obvious value for identifying electrocardiographic changes predicting major cardiovascular events [5].

Several studies have highlighted the effects of age, sex and race on electrocardiographic parameters [6–10]. However, there is a scarcity of studies on normal ECG limits in African populations, especially in sub-Saharan Africa (SSA). A literature review revealed only two references to ECG findings in SSA using automated methods. Zerkiebel et al. (2000), in a study conducted in the Seychelles Islands, included 709 black individuals (343 males and 366 females) between 25 and 64 years of age to establish reference values for ECG findings in a

* Corresponding author at: Centro de Investigação em Saúde de Angola (CISA), Caxito, Bengo, Angola.
E-mail address: miguel.brito@estesl.ipl.pt (M. Brito).

https://doi.org/10.1016/j.jelectrocard.2020.10.011
0022-0736/© 2020 The Author(s). Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

population of African descent before suggesting the need to consider gender, age and ethnicity whenever interpreting electrocardiographic tracings [11]. In another study, Katibi et al. (2013) analysed 1261 Nigerian individuals (782 male and 479 female) aged between 20 and 87 in order to conclude both that the study allowed for the determination of the normal ECG limits in this population and the continuing need to evaluate the differences in comparison with other racial groups to improve the analysis and automation of the ECG reports in Africans [12].

There is no information available in the medical literature on the parameters of electrocardiographic normality in Angolans. Although there are some data on some African populations, local studies are needed in keeping with the variations in environmental, genetic and behavioural conditions across the different population groups.

An epidemiological study - the CardioBengo Study – seeking to analyze cardiovascular risk factors in an adult population in Bengo province, Angola, served to evaluate the sociodemographic, behavioural and physical characteristics associated with cardiovascular risk factors [13]. Deploying the same collected data, the present study aims to establish the normal limits (NL) for the ECG in Angolans, without established heart disease, stratified by gender and age, through recourse to automated electrocardiographic analysis methods.

Methods

Study design and data collection

This study analysed data from a population sample drawn from the municipality of Dande, in the northern Angolan province of Bengo, located 60 km north of the national capital, Luanda, with a total population of around 356,000 individuals. This was a cross-sectional community-based survey conducted between September 2013 and March 2014 in an area covered by the Dande Health and Demographic Surveillance System (Dande-HDSS).

A stratified sample by gender and age was randomly selected from a list of 3515 black individuals between 15 and 74 years of age. A total of 2576 individuals were analysed and with 76 individuals excluded due a lack of anthropometric measures alongside 116 pregnant women, 4 individuals without ECG and 211 individuals with cardiovascular disease, resulting in a database of 2169 individuals without any established cardiac disease [13,14]. Cardiovascular disease (CVD) was defined as any clinical history of heart failure, stroke, patients with ECG hypertension with minor and major abnormalities, ischaemic heart disease (previous coronary disease), and any major ECG alterations in accordance with the Minnesota Code.

This involved the decision to maintain patients with hypertension without any ECG alterations ($n = 389$), classified according to the Minnesota Code, following the precedent of a study conducted in Brazil [9]. Furthermore, the analyses were performed while both including and then excluding hypertensive participants in order to evaluate the impact of this pathology on electrocardiographic parameters.

The information and details regarding age, education, alcohol and tobacco consumption were collected through a structured interview conducted by trained and certified interviewers in accordance with the standardized protocol of the World Health Organization (WHO), based on the Surveillance Manual (STEPS) for Risk Factors for Chronic Diseases (central and expanded version 3.0) [15]. Moreover, blood pressure, glucose and cholesterol levels were also measured in addition to collating the anthropometric and the ECG data. The study protocol was previously described in detail [13].

The study considered the following risk factors for CVD: participants who reported being on some antihypertensive medication or who presented mean values of SBP ≥ 140 mmHg and/or DBP ≥ 90 mmHg were classified as hypertensive; participants with a defined diagnosis or treatment for diabetes or fasting glycemia>126 mg/dL or postprandial glycemia>200 mg/dL) were considered diabetic; participants with total cholesterol levels >240 mg/dL (6.2 mmol/L) or undergoing statin prescriptions were considered as having Hypercholesterolemia; participants with a body mass index ≥30 kg/m^2 were classified as obese; with participants who currently smoked as smokers.

ECG registration

A 12-lead electrocardiogram and a rhythm strip were recorded for all participants on a 12-channel AsCARD Mr.Grey V 201 electrocardiograph (ASPEL, Zabierzów, Poland). The examination was performed privately behind closed curtains, with the individual at rest, in a supine position, fully respecting the rights of participants to privacy. The exam was digitally recorded through recourse to cardio TEKA v001 database software (ASPEL, Zabierzów, Poland), and subsequently transferred to the Central Electrocardiography Laboratory at the University of Glasgow, where they were analysed and processed by the University of Glasgow software and coded according to the Minnesota Code (MC) [3,16].

For the present study, P, T and QRS complex durations, PR and QT intervals, and P, T and QRS complex wave axes were automatically measured. The QT interval was corrected by the Hodges, Bazett, Fridericia and Framinghan formula [17–20]. The Sokolow-Lyon (S-L) index (SV1 or SV2 + RV5 or V6) was calculated, and considering left ventricular hypertrophy (LVH) whenever determining an index of ≥3.5 mV or 35 mm, as well as the Cornell Index (S in V3 + R in aVL), for hypertrophy when ≥2.8 mV in males and ≥ 2.0 mV for females [21].

The MC classified the electrocardiograms as presenting major, minor alterations or an absence of abnormalities [16]. Thus, this took into account the following important changes: major Q waves (old myocardial infarctions, MC 1–1, 1–2), minor Q waves plus ST-T abnormalities (possible old myocardial infarction MC 1–3 plus MC 4–1, 4–2, 5–1, or 5–2), major isolated ST-T abnormalities (MC 4–1, 4–2, 5–1, or 5–2), left ventricular hypertrophy plus ST-T abnormalities (MC 3–1 plus MC 4–1, 4–2, 5–1, or 5–2), intraventricular conduction abnormalities (complete/intermittent right and left bundle branch block, nonspecific intraventricular block, MC 7–1, 7–2, or 7–4), right bundle branch block plus left anterior divisional block (MC 7–8), the Brugada Pattern (MC 7–9), atrial fibrillation/flutter (MC 8–3), atrioventricular conduction abnormalities (second- and third-degree atrioventricular block) (MC 6–1, 6–2), ventricular pre-excitation, such as Wolff Parkinson White syndrome (MC 6–4), artificial pacemaker (MC 6–8), supraventricular tachycardia (MC 8–4-2) and major QT prolongation index (QT index ≥116%) [16].

In order to ensure the quality of coding, the ECG tests classified as displaying major alterations were then manually reviewed by two cardiologists.

Statistical analysis

The data were analysed according to gender and/or age group stratification (establishing the following age ranges in years: 15–29, 30–44,44–59, ≥ 60). Data were presented as mean ± standard deviation (SD) and proportions, as appropriate. The normal parameter limits adopted were the 2nd and 98th percentiles of the measurement distribution per gender and/or age groups. The median values were also calculated with the Mann-Whitney and Kruskal-Wallis tests applied whenever comparing medians between two or more than two independent groups, respectively. A *t*-test was run to compare the means between two independent groups. Comparing the proportions between two independent groups involved calculating the difference between two independent proportions of the population tested. Bonferroni adjustments served for multiple testing. To analyze for the impact of the presence of individuals with hypertension within the normal limits, the same statistical analysis was carried out with and without these individuals. Continuous age-dependent percentile curves were obtained through applying Models for Location, Scale and Shape (GAMLSS). The model parameters were evaluated according to their

Box–Cox–Cole–Green, Log Normal, Box-Cox-Power-Exponential and ex-Gaussian distributions. The parsimonious models were selected according to the Schwarz Bayesian Criterion. Furthermore, the goodness of fit was examined through consulting the normal Q–Q plots, worm plots and plots of residual regression. The significance threshold was set at 0.05 and all the statistical analyses adopted were implemented through the open-source R software (version 3.6.2, www.r-project.org), the gamlss library and IBM SPSS® version 26.

Ethical concerns

The study was approved by the Independent Ethics Committee of the Angolan Ministry of Health and by the independent ethics committee of the Faculty of Medicine of the Agostinho Neto University. Written informed consent was obtained from all participants prior to data collection in keeping with all human research standards under the Helsinki declaration.

Results

Demographic, clinical and biological characterization of the sample

Table 1 sets out the physical, demographic, hemodynamic and biochemical characteristics of the 2169 individuals (815 males and 1354 females). Considering all participants, the mean age was 33.6 ± 14 years (ranging from 15 to 74 years of age), with the largest proportion in the 15–29 age group, accounting for 48.7% with the ≥60 years as the least represented age group, representing 4.7%. (See Figs. 1 and 2.)

Compared to men, women displayed significantly higher mean values of age, body mass index, hip circumference, waist circumference, heart rate, blood pressure (diastolic, mean and pulse pressure) and total cholesterol; whereas men returned higher systolic blood pressure, weight, height and level of blood glucose.

Regarding cardiovascular risk factors, the results identify how women had significantly higher proportions of hypertension, obesity and hypercholesterolemia than men while the latter also accounted for a higher proportion of smokers. There were no significant differences in other characteristics.

Table 1
Demographic, physical, hemodynamic, biochemical and prevalence of cardiovascular risk factors in the studied population, according to gender and total (mean ± SD for continuous parameters, % for categorical parameters).

Parameters	Male n = 815	Female n = 1354	p	Total n = 2169
Age groups				
15–29 years	59.7%	42.8%	<0.001*	48.7%
30–44 years	22.6%	29.1%	0.004*	26.6%
45–59 years	14.1%	23.3%	<0.001*	19.9%
≥ 60 years	4.7%	4.8%	0.999*	4.7%
Physical characteristics				
Age (years)	31.0 ± 13.6	35.1 ± 14.0	<0.001**	33.6 ± 14.0
Body weight (kg)	60.2 ± 11.1	57.2 ± 12.8	<0.001**	58.3 ± 12.3
Height (cm)	166.0 ± 6.9	156.0 ± 6.4	<0.001**	160.0 ± 8.3
BMI (Kg/m^2)	22.2 ± 6.9	23.7 ± 6.1	<0.001**	23.0 ± 6.4
Waist circumference (cm)	74.8 ± 9.1	78.8 ± 13.0	<0.001**	77.3 ± 11.8
Hip circumference (cm)	90.4 ± 7.6	94.9 ± 10.4	<0.001**	93.2 ± 9.7
HWR	0.8 ± 0.1	0.8 ± 0.1	0.691**	0.8 ± 0.1
Hemodynamic characteristics				
SBP (mmHg)	118.6 ± 16.4	113.8 ± 19.8	<0.001**	115.6 ± 18.7
DBP (mmHg)	73.1 ± 11.9	74.9 ± 12.9	0.002**	74.2 ± 12.5
PP (mmHg)	39.7 ± 10.9	42.7 ± 11.7	<0.001**	41.6 ± 11.5
MBP (mmHg)	85.8 ± 12.7	89.5 ± 14.4	<0.001**	88.1 ± 13.9
HR (bpm)	74.1 ± 34.6	81.5 ± 37.4	<0.001**	78.4 ± 36.5
Biochemical characteristics				
Glycemia (mg/dL)	115.5 ± 64.8	111.2 ± 40.7	<0.001**	112.8 ± 51.1
Total cholesterol (mg/dL)	169.9 ± 29.4	182.1 ± 30.1	<0.001**	177.9 ± 30.4
Prevalence of risk factors (%)				
Hypertension (%))	12.4	13.9	<0.001***	13.3
Diabetes (%)	9.5	8.8	0.583***	9.1
Hypercholesterolemia (%)	1.4	4.8	<0.001***	18.6
Obesity (%)	2.7	10.4	<0.001***	7.5
Smoking	10.5	2.2	<0.001***	5.3

BMI - Body mass index; HWR - Hip waist ratio; SBP - Systolic blood pressure; DBP - Diastolic blood pressure; PP - Pulse pressure; MBP - Mean blood pressure; HR - Average heart rate; bpm - beats per minute

* Test for the difference between two independent population proportions, *P*-values adjusted by the Bonferroni method.

** *t*-test for independent populations.

*** Test for the difference between two independent population proportions.

Electrocardiographic parameters

Table 2 details the ECG parameters by gender and Table 3 conveys the normal (2nd and 98th) percentile limits and the ECG median parameters according to gender and age.

Women showed higher median heart rate values, as well as the QT interval corrected by the Hodges, Bazzet, Fridericia and Framinghan formula, while men displayed a higher QRS interval, P, T and QRS wave axes as well as higher results for the S-L and Cornell indexes. The P wave duration and PRI were similar for both sexes.

The previous results for the electrocardiographic parameters were then compared with the normal limits obtained when individuals with hypertension but without ECG alterations and not hypertensive were removed from the samples but leading to the results remaining the same (supplemental table 1A).

There was a 13.3% proportion of hypertensive patients in the study without ECG alterations and thus it was decided to retain these participants in the analysis. The electrocardiographic parameters obtained for participants when those with hypertension are excluded very closely resemble the general group and as demonstrated in supplemental table 1A.

Discussion

This study analysed data from the population in the municipality of Dande, in the northern Angolan province of Bengo. This province, with a total population of around 356,000 individuals, represents only 1.4% of the total Angola inhabitants even though the Dande-HDSS data [22] curiously reflects the 2014 national demographic structure of Angola correspondingly reflecting a young population. The average age was 20.6 years, with 50.3% of the population aged 15 to 64 years and only 2.4% of the population aged 65 or older. Moreover, 52% of the population was female and with 68% resident in urban areas [22].

The results of this study demonstrate significant differences by gender and age across most of the ECG parameters analysed. They report higher median HR values in females, which decreased with age in both genders. Our results are consistent with the findings of the study of black individuals living in Africa [11,12], in Chinese [23] and in Dutch individuals [24] but with slightly higher HR values in males and significantly higher in females when compared to black Brazilian individuals [9]. Some authors argue that a lower HR in males derives from the higher average rate of physical activity generally found in males than in females, resulting in better cardiovascular conditioning while others argue that, in addition to physical activity, this phenomenon is associated with other factors such as sympathetic and parasympathetic activity [25,26].

Regarding the P wave and PRI durations, these returned similar values for males and females; however, these results differ from the findings of other studies, which revealed longer P wave and PRI durations in males [9,11,12,23,24,27]. Our results identify an increase in the duration both of the P wave and of PRI over age in males and

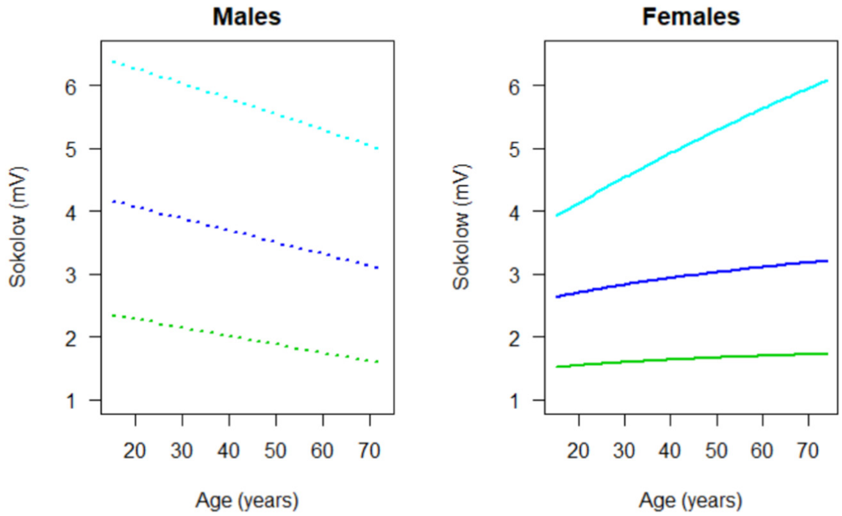

Fig. 1. Continuous age-dependent percentile curves by gender for the Sokolow parameter (the lower, middle and upper curves represent the 2th, 50th and 98th percentiles, respectively).

females, which aligns with most published studies [9,11,12,23–25]. This study found that the P wave duration was 10 ms higher than the conventionally defined normal limit value of 120 ms, although within the limits mentioned in previous studies [28].

The PRI median was found to increase gradually with advancing age, especially in males, while PRI increases correspond with reductions in HR. PRI should therefore be analysed with particular attention as the normal upper limit obtained in the present study varied within the percentiles, with values above those traditionally defined (200 ms) and that constitute the cut-off point for the detection of first-degree atrioventricular block. These values were comparable to those reported for another African population and a black population sample in Brazil [9,11,29].

The median duration of the QRS complex emerged as higher in males, which is in agreement with most existing studies, and with a slight increase over age in females but remaining stable throughout age in males [9,11,12,23,24,27].

In this study, the upper limit of the normal QRS duration stood at about 110 ms. Males had a longer QRS complex duration of about 4 ms than females across all age groups. For a long time, it was thought this stemmed only from the larger cardiac dimensions of males but one study demonstrated how the increase in voltage and duration of the QRS complex does not only relate to left ventricular mass but also to changes in the electrophysiological properties of the myocardium [30].

The median QTI duration was 377 ms and slightly higher in females, without any statistically significant differences, and with a slight increase in QTI over age in both genders. These results agree with most existing studies [12,23,24,31]. The upper QTI limit was 441 ms for both sexes. In addition, the duration of QTI is usually normalized by the heart rate. QTIc was calculated according to four different correction formulas and with the results consistently higher than those for QTI, which results from median heart rates higher than the 60 bpm standard. In the QTIc tests made according to the Hodges, Bazett, Fridericia and Framingham formula, NL levels were higher in females with statistically significant differences. There was an increase in QTIc over age in both genders with these results corroborating most existing studies [11,12,18–20].

Correcting QTI by the Bazett formula, the most widely used approach, in this study returned results registering normal range for Bazett formula QTIc duration of 359 ms - 445 ms in males and 371 ms - 462 ms in females, which are values within the traditionally established limits (340 ms - 450 ms in males and 340–470 ms in

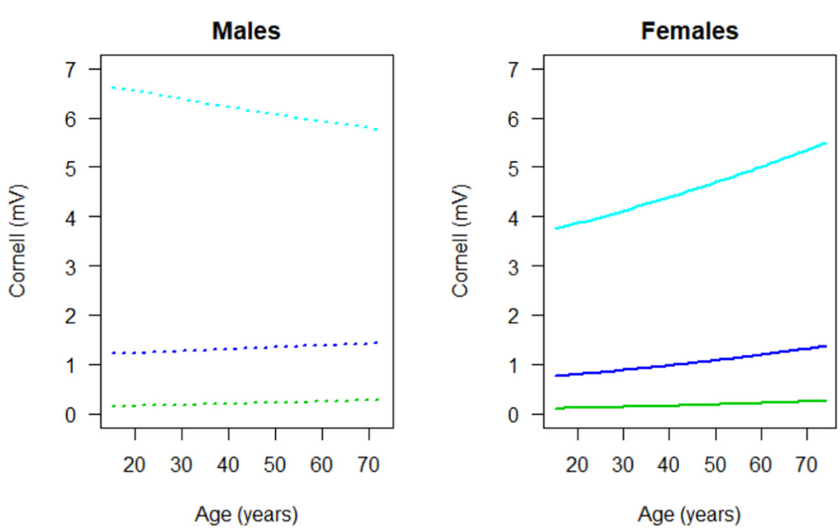

Fig. 2. Continuous age-dependent percentile curves by gender for the Cornell Index (lower, middle and higher curves represent the 2nd, 50th and 98th percentiles, respectively).

Table 2
Normal limits for ECG parameters according to gender: median (percentiles 2 and 98).

Parameters	Male	Female	p*
HR (bpm)	67 (49, 100)	74 (55, 108)	<0.001
P wave duration (ms)	108 (81, 130)	108 (84, 130)	0.204
PRI duration (ms)	152 (119, 210)	152 (120,202)	0.385
QRS duration (ms)	90 (74, 110)	85 (70, 104)	<0.001
QTI (ms)	376 (324, 441)	378 (314, 438)	0.582
QTIc, Hodges (ms)	392 (360, 434)	404 (367, 443)	<0.001
QTIc, Bazett (ms)	401 (359, 445)	418 (371, 462)	<0.001
QTIc, Fridericia, (ms)	392 (361, 434)	404 (363, 446)	<0.001
QTIc, Framinghan, (ms)	393 (358, 433)	404 (366, 445)	<0.001
P-wave axis (^{0})	63 (−29, 85)	59 (−18, 81)	<0.001
QRS axis (^{0})	51 (−13, 85)	48 (−18, 82)	<0.001
T-wave axis (^{0})	45 (0, 72)	41 (−8; 73)	<0.001
Sokolow-Lyon Index (mV)	3.86 (2.13, 6.21)	2.87 (1.60, 4.87)	<0.001
Cornell Index (mV)	1.27 (0.17, 6.24)	0.930 (0.14, 4.35)	<0.001

HR - Heart rate; bpm - beats per minute; PRI - PR interval; QTI - QT interval; QTIc - QT interval corrected; Sokolow-Lyon index (SV1 or SV2 + RV5 or V6), Cornell Index (S in V3 + R in aVL).
* P-values obtained by the Mann-Whitney test.

females) [32,33]. The Bazett formula medians in both genders were higher than the remaining QTI correction formulas. Luo et al. compared the different QTIc correction formulas and concluded that Bazett's correction systematically differed to other formulas, specifically those of Hodges, Fridericia and Framingham that report very similar medians to each other and in agreement with other existing studies [23,24,27,34].

The median P-wave axis was higher in males with ageing bringing about an increase in both genders. The normal range for the P wave axis ranged between -29^0 and 85^0 in males, and -18^0 and 81^0 in females with these values in line with the findings of Katibi et al. and Rijneebek et al., who reported values very approximate to those of this study [12,24]. Pinto Filho et al. and Zerkiebel et al. found lower P wave limits that differed to those found in this study [9,11].

The median QRS axis was higher among males, with a slight increase in older males and a slight decrease in older females. The QRS axis NL ranged between -13^0 and 85^0 in males, and −18° and 82° in females with the lower limits of the male QRS axis significantly different than those in the Nigeria study in which the QRS axis limits ranged from −38° to 94° in males and from −21° to 81° in females and different to the results of the Seychelles study that encountered limits of −25° to 80° in males and − 23° to 71° in females as well as the Brazilian black population results of −41° to 82° in males and − 24° to 80° in females [9,11,12]. Our results demonstrate how 0.9% of participants had superiorly directed QRS axes.

The median T-wave axis was higher in males and registered a slight increase in older individuals in both sexes. The T-wave normal range varied between 0 ^{0} and 72^0 in males, and − 8^0 and 73^0 in females with these values corroborating the findings of Katibi et al. while differing from those of Zerkiebel et al., and Pinto Filho et al. in which the lower limits differed significantly to those in this study [9,11,12].

Regarding the S-L index, the median was higher in males, with a marked decrease over age in males but increasing over age in females., which agree with other existing studies [11,12,24]. The most commonly used criterion for determining LVH is the S-L ≥ 3.5 mV index [21]. In this study, the normal range varied between 2.13 mV and 6.21 mV in males and 1.60 mV and 4.87 mV in females. The upper limits were therefore extremely high in both sexes. These results align with both those returned by Zerkiebel et al., who reported found normal S-L limits of 2.04 mV and 5.70 mV in males and 1.61 mV and 4.23 mV in females [11], and by Katibi et al., who also recorded excessively high normal upper S-L limits, especially in females [12]. Our results thus differed from the studies by Wu et al., Macfarlane et al. and Rijnbeek et al. that presented significantly lower values [23,24,31]. The prevalence of LVH in this study in accordance with the S-L index was 64% in males and 19% in females. These results therefore lead us to reinforce the position that the LVH criteria in a black population cannot be the same as in Caucasian and Asian populations whenever applying the S-L index.

Regarding the Cornell index, the median was higher in both sexes ($p < 0.0001$), with a slight decrease in the upper limit of normality throughout age in males while increasing over age in females. The LN ranged between 0.17 mV and 6.24 mV in males and 0.14 mV and 4.35 mV in females. These results contain extremely high upper limits, and differed from the findings of Zerkiebel et al., who recorded normal range between 0.79 mV and 3.29 mV in men and 0.48 mV and 2.70

Table 3
Normal ECG parameter limits according to gender and age group: median (percentiles 2 and 98).

Parameters	Gender	Age Class (years)			
		15–29 (n = 1057)	30–44 (n = 578)	45–59 (n = 431)	≥60 (n = 103)
HR (bpm)	Male	66 (47, 104)	69 (49, 104)	67 (46, 96)	70 (43, 93)
	Female	75 (55, 112)	75 (54, 108)	71 (52, 100)	71 (51, 112)
P wave duration (ms)	Male	106 (81, 129)	112 (71, 133)	112 (69,135)	112 (84,134)
	Female	106 (81, 126)	110 (84, 132)	110 (84, 136)	112 (72, 135)
PRI duration (ms)	Male	150 (118, 210)	152 (120, 219)	158 (120, 204)	153 (118, 205)
	Female	148 (118, 194)	156 (120, 208)	156 (120, 207)	152 (119, 237)
QRS duration (ms)	Male	90 (74, 110)	90 (72, 110)	90 (74, 109)	88 (70, 110)
	Female	84 (70, 102)	86 (70, 104)	86 (70, 106)	86 (61, 105)
QTI (ms)	Male	374 (321, 435)	378 (325, 431)	384 (331, 455)	381 (342, 486)
	Female	370 (310, 427)	376 (317, 438)	388 (338, 455)	394 (299, 459)
QTIc, Hodges (ms)	Male	389 (358, 429)	395 (358, 425)	398 (371, 444)	400 (371, 459)
	Female	399 (363, 432)	405 (368, 441)	408 (372, 455)	411 (352, 458)
QTIc, Bazett (ms)	Male	397 (355, 444)	406 (361, 444)	408 (370, 457)	413 (365, 454)
	Female	415 (366, 455)	421 (377, 461)	423 (374, 468)	425 (361, 489)
QTIc, Fridericia, (ms)	Male	389 (358, 431)	396 (356, 425)	399 (370, 441)	401 (369, 445)
	Female	398 (363, 431)	406 (364, 446)	410 (370, 456)	412 (344, 464)
QTIc, Framinghan (ms)	Male	390 (357, 432)	397 (360, 425)	401 (371, 440)	403 (367, 443)
	Female	400 (365, 431)	407 (369, 443)	410 (373, 455)	413 (352, 460)
P-wave axis (^{0})	Male	60 (−46, 83)	66 (−3, 82)	66 (−30, 85)	65 (−12, 93)
	Female	54 (−31, 82)	61 (−10, 80)	63 (−4, 82)	62 (−7, 83)
QRS axis (^{0})	Male	55 (−6, 89)	44 (−16, 81)	44 (−21, 81)	47 (−32, 79)
	Female	53 (−4, 85)	47 (−16, 80)	37 (−21, 75)	31 (−56, 74)
T-wave axis (^{0})	Male	46 (6, 71)	43 (−10, 71)	47 (−1, 76)	46 (−16, 72)
	Female	40 (−9, 69)	39 (−11, 70)	44 (−1, 74)	45 (−70, 125)

HR - Heart rate; bpm - beats per minute; ms - milliseconds; PRI – PR interval; QTI – QT interval; QTIc - QT interval corrected.

mV in women [11]. The results also revealed upper Cornell limits with extremely high values compared to other existing studies [12,23,24,31]. According to the Cornell index, the prevalence of LVH in this study stood at 12% in males and 11.4% in females.

Most existing studies exclude patients with hypertension from their analysis [12,23,24,27]. The decision in this study was taken to retain hypertensive patients without ECG alterations in keeping with a study conducted in Brazil. Undertaking the same analytical procedures after excluding hypertensive individuals did not generate any significant differences for the measurements evaluated, thus corroborating the study conducted by Pinto Filho et al. (2017) [9].

The changes occurring in the ECGs for more elderly individuals remains a matter still under study even though there is a perception that the mechanisms underpinning the basis of these transformations, stem the variable topography of the heart in relation to the thorax and diaphragm, other changes in the constituents of volume and conductor (skin, subcutaneous fat, pulmonary parenchyma) and also due to changes in cardiac configuration and intracardiac conduction [35].

This correspondingly highlights an important limitation of this dataset; the lack of representativeness of the over 64 years of age group. This stems from the methodological choices made in the setup of the CardioBengo study and the intent to include younger individuals for future follow-up surveys [13]. Therefore, this study contains other strengths: 1) it is one of the first population-based studies carried out in Angola with a randomly selected and representative sample; 2) it represents the largest study to date establishing normal ECG limits for an autochthonous population of sub-Saharan Africa through recourse to automated analysis methods; 3) the ECG collection and recording procedures were standardized and did not vary throughout the study as they were performed by a single trained technician and with the examinations digitally recorded with reliable database software.

Conclusions

This is a pioneering study in Angola and the largest study ever carried out on normal ECG limits in black individuals, living in Africa, without established heart disease, through recourse to automated analysis methods.

The present study presents an overview of normal ECG limits in a randomly selected African population. The values described for the electrocardiographic measurements can serve as a reference framework for Angolan adults without established heart disease.

Compared with other studies, the majority of the ECG parameters analysed in this research were identical, with the exception of the P wave and PR interval durations in which substantial variations occurred, as well as for the Sokolov-Lyon and Cornell measures in which the results of this study demonstrated significantly higher values in comparison with other studies.

The results of this study convey how gender determines changes in all the ECG parameters analysed, except for the P wave duration and the PR interval. As regards age, the results identify differences across all the age groups.

Declaration of Competing Interest

None.

Acknowledgments

We would thank all Dande - Health Demographic Surveillance System and Bengo General Hospital staff for their continuing support during the fieldwork, in particular Joana Paz and Ana Oliveira, who supervised this process, Eduardo Saraiva for data entry supervision and database management, Edite Rosário for training the field workers and assistance in data collection and, most importantly, the local administration alongside all of the individuals who agreed to participate in the study. Moreover, we would also like to thank Brian Devine Peter Macfarlane for support in ECG analysis and Mário Fresta for scientific support. We acknowledge the CISA promoters: Camões, Institute for Cooperation and Language, Calouste Gulbenkian Foundation, Angolan Ministry of Health, Bengo Provincial Government and the Ministry of Health of Angola, for their contribution in developing this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jelectrocard.2020.10.011.

References

[1] Barold SS. Willem Einthoven and the birth of clinical electrocardiography a hundred years ago. Card Electrophysiol Rev. 2003;7:99–104. https://doi.org/10.1023/A:1023667812925.

[2] Blackburn H, Keys A, Simonson E, Rautaharju P, Punsar S. The electrocardiogram in population studies. A classification system. Circulation. 1960. https://doi.org/10.1161/01.CIR.21.6.1160.

[3] Macfarlane PW, Oosterom A, van Pahlm O, Kligfield P, Janse MCJ. Comprehensive Electrocardiology. 2.a ed. London: Springer-Verlag; 2010.

[4] Dawber TR, Meadors GF, Moore FE. Epidemiological disease : the approaches to heart Framingham study. Am J Public Health. 1951;41. https://doi.org/10.2105/AJPH.41.3.279.

[5] Mozaffarian D, Benjamin EJ, Go AS, Arnett DK, Blaha MJ, Cushman M, et al. Heart disease and stroke statistics-2016 update a report from the American Heart Association. . 2016;133. https://doi.org/10.1161/CIR.0000000000000350.

[6] Macfarlane PW, McLaughlin SC, Devine B, Yang TF. Effects of age, sex, and race on ECG interval measurements. J Electrocardiol. 1994;27:14–9. https://doi.org/10.1016/S0022-0736(94)80039-1.

[7] Rautaharju PM, Zhou SH, Calhoun HP. Ethnic differences in ECG amplitudes in north American white, black, and Hispanic men and women. Effect of obesity and age. J Electrocardiol. 1994;27:20–31. https://doi.org/10.1016/S0022-0736(94)80040-5.

[8] Macfarlane PW, Katibi IA, Hamde ST, Singh D, Clark E, Devine B, et al. Racial differences in the ECG - selected aspects. J Electrocardiol. 2014;47:809–14. https://doi.org/10.1016/j.jelectrocard.2014.08.003.

[9] Pinto Filho MM, Brant LCC, Padilha-da-Silva JL, Foppa M, Lotufo PA, Mill JG, et al. Electrocardiographic findings in Brazilian adults without heart disease: ELSA-Brasil. Arq Bras Cardiol. 2017;109:416–24. https://doi.org/10.5935/abc.20170146.

[10] Santhanakrishnan R, Wang N, Larson MG, Magnani JM, Vasan RS, Wang TJ, et al. Racial differences in electrocardiographic characteristics and prognostic significance in whites versus Asians. J Am Heart Assoc. 2015;5:1–9. https://doi.org/10.1161/JAHA.115.002956.

[11] Zerkiebel N, Perret F, Bovet P, Abel M, Jaggy C, Paccaud F, et al. Electrocardiographic findings in a middle-aged African population in the Seychelles Islands. J Electrocardiol. 2000;33:1–15.

[12] Katibi I, Clark EN, Devine B, Lloyd SM, MacFarlane PW. Normal limits of the electrocardiogram in Nigerians. J Electrocardiol. 2013;46:289–95. https://doi.org/10.1016/j.jelectrocard.2013.04.002.

[13] Pedro JM, Rosário E, Brito M, Barros H. CardioBengo study protocol: a population based cardiovascular longitudinal study in Bengo Province, Angola. BMC Public Health. 2016;16. https://doi.org/10.1186/s12889-016-2759-9.

[14] Pedro JM, Brito M, Barros H. Prevalence, awareness, treatment and control of hypertension, diabetes and hypercholesterolemia among adults in dande municipality, Angola. Cardiovasc J Afr. 2018;29:73–81. https://doi.org/10.5830/CVJA-2017-047.

[15] World Health Organization. The STEPS Instrument and Support Materials; 2015.

[16] Prineas R, Crow RBH. The Minnesota code classification system = for electrocardiographic findings. Minnesota Code Man Electrocardiogr Find. 1982:1–3.

[17] Hodges M, Salerno DED. Bazett's QT correction reviewed. Evidence that a linear QT correction for heart is better. J Am Coll Cardiol. 1983;1:694.

[18] Bazett HC. An analysis of the time relations of electrocardiograms. Heart. 1920;7:353–70.

[19] Fridericia LS. Die systolendauer im electrokardiogramm bei normalenmenschen und bei herzkranken. Acta Med Scand. 1920;53:469–86.

[20] Sagie A, Larson MG, Goldberg RJ, Bengtson JR, Levy D. An improved method for adjusting the QT interval for heart rate (the Framingham Heart Study). Am J Cardiol. 1992 Sep 15;70(7):797–801 10.1016/0002-9149(92)90562-d.

[21] Casale PN, Devereux RB, Kligfield P, Eisenberg RR, Miller DH, Chaudhary BS, et al. Electrocardiographic detection of left ventricular hypertrophy: development and prospective validation of improved criteria. J Am Coll Cardiol. 1985;6:572–80. https://doi.org/10.1016/S0735-1097(85)80115-7.

[22] INE. Resultados definitivos do Recenseamento Geral da População e Habitação de Angola 2014; 2016.

[23] Wu J, Kors JA, Rijnbeek PR, Van Herpen G, Lu Z, Xu C. Normal limits of the electrocardiogram in Chinese subjects. Int J Cardiol. 2003;87:37–51. https://doi.org/10.1016/S0167-5273(02)00248-6.

[24] Rijnbeek PR, Van Herpen G, Bots ML, Man S, Verweij N, Hofman A, et al. Normal values of the electrocardiogram for ages 16-90 years. J Electrocardiol. 2014;47:914–21. https://doi.org/10.1016/j.jelectrocard.2014.07.022.

[25] Ryan SM, Goldberger AL, Pincus SM, Mietus J, Lipsitz LA. Gender- and age-related differences in heart rate dynamics: are women more complex than men? J Am Coll Cardiol. 1994;24:1700–7. https://doi.org/10.1016/0735-1097(94)90177-5.

[26] Parati G, Di Rienzo M. Determinants of heart rate and heart rate variability. J Hypertens. 2003;21:477–80. https://doi.org/10.1097/00004872-200303000-00007.

[27] Palhares DMF, Marcolino MS, Santos TMM, da Silva JLP, Gomes PR, Ribeiro LB, et al. Normal limits of the electrocardiogram derived from a large database of Brazilian primary care patients. BMC Cardiovasc Disord. 2017;17:1–23. https://doi.org/10.1186/s12872-017-0572-8.

[28] Caceres CA, Kelser GA. Duration of the normal P wave. Am J Cardiol. 1959;3:449–52. https://doi.org/10.1016/0002-9149(59)90365-0.

[29] Soliman EZ, Alonso A, Misialek JR, Jain A, Watson KE, Lloyd-jones DM, et al. Reference ranges of PR duration and P-wave indices in individuals free of cardiovascular disease : the multi-ethnic study of atherosclerosis (MESA). J Electrocardiol. 2013;46:702–6. https://doi.org/10.1016/j.jelectrocard.2013.05.006.

[30] Rodriguez-padial L, Bacharova L. Electrical remodeling in left ventricular hypertrophy — is there a unifying hypothesis for the variety of electrocardiographic criteria for the diagnosis of left ventricular hypertrophy ? J Electrocardiol. 2012;45:494–7. https://doi.org/10.1016/j.jelectrocard.2012.06.003.

[31] Macfarlane PW, Lloyd SM, Singh D, Hamde S, Clark E, Devine B, et al. Normal limits of the electrocardiogram in Indians. J Electrocardiol. 2015;48:652–68. https://doi.org/10.1016/j.jelectrocard.2015.04.013.

[32] Camm AJ, Marik MYY. Acquired long-QT syndrome. Massachusetts: Blackwell Publishing; 2004.

[33] Rautaharju PM, Surawicz B, Gettes LS. AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram: part IV: the ST segment, t and u waves, and the QT interval: a scientific statement from the American Heart Association electrocardiography and arrhythmias C. Circulation. 2009;119:241–51. https://doi.org/10.1161/CIRCULATIONAHA.108.191096.

[34] Luo S, Michler K, Johnston P, Macfarlane PW. A comparison of commonly used QT correction formulae : the effect of heart rate on the QTc of Normal ECGs. J Electrocardiol. 2004;37. https://doi.org/10.1016/j.jelectrocard.2003.08.030.

[35] Bourdillon PJ, Dawson D, Ritsema van Eck HJ, Gorter S. Classification of the sex of healthy and abnormal subjects using the electrocardiogram. Comput Cardiol. 1975:55–7.