Received: 11 November 2018 | Revised: 15 December 2018 | Accepted: 28 December 2018
DOI: 10.1111/anec.12634

ORIGINAL ARTICLE

WILEY

A Population-wide study of electrocardiographic (ECG) norms and the effect of demographic and anthropometric factors on selected ECG characteristics in young, Southeast Asian males—results from the Singapore Armed Forces ECG (SAFE) study

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Abstract

Background: Routine use of pre-participation electrocardiograms (ECGs) has been used by the Singapore Armed Forces, targeting early detection of significant cardiac diseases. We aim to describe the impact of demographic and anthropometric factors on ECG variables and establish a set of electrocardiographic reference ranges specific to a young male multiethnic Southeast Asian cohort.

Methods and results: Between November 1, 2009, and December 31, 2014, 144,346 young male conscripts underwent pre-participation screening that included a 12-lead ECG, demographic and anthropometric measurements. The Chinese population had the longest PR interval (146.7 ± 19.7 vs. 145.21 ± 19.2 in Malays vs. 141.2 ± 18.8 ms in Indians), QRS duration (94.5 ± 9.8 vs. 92.6 ± 9.7 in Malays vs. 92.5 ± 9.4 ms in Indians) and QTcB interval (408.3 ± 21.3 vs. 403.5 ± 21.6 in Malays vs. 401.2 ± 21.4 ms in Indians) (all $p < 0.001$). Body mass index (BMI) >25 kg/m^2 and body fat >25% were independently associated with lower prevalence of increased QRS voltage on ECG. Systolic blood pressure of >140 mmHg or diastolic blood pressure of >90 mmHg independently increased the prevalence of increased QRS voltage on ECG.

Conclusions: Electrocardiographic parameters vary across different ethnicities and in comparison with international norms. In our population, diagnosis of increased QRS voltage by ECG is less prevalent with obesity and increased body fat. Further analysis of gold standard measurements for the diagnosis of LVH in our population is ongoing, to improve the accuracy of the ECG screening process.

KEYWORDS
anthropometric, electrocardiogram, male, norms

1 | INTRODUCTION

The role of routine electrocardiography (ECG) in pre-participation screening remains contentious (Baggish, 2015; Maron et al., 2014; Mont et al., 2017; Yeo and Sharma, 2016). Early detection of preexisting cardiac conditions that predispose individuals to sudden cardiac death remains key to creating a safe training environment for vigorous physical exertion. This is even more vital in a country like Singapore where conscription is mandatory for all able-bodied Singaporean males in determining fitness for participation in military training.

The Singapore Armed Forces (SAF) has used the routine use of ECGs as part of its cardiovascular screening system since 2008 (Ng et al., 2012). This was based on an Italian pre-participation cardiovascular screening system proposed by Corrado et al. (Corrado et al., 2005). ECG screening is, however, influenced by a myriad of factors including demographics, anthropometrics and level of physical fitness. Different groups of authors have established that population-specific reference ranges exist among distinct population groups (Chen et al., 1989; Dewhurst et al., 2014; Katibi et al., 2013; Khumrin et al., 2015; Macfarlane et al., 2015, 2010; Mason et al., 2007; Palhares et al., 2017; Rijnbeek et al., 2014; Wu et al., 2003; Zhou et al., 2009). This underscores the fundamental principle that effective ECG screening needs to be based on population-specific reference ranges, with an eventual view to developing population-specific screening criteria to optimize pre-participation screening.

We aim to describe the impact of demographic and anthropometric factors on ECG variables and establish a novel set of electrocardiographic reference ranges specific to a population-wide young male multiethnic Southeast Asian cohort.

2 | METHODS

2.1 | Subjects and screening process

Singapore Armed Forces ECG (SAFE) study is a retrospective cohort study comprising 144,346 young male conscripts who completed pre-participation medical screening between November 1, 2009, and December 31, 2014. Singapore is a multiethnic nation in which conscription (National Service) is a statutory requirement for all able-bodied Singaporean males. Prior to conscription, all individuals undergo pre-participation screening at a single centralized medical screening facility manned by military doctors. The pre-participation screening consisted of a detailed medical and family history, clinical examination, chest radiograph, blood pressure and body fat percentage measurement via bioelectric impedance analysis. Baseline demographic, anthropometric and clinical data were captured on an electronic medical records system.

2.2 | Measurements of 12-lead body surface resting ECG

A standard 12-lead resting ECG was performed by trained personnel with the subject in supine position using the Philips PageWriter TC70 ECG machine at a sampling rate of 500 Hz. Electronic ECG parameters were captured using a proprietary Philips^{TM} modular ECG analysis system, in accordance with international standards (Zhou et al., 2009). Specific ECG variables of interest captured included: ECG axis, PR interval, QRS duration, QT interval corrected by Bazett's formula (QTcB) (Bazett, 1997), QT interval corrected by Fridericia's formula (QTcF) (Fridericia, 1920) and P-, R- and S-wave amplitudes in all leads. All ECGs were reviewed manually by a trained military doctor at the time of acquisition. ECGs that were technically unsatisfactory (e.g., motion artifact and limb lead misplacement) were discarded, and a repeat ECG was performed until it is deemed to be satisfactory and interpretable by the trained military doctor.

2.3 | ECG Criteria for LVH

Electrocardiographic LVH was diagnosed according to different criteria, as suggested by 2013 ESH/ESC guidelines (Sokolow and Lyon, 1949). The Sokolow–Lyon criterion was defined as $SV_1 + RV_{5/6} > 3.5$ mV (Sokolow and Lyon, 1949). The Corrado criterion was defined as an amplitude of R or S wave in a standard lead ≥2 mV, $S_{V1/V2}$ ≥3 mV or $R_{V5/6}$ ≥ 3 mV (Corrado et al., 1998). The Cornell product was defined as the product of the value of $S_{V3} + R_{aVL}$ and the QRS duration. A value greater than 2,440 mVms was taken as positive (Molloy et al., 1992). Romhilt–Estes score was calculated from six ECG features with different points assigned to the various features: R or S wave in any limb lead ≥2 mV or $S_{V1/2}$ ≥ 3 mV or $R_{V5/6}$ ≥ 3 mV (3 points); P terminal force in V1 ≥0.1 mV in depth and ≥0.04 ms (3 points); left ventricular strain defined as ST segment and T-wave changes in the opposite direction to QRS in V5/6 without digitalis (3 points); left axis deviation with QRS axis ≤-30 degrees (2 points); QRS duration ≥0.09 ms (1 point); intrinsicoid deflection in V5/6 ≥ 0.05 ms (1 point) (Romhilt and Estes, 1968).

2.4 | Statistical analysis

Statistical analysis was performed with SPSS statistical software version 20.0 (SPSS Inc., Chicago, IL, USA), and a *p* value of <0.05 was considered to be significant. Continuous variables are expressed as mean and standard deviation or median and the 2nd and 98th percentiles; categorical variables are expressed as absolute numbers and percentages. Numerical predictors were analyzed by using 2-sample *t* test or Mann-Whitney *U* test where applicable. Categorical variables were evaluated using chi-square test or Fisher's exact test where applicable. Variables that were found to have a significant association ($p < 0.05$) were entered into the multivariable model to perform backward stepwise logistic regression to determine the associations of demographic data with an ECG diagnosis of left ventricular hypertrophy (LVH). Associations are presented as odds ratios (OR) with corresponding 95% confidence intervals (CIs).

3 | RESULTS

3.1 | Baseline demographics

A total of 144,346 male conscripts were screened from November 1, 2009, to December 31, 2014. The ethnicity distribution of the conscripts was consistent with the national population as follows: Chinese 72.2% (n = 104,223), Malay 17.6% (n = 25,405), Indian 8.2% (n = 11,865) and others (such as those of Eurasian and Caucasian descent) 2.0% (n = 2,853). The mean age of the population was 18.5 ± 1.2 years (range: 16–37 years). To study the effects of age on the ECG parameters, we compared the parameters across tertiles of age. While there was a statistically significant difference, the absolute interval differences were less than 3 ms and were hence deemed not to be clinically significant as this is practically indistinguishable on the electrocardiogram. Baseline demographics of all conscripts stratified by ethnicity are reflected in Table 1. Of the anthropometric data accrued, the Chinese had significantly lower body mass index (BMI), and Indians, the highest body fat percentage. Mean heart rate, systolic and diastolic blood pressures were similar across the different ethnic groups.

3.2 | Clinical associations with ECG parameters

3.2.1 | Ethnicity

The Chinese population had the longest PR interval (146.7 ± 19.7 vs. 145.2 ± 19.2 in Malays vs. 141.2 ± 18.8 ms in Indians), QRS duration (94.5 ± 9.8 vs. 92.6 ± 9.7 in Malays vs. 92.5 ± 9.4 ms in Indians) and QTcB interval (408.3 ± 21.3 vs. 403.5 ± 21.6 in Malays vs. 401.2 ± 21.4 ms in Indians) (all $p < 0.001$).

TABLE 1 Baseline demographic, clinical, anthropometric and electrocardiographic parameters stratified by ethnicity

Variables	Chinese	Malay	Indian	*p* value
Number (%)	104,223 (72.2%)	25,405 (17.6%)	11,865 (8.2%)	
Age, years	18.5 ± 1.2$^{\#,*}$	18.5 ± 1.2*	18.4 ± 1.3	<0.001
Height, cm	172.3 ± 6.2$^{\#,*}$	170.2 ± 6.2*	173.4 ± 6.6	<0.001
Weight, kg	65.5 ± 14.0$^{\#,*}$	67.4 ± 17.8*	69.2 ± 17.0	<0.001
Body mass index, kg/m^2	22.0 ± 4.3$^{\#,*}$	23.2 ± 5.7	23.0 ± 5.3	<0.001
Body fat percentage, %	20.4 ± 7.3$^{\#,*}$	21.9 ± 9.3*	25.3 ± 9.9	<0.001
Mean heart rate, bpm	80.4 ± 14.7$^{\#,*}$	79.3 ± 15.3*	77.3 ± 14.7	<0.001
Median heart rate, bpm	79 (55, 115)	78 (53, 115)	76 (52, 113)	
Systolic blood pressure, mmHg	115.1 ± 13.3$^{\#,*}$	114.5 ± 13.5*	112.4 ± 13.5	<0.001
Diastolic blood pressure, mmHg	66.0 ± 10.8$^{\#,*}$	65.7 ± 10.8*	64.2 ± 11.1	<0.001
Mean PR interval, ms	146.7 ± 19.7$^{\#,*}$	145.2 ± 19.2*	141.2 ± 18.8	<0.001
Median PR interval, ms	145 (113, 192)	144 (112, 189)	140 (110, 185)	
Mean QRS duration, ms	94.5 ± 9.8$^{\#,*}$	92.6 ± 9.7	92.5 ± 9.4	<0.001
Median QRS duration, ms	94 (76, 115)	92 (75, 113)	92 (75, 113)	
Mean QT interval, ms	364.4 ± 28.6$^{\#,*}$	362.6 ± 29.2*	365.6 ± 28.8	<0.001
Median QT interval, ms	363 (312, 429)	360 (310, 428)	364 (312, 430)	
Mean QTcB, ms	408.3 ± 21.3$^{\#,*}$	403.5 ± 21.6*	401.2 ± 21.4	<0.001
Median QTcB, ms	409 (370, 450)	405 (365, 446)	404 (364, 444)	
Mean QTcF, ms	392.7 ± 18.0$^{\#,*}$	389.0 ± 17.9	388.6 ± 17.6	<0.001
Median QTcF, ms	392 (358, 429)	388 (354, 426)	388 (354, 426)	
Mean Sokolow–Lyon voltage, mV	2.68 ± 0.79$^{\#,*}$	2.72 ± 0.79*	2.65 ± 0.75	<0.001
Mean Cornell product, mVms	1,509 ± 636$^{\#,*}$	1,435 ± 626*	1,396 ± 618	<0.001

Note. Variables are reported as mean ± SD and/or medians (2nd and 98th percentile); QTcB, QTc by Bazett's formula; QTcF by Fridericia's formula.
ANOVA was used to analyze means.
$^{\#}p < 0.05$ versus Malay. $^{*}p < 0.05$ versus Indian; with post hoc Bonferroni correction.

TABLE 2 Comparing the differences in QTcB stratified by ethnicity and compared against a Caucasian population

	SAFE study QTcB (ms)				
Percentile	Whole population (n = 122,352)	Chinese (n = 89,047)	Malay (n = 21,247)	Indian (n = 9,693)	Kobza et al. QTcB (ms) (n = 40,760)
2	368	370	365	364	351
2.5	370	371	367	366	352
97.5	447	448	445	442	437
98	449	450	446	444	439

TABLE 3 Comparing the prevalence of a long QTc (QTcF and QTcB) at various cutoff levels stratified by ethnicity ($p < 0.05$ across ethnicities for both QTcF and QTcB for all the reported QTc cutoffs)

	Number and percentage of subjects within the various subgroups at different QTc cutoffs							
	Whole population (n = 122,352)		Chinese (n = 89,047)		Malay (n = 21,247)		Indian (n = 9,693)	
QTc cutoff (ms)	QTcF	QTcB	QTcF	QTcB	QTcF	QTcB	QTcF	QTcB
≥450	216 (0.2%)	2,219 (2.0%)	185 (0.2%)	1797 (2.0%)	24 (0.1%)	278 (1.3%)	4 (0.0%)	105 (1.1%)
≥460	115 (0.1%)	695 (0.6%)	101 (0.1%)	567 (0.6%)	11 (0.1%)	6 (0.4%)	1 (0.0%)	31 (0.3%)
≥470	75 (0.1%)	167 (0.1%)	66 (0.1%)	143 (0.2%)	7 (0.0%)	19 (0.1%)	1 (0.0%)	2 (0.0%)

TABLE 4 Comparing the prevalence of a short QTc (QTcF and QTcB) at various cutoff levels stratified by ethnicity

	Number and percentage of subjects within the various subgroups at different QTc cutoffs							
	Whole population (n = 122,352)		Chinese (n = 89,047)		Malay (n = 21,247)		Indian (n = 9,693)	
QTc cutoff (ms)	QTcF	QTcB	QTcF	QTcB	QTcF	QTcB	QTcF	QTcB
≤300	1 (0.0%)	0 (0%)	1 (0.0%)	0 (0%)	0 (0.0%)	0 (0%)	0 (0%)	0 (0%)
≤310	5 (0.0%)	0 (0%)	5 (0.0%)	0 (0%)	0 (0.0%)	0 (0%)	0 (0%)	0 (0%)
≤320	15 (0.0%)	4 (0.0%)	11 (0.0%)	4 (0.0%)	4 (0.0%)	0 (0%)	0 (0%)	0 (0%)
≤330	36 (0.0%)	12 (0.0%)	24 (0.0%)	11 (0.0%)	8 (0.0%)	1 (0.0%)	4 (0.0%)	0 (0%)
≤340*	189 (0.2%)	37 (0.0%)	108 (0.1%)	21 (0.0%)	55 (0.3%)	10 (0.0%)	22 (0.2%)	6 (0.1%)

*$p < 0.05$ across ethnicities at the QTc cutoff of ≤340 only

A sub-sectional analysis of the QT intervals is given in Table 2. There were 122,352 subjects included in this analysis with a mean age of 18.5 ± 1.1 years. For our cohort, the QTcB range is 368–449 ms (2nd to 98th percentiles) and the QTcF range is 356–428 ms (2nd to 98th percentiles). The Chinese had the longest QTcB and QTcF across percentiles. In addition, we compared our results against a prior study performed by Kobza et al. in a similar Swiss conscript population (Kobza et al., 2009). Further analyses comparing the prevalence of QTcB and QTcF in different ethnicities at various cutoff levels are reflected in Tables 2, 3, 4.

3.2.2 | Body size

We performed a cross-sectional analysis to determine whether BMI and body fat affect various ECG criteria for LVH. In total, 19,868 (13.8%) subjects fulfilled the Sokolow–Lyon criterion, 21,816 (15.1%) fulfilled the Cornell product criterion, 10,997 (7.6%) fulfilled the Romhilt–Estes point system for definite LVH (5 points) and 17,652 (12.2%) fulfilled the combined Corrado voltage criterion.

Compared with normal-weight conscripts, overweight conscripts by BMI had a lower prevalence of ECG LVH and vice versa for underweight conscripts (Figure 1). The only exception was when using the Sokolow–Lyon criterion; there was a lower prevalence of ECG LVH in the underweight group (14.4% vs. 17.0%, $p < 0.001$). A similar comparison was made using body fat percentage, and the results were consistent with those having a higher body fat percentage and having a lower incidence of ECG LVH.

After adjustment for age, ethnicity, blood pressure and total cholesterol/HDL ratio by logistic regression analysis, overweight body mass index (BMI>25 kg/m^2) and increased body fat (>25%) were both independently associated with a lower prevalence of an ECG diagnosis of LVH. Significantly, an elevated systolic blood pressure of more

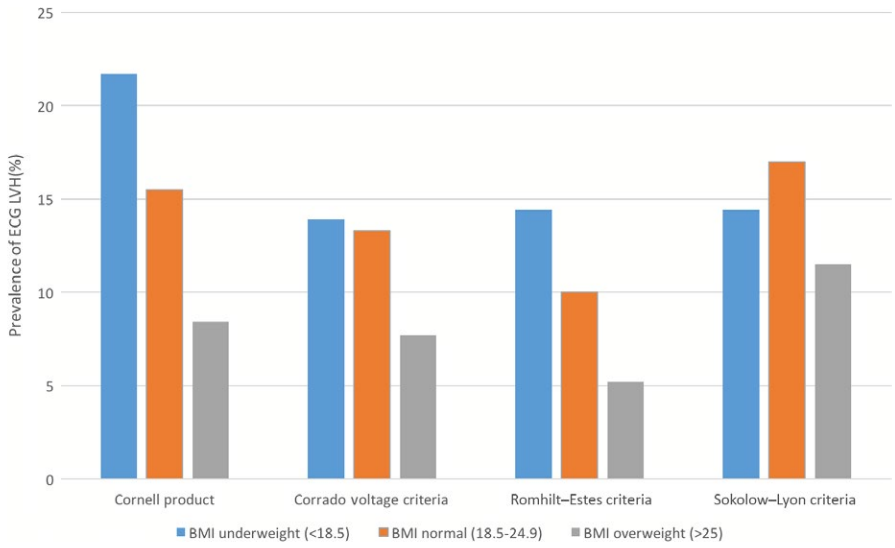

FIGURE 1 Prevalence of ECG LVH criteria in underweight, normal weight and overweight conscripts by BMI

TABLE 5 Multivariate logistic regression model to show the effects of BMI, body fat and hypertension on risk of having ECG LVH after adjusting for age, ethnicity, blood pressure and total cholesterol/HDL ratio

	BMI						Body fat		Elevated baseline blood pressure (SBP>140 or DBP>90)	
	Underweight (<18.5)		Overweight (25–29.9)		Severely overweight (>30)		Obese (≥25%)			
ECG LVH criteria	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Cornell product	1.59	1.33–1.89	0.74	0.60– 0.91	0.64	0.52–0.80	0.69	0.56–0.85	1.4	1.14–1.77
Corrado voltage criteria	1.19[*]	0.98–1.45	0.66	0.53–0.82	0.48	0.38–0.61	0.8	0.64–0.99	1.4	1.08–1.75
Romhilt–Estes criteria	1.51	1.2–1.9	0.63	0.48–0.84	0.53	0.39–0.72	0.67	0.50–0.89	1.6	1.19–2.16
Sokolow–Lyon criteria	0.75	0.61–0.92	0.73	0.61–0.89	0.49	0.40–0.60	0.77	0.64–0.93	1.5	1.24–1.86

[*] All p values <0.05 except for underweight individuals with the Corrado voltage criteria–$p = 0.07$.

than 140 mmHg or an elevated diastolic blood pressure of more than 90 mmHg also independently increased the odds of fulfilling ECG criterion for LVH across all the four criteria analyzed (Table 5).

4 | DISCUSSION

Electrocardiographic screening examined in a pre-participation context serves to detect clinically significant pathological processes such as potentially lethal arrhythmias associated with a long or short QT interval on ECG, for example (Dhutia et al., 2016; Maron et al., 2014; Mont et al., 2017). It also screens for left ventricular hypertrophy that could signify underlying hypertensive heart disease, valvular abnormalities or hypertrophic cardiomyopathy (Corrado et al., 1998). Although these conditions are rare in an otherwise healthy young population, early identification in pre-participation could help to prevent the disastrous complication of sudden cardiac death during vigorous exercise.

At the same time, ECG pre-participation screening comes at a high cost with a large amount of resources expended (Fuller, 2000; Halkin et al., 2012; Tanaka et al., 2006; Wheeler et al., 2010). An abnormal ECG typically warrants further cardiac investigations such as a two-dimensional echocardiogram, exercise stress testing, cardiac magnetic resonance imaging and/or electrophysiological study. These costs include not just the financial costs borne by the military, but also the intangible costs of anxiety to the individuals having to undergo additional testing based on an abnormal ECG.

The key to balancing the lifesaving potential of ECG screening with the high financial and other costs involved would be a population-specific screening criterion that could enable more accurate testing based on population-specific ECG norms.

Our study describes ECG reference ranges in a large cohort of young unselected multiethnic Southeast Asian males and the impact of demographic and anthropometric factors on selected ECG variables. This is the first step toward the overall aim of creating a pre-participation screening protocol validated for a predominantly

Southeast Asian population to improve the safety of pre-conscription medical screening in Singapore while reducing costs.

We compared our ECG reference ranges with earlier studies conducted in similar populations of predominantly young males.

4.1 | PR interval

Comparing the ECG reference ranges we derived in our study against a study conducted by Wu et al. on 5,360 healthy Chinese subjects, the median PR interval derived in our study of 144 ms (combined population) was shorter than the median PR interval of 149 ms reported in their study for males aged 18–29 (*n* = 680) (Wu et al., 2003). The median PR interval in the Chinese study, however, was closer to the median PR interval in the Chinese subset of our population of 147 ms. Similarly, a Thai study conducted by Khumrin et al. reported the mean PR interval in males aged below 20 years was 148 ms (Khumrin et al., 2015). The median PR interval reported by Mason et al. in their study for subjects aged between 10 and 19 years was 141 ms (*n* = 1,345), although this analysis included females and did not provide a subset analysis of the PR intervals of only the young male subjects (Mason et al., 2007). Lastly, a study by Palhares et al. in a Latin-American population showed a median PR interval of 142 in males aged 16–19 years (*n* = 11,295) (Palhares et al., 2017).

4.2 | QRS duration

The median QRS duration of 94 ms reported in our analysis was similar to the median QRS duration of 94 ms reported in the study by Wu et al. as well as in the subset of males aged 16–19 in the study by Palhares et al. (Palhares et al., 2017; Wu et al., 2003). This was, however, longer than the median QRS duration of 89 ms reported by Mason et al. (Mason et al., 2007).

4.3 | QTcB

The median and mean QTcB in our study was 409 ms and 408 ms, respectively. Mason et al. reported a median QTcB of 403 ms in their study (*n* = 776, males aged 10–19 years) (Mason et al., 2007). Palhares et al. reported a median QTcB of 406 among the subset of males aged 16–19 years (Palhares et al., 2017). This was longer than the mean QTcB of 394 ms reported by Kobza et al. in their study of 41,767 predominantly male Swiss conscripts with an age profile largely similar to our study population (Kobza et al., 2009). Observed differences in normal values of QTcB based on demographics suggest a need to further scrutinize and contextualize diagnostic criteria derived from other populations to our local norms.

The prevalence of a short QT interval in our population was 0.0098% (*n* = 12) at a cutoff of 330 ms and 0.030% (*n* = 37) at a cutoff of 340 ms (Rudic et al., 2014) (Table 4). This suggests that the prevalence of a short QT interval in our population is exceedingly rare.

The prevalence of a long QT interval in our population was calculated based on different cutoff values (Table 3). Prevalence was 0.1% (*n* = 112) at a cutoff of 480 ms, 0.1% (*n* = 167) at a cutoff of 470 ms, 0.6% (*n* = 695) at a cutoff of 460 ms, 2.0% (*n* = 2,219) at a cutoff of 450 ms and 5.9% (*n* = 6,671) using a criterion of 440 ms.

4.4 | QTcF

The reported QTcF values were generally shorter than the reported QTcB values. This reduced the proportion of subjects classified with a long QT interval (Table 3). This has implications on screening as the previously proposed Schwartz score to diagnose long QT syndrome used QTcB instead of QTcF as part of its diagnostic criterion (Schwartz et al., 2012), and adopting the Schwartz score may misdiagnose individuals. Using the aforementioned definition of short QT syndrome of ≤330 ms, we found a prevalence of short QT syndrome of 0.029% (*n* = 36). While this is higher than those classified by QTcB, the prevalence is still exceedingly rare.

These results are consistent with prior studies which show that age and race affect the various ECG parameters and that age-, race- and population-specific ECG screening criteria may be necessary to improve the veracity of pre-participation screening. Furthermore, absolute differences between the reported values are small and are unlikely to be clinically significant.

4.5 | ECG LVH criteria

Electrocardiographic screening for LVH is well known to have significant limitations, particularly in young otherwise healthy individuals. As such, interpretation of individuals meeting ECG LVH criteria may actually reflect normal individuals with increased QRS voltages with no actual underlying LVH (Drezner et al., 2017). Okin et al. investigated the effect of obesity on electrocardiographic LVH in hypertensive patients and found that the prevalence of ECG LVH by the Sokolow–Lyon voltage criterion was significantly lower in obese subjects compared to normal-weight subjects (Okin et al., 1996). In contrast, compared with normal-weight subjects, overweight subjects had a higher prevalence of ECG LVH by the Cornell product criterion. The results of our study showed a lower prevalence of ECG LVH for obese subjects in all the four criteria analyzed, including the Cornell product. There are currently scarce data on the prevalence of LVH among obese subjects in our young male multiethnic Southeast Asian cohort. The implication of obesity and body fat on diagnosis of LVH in our population would require analysis of gold standard measurements for LVH such as cardiac magnetic resonance imaging. This is currently a work in progress as part of the next phase of the SAFE study. Ultimately, a combination of these factors would probably need to be taken into consideration when creating a novel ECG criterion for LVH detection corroborated by further imaging, which is a long-term aim of this study. Nevertheless, this analysis is still relevant because there is a suggestion that ECG LVH alone without imaging data still has prognostic value in predicting cardiovascular events (Iribarren et al., 2017).

4.6 | Limitations

The study population included all Singaporean men undergoing pre-conscription medical screening. The lack of a significant female population means our results are based on the specific male cohort studied. In addition, we studied only pre-conscription but not post-conscription cardiovascular status, which limits the characterization and analysis of longitudinal changes with training.

A small number of individuals in our study may have had a history of preexisting cardiac diseases. We were unable to exclude such individuals with preexisting cardiac diagnoses from the analysis due to the large study cohort. However, based on previous studies conducted by Ng CT et al. in a similar cohort, the prevalence of significant cardiac pathology was found to be low (Ng et al., 2011; Ng, Ong, Cheok, Chua, & Ching, 2012). Specifically, the prevalence of HCM was estimated at 0.005%, while the prevalence of other abnormalities (e.g., Brugada pattern) was also low at 0.41%. A study by Maron et al. in young adults estimated the prevalence of HCM to be 0.02% (Maron et al., 1995). As such, the overall prevalence of preexisting cardiac diagnoses in our cohort is likely to be low, and presentation of the intervals with the median and 2nd and 98th percentiles is meant to provide reference ranges for the population.

Given the large patient cohort, there was a statistically significant difference in the demographics studied among the races. These were deemed to be clinically insignificant based on the very small absolute difference, except for the body fat percentage that appeared to show a clinically significant difference between the races.

In Table 2, we compared the QTcB in our population against that derived from the Swiss study by Kobza et al. Kobza's study used the SCHILLER AG ECG software technology system compared to the Phillips ECG software used in our study. There are reported differences in ECG intervals obtained from different automated ECG systems (Kligfield et al., 2018). However, there was still a statistically significant difference observed between the racial groups in our study based on the Phillips ECG software.

The current study does not have imaging data in the form of two-dimensional echocardiogram or CMR that would have validated the presence or absence of LVH. The correlation of ECG LVH to gold standard imaging modalities will be a future aim of the study.

5 | CONCLUSION

Electrocardiographic parameters in young Singaporean males vary significantly across different ethnicities and in comparison with published international norms. Further investigation on the use of ethnic-specific ECG norms for pre-exercise screening would be indicated. These norms may be helpful in the diagnosis of arrhythmic cardiac diagnoses such as long and short QT syndromes, although long-term follow-up studies will be necessary in further characterization of these syndromes.

Anthropometric factors may also significantly influence ECG parameters, although this needs to be corroborated with imaging data. In our population, the diagnosis of LVH by ECG is less prevalent in obese individuals and those with increased body fat. More studies are required to develop novel ECG criteria for LVH, which incorporates these anthropometric factors.

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REFERENCES

Baggish, A. L. (2015). A decade of athlete ECG criteria: Where we've come and where we're going. *J Electrocardiology*, *48*(3), 324–328.

Maron, B. J., Friedman, R. A., Kligfield, P., Levine, B. D., Viskin, S., Chaitman, B. R., … Council on Quality of Care and Outcomes Research, and American College of Cardiology. (2014). Assessment of the 12-lead electrocardiogram as a screening test for detection of cardiovascular disease in healthy general populations of young people (12–25 years of age): a scientific statement from the American Heart Association and the American College of Cardiology. *Journal of the American College of Cardiology*, *64*(14), 1479–1514.

Mont, L., Pelliccia, A., Sharma, S., Biffi, A., Borjesson, M., Terradellas, J. B., … Piepoli, M. Pre-participation cardiovascular evaluation for athletic participants to prevent sudden death: Position paper from the EHRA and the EACPR, branches of the ESC. Endorsed by APHRS, HRS, and SOLAECE. *Europace*. 2017;*19*(1):139–163.

Yeo, T. J., & Sharma, S. (2016). Using the 12-Lead Electrocardiogram in the Care of Athletic Patients. *Cardiology Clinics*, *34*(4), 543–555. https://doi.org/10.1016/j.ccl.2016.06.004

Ng, C. T., Ong, H. Y., Cheok, C., Chua, T. S., & Ching, C. K. (2012). Prevalence of electrocardiographic abnormalities in an unselected young male multi-ethnic South-East Asian population undergoing pre-participation cardiovascular screening: results of the Singapore Armed Forces Electrocardiogram and Echocardiogram screening protocol. *Europace.*, *14*(7), 1018–1024. https://doi.org/10.1093/europace/eur424

Corrado, D., Pelliccia, A., Bjornstad, H. H., Vanhees, L., Biffi, A., Borjesson, M., … Thiene, G. (2005). Cardiovascular pre-participation screening of young competitive athletes for prevention of sudden death: proposal for a common European protocol. Consensus Statement of the Study Group of Sport Cardiology of the Working Group of Cardiac Rehabilitation and Exercise Physiology and the Working Group of Myocardial and Pericardial Diseases of the European Society of Cardiology. *European Heart Journal*, *26*(5), 516–524. https://doi.org/10.1093/eurheartj/ehi108

Chen, C. Y., Chiang, B. N., & Macfarlane, P. W. (1989). Normal limits of the electrocardiogram in a Chinese population. *Journal of Electrocardiology*, *22*(1), 1–15. https://doi.org/10.1016/0022-0736(89)90018-6

Dewhurst, M. J., Di Marco, L. Y., Dewhurst, F., Adams, P. C., Murray, A., Orega, G. P., … Langley, P.. (2014). Electrocardiographic reference values for a population of older adults in sub-Saharan Africa. *Annals of Noninvasive Electrocardiology*, *19*(1), 34–42. https://doi.org/10.1111/anec.12078

Katibi, I., Clark, E. N., Devine, B., Lloyd, S. M., & Macfarlane, P. W. (2013). Normal limits of the electrocardiogram in Nigerians. *Journal of Electrocardiology*, *46*(4), 289–295. https://doi.org/10.1016/j.jelectrocard.2013.04.002

Khumrin, P., Srisuwan, P., Lertprayoonmit, W., Leelarphat, L., & Phumphuang, C. (2015). Effective ECG reference ranges for Northern Thai people. *Heart Asia*, *7*(1), 32–40. https://doi.org/10.1136/heartasia-2014-010584

Macfarlane, P. W., Lloyd, S. M., Singh, D., Hamde, S., Clark, E., Devine, B., … Kumar, V.. (2015). Normal limits of the electrocardiogram in

Indians. *Journal of Electrocardiology*, *48*(4), 652–668. https://doi.org/10.1016/j.jelectrocard.2015.04.013

Macfarlane, P. W., vanOosterom, A., Pahlm, O., Kligfield, P., Janse, M., & Camm, J. *Comprehensive Electrocardiology*. London, UK: Springer; 2010.

Mason, J. W., Ramseth, D. J., Chanter, D. O., Moon, T. E., Goodman, D. B., & Mendzelevski, B. (2007). Electrocardiographic reference ranges derived from 79,743 ambulatory subjects. *Journal of Electrocardiology*, *40*(3), 228–234. https://doi.org/10.1016/j.jelectrocard.2006.09.003

Palhares, D. M. F., Marcolino, M. S., Santos, T. M. M., da Silva, J. L. P., Gomes, P. R., Ribeiro, L. B., ... Ribeiro, A. L. P.. (2017). Normal limits of the electrocardiogram derived from a large database of Brazilian primary care patients. *BMC Cardiovascular Disorders*, *17*(1), 152. https://doi.org/10.1186/s12872-017-0572-8

Rijnbeek, P. R., van Herpen, G., Bots, M. L., Man, S., Verweij, N., Hofman, A., ... Kors, J. A. (2014). Normal values of the electrocardiogram for ages 16–90 years. *Journal of Electrocardiology*, *47*(6), 914–921. https://doi.org/10.1016/j.jelectrocard.2014.07.022

Wu, J., Kors, J. A., Rijnbeek, P. R., van Herpen, G., Lu, Z., & Xu, C. (2003). Normal limits of the electrocardiogram in Chinese subjects. *International Journal of Cardiology*, *87*(1), 37–51. https://doi.org/10.1016/S0167-5273(02)00248-6

Zhou, S. H., Helfenbein, E. D., Lindauer, J. M., Gregg, R. E., & Feild, D. Q. (2009). Philips QT interval measurement algorithms for diagnostic, ambulatory, and patient monitoring ECG applications. *Annals of Noninvasive Electrocardiology*, *14*(Suppl 1), S3–S8.

Bazett, H. C. (1997). An analysis of the time-relations of electrocardiograms. *Annals of Noninvasive Electrocardiology*, *2*(2), 177–194. https://doi.org/10.1111/j.1542-474X.1997.tb00325.x

Fridericia, L. S. (1920). Die Systolendauer im Elektrokardiogramm bei normalen Menschen und bei Herzkranken. *Acta Medica Scandinavica*, *53*(1), 469–486. https://doi.org/10.1111/j.0954-6820.1920.tb18266.x

Sokolow, M., & Lyon, T. P. (1949). The ventricular complex in left ventricular hypertrophy as obtained by unipolar precordial and limb leads. *American Heart Journal*, *37*(2), 161–186. https://doi.org/10.1016/0002-8703(49)90562-1

Corrado, D., Basso, C., Schiavon, M., & Thiene, G. (1998). Screening for hypertrophic cardiomyopathy in young athletes. *New England Journal of Medicine*, *339*(6), 364–369. https://doi.org/10.1056/NEJM199808063390602

Molloy, T. J., Okin, P. M., Devereux, R. B., & Kligfield, P. (1992). Electrocardiographic detection of left ventricular hypertrophy by the simple QRS voltage-duration product. *Journal of the American College of Cardiology*, *20*(5), 1180–1186. https://doi.org/10.1016/0735-1097(92)90376-X

Romhilt, D. W., & Estes, E. H. Jr (1968). A point-score system for the ECG diagnosis of left ventricular hypertrophy. *American Heart Journal*, *75*(6), 752–758. https://doi.org/10.1016/0002-8703(68)90035-5

Kobza, R., Roos, M., Niggli, B., Abacherli, R., Lupi, G. A., Frey, F., ... Erne, P.. (2009). Prevalence of long and short QT in a young population of 41,767 predominantly male Swiss conscripts. *Heart Rhythm: the Official Journal of the Heart Rhythm Society*, *6*(5), 652–657. https://doi.org/10.1016/j.hrthm.2009.01.009

Dhutia, H., Malhotra, A., Parpia, S., Gabus, V., Finocchiaro, G., Mellor, G., ... Sharma, S. (2016). The prevalence and significance of a short QT interval in 18,825 low-risk individuals including athletes. *British Journal of Sports Medicine*, *50*(2), 124–129.

Corrado, D., Basso, C., Schiavon, M., & Thiene, G. (1998). Screening for hypertrophic cardiomyopathy in young athletes. *New England Journal of Medicine*, *339*(6), 364–369. https://doi.org/10.1056/NEJM199808063390602

Fuller, C. M. (2000). Cost effectiveness analysis of screening of high school athletes for risk of sudden cardiac death. *Medicine & Science in Sports & Exercise*, *32*(5), 887–890. https://doi.org/10.1097/00005768-200005000-00002

Halkin, A., Steinvil, A., Rosso, R., Adler, A., Rozovski, U., & Viskin, S. (2012). Preventing Sudden Death of Athletes With Electrocardiographic Screening. What Is the Absolute Benefit and How Much Will it Cost? *Journal of the American College of Cardiology*, *60*(22), 2271–2276. https://doi.org/10.1016/j.jacc.2012.09.003

Tanaka, Y., Yoshinaga, M., Anan, R., Tanaka, Y., Nomura, Y., Oku, S., ... Arima, K.. (2006). Usefulness and cost effectiveness of cardiovascular screening of young adolescents. *Medicine & Science in Sports & Exercise*, *38*(1), 2–6. https://doi.org/10.1249/01.mss.0000183187.88000.53

Wheeler, M. T., Heidenreich, P. A., Froelicher, V. F., Hlatky, M. A., & Ashley, E. A. (2010). Cost-effectiveness of preparticipation screening for prevention of sudden cardiac death in young athletes. *Annals of Internal Medicine*, *152*(5), 276–286. https://doi.org/10.7326/0003-4819-152-5-201003020-00005

Rudic, B., Schimpf, R., & Borggrefe, M. (2014). Short QT Syndrome – Review of Diagnosis and Treatment. *Arrhythmia & Electrophysiology Review.*, *3*(2), 76–79. https://doi.org/10.15420/aer.2014.3.2.76

Schwartz, P. J., Md, L. C., & Insolia, R. (2012). Long QT Syndrome: From Genetics to Management. *Circulation Arrhythmia and Electrophysiology.*, *5*(4), 868–877. https://doi.org/10.1161/CIRCEP.111.962019

Drezner, J. A., Sharma, S., Baggish, A., Papadakis, M., Wilson, M. G., Prutkin, J. M., ... Corrado, D. (2017). International criteria for electrocardiographic interpretation in athletes: Consensus statement. *British Journal of Sports Medicine*, *51*(9), 704–731. https://doi.org/10.1136/bjsports-2016-097331

Okin, P. M., Roman, M. J., Devereux, R. B., & Kligfield, P. (1996). Electrocardiographic identification of left ventricular hypertrophy: test performance in relation to definition of hypertrophy and presence of obesity. *Journal of the American College of Cardiology*, *27*(1), 124–131. https://doi.org/10.1016/0735-1097(95)00421-1

Iribarren, C., Round, A. D., Lu, M., Okin, P. M., & McNulty, E. J. (2017). Cohort Study of ECG Left ventricular hypertrophy trajectories: Ethnic disparities, associations with cardiovascular outcomes, and Clinical Utility. *Journal of the American Heart Association*, *6*(10).

Ng, C. T., Chee, T. S., Ling, L. F., Lee, Y. P., Ching, C. K., Chua, T. S., ... Ong, H. Y.. (2011). Prevalence of hypertrophic cardiomyopathy on an electrocardiogram-based pre-participation screening programme in a young male South-East Asian population: results from the Singapore Armed Forces Electrocardiogram and Echocardiogram screening protocol. *Europace*, *13*(6), 883–888. https://doi.org/10.1093/europace/eur051

Maron, B. J., Gardin, J. M., Flack, J. M., Gidding, S. S., Kurosaki, T. T., & Bild, D. E. (1995). Prevalence of hypertrophic cardiomyopathy in a general population of young adults. Echocardiographic analysis of 4111 subjects in the CARDIA Study. Coronary Artery Risk Development in (Young) Adults. *Circulation*, *92*(4), 785–789. https://doi.org/10.1161/01.CIR.92.4.785

Kligfield, P., Badilini, F., Denjoy, I., Babaeizadeh, S., Clark, E., De Bie, J., , ... Green, C. L. (2018). Comparison of automated interval measurements by widely used algorithms in digital electrocardiographs. *American Heart Journal*, *200*, 1–10. https://doi.org/10.1016/j.ahj.2018.02.014

How to cite this article: Sia C-H, Dalakoti M, Tan BYQ, et al. A Population-wide study of electrocardiographic (ECG) norms and the effect of demographic and anthropometric factors on selected ECG characteristics in young, Southeast Asian males—results from the Singapore Armed Forces ECG (SAFE) study. *Ann Noninvasive Electrocardiol*. 2019;e12634. https://doi.org/10.1111/anec.12634