Sharafi *et al.*
European Journal of Medical Research (2025) 30:309
https://doi.org/10.1186/s40001-025-02569-5

European Journal
of Medical Research

RESEARCH

Open Access

Association between body composition components and electrocardiogram parameters: results from the Fasa Adults Cohort Study (FACS)

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Abstract

Objective Cardiovascular diseases as the leading cause of death and disability are increasing worldwide. The present study aimed to investigate the association between total body water, total fat percent, and trunk fat percent with electrocardiogram (ECG) parameters in the Persian Fasa Adult Cohort Study (FACS).

Methods This cross-sectional study was performed on the baseline information obtained from 3217 35–70-year-old participants of the FACS, southern Iran. Various ECG and body composition parameters were obtained from the FACS baseline database. Independent t-test, Chi-square test and linear regression were used for data analysis.

Results Total body water (TBW) was positively associated with QRS length in men and women, and with PD and PR interval in women, exclusively. Additionally, in participants without chronic diseases (healthy group), TBW was shown to be positively associated with QRS length and PD; however, it was associated with QRS length and S wave in V3 lead (S_{V3}) among those with type two diabetes, hypertension or ischemic heart disease (defined as unhealthy group). Total body fat percent (TBFP) was linearly associated with S_{V3} in unhealthy group. None of the studied ECG parameters was associated with TBFP in men, women and healthy group. Moreover, trunk fat percent was shown to be positive associated with R wave in aVL lead in women and unhealthy groups.

Conclusion Body fat percentage and fat distribution may affect ECG parameters, and subsequently associated with cardiovascular diseases, such as arrhythmias. Thus, these indicators may carry the potential for screening high-risk individuals.

Keywords Electrocardiography, Body composition, Body water, Total fat percent, Trunk fat percent

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Introduction

Obesity is characterized by excessive fat accumulation in the body, which may cause serious health problems and complications in various organs and systems of the body [1]. Total body fat can be accurately measured using several methods, including ultrasound, imaging techniques, and computed tomography (CT) scans. In epidemiological research, the body mass index (BMI) is commonly used due to the simplicity and affordability of this method. However, BMI measures do not show strong correlation with total body fat percentage (TBFP) in body composition analysis [2]. The World Health Organization (WHO) has recommended a cut-off point for TBFP as 25% for men and 35% for women with a BMI equal or higher than 30 [3]. However, in Asian populations, due to higher TBPF, lower rate of BMI is considered as obese [4]; that is, these measures may not be appropriate for certain populations.

Excess body fat and obesity significantly impact the incidence and mortality of cardiovascular diseases (CVDs) [5]. In Iran, CVDs are the first and most common cause of death at all ages in both men and women [6]. As a result, screening high-risk populations for these diseases to reduce mortality rates is of great importance [7]. Electrocardiography (ECG) is an affordable non-invasive method widely used to diagnose CVDs, left ventricular hypertrophy and cardiac arrhythmia [8]. Empirical evidence has shown that many cardiovascular diseases can be better diagnosed, controlled and prevented through continuous monitor as well as analysis of ECG signals [9]. Consequently, while reference ranges for various ECG parameters have been defined based on specific populations in several studies, ECG screening is known to be influenced by many factors, including body fat and obesity [10, 11].

Obesity significantly changes cardiac electrophysiology, which is measurable in ECG, that may elevate cardiovascular risk. A well-documented effect of obesity is its effect on heart rate variability (HRV), defined as fluctuations in the R-R interval due to autonomic dysfunction [12]. This is compounded by chronic low-grade inflammation in obesity, which directly impairs cardiac autonomic function and promotes arrhythmogenesis [13]. Furthermore, obesity is associated with prolonged ventricular repolarization (i.e., an extended QT interval), which is a predictor of ventricular arrhythmias and sudden cardiac death [13]. Ardahanli and Celik [14] corroborated this finding, as they showed that even in prediabetic populations—a frequent comorbidity of obesity, abnormal Tp-e intervals and Tp-e/QTc ratios further represet arrhythmia susceptibility. Notably, adipose tissue-derived cytokines may exacerbate QT prolongation by disrupting myocardial potassium channels [15]. Similarly, increased adiposity correlates with longer QRS durations, reflecting a higher chance of conduction abnormalities [16]. These changes may be exacerbated by obesity-related left ventricular hypertrophy (LVH) [17], and are further amplified by epicardial fat deposition, which independently disrupts myocardial conduction pathways [18]. Ardahanli et al. [19] expanded on these concepts by proposing the index of cardiac electrophysiological balance (iCEB) to refine arrhythmia risk stratification in metabolic disorders. Additionally, fluid and electrolyte imbalances that is common in obese individuals may further distort ECG parameters, as suggested by Ardahanli and Akyuz [20] in their analysis of hemodialysis patients. Collectively, it appears that obesity exhibits multifaceted impact on cardiac electrical activity; therefore, there is a need for body composition-adjusted ECG interpretation in clinical practice.

Investigating these relationships, better understand the impact of body composition on cardiovascular health can potentially identify more accurate measures for assessing cardiovascular risk in populations. While there is a limited number of studies on this topic in Iran, this study was performed to examine the relationship between body water and fat indices with ECG parameters in southern Iran.

Methods

Setting and participants

This cross-sectional study utilized baseline data from 10,123 participants aged 35–70 years who registered in the recruitment phase from October 2014 to September 2016 in the Fasa Adults Cohort Study (FACS), Sheshdeh district, Fars province, southern Iran. FACS is a branch of the PERSIAN cohort study, which is a prospective study of approximately 180,000 middle-aged Iranian adults from 18 geographically distinct areas of Iran aiming to investigate the demographic, socioeconomic, anthropometric, nutritional, lifestyle, medical, and environmental risk factors associated with non-communicable diseases [21]. For the present analysis, 6906 participants with incomplete ECG and body composition data were excluded, resulting in a final sample size of 3217 participants. The flow diagram for the participants is displayed in Fig. 1.

The study was in agreement with the Helsinki declaration and Iranian national guidelines for ethics in research. The protocol of the study was approved by the regional and national Research Ethics Committees (equivalent of institutional review boards) of Fasa University of Medical Sciences (reference ID: IR.FUMS.REC.1399.212). All participants were asked to sign a written informed consent approved by the Research Ethics Committee. The participants are able to withdraw from the study when they

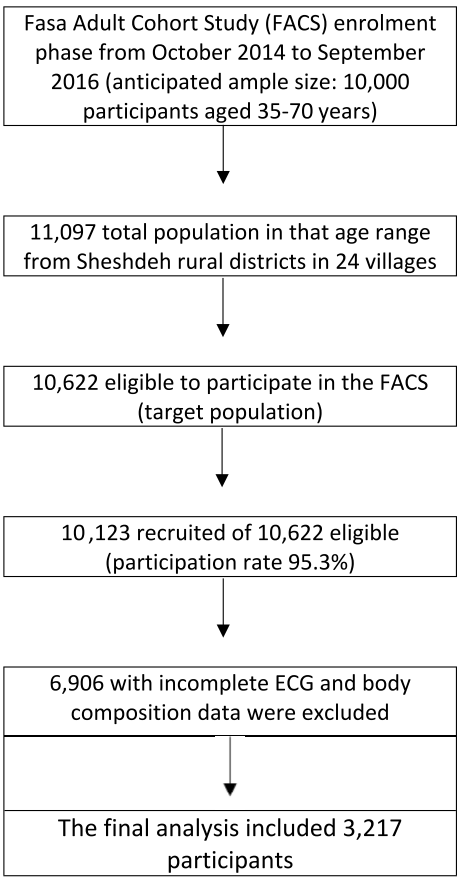

Fig. 1 Flow diagram of the included participants

wish. Data collected were stored in a codified confidential database.

Measurement of included variables

Baseline assessments in FACS is included of demographic variables and socio-economic status, routine laboratory tests and biobank preparation, personal and familial medical history, physical examinations, anthropometric indicators, physical activity, sleep pattern, nutritional status, lifestyle and high-risk behaviors, ECG recordings, and body composition analysis, which carried out for each individual in the form of face-to-face interviews, completed by trained personnel, digitally stored, and accessed online.

The 12-lead ECG was recorded before the interview, performed by a specialist technician, and stored in the standard format of Health Level-7. For better results, all subjects were asked to shave their precordium area. The ECG recordings were initially interpreted by the device's internal software (Cardiax®, version 3.50.2, International Medical Equipment Developing Co. Ltd., Budapest, Hungary). Then, the automatic diagnoses were reviewed by a cardiologist. The ECG records for each participant were digitally transferred into the central data collection software, then automatically connected to the baseline information of participants. The stored ECG-derived parameters comprised 156 values for various intervals and segment deviations, duration, vector analysis, heart rate, and 12-lead deflection voltage amplitude [15]. For this study, the analyzed data included of heart rate (HR), PR interval (ms), P wave duration PD (ms), QRS length (ms), QRS axis, R wave in aVL lead (R_{aVL}; mm), and S wave in V3 lead (S_{V3}; mm).

Additionally, demographic variables (i.e., age, sex, education level, marital status), chronic diseases (i.e., type two diabetes, hypertension, and ischemic heart disease), and smoking status were retrieved from baseline data of FACS. Anthropometric parameters, including body mass index (BMI), waist circumference (WC), hip circumference, wrist circumference, and waist-to-hip ratio (WHR) were measured. Height was recorded to the nearest 0.1 cm using a stadiometer (SECA 222, Germany), and weight was measured using a calibrated digital scale (SECA 888, Germany). WC was measured at the midpoint between the lowest rib and the iliac crest, hip circumference at the maximal buttock extension, and wrist circumference just distal to the radial/ulnar prominences. Blood biochemical tests (i.e., triglyceride (TG), cholesterol, low-density lipoprotein (LDL), and high-density lipoprotein (HDL)) were analyzed via colorimetry (Pars Azmoon kits, Iran) from samples stored at −70 °C. Physical activity was assessed using the International Physical Activity Questionnaire (IPAQ), with MET scores calculated by multiplying activity duration by its respective MET-value. Body composition data were also obtained from FACS baseline records.

The body composition obtained by bioelectrical impedance method using Tanita b-480 set with minimal clothing. For each Bioelectrical Impedance Analysis (BIA), age, height and sex were entered manually into the set prior to the impedance analysis. Testing was planned to let the participants for a 10–12 h fasting and limited physical activity. For accuracy, participants were asked to empty their bladder before body fat percent analysis. To ensure best contact, feet were placed on the BIA foot sensors. All BIA assessments were performed according to the device instructions by an expert investigator. BIA variables included total body water (TBW), total body fat percent (TBFP), and trunk fat percent (TFP), which have been selected based on the principal component analysis (PCA).

Comparisons and relationships between BIA and ECG indices were made based on sex and individuals' health status, separately. In this respect, unhealthy group was defined as having one of the chronic diseases of type two

diabetes, hypertension and ischemic heart disease [22, 23].

Statistical analysis

Stata version 14.0 (Stata Corporation, College Station, TX, USA) was used for data analysis. Quantitative and qualitative variables were presented as mean (standard deviation) and frequency (percentage), respectively. The Kolmogorov–Smirnov test and histogram chart were utilized to determine the data normality, and they were found to be normal. Independent t-test and Chi-square test were used to investigate the univariable associations of continuous and categorical variables with sex and health status, respectively. Additionally, the simple and multiple linear regression (for adjusted potential confounders) were used to estimate the beta coefficient (B) with 95% confidence interval (95% CI). In all analyzes, the significance level was set at p value < 0.05.

Results

A total of subjects 3217 participants (56.0% female) included. More than 60% of participants (n = 2,067, 64.30%) were healthy and 1150 (35.70%) were unhealthy. Males and females, as well as healthy and unhealthy groups, showed a significant diversity in almost all of the studies variables (Table 1). Specifically, mean TBW, TBFP, and TFP were significantly different between men and women (40.29 ± 5.78, 19.49 ± 7.11, 21.45 ± 8.32 vs. 31.21 ± 3.59, 34.12 ± 6.98, 29.59 ± 8.34; p < 0.001 for all comparisons, respectively), as well as healthy and unhealthy groups (35.82 ± 6.67, 25.24 ± 9.94, 24.05 ± 9.14 vs. 34.09 ± 6.02, 32.09 ± 8.85, 29.54 ± 8.39; p < 0.001 for all comparisons, respectively). For ECG parameters, males and females had a statistically difference in QRS length (99.24 ± 10.59 vs. 95.56 ± 10.28; p < 0.001), QRS axis (38.66 ± 44.41 vs. 31.75 ± 33.54; p < 0.001) and R_{aVL} (0.14 ± 0.35 vs. 0.19 ± 0.39; p < 0.001); but they were not different for PR interval, PD, and S_{V3}. In addition, except for the PR interval (134.15 ± 39.62 vs. 135.83 ± 38.01; p = 0.242), healthy and unhealthy groups were significantly different for the studied ECG parameters, PD (96.88 ± 28.13 vs. 99.97 ± 27.78; p = 0.003), QRS length (96.89 ± 10.28 vs. 97.85 ± 11.03; p = 0.014), QRS axis (38.39 ± 39.58 vs. 28.33 ± 36.64; p < 0.001), R_{aVL} (0.13 ± 0.34 vs. 0.23 ± 0.42; p < 0.001), and S_{V3} (−0.0.05 ± 0.21 vs. −0.08 ± 0.27; p < 0.001).

TBW was positively associated with QRS length in men (β = 0.195 [95% CI: 0.01, 0.38]; p = 0.038) and women (β = 0.303 [95% CI: 0.06, 0.54]; p = 0.012). Also, in women, TBW was positively associated with PR (β = 1.021 [95% CI: 0.15, 1.89]; p = 0.021) and PD (β = 0.643 [95% CI: 0.02, 1.25]; p = 0.040). In the healthy group, the TBW was positively associated with QRS length (β = 0.273 [95% CI: 0.10, 0.43]; p = 0.001) and PD (β = 0.518 [95% CI: 0.07, 1.23]; p = 0.023); but the unhealthy group associated with QRS length (β = 0.291 [95% CI: 0.11, 0.46]; p = 0.001), and S_{V3} (β = −0.005 [95% CI: −0.009, −0.001]; p = 0.023) (Table 2).

Moreover, TBFP showed no association with ECG indices in men and women. Likewise, TBFP was not associated with ECG parameters in the healthy and unhealthy groups, except a positive associated with S_{V3} in the unhealthy group (β = 0.004 [95% CI: 0.001, 0.008]; p = 0.021) (Table 3).

Furthermore, in the male general population, the TFP was not found to be associated with ECG parameters. Nevertheless, TFP was positively associated with R_{aVL} in female participants (β = 0.006 [95% CI: 0.002, 0.009]; p = 0.001). No significant association was observed between TFP and other parameters in women. Additionally, in healthy participants, TFP was not associated with ECG parameters; however, there was a statistically significant linear association between TFP and R_{aVL} (β = 0.005 [95% CI: 0.001, 0.011]; p = 0.029) among unhealthy participants (Table 4).

Discussion

This cross-sectional study included 3,217 participants who enrolled in FACS, southern Iran. We examined the association between TBFP, TFP, and TBW with ECG parameters based on sex and a health-status definition, separately, by adjusting several potentially confounding factors.

According to the literature, BIA (Bioelectrical Impedance Analysis) parameters have been shown prognostic utilities in human immunodeficiency virus infection, cancer, patients with end-stage renal disease on dialysis, and heart failure [24]. Scicchitano et al. reported BIA to have prognostic value in heart failure patients and the prediction of kidney related adverse events in heart failure patients [25]. Another study demonstrated height, weight, body capacitance, fat mass, extra cellular mass to body cell mass ratio, basal metabolic rate, and intracellular water as significant predicting factors for the incidence of coronary heart diseases.

Our study showed a positive association between TBFP and S_{V3} amplitude specifically in the unhealthy group. In should be noticed that the BMI was in the range of maximally class 1 obesity in unhealthy subjects while it was not the case among healthy subjects. Taking these two findings together, one can suggest that even class 1 obesity may influence ECG parameters when accompanied by metabolic dysfunction. Additionally, while both groups fell below the threshold for severe obesity, the observed association in the unhealthy group might indicate that metabolic status modifies adiposity effects

Table 1 Basic characteristics of study population

Characteristic	Sex			Health status		
	Male [n = 1,415 (44.0%)]	Female [n = 1802 (56.0%)]	*p*	Healthy [n = 2067 (64.30%)]	Unhealthy[a] [n = 1150 (35.70%)]	*p*
Age, *year*	47.41 ± 9.23	48.13 ± 9.56	0.032	45.46 ± 8.50	52.05 ± 9.50	<0.001
Years of education	6.00 ± 4.10	3.92 ± 3.55	<0.001	5.50 ± 3.95	3.65 ± 3.62	<0.001
Marital status						
Unmarried	38 (30.60)	86 (69.40)	<0.001	109 (87.90)	15 (12.10)	<0.001
Married	1375 (48.20)	1479 (51.80)		1858 (65.10)	996 (34.90)	
Widow/divorced	2 (0.80)	237(99.20)		100 (41.80)	139 (58.20)	
Diabetes						
Yes	104 (25.60)	302 (74.40)	<0.001	0 (0.00)	406 (100.00)	<0.001
No	1311 (46.6)	1500 (53.40)		2067 (73.50)	744 (26.50)	
Hypertension						
Yes	142 (22.2)	497 (77.80)	<0.001	0 (0.00)	639 (100.00)	<0.001
No	1273 (49.40)	1305 (50.60)		2067 (80.20)	511 (19.80)	
Ischemic heart disease						
Yes	80 (28.00)	206 (72.00)	<0.001	0 (0.00)	286 (100.00)	<0.001
No	1335 (45.50)	1596 (54.50)		2067 (70.50)	864 (29.50)	
Smoking			<0.001			
Yes	795 (92.20)	67 (7.80)		69 (77.60)	193 (22.40)	<0.001
No	620 (26.30)	1735 (73.70)		1398 (59.40)	957 (40.60)	
Waist circumference, *cm*	88.64 ± 11.35	96.25 ± 11.73	<0.001	90.31 ± 11.67	97.55 ± 11.64	<0.001
Hip circumference, *cm*	97.43 ± 7.69	101.53 ± 9.40	<0.001	98.59 ± 8.51	101.77 ± 9.29	<0.001
Wrist circumference, *cm*	17.20 ± 1.27	16.25 ± 1.27	<0.001	16.64 ± 1.36	16.73 ± 1.34	0.076
WHR	0.90 ± 0.06	0.94 ± 0.06	<0.001	0.91 ± 0.06	0.95 ± 0.06	<0.001
BMI, kg/m^2	23.97 ± 4.51	27.03 ± 4.98	<0.001	24.77 ± 4.83	27.33 ± 4.92	<0.001
MET, *per min*	45.06 ± 13.85	38.95 ± 6.51	<0.001	42.70 ± 11.59	39.71 ± 8.98	<0.001
TG, *mg/dl*	134.17 ± 86.68	125.39 ± 69.52	0.001	123.36 ± 74.36	139.83 ± 81.78	<0.001
Cholesterol, *mg/dl*	178.08 ± 38.57	189.00 ± 39.24	<0.001	181.91 ± 37.36	188.31 ± 42.31	<0.001
HDL, *mg/dl*	43.50 ± 9.18	49.62 ± 10.31	<0.001	46.58 ± 10.16	47.55 ± 10.50	0.010
LDL, *mg/dl*	107.75 ± 30.90	114.26 ± 32.89	<0.001	110.62 ± 30.93	112.79 ± 34.31	0.067
TBW, *%*	40.29 ± 5.78	31.21 ± 3.59	<0.001	35.82 ± 6.67	34.09 ± 6.02	<0.001
TBFP, *%*	19.49 ± 7.11	34.12 ± 6.98	<0.001	25.24 ± 9.94	32.09 ± 8.85	<0.001
TFP, *%*	21.45 ± 8.32	29.59 ± 8.34	<0.001	24.05 ± 9.14	29.54 ± 8.39	<0.001
HR	65.61 ± 10.79	74.51 ± 11.76	<0.001	69.15 ± 11.70	73.20 ± 12.57	<0.001
PR length, *ms*	136.22 ± 41.67	133.61 ± 36.84	0.060	134.15 ± 39.62	135.83 ± 38.01	0.242
PD, *ms*	98.33 ± 30.24	97.72 ± 26.19	0.544	96.88 ± 28.13	99.97 ± 27.78	0.003
QRS length, *ms*	99.24 ± 10.59	95.56 ± 10.28	<0.001	96.89 ± 10.28	97.85 ± 11.03	0.014
QRS axis, *degree*	38.66 ± 44.41	31.75 ± 33.54	<0.001	38.39 ± 39.58	28.33 ± 36.64	<0.001
R_{aVL}, *mm*	0.14 ± 0.35	0.19 ± 0.39	<0.001	0.13 ± 0.34	0.23 ± 0.42	<0.001
S_{V3}, *mm*	−0.06 ± 0.24	−0.05 ± 0.22	0.189	−0.05 ± 0.21	−0.08 ± 0.27	<0.001

[a] Defined as having one of the chronic diseases of type two diabetes, hypertension and ischemic heart disease

BMI body mass index, *TG* triglyceride, *LDL* low-density lipoprotein, *HDL* high-density lipoprotein, *MET* metabolic equivalent of task, *TBW* total body water, *TBFP* total body fat percent, *TFP* trunk fat percent, *HR* heart rate, *PD* P-wave duration, *WHR* waist-to-hip ratio

more substantially than BMI alone. In other words, as it has been mentioned previously, TBFP is a better predictor of cardiovascular incidence compared to BMI [26]. As an example, A cross-sectional study on 5,534 male adults found that high TBFP was linked with increased risk of CVDs regardless of BMI level, which suggests that both the amount and distribution of TBFP should be considered when estimating the risk of CVDs [27]. This finding might be explained by the fat paradox phenomenon described by Lavie et al. [5], where adiposity may

Table 2 Association between ECG parameters and TBW, stratified by sex and health status

Variable	Sex				Health status			
	Male		Female		Healthy		Unhealthy	
	B [95% CI]	*p*	B [95% CI]	*p*	B [95% CI]	*p*	B [95% CI]	*p*
PR, *ms*	0.575 [−0.26, 1.41]	0.180	1.021 [0.15, 1.89]	0.021	0.621 [−0.03, 1.28]	0.065	0.224 [−0.40, 0.85]	0.484
PD, ms	0.568 [−0.03, 1.17]	0.066	0.643 [0.02, 1.25]	0.040	0.518 [0.07, 1.23]	0.023	0.136 [−0.32, 0.59]	0.561
QRS, *ms*	0.195 [0.01, 0.38]	0.038	0.303 [0.06, 0.54]	0.012	0.273 [0.10, 0.43]	0.001	0.291 [0.11, 0.46]	0.001
QRS axis	0.336 [−0.42, 1.09]	0.387	−0.253 [−1.03, 0.52]	0.526	−0.465 [−1.10, 0.17]	0.161	−0.358 [−0.96, 0.24]	0.246
R_{aVL}, *mm*	0.001 [−0.004, 0.007]	0.646	−0.002 [−0.011, 0.006]	0.639	0.003 [−0.002, 0.008]	0.226	0.0006 [−0.006, 0.007]	0.844
S_{V3}, *mm*	−0.003 [−0.007, 0.003]	0.230	−0.003 [−0.005, 0.007]	0.904	−0.001 [−0.005, 0.001]	0.272	−0.005 [−0.009, −0.001]	0.023

Adjusted for age, marital status, years of education, BMI, MET, waist circumference, hip circumference, wrist circumference, smoking, ischemic heart disease, hypertension, diabetes, TG, cholesterol, LDL, and HDL

B beta coefficient, *PD* P-wave duration, *CI* confidence interval

Table 3 Association between ECG parameters and TBFP, stratified by sex and health status

Variable	Sex				Health status			
	Male		Female		Healthy		Unhealthy	
	B [95% CI]	*p*	B [95% CI]	*p*	B [95% CI]	*p*	B [95% CI]	*p*
PR, *ms*	0.194 [−0.42, 0.85]	0.562	−0.185 [−0.68, 0.30]	0.460	−0.021 [−0.53, 0.49]	0.934	0.010 [−0.50, 0.52]	0.967
PD, *ms*	0.185 [−0.29, 0.66]	0.445	−0.049 [−0.42, 0.32]	0.795	−0.003 [−0.37, 0.36]	0.986	0.073 [−0.30, 0.45]	0.705
QRS, *ms*	0.049 [−0.11, 0.21]	0.552	0.032 [−0.11, 0.17]	0.657	−0.002 [−0.13, 0.12]	0.974	−0.099 [−0.24, 0.04]	0.189
QRS axis	−0.345 [−1.01, 0.32]	0.314	−0.165 [−0.641, 310]	0.495	−0.121 [−0.62, 0.38]	0.635	−0.134 [−0.63, 0.36]	0.598
R_{aVL}, *mm*	0.002 [−0.002, 0.007]	0.386	0.007 [0.001, 0.012]	0.010	0.002 [−0.002, 0.006]	0.360	0.003 [−0.002, 0.008]	0.269
S_{V3}, *mm*	0.001 [−0.002, 0.004]	0.582	−0.001 [−0.003, 0.002]	0.741	−0.001 [−0.002, 0.003]	0.656	0.004 [0.001, 0.008]	0.021

Adjusted for age, marital status, years of education, BMI, MET, waist circumference, hip circumference, wrist circumference, smoking, ischemic heart disease, hypertension, diabetes, TG, cholesterol, LDL, and HDL

B beta coefficient, *PD* P-wave duration, *CI* confidence interval

Table 4 Association between ECG parameters and TFP, stratified by sex and health status

Variable	Sex				Health status			
	Male		Female		Healthy		Unhealthy	
	B [95% CI]	*p*	B [95% CI]	*p*	B [95% CI]	*p*	B [95% CI]	*p*
PR, *ms*	0.175 [−0.32, 0.67]	0.491	−0.084 [−0.45, 0.28]	0.654	−0.021 [−0.53, 0.49]	0.934	0.136 [−0.33, 0.61]	0.574
PD, *ms*	0.168 [−0.19, 0.53]	0.360	−0.035 [−0.29, 0.22]	0.792	−0.003 [−0.37, 0.36]	0.986	0.185 [−0.16, 0.53]	0.296
QRS, *ms*	0.061 [−0.06, 0.18]	0.332	0.044 [−0.05, 0.14]	0.386	−0.002 [−0.13, 0.12]	0.974	0.006 [−0.12, 0.14]	0.927
QRS axis	−0.236 [−0.74, 0.27]	0.367	−0.112 [−0.44, 0.22]	0.507	−0.109 [−0.60, 0.38]	0.665	−0.446 [−0.90, 0.01]	0.056
R_{aVL}, *mm*	0.001 [−0.002, 0.005]	0.551	0.006 [0.002, 0.009]	0.001	0.001 [−0.002, 0.005]	0.417	0.005 [0.001, 0.011]	0.029
S_{V3}, *mm*	0.001 [−0.001, 0.004]	0.445	−0.001 [−0.002, 0.001]	0.697	−0.001 [−0.003, 0.002]	0.680	0.002 [−0.001, 0.005]	0.215

Adjusted for age, marital status, years of education, BMI, MET, waist circumference, hip circumference, wrist circumference, smoking, ischemic heart disease, hypertension, diabetes, TG, cholesterol, LDL, and HDL

B beta coefficient, *PD* P-wave duration, *CI* confidence interval

unexpectedly increase QRS voltage in certain metabolic conditions, contrary to the traditional view that obesity attenuates ECG signals due to insulating effects of adipose tissue [10]. In addition, this is shown that mild obesity with metabolic syndrome exert distinct cardiovascular effects compared to metabolically healthy

obesity [5]. Such association could be driven by several mechanisms. In metabolically unhealthy individuals, excess epicardial fat may alter ventricular depolarization patterns through local inflammation or lipid infiltration into myocardial tissue [28], leading to right ventricular forces amplification reflected in S_{V3}. This is supported by studies linking epicardial adiposity to pro-fibrotic signaling and conduction disturbances. However, our results contrast with the Singapore Armed Forces (SAFE) study of 144,346 young men [29], which found that TBFP > 25% was associated with lower prevalence of LVH by ECG criteria. This discrepancy might reflect population differences, as our unhealthy cohort likely had higher degrees of metabolic dysfunction compared to their healthy military population. In addition, ECG lead specificity were different in these study (e.g., S_{V3} vs. Sokolow-Lyon criteria for LVH). Of note, other studies have shown that obesity-related ECG changes are highly context-dependent with varying ECG-obesity relationships; for example, Sun et al. [30] reported wider QRS durations in obese participants. Additionally, Seyfeli et al. [31] found increased P-wave dispersion in obese women. These finding may indicate the complex interplay between adiposity and electrical parameters. From clinical point of view, linking TBFP to cardiovascular outcomes can be potentially used for cardiovascular risk stratification [32]. Cepeda-Valery et al. [33] showed that TBFP was associated with increased mortality. The elevated risk of CVDs in subjects with higher TBFP could be explained by the impact of TBFP on sympathetic activation [34]. Arai et al. [35] showed correlations between fat metrics and autonomic dysfunction markers. Our results might suggest that in unhealthy individuals with elevated TBFP, increased S_{V3} amplitude represents early electrical remodeling secondary to metabolic derangements rather than pure hypertrophy, as Sztajzel et al. [36] have shown obese individuals often have autonomic imbalances that could exacerbate arrhythmia risk. Nonetheless, future studies should investigate whether targeted reduction of visceral adiposity normalizes these ECG changes and whether such modifications correlate with improved outcomes or fat distribution (e.g., epicardial vs. subcutaneous) modulates this relationship.

We found that TFP was positively associated with R_{aVL} amplitude in both female participants and unhealthy individuals. Established ECG-LVH criteria support this finding; that is, increased R_{aVL} voltage (≥1.1 mV) reflects lateral left ventricular forces and potential hypertrophy [37]. In addition, Peiris et al. found a significant association between intra-abdominal fat increment and prolonged QTc interval, which may increase the risk of cardiac arrhythmias [38]. The sex-specific association in women might stem from adiposity distribution patterns—android (central) fat deposition that commonly observed in postmenopausal women, correlates strongly with LV mass independent of BMI [39]. In addition, in metabolically unhealthy individuals, elevated TFP may promote pro-hypertrophic signaling via inflammatory mediators (e.g., leptin, IL-6), insulin resistance or dyslipidemia [40]. The linear TFP-R_{aVL} relationship in unhealthy participants further supports the metabolic-ECG axis; that is, central obesity drives ectopic fat deposition (e.g., epicardial/perivascular fat), which may alter myocardial conduction through localized inflammation [28]. Notably, this contrasts with subcutaneous fat, which exerts paracrine anti-inflammatory effects; That is, it is hypothesized that TFP exert paracrine anti-inflammatory actions and is more sensitive to lipolytic stimulation, and more resistant against insulin-induced lipolysis suppression compared to subcutaneous regions [40–42]. Of course, clinically, TFP can potentially serve as a sex-specific marker of electrical remodeling; although it warrants further investigation into whether R_{aVL} amplitude changes track with visceral fat reduction interventions.

Moreover, our study found several clinically important associations between TBW and ECG parameters. The positive association between TBW and QRS duration across all participants might reflect fluid overload effects on ventricular conduction, as increased extracellular volume can mechanically stretch cardiomyocytes and slow depolarization through mechanoelectrical feedback [43–45]. This explanation is previously given that QRS prolongation is an established marker of ventricular dysfunction [46, 47]. The sex-specific associations—particularly the TBW-PR interval relationship in women—might be explained by hormonal modulation of fluid distribution, in which estrogen-mediated sodium retention could increase atrial stretch, leading to AV nodal conduct delay [48, 49]. Moreover, considering the TBW, the divergent findings between healthy and unhealthy participants are noticeable. We found in healthy individuals that TBW showed positive associations with PD, suggesting that fluid volume might be the dominant determinant on atrial conduction [50], and in diseased states (unhealthy subjects), fibrosis or remodeling might mask such TBW effect. However, in our unhealthy subjects, the negative TBW-S_{V3} relationship might indicate a pathological process like chronic inflammation or interstitial edema (conductivity loss), which might attenuate right ventricular forces [28]. This dichotomy supports the concept that TBW's cardiovascular effects are context-dependent, varying by health status and possibly mediated through different mechanisms—volume overload in healthy individuals vs. structural remodeling in diseased states. In general, while a prospective cohort has linked elevated TBW to cardiovascular risk [51], our study

yielded several insights on how TBW alterations manifest on ECG across different populations. Further researches are recommended to investigate these finding in different populations.

Our study was limited by its cross-sectional design, which precludes causal inferences. Also, more results could be obtained through measuring 24-h ECG and a longer follow-up. Additionally, while BIA is widely used in clinical and epidemiological settings due to its affordability and portability, it has notable limitations. BIA estimates body composition indirectly and may be affected by hydration status, recent physical activity, or meal timing, potentially introducing measurement error. These factors could impair observed relationships between body composition and ECG parameters. Furthermore, although participants yielded medical records, chronic diseases and smoking status were self-reported, which might cause underestimation. Residual confounding (e.g., lifestyle factors) might also persist despite adjustment for known variables. Importantly, our findings in an Iranian population might not fully generalize to other ethnic groups, as Asian populations often have higher body fat percentages at lower BMIs compared to European populations, which could affect both BIA accuracy and cardiovascular risk stratification. Despite these limitations, the large sample size and adjustment of various confounding variables are some strengths of this study.

Despite these limitations, we may suggest some actionable opinions for cardiovascular risk assessment. The European Society of Cardiology (ESC) guidelines on cardiovascular prevention emphasize the importance of early detection of metabolic risk factors, including obesity-related ECG changes, particularly in high-risk ethnic groups. For example, monitoring TBW and fat mass via BIA—particularly in obese individuals—may identify those at higher risk of ECG abnormalities (e.g., prolonged QT or QRS intervals) for early intervention. Clinicians could integrate BIA with routine ECG screening in high-risk populations to improve risk stratification, though standardized protocols for hydration and measurement timing are needed to minimize variability. However, future longitudinal studies with 24-h ECG monitoring and repeated BIA measurements across diverse ethnic groups are warranted to clarify temporal relationships and refine clinical thresholds, potentially informing more population-specific guidelines.

Conclusion

The present study reported the association between the body fat and water distribution with various ECG parameters such as QRS length, R_{aVL} and S_{V3} in a sample of general population in southern Iran. In conclusion, BIA indices might affect ECG parameters, leading to development of CVDs, such as arrhythmias. Further researches are required to confirm our findings to improve cardiovascular risk stratification and investigate its implications on cardiovascular treatment strategies in obese patients.

Acknowledgements
We appreciate the all individuals who participated in the study.

Author contributions
SA, MSH, and MF conceptualized and designed the study. MSH performed formal data analysis. OK, MAA, HA, and SD curated the data. OK, MAA, HA, MT, and EH drafted the manuscript. MF, SA, and AM provided critical revisions to the manuscript. MSH, SA, and MF supervised the study. All the authors have read and approved the final version of the manuscript.

Funding
This study was financially supported by Fasa University of Medical Sciences, Fasa, Iran.

Availability of data and materials
The datasets generated and/or analyzed during the current study are not publicly available due to its being the intellectual property of Fasa University of Medical Sciences but are available from the corresponding author (Dr. Afrashteh) on reasonable request.

Declarations

Ethics approval and consent to participate
PERSIAN Cohort Study was approved by the Ethics Committees of the Ministry of Health. This study is in agreement with the Helsinki declaration and Iranian national guidelines for ethics in research (reference ID: IR.FUMS.REC.1399.21).

Consent for publication
Written informed consent for publication was obtained from each participant.

Competing interests
The authors declare no competing interests.

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Received: 23 October 2024 Accepted: 8 April 2025
Published online: 19 April 2025

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