ORIGINAL ARTICLE

WILEY

Visceral fat level correction of the left ventricular hypertrophy electrocardiographic criteria

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Abstract

Background: Left ventricular hypertrophy (LVH) is a well-known risk factor for cardiovascular events. Even though there are many electrocardiographic (ECG) criteria for LVH, they still provide poor performance, especially among obese patients. The aim of this study was to examine whether adding visceral fat to ECG LVH criteria improves accuracy in the diagnosis.

Methods: One thousand seven hundred twenty two patients were included in the study. All patients underwent a complete physical examination, office blood pressure measurement, analysis of body composition, 12-lead ECG, and M-mode two-dimensional echocardiography. Four standard ECG criteria for LVH were analyzed, including Cornell voltage criteria, Cornell duration criteria, Sokolow–Lyon voltage criteria, and Sokolow–Lyon product criteria. Adjustments of ECG LVH criteria were performed using visceral fat level (VFATL) and BMI. Transthoracic echocardiography was used as a reference method to compare the quality of ECG LVH criteria.

Results: Multivariate logistic regression models were created and revealed a significant increase of area under curve (AUC) after VFATL and BMI addition to ECG LVH criteria. Improvement of sensitivity at 90% specificity was observed in all created models. The odds ratio (OR) of the analyzed ECG criteria increased after adding VFATL and BMI to the models. Furthermore, ROC curves analysis exposed better characteristics in detecting LVH of VFATL-adjusted criteria than BMI-adjusted and unadjusted criteria.

Conclusions: Adjusting ECG indexes to BMI or VFATL improves the sensitivity of LVH detection. VFATL-corrected indexes are more sufficiently than BMI-corrected. After advancements in indexes, both lean and morbidly obese individuals outcomes show a greater prevalence of correct LVH diagnosis.

KEYWORDS
electrocardiographic criteria, left ventricular hypertrophy, visceral fat

1 | INTRODUCTION

Left ventricular hypertrophy (LVH) is an essential factor for adverse cardiovascular outcomes and an independent predictor of all-cause death (Kannel et al., 1969; Stewart et al., 2018). It is important to find a cost-effective and efficient method to diagnose LVH. There are many ways we can assess the structure of the heart muscle. The most accurate performance with high specificity and sensitivity concerning heart hypertrophy can be obtained using echocardiography (ECHO) or cardiac magnetic resonance imaging (MRI). MRI is the so-called "gold standard" in LVH diagnosis (Bottini et al., 1995). Unfortunately, both methods require experienced, well-trained staff and expensive devices, hence are poorly available and costly. Another commonly used, cheap, and non-invasive method to detect LVH is electrocardiography (ECG). However, results obtained by ECG are not 100% consistent with the results of ECHO. There are various electrocardiographic criteria for LVH, which lack specificity and sensitivity compared to methods mentioned before (Nomsawadi & Krittayaphong, 2019). For example, the sensitivity of 8%–40% for Sokolow–Lyon voltage and 2%–41% for Cornell voltage criterion (Pewsner et al., 2007). The specificity is relatively decent and ranges 53%–100% and 89%–100%, respectively, for criterion mentioned before (Pewsner et al., 2007).

Nevertheless, there are some ways to improve the diagnostic value of ECG LVH criteria (Cuspidi et al., 2016; Robinson et al., 2016). One of the reasons behind the poor performance of ECG in LVH diagnosis is excess fat tissue covering the heart and subcutaneous tissue that thickens the chest wall in obese patients. It is already known that obese patients' ECG results present lower voltage amplitude hence decreased sensitivity considering LVH detection compared to non-obese patients (Cuspidi et al., 2016; Nomsawadi & Krittayaphong, 2019; Robinson et al., 2016). The importance of this is because obese people more often suffer from cardiovascular diseases, as obesity is a crucial risk factor for CVD. There are publications where different ECG LVH criteria achieved much higher specificity and sensitivity in detecting LVH when corrected by BMI or WHR (Angeli et al., 2014; Elffers et al., 2019; Robinson et al., 2016). Our study aims to examine whether adding visceral fat to ECG LVH criteria improves accuracy in the diagnosis of LVH.

2 | MATERIALS AND METHODS

The cross-sectional study evaluated data from 1722 consecutive adults, aged between 40 and 70. The data have been collected from 2011 to 2020. All of the patients were informed about the aim of the study and gave their written consent.

The patients underwent a complete physical examination, office blood pressure measurement, analysis of body composition, 12-lead electrocardiography (ECG), and M-mode two-dimensional echocardiography. Patients with left bundle branch block, right bundle branch block, Wolf–Parkinson–White syndrome, and atrial fibrillation were excluded from the study.

2.1 | Electrocardiography

Standard 12-lead ECG was recorded at 25 mm/s and 1.0 mV/cm. We investigated the four most widely used ECG criteria for left ventricular hypertrophy (LVH). The analyzed criteria are listed in Table 1.

2.2 | Echocardiography

The transthoracic two-dimensional M-mode echocardiography was performed to evaluate left ventricular mass (LVM). LVM was assessed using ASE (American Society of Echocardiography) formula: LVM (g) = $0.8 \times \{1.04 \times [(\text{LVIDd} + \text{PW} + \text{IVSd})^3 - (\text{LVIDd})^3]\} + 0.6$ and indexed to body surface area (Marwick et al., 2015); where LVIDd—Left ventricle internal dimension diastole, PW—posterior wall thickness, IVSd—inter-ventricular septum diastole.

According to ASE/EACVI 2015 guidelines, LVH was diagnosed in individuals with left ventricular mass index (LVMI) > 115 g/m^2 in men and >95 g/m^2 in women (Marwick et al., 2015). Echocardiographic LVH was used as a reference standard to compare the quality of ECG LVH criteria.

2.3 | Analysis of body composition

The body composition analysis was performed using a Multi-Frequency Body Composition Analyzer (MC-180MA; Tanita). The body composition was estimated by measuring the body's bioelectrical impedance using 8 points of tactile electrodes (two thumbs, two palms, two fronts soles, two heels). Participants were standing barefoot on the device with electrodes placed in both hands. All testing was performed according to the instruction of the manufacturer. Patients were instructed to avoid strenuous exercise or excessive consumption directly before the test. The evaluated data include BMI, fat %, fat mass, visceral fat level, muscle mass, non-fat components, bone mass, and total body water weight. Visceral fat level (VFATL) is an index of fat level in the internal abdominal cavity. VFATL, which was estimated by bioelectrical impedance analysis, is rating from 1 to 59. The calculating equation was derived from multiple regression analysis.

TABLE 1 Analyzed left ventricular hypertrophy ECG criteria

Left ventricular hypertrophy ECG criteria
Cornell voltage criteria: $\text{RaV}_L + \text{SV}_3 \geq$ 20 mm for women and ≥28 mm for men
Cornell duration criteria: ($\text{RaV}_L + \text{SV}_3 +$ for women, add 8 mm) × QRS duration ≥ 2440 mm × ms
Sokolow–Lyon voltage criteria: $\text{SV}_1 + \text{RV}_5$ or $\text{V}_6 \geq$ 35 mm
Sokolow–Lyon product criteria: ($\text{SV}_1 + \text{RV}_5$ or V_6) × QRS duration ≥ 3710 mm × ms

2.4 | Statistical analysis

Statistical analysis was conducted using Statsoft Statistica 13.3 software (TIBCO Software Inc., 2017). p-Value < .05 was considered statistically significant. The expression of categorical variables was shown as numbers and percentages (presented in parentheses). Continuous variables were displayed as mean ± standard deviation (SD). Normal distribution of the continuous variables was verified using Shapiro–Wilk test. Univariate logistic regression models were created and analyzed with LVH as the dependent variable and electrocardiographic LVH criteria, VFATL, and BMI as independent variables. Using backward stepwise regression analysis, multivariate logistic regression analysis was performed with BMI, VFATL, and each of 4 analyzed electrocardiographic criteria for LVH (Sokolow–Lyon voltage, Sokolow–Lyon product, Cornell voltage, and Cornell product) in three groups: all patients, women, and men. Adjustments of ECG LVH criteria were performed using VFATL and BMI. Receiver operating curves (ROC) were assessed and compared using a two-tailed univariate z test of the difference between the areas under two performance curves. Sensitivities of electrocardiographic criteria were determined at a specificity of 90% and were compared using the z test for proportions.

3 | RESULTS

One thousand seven hundred twenty two patients were included in the study, and 352 patients (20.4%) had LVH diagnosis based on LVMI measurement. The main characteristics of the entire population, population with LVH, and population without LVH are presented in Table 2.

Univariate model of logistic regression analysis revealed that Sokolow–Lyon duration product is the most potent index from analyzed electrocardiographic left ventricular hypertrophy criteria, (OR = 5,255; 95% CI = 3,190–8,659). Furthermore, the least essential indicator for LVH between analyzed ECG LVH criteria is Cornell voltage (OR = 2,759; 95% CI = 1,753–4,342). The remaining results of univariate logistic regression are presented in the forest plot (Figure 1).

In every multivariate logistic regression model, BMI was removed by the software, because of decreasing accuracy of the model except in the group of women in which BMI remained in the model. In comparison with models without addition of BMI and VFATL, created models improved the AUC to 0.738 with Sokolow–Lyon voltage; improved the AUC with Sokolow–Lyon product to 0.743; improved the AUC with Cornell voltage to 0.735; and improved the AUC with Cornell duration product to 0.748. Analogous results were achieved in women and men group. Results are shown in Table 3. Furthermore, improvement of sensitivity at 90% specificity was observed in all created models. Comparison of R^2 of the multivariate regression models is also presented in Table 3, which is the highest in Sokolow–Lyon duration product (0.19). The odds ratio (OR) of the analyzed ECG criteria increased after adding VFATL and BMI to the models. However, OR of Cornell duration product decreased from 2,96 (95% CI = 2,15–4,10) to 2,86 (95% CI = 2,02–4,03). This decrease was not observed when group was divided according to sex.

Further analysis included comparing the ROC curves to compare areas under the curve (AUC) of VFATL-corrected and uncorrected ECG LVH criteria for LVH. The results are presented in Figure 2. The VFATL-corrected Sokolow–Lyon voltage, VFATL-corrected Sokolow–Lyon duration product, VFATL-corrected Cornell voltage, and VFATL-corrected Cornell duration product criteria had

TABLE 2 Characteristics of the population study, n = 1722 participants of the study

Variable	All	LVH	No LVH
Female sex, No. (%)	832 (48.3)	105 (29.8)	727 (53.1)
Age, years	55.26 ± 15.05	60.48 ± 12.6	53.92 ± 15.33
BMI kg/m²	28.76 ± 14.31	30.5 ± 5.49	27.80 ± 4.91
SBP, mmHg	144.25 ± 22.41	156.15 ± 24.59	141.20 ± 20.75
DBP, mmHg	83.73 ± 13.52	87.82 ± 14.83	82.69 ± 12.66
VFATL	9.49 ± 4.65	12.36 ± 4.79	8.75 ± 4.32
LVM ASE, g	192.06 ± 63.51	280.40 ± 57.82	169.36 ± 41.13
LVMI ASE, g/m²	97.43 ± 26.72	136.76 ± 23.09	87.32 ± 16.15
BMI ≥ 30 kg/m², No. (%)	582 (33.8)	188 (53.4)	394 (28.8)
LVH, No. (%)	352 (20.4)	352 (100)	0 (0)
HTN, No. (%)	1533 (89.0)	342 (97.2)	1191 (86.9)
Cornell voltage, μV	16.86 ± 6.24	19.92 ± 7.05	16.07 ± 5.76
Cornell product, μV ms	1670.39 ± 737.89	2080.13 ± 925.40	1563.90 ± 639.59
Sokolow–Lyon voltage, μV	22.43 ± 7.34	24.32 ± 8.52	21.93 ± 6.92
Sokolow–Lyon product, μV ms	2196.33 ± 789.44	2507.91 ± 942.32	2115.36 ± 723.39

Abbreviations: DBP, diastolic blood pressure; HTN, hypertension; LVH, left ventricular hypertrophy; LVM, left ventricular mass; LVMI, left ventricular mass index; SBP, systolic blood pressure; VFATL, visceral fat level.
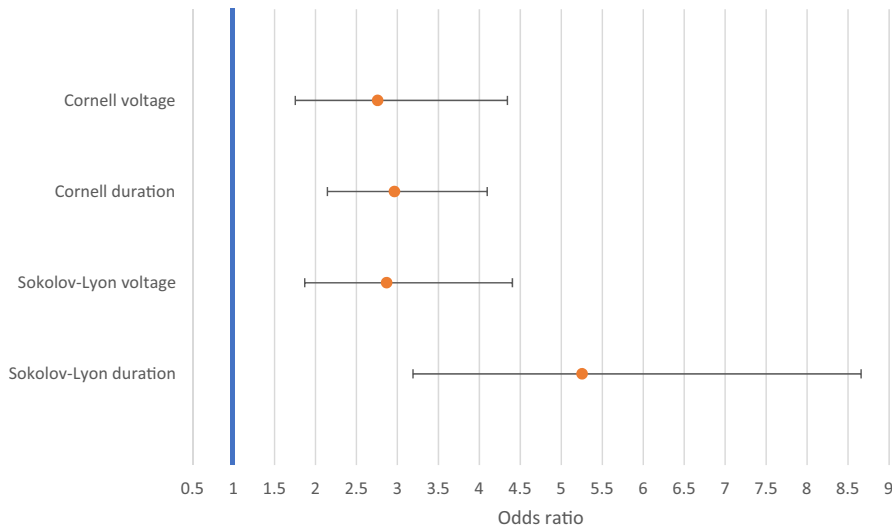
better characteristics in detecting LVH than unadjusted criteria, and BMI-adjusted criteria. AUC for VFATL-corrected vs. BMI-corrected was, respectively, 0.729 vs. 0.665; 0.746 vs. 0.700; 0.765 vs. 0.727; 0.773 vs. 0.739. All differences were statistically significant, respectively, $p < .001$; $p < .001$; $p < .001$; $p = .0015$. Results are shown in Table 4. AUC for uncorrected ECG criteria for detection of LVH was in all cases significantly lower ($p < .05$) than BMI-corrected and VFATL-corrected (results not displayed). Analysis of the ROC curves revealed improvement of sensitivity at 90% specificity after VFATL correction comparing to BMI correction of ECG criteria for LVH. Sensitivity at 90% specificity was, respectively, 26% vs. 37% ($p < .05$) for Sokolow–Lyon voltage; 31% vs. 36% ($p < .05$) for Sokolow–Lyon duration product; 30% vs. 35% ($p < .05$) for Cornell voltage; and 31% vs. 37% ($p < .05$) for Cornell duration product.

4 | DISCUSSION

Literature reports more than 30 ECG indexes for LVH diagnosis, and the most prevalent in clinical practice is based on QRS voltage (Cuspidi et al., 2013; Hancock et al., 2009). Accuracy of ECG indexes for detecting LVH is inefficient (Pewsner et al., 2007). Systematic review reveals the sensitivity of Sokolow–Lyon voltage criteria varies from 8% to 40% at specificities 53%–100%, and sensitivity of Cornell voltage criteria ranged from 2% to 19% at specificities 89%–100% (Pewsner et al., 2007). As a matter of fact, among patients with BMI ≥35 kg/m^2 sensitivity tends to be even lower and reaches 5.5%–0% for most commonly used criteria for the diagnosis of left ventricular hypertrophy (Domienik-Karłowicz et al., 2011, 2018). Also numerously morbidities may decrease sensitivity and specificity of the ECG criteria of LVH, for instance in patients with moderate and severe aortic stenosis (Bula et al., 2019). The pioneering study concerning sensitivity and specificity of 10 ECG criteria vs. ECHO alterations for LVH (i.e., internal dimension, wall thickness, LV mass) revealed non-satisfying outcomes 0%–13%, 0%–20%, and 0%–12%, respectively (Nath et al., 1988). Sensitivity and specificity of ECG

criteria for diagnosis LVH with ECHO, MRI, or during autopsy had been described as circa 25% and up to 90%, respectively (Jain et al., 2010; Pewsner et al., 2007).

Features of standard 12-lead ECG (little cost, extensive availability, good reproducibility, non-invasiveness) find it as the first-line examination for LVH detection (Cuspidi et al., 2013; Hancock et al., 2009). Undoubtedly, obesity is closely linked to ECG changes that may derange the correct diagnosis of cardiac disorders, including LVH (Poirier et al., 2006). The increased amount of adipose tissue in severe obese individuals reduces QRS voltage in precordial leads and peripheral limb leads (Abächerli et al., 2009; Shirani et al., 1995). ECG also reveals abnormalities frequently associated with obesity, namely alterations of the P wave, QRS and T wave, prolongation of QRS and QT duration, supraventricular and ventricular arrhythmias, left-axis deviation, left atrial abnormalities, and false-positive criteria for inferior myocardial infarction (Cuspidi et al., 2013; Fraley et al., 2005; Poirier et al., 2006). Poor sensitivity and variability of the outcomes depending on the level of fat tissue cause imperfection of that method (Hancock et al., 2009; Williams et al., 2018). In view of the aspects mentioned above, echocardiography and MRI become "gold standard" in LVH diagnosis (Aro & Chugh, 2016; Devereux et al., 1997; Hancock et al., 2009; Levy et al., 1990).

Framingham Heart Study presented outcomes that ECG evidence of LVH is associated with three- to fourfold increased risk of cardiovascular and all-cause mortality (Kannel et al., 1969, 1970). LVH in normotensive and hypertensive obese individuals occurs in echocardiography in 20%–85% (Cuspidi et al., 2014). LVH is caused by an extensive left ventricular mass. However, the cardiac electrical voltage is not dependent on the mass of the myocardium. As the study suggests, it relies on the heart's active and passive attributes and the torsum. These factors are modified by the fetch between left ventricular and electrode, which are influenced by the location of the electrode lung movements, abnormalities, and myocardium fibrosis (Peguero et al., 2017).

Over the past few decades, due to the negative dietary and physical activity pattern, obesity prevalence has increased worldwide to

TABLE 3 Performance of univariate logistic regression models for conventional ECG criteria for LVH and multivariate logistic regression performance for conventional ECG criteria for LVH, with BMI and VFATL in a) all patients, b) men, and c) women

a)	AUC	R^2	Sensitivity at 90% specificity, %	OR of ECG criteria
Sokolow–Lyon voltage	0.571		20	2.87 (95% CI = 1.87–4.40)
Sokolow–Lyon voltage and VFATL	0.738	0.17	34	3.98 (95% CI = 2.48–6.39)
Sokolow–Lyon product	0.619		21	5.26 (95% CI = 3.19–8.66)
Sokolow–Lyon product and VFATL	0.743	0.19	37	7.27 (95% CI = 4.18–12.65)
Cornell voltage	0.672		21	2.76 (95% CI = 1.75–4.34)
Cornell voltage and VFATL	0.735	0.16	31	3.31 (95% CI = 2.03–5.38)
Cornell product	0.696		24	2.96 (95% CI = 2.15–4.10)
Cornell product and VFATL	0.748	0.18	33	2.86 (95% CI = 2.02–4.03)
b)				
Sokolow–Lyon voltage	0.527		19	2.14 (95% CI = 1.33–3.44)
Sokolow–Lyon voltage and VFATL	0.702	0.14	32	3.45 (95% CI = 2.04–5.82)
Sokolow–Lyon product	0.561		21	3.85 (95% CI = 2.25–6.57)
Sokolow–Lyon product and VFATL	0.714	0.17	31	6.27 (95% CI = 3.46–11.36)
Cornell voltage	0.625		17	2.21 (95% CI = 1.29–3.77)
Cornell voltage and VFATL	0.691	0.13	27	2.83 (95% CI = 1.61–4.97)
Cornell product	0.636		19	2.04 (95% CI = 1.39–2.98)
Cornell product and VFATL	0.699	0.13	26	2.23 (95% CI = 1.49–3.32)
c)				
Sokolow–Lyon voltage	0.560		17	2.39 (95% CI = 0.75–7.57)
Sokolow–Lyon voltage, VFATL and BMI	0.723	0.13	33	3.47 (95% CI = 0.95–12.62)
Sokolow–Lyon product	0.614		21	3.55 (95% CI = 0.64–19.66)
Sokolow–Lyon product, VFATL and BMI	0.717	0.13	31	7.58 (95% CI = 1.23–46.80)
Cornell voltage	0.712		30	2.86 (95% CI = 1.17–7.05)
Cornell voltage, VFATL and BMI	0.723	0.13	33	3.76 (95% CI = 1.43–9.92)
Cornell product	0.735		34	4.19 (95% CI = 2.23–7.89)
Cornell product, VFATL and BMI	0.738	0.16	40	4.50 (95% CI = 2.27–8.91)

a pandemic dimension (Blüher, 2019; Chooi et al., 2019; Swinburn et al., 2019). Obesity is a major risk factor for three of four main non-communicable diseases: cardiovascular diseases, DM2, and certain cancers responsible for greater than 70% of early deaths (Blüher, 2019; Swinburn et al., 2019). Obesity could lead to diminished quality of life, depression, dementia, social problems, and unemployment (Blüher, 2019; Chooi et al., 2019). Through various mechanisms (increased total blood volume, increased cardiac output, and metabolic and inflammatory alterations), epicardial and intramural fat accumulation leads to LV enlargement and LVH, or either of them, and consequently to systolic and diastolic heart failure. The prevention and treatment of obesity strongly protect from incident heart failure (Cuspidi et al., 2014; Poirier et al., 2006). Cuspidi et al. (2014) in meta-analysis revealed that LVH prevalence is superior in the obese group than in non-obese.

According to Muiesan et al. (2017), the BMI-adjusted prevalence of ECG-LVH could refine cardiovascular risk stratification independently of accompanying factors such as age, sex, smoking, hypertension, hypercholesterolemia, diabetes, income, education,

and physical activity. Many studies submitted that waist-hip ratio or waist circumference, as indicators of central adiposity phenotypes, more precisely correlated with CVD than BMI (Canoy et al., 2013; O'Donnell et al., 2016; Yusuf et al., 2005). The supremacy of VFATL (measured using the electrical impedance) over BMI in detecting CVD was revealed in two Japanese studies (in these studies, LVH was not present) (Kobayashi et al., 2006; Yamashita et al., 2012). Feng et al revealed that VFATL might be superior to BMI or waist circumference in predicting LVH in the population aged ≥65 years (Feng et al., 2018).

Comparison with the previous literature reveals that adjusting to body fat measurement improves detecting LVH in ECG. Our study also confirms these outcomes. Improved Sokolow–Lyon voltage, Sokolow–Lyon product, Cornell voltage, and Cornell product adjusted to BMI or BMI with QRS T angle are more significant in detecting LVH than conventional indexes. Sensitivity at 90% specificity indexes was 16%–25% before correction, 32%–38% after BMI correction, and 41%–44% after BMI and QRS T angle correction (Elffers et al., 2019). In the hypertension population, a combination
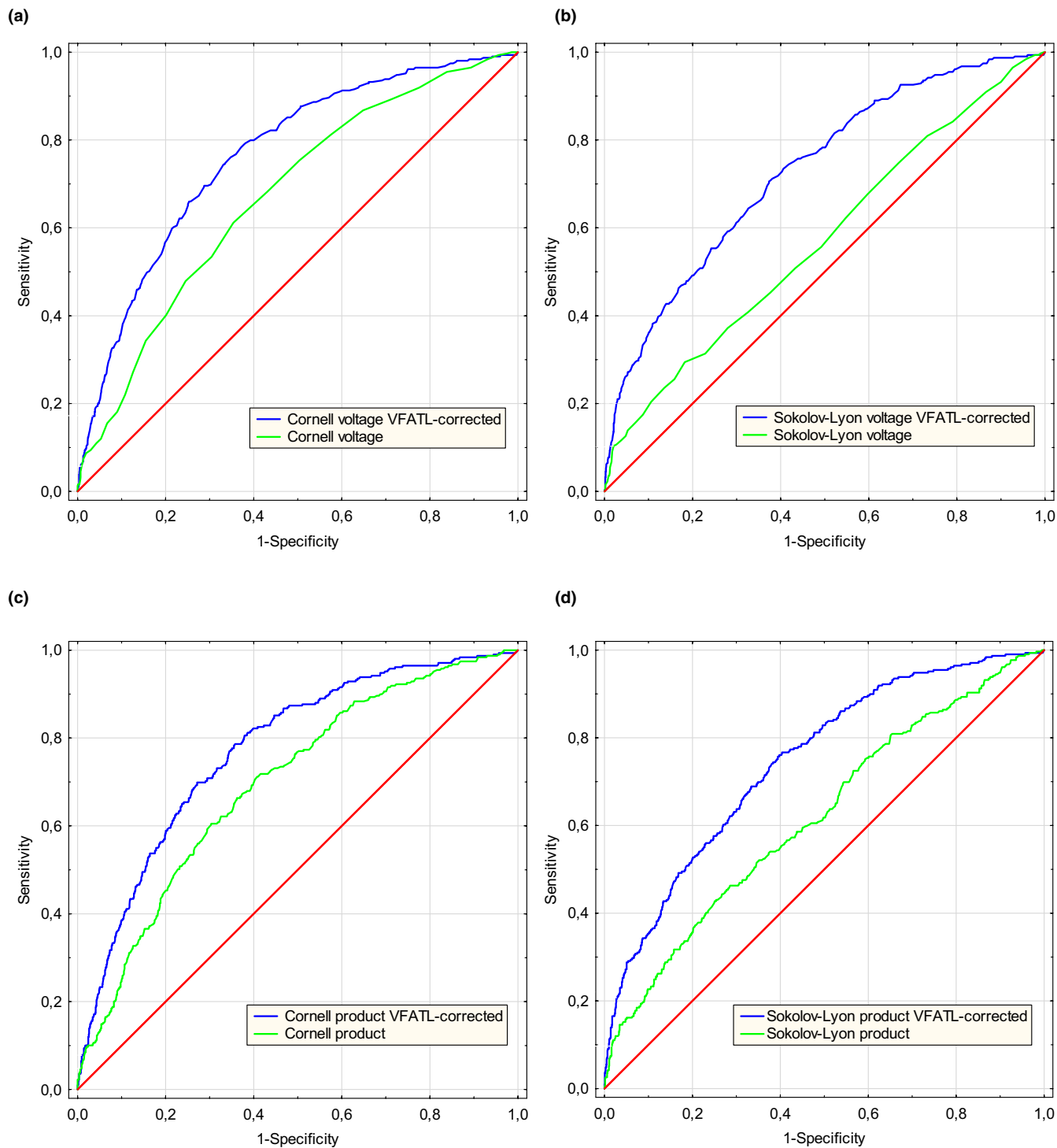
FIGURE 2 Receiver operating characteristics (ROC) curves of electrocardiographic criteria with and without VFATL correction for detection of LVH. (a) Cornell voltage and VFATL-corrected Cornell voltage (b) Sokolow–Lyon voltage and VFATL-corrected Sokolow–Lyon voltage (c) Cornell duration product and VFATL-corrected Cornell duration product (d) Sokolow–Lyon duration product and VFATL-corrected Sokolow–Lyon duration product [Color figure can be viewed at wileyonlinelibrary.com]

of Cornell voltage with BMI improved LVH detection (Angeli et al., 2014).

Sokolow–Lyon voltage and Sokolow–Lyon product more than Cornell voltage and Cornell products depend on precordial leads; therefore, after adjusting, the more significant transition in

sensitivity at 90% specificity is observed in Sokolow–Lyon voltage and Sokolow–Lyon product, respectively, 14, 16, 10, and 9 percentage points. Elffers et al. (2019) created a similar hypothesis. Their outcomes also correspond to the findings in this study. However, ECG advocacy's convenience is in further improvement due to

TABLE 4 Performance of BMI-corrected and VFATL-corrected conventional ECG criteria for detection of LVH. Results of comparison (*p*-values) of AUC

	AUC	*p* (BMI- vs. VFATL-adjusted criteria)	Sensitivity at 90% specificity, %
Sokolow–Lyon voltage*BMI	0.665		26
Sokolow–Lyon voltage*VFATL	0.729	<.001	37
Sokolow–Lyon product*BMI	0.700		31
Sokolow–Lyon product*VFATL	0.746	<.001	36
Cornell voltage*BMI	0.727		30
Cornell voltage*VFATL	0.765	<.001	35
Cornell product*BMI	0.739		31
Cornell product*VFATL	0.773	.0015	37

clinical practice, epidemiological studies, and clinical trials (Hancock et al., 2009). It is essential to adjust noted patient-dependent variables (age, gender, race, body habitus, and temporal separation between 2 tests), when such criteria have been ascertained (Aro & Chugh, 2016; Hancock et al., 2009).

As in our study, EBM constantly endeavors to improve ECG indexes' accuracy in detecting LVH, including obese patients. The main finding of the presented report is as follows:

1. The most potent index for the prevalence of LVH is Sokolow–Lyon duration product (OR = 5,255; 95% CI = 3,190–8,659).
2. All examined indexes sensitivity at 90% specificity is improved after VFATL correction compared to BMI correction or unadjusted criteria.
3. AUC of VFATL-adjusted criteria, compared to BMI correction, in detecting LVH is significantly higher.
4. Multivariate logistic regression, for conventional ECG criteria for LVH, with BMI and VFATL, expressed higher OR of the ECG criteria than OR of the ECG criteria without BMI and VFATL (except Cornell duration product, which revealed similar OR).
5. All results were observed also when group was divided according to sex.

Inseparable issue is normalization of body weight among LVH patients which must be concerned and analyzed. Studies have shown changes in ECG examination after restoring correct body weight composition. After substantial weight loss, alterations in ECG characteristic to severely obese patients (the leftward shift in P-wave, QRS, and T-wave axes) retreat and make ECG report more comparable to lean individuals. Crucial is the restoration of correct QRS voltage due to reduction of amount chest wall fat. Also, Alpert et al. (2001) underline the importance of normalization of body weight on detecting LVH mainly because of underdiagnosing that pathology attributable to greater frequency of low QRS voltage (Alpert et al., 2001; Eisenstein et al., 1982).

In healthy adults with correct BMI (18.5–25.0 kg/m^2), discrete ECG alterations (similar to obesity although significantly less intense) are observed. These were related to altered atrial conduction, the leftward shift of the heart axis, and decreased Sokolow–Lyon

voltage (Hassing et al., 2019). Even slight changes impact on detection pathologies of heart muscle like LVH. Our study showed that independently in a regular BMI group adjusting to BMI or VFATL also improved LVH detection more sufficiently.

Several limitations require clarification. The study was performed in a population-based cohort study of middle-aged Caucasian individuals (55.26 ± 15.05 years old). These outcomes should not be extrapolated to different ethnic races, such as Asian background and pediatric patients, in the absence of deliberation. Our group was recruited mainly in hypertensive individuals; namely, 89.02% of the patients diagnosed with arterial hypertension. Only 4 LVH indexes were analyzed in our study. It is not possible to predict the correlation of other indexes. Presumably, indexes based on precordial leads are more adequate.

However, the study has multiple strengths. The whole group was tested with the gold-standard transthoracic two-dimensional M-mode ECHO to control the accuracy of our findings. Sequentially, we assessed both BMI and VFATL and compared them in the efficiency of detecting LVH. This study was performed on either normotensive and hypertensive population and correct and disturbed bodyweight composition.

5 | CONCLUSIONS

Bodyweight composition significantly impacts on efficacy of ECG outcomes. Adjusting indexes to BMI or VFATL improves the sensitivity of LVH detection both in women and men. VFATL-corrected indexes are more sufficiently than BMI-corrected. After advancements in indexes, both lean and morbidly obese individuals' outcomes show a greater prevalence of correct LVH diagnosis. Increased body weight is an independent factor of LVH, and VFATL elevates the risk of occurrence of LVH more than BMI.

CONFLICTS OF INTEREST
The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other

equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

AUTHOR CONTRIBUTIONS

ETHICAL APPROVAL

Informed consent for publication of data was obtained from each patient.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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REFERENCES

Abächerli, R., Zhou, L., Schmid, J. J., Kobza, R., Niggli, B., Frey, F., & Erne, P. (2009). Correlation relationship assessment between left ventricular hypertrophy voltage criteria and body mass index in 41,806 Swiss conscripts. *Annals of Noninvasive Electrocardiology*, *14*(4), 381–388. https://doi.org/10.1111/j.1542-474X.2009.00330.x

Alpert, M. A., Terry, B. E., Hamm, C. R., Fan, T. M., Cohen, M. V., Massey, C. V., & Painter, J. A. (2001). Effect of weight loss on the ECG of normotensive morbidly obese patients. *Chest*, *119*(2), 507–510. https://doi.org/10.1378/chest.119.2.507

Angeli, F., Verdecchia, P., Iacobellis, G., & Reboldi, G. (2014). Usefulness of QRS voltage correction by body mass index to improve electrocardiographic detection of left ventricular hypertrophy in patients with systemic hypertension. *The American Journal of Cardiology*, *114*(3), 427–432. https://doi.org/10.1016/j.amjcard.2014.05.016

Aro, A. L., & Chugh, S. S. (2016). Clinical diagnosis of electrical versus anatomic left ventricular hypertrophy. *Circulation: Arrhythmia and Electrophysiology*, *9*(4), e003629. https://doi.org/10.1161/CIRCEP.115.003629

Blüher, M. (2019). Obesity: Global epidemiology and pathogenesis. *Nature Reviews Endocrinology*, *15*(5), 288–298. https://doi.org/10.1038/s41574-019-0176-8

Bottini, P., Carr, A., Prisant, L., Flickinger, F., Allison, J., & Gottdiener, J. (1995). Magnetic resonance imaging compared to echocardiography to assess left ventricular mass in the hypertensive patient. *American Journal of Hypertension*, *8*(3), 221–228. https://doi.org/10.1016/0895-7061(94)00178-E

Bula, K., Ćmiel, A., Sejud, M., Sobczyk, K., Ryszkiewicz, S., Szydło, K., Wita, M., & Mizia-Stec, K. (2019). Electrocardiographic criteria for left ventricular hypertrophy in aortic valve stenosis: Correlation with echocardiographic parameters. *Annals of Noninvasive Electrocardiology*, *24*(5), e12645. https://doi.org/10.1111/anec.12645

Canoy, D., Cairns, B. J., Balkwill, A., Lucy Wright, F., Green, J., Reeves, G., Beral, V. & Million Women Study Collaborators (2013). Coronary heart disease incidence in women by waist circumference within categories of body mass index. *European Journal of Preventive Cardiology*, *20*(5), 759–762. https://doi.org/10.1177/2047487313492631

Chooi, Y. C., Ding, C., & Magkos, F. (2019). The epidemiology of obesity. *Metabolism: Clinical and Experimental*, *92*, 6–10. https://doi.org/10.1016/j.metabol.2018.09.005

Cuspidi, C., Facchetti, R., Bombelli, M., Sala, C., Tadic, M., Grassi, G., & Mancia, G. (2016). Does QRS voltage correction by body mass index improve the accuracy of electrocardiography in detecting left ventricular hypertrophy and predicting cardiovascular events in a general population? *The Journal of Clinical Hypertension*, *18*(5), 415–421. https://doi.org/10.1111/jch.12678

Cuspidi, C., Rescaldani, M., Sala, C., & Grassi, G. (2014). Left-ventricular hypertrophy and obesity. *Journal of Hypertension*, *32*(1), 16–25. https://doi.org/10.1097/HJH.0b013e328364fb58

Cuspidi, C., Sala, C., & Grassi, G. (2013). Detection of left ventricular hypertrophy in obesity: Mission impossible? *Journal of Hypertension*, *31*(2), 256–258. https://doi.org/10.1097/HJH.0b013e32835ca135

Devereux, R. B., Pini, R., Aurigemma, G. P., & Roman, M. J. (1997). Measurement of left ventricular mass: Methodology and expertise. *Journal of Hypertension*, *15*(8), 801–809. Lippincott Williams and Wilkins. https://doi.org/10.1097/00004872-199715080-00002

Domienik-Karłowicz, J., Lichodziejewska, B., Lisik, W., Ciurzyński, M., Bienias, P., Chmura, A., & Pruszczyk, P. (2011). Electrocardiographic criteria of left ventricular hypertrophy in patients with morbid obesity. *Annals of Noninvasive Electrocardiology*, *16*(3), 258–262. https://doi.org/10.1111/j.1542-474X.2011.00440.x

Domienik-Karłowicz, J., Rymarczyk, Z., Lisik, W., Kurnicka, K., Ciurzyński, M., Bielecki, M., Kosieradzki, M., & Pruszczyk, P. (2018). Questionable validity of left ventricular hypertrophy cutoff values in morbidly and super-morbidly obese patients. *Annals of Noninvasive Electrocardiology*, *23*(6), e12564. https://doi.org/10.1111/anec.12564

Eisenstein, I., Edelstein, J., Sarma, R., Sanmarco, M., & Selvester, R. H. (1982). The electrocardiogram in obesity. *Journal of Electrocardiology*, *15*(2), 115–118. https://doi.org/10.1016/S0022-0736(82)80003-4

Elffers, T. W., Trompet, S., de Mutsert, R., Maan, A. C., Lamb, H. J., Macfarlane, P. W., Rosendaal, F. R., & Jukema, J. W. (2019). Electrocardiographic detection of left ventricular hypertrophy; adding body mass index and spatial QRS-T angle: A cross-sectional study. *Cardiology and Therapy*, *8*(2), 345–356. https://doi.org/10.1007/s40119-019-00151-9

Feng, P., Huang, Y., Wang, S., Yu, G., Li, G., Lei, H., Qin, S., & Huang, W. (2018). Analysis of the associations between obesity indices and left ventricular mass. *Cardiology*, *141*(4), 183–189. https://doi.org/10.1159/000496177

Fraley, M. A., Birchem, J. A., Senkottaiyan, N., & Alpert, M. A. (2005). Obesity and the electrocardiogram. *Obesity Reviews*, *6*(4), 275–281. https://doi.org/10.1111/j.1467-789X.2005.00199.x

Hancock, E. W., Deal, B. J., Mirvis, D. M., Okin, P., Kligfield, P., & Gettes, L. S. (2009). AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram. Part V: Electrocardiogram changes associated with cardiac chamber hypertrophy a scientific statement from the American Heart Association Electrocardiography. *Journal of the American College of Cardiology*, *53*(11), 992–1002. https://doi.org/10.1016/j.jacc.2008.12.015

Hassing, G. J., van der Wall, H. E. C., van Westen, G. J. P., Kemme, M. J. B., Adiyaman, A., Elvan, A., Burggraaf, J., & Gal, P. (2019). Body mass index related electrocardiographic findings in healthy young individuals with a normal body mass index. *Netherlands Heart Journal*, *27*(10), 506–512. https://doi.org/10.1007/s12471-019-1282-x

Jain, A., Tandri, H., Dalal, D., Chahal, H., Soliman, E. Z., Prineas, R. J., Folsom, A. R., Lima, J. A. C., & Bluemke, D. A. (2010). Diagnostic and prognostic utility of electrocardiography for left ventricular hypertrophy defined by magnetic resonance imaging in relationship to ethnicity: The Multi-Ethnic Study of Atherosclerosis (MESA). *American Heart Journal*, *159*(4), 652–658. https://doi.org/10.1016/j.ahj.2009.12.035

Kannel, W. B., Gordon, T., Castelli, W. P., & Margolis, J. R. (1970). Electrocardiographic left ventricular hypertrophy and risk of coronary heart disease. The Framingham study. *Annals of Internal Medicine*, *72*(6), 813–822. https://doi.org/10.7326/0003-4819-72-6-813

Kannel, W. B., Gordon, T., & Offutt, D. (1969). Left ventricular hypertrophy by electrocardiogram. Prevalence, incidence, and mortality in the Framingham study. *Annals of Internal Medicine*, *71*(1), 89–105. https://doi.org/10.7326/0003-4819-71-1-89

Kobayashi, J., Murano, S., Kawamura, I., Nakamura, F., Murase, Y., Kawashiri, M. A., Nohara, A., Asano, A., Inazu, A., & Mabuchi, H. (2006). The relationship of percent body fat by bioelectrical impedance analysis with blood pressure, and glucose and lipid parameters. *Journal of Atherosclerosis and Thrombosis*, *13*(5), 221–226. https://doi.org/10.5551/jat.13.221

Levy, D., Garrison, R. J., Savage, D. D., Kannel, W. B., & Castelli, W. P. (1990). Prognostic implications of echocardiographically determined left ventricular mass in the Framingham heart study. *New England Journal of Medicine*, *322*(22), 1561–1566. https://doi.org/10.1056/nejm199005313222203

Marwick, T. H., Gillebert, T. C., Aurigemma, G., Chirinos, J., Derumeaux, G., Galderisi, M., Gottdiener, J., Haluska, B., Ofili, E., Segers, P., Senior, R., Tapp, R. J., & Zamorano, J. L. (2015). Recommendations on the use of echocardiography in adult hypertension: A report from the European Association of Cardiovascular Imaging (EACVI) and the American Society of Echocardiography (ASE). *Journal of the American Society of Echocardiography*, *28*(7), 727–754. https://doi.org/10.1016/j.echo.2015.05.002

Muiesan, M. L., Salvetti, M., Di Castelnuovo, A., Paini, A., Assanelli, D., Costanzo, S., Badilini, F., Vaglio, M., Donati, M. B., Rosei, E. A., De Gaetano, G., Iacoviello, L. & Moli-sani Study Investigators (2017). Obesity and ECG left ventricular hypertrophy. *Journal of Hypertension*, *35*(1), 162–169. https://doi.org/10.1097/HJH.0000000000001121

Nath, A., Alpert, M. A., Terry, B. E., & Kelly, D. L. (1988). Sensitivity and specificity of electrocardiographic criteria for left and right ventricular hypertrophy in morbid obesity. *The American Journal of Cardiology*, *62*(1), 126–130. https://doi.org/10.1016/0002-9149(88)91377-X

Nomsawadi, V., & Krittayaphong, R. (2019). Diagnostic performance of electrocardiographic criteria for left ventricular hypertrophy among various body mass index groups compared to diagnosis by cardiac magnetic resonance imaging. *Annals of Noninvasive Electrocardiology*, *24*(4), e12635. https://doi.org/10.1111/anec.12635

O'Donnell, M. J., Chin, S. L., Rangarajan, S., Xavier, D., Liu, L., Zhang, H., Rao-Melacini, P., Zhang, X., Pais, P., Agapay, S., Lopez-Jaramillo, P., Damasceno, A., Langhorne, P., McQueen, M. J., Rosengren, A., Dehghan, M., Hankey, G. J., Dans, A. L., Elsayed, A., … Yusuf, S. (2016). Global and regional effects of potentially modifiable risk factors associated with acute stroke in 32 countries (INTERSTROKE): A case-control study. *The Lancet*, *388*(10046), 761–775. https://doi.org/10.1016/S0140-6736(16)30506-2

Peguero, J. G., Lo Presti, S., Perez, J., Issa, O., Brenes, J. C., & Tolentino, A. (2017). Electrocardiographic criteria for the diagnosis of left ventricular hypertrophy. *Journal of the American College of Cardiology*, *69*(13), 1694–1703. https://doi.org/10.1016/j.jacc.2017.01.037

Pewsner, D., Jüni, P., Egger, M., Battaglia, M., Sundström, J., & Bachmann, L. M. (2007). Accuracy of electrocardiography in diagnosis of left ventricular hypertrophy in arterial hypertension: Systematic review. *British Medical Journal*, *335*(7622), 711–714. BMJ Publishing Group. https://doi.org/10.1136/bmj.39276.636354.AE

Poirier, P., Giles, T. D., Bray, G. A., Hong, Y., Stern, J. S., Pi-Sunyer, F. X., & Eckel, R. H. (2006). Obesity and cardiovascular disease: Pathophysiology, evaluation, and effect of weight loss: An update of the 1997 American Heart Association scientific statement on obesity and heart disease from the Obesity Committee of the Council on Nutrition, Physical activity, and metabolism. *Circulation*, *113*(6), 898–918. https://doi.org/10.1161/CIRCULATIONAHA.106.171016

Robinson, C., Woodiwiss, A. J., Libhaber, C. D., & Norton, G. R. (2016). Novel approach to the detection of left ventricular hypertrophy using body mass index-corrected electrocardiographic voltage criteria in a group of African ancestry. *Clinical Cardiology*, *39*(9), 524–530. https://doi.org/10.1002/clc.22560

Shirani, J., Berezowski, K., & Roberts, W. C. (1995). Quantitative measurement of normal and excessive (cor adiposum) subepicardial adipose tissue, its clinical significance, and its effect on electrocardiographic QRS voltage. *The American Journal of Cardiology*, *76*(5), 414–418. https://doi.org/10.1016/S0002-9149(99)80116-7

Stewart, M. H., Lavie, C. J., Shah, S., Englert, J., Gilliland, Y., Qamruddin, S., Dinshaw, H., Cash, M., Ventura, H., & Milani, R. (2018). Prognostic Implications of left ventricular hypertrophy. *Progress in Cardiovascular Diseases*, *61*(5-6), 446–455. W.B. Saunders. https://doi.org/10.1016/j.pcad.2018.11.002

Swinburn, B. A., Kraak, V. I., Allender, S., Atkins, V. J., Baker, P. I., Bogard, J. R., Brinsden, H., Calvillo, A., De Schutter, O., Devarajan, R., Ezzati, M., Friel, S., Goenka, S., Hammond, R. A., Hastings, G., Hawkes, C., Herrero, M., Hovmand, P. S., Howden, M., … Dietz, W. H. (2019). The global syndemic of obesity, undernutrition, and climate change: The Lancet commission report. *The Lancet*, *393*(10173), 791–846. Lancet Publishing Group. https://doi.org/10.1016/S0140-6736(18)32822-8

Williams, B., Mancia, G., Spiering, W., Rosei, E. A., Azizi, M., Burnier, M., Clement, D. L., Coca, A., De Simone, G., Dominiczak, A., Kahan, T., Mahfoud, F., Redon, J., Ruilope, L., Zanchetti, A., Kerins, M., Kjeldsen, S. E., Kreutz, R., Laurent, S., … Zamorano, J. L. (2018). 2018 ESC/ESH Guidelines for the management of arterial hypertension. *European Heart Journal*, *39*(33), 3021–3104. Oxford University Press. https://doi.org/10.1093/eurheartj/ehy339

Yamashita, K., Kondo, T., Osugi, S., Shimokata, K., Maeda, K., Okumura, N., Matsudaira, K., Shintani, S., Muramatsu, T., Matsushita, K., & Murohara, T. (2012). The significance of measuring body fat percentage determined by bioelectrical impedance analysis for detecting subjects with cardiovascular disease risk factors. *Circulation Journal*, *76*(10), 2435–2442. https://doi.org/10.1253/circj.CJ-12-0337

Yusuf, S., Hawken, S., Ôunpuu, S., Bautista, L., Franzosi, M. G., Commerford, P., Lang, C. C., Rumboldt, Z., Onen, C. L., Lisheng, L., Tanomsup, S., Wangai, P., Razak, F., Sharma, A. M., Anand, S. S. & INTERHEART Study Investigators (2005). Obesity and the risk of myocardial infarction in 27 000 participants from 52 countries: A case-control study. *Lancet*, *366*(9497), 1640–1649. https://doi.org/10.1016/S0140-6736(05)67663-5