University Clinical Center of Vojvodina, Novi Sad
Clinic of Nephrology and Immunology[1]
University of Novi Sad, Faculty of Medicine Novi Sad[2]
Institut of Cardiovascular Diseases Vojvodine, Sremska Kamenica[3]

Professional article
Stručni članak
UDK 616.124-007.61-073
https://doi.org/10.2298/MPNS2306156D

CORRELATION BETWEEN ELECTROCARDIOGRAPHIC AND ECHOCARDIOGRAPHIC PARAMETERS IN THE DIAGNOSIS OF LEFT VENTRICULAR HYPERTROPHY IN HYPERTENSIVE PATIENTS

KORELACIJA ELEKTROKARDIOGRAFSKIH I EHOKARDIOGRAFSKIH PARAMETARA U DIJAGNOSTICI HIPERTROFIJE LEVE KOMORE KOD BOLESNIKA SA HIPERTENZIJOM

Vladimir ĐUROVIĆ[1], Aleksandra VULIN[2, 3], Milovan PETROVIĆ[2, 3] and Milica POPOVIĆ[1, 2]

Summary

Introduction. Left ventricular hypertrophy is defined as an increase in the left ventricular mass. Electrocardiography is a widely used and cost-effective method for the initial screening of the condition, but it has limited sensitivity and specificity. The Sokolow-Lyon and Cornell criteria are still most commonly used in diagnosing the disease; their sensitivity, however, is low. On the contrary, the Romhilt-Estes scoring system incorporates atrial abnormalities and repolarization phases making this scoring system a better diagnostic tool. This study explores the correlation between electrocardiography and echocardiography in the diagnosis of left ventricular hypertrophy. **Material and Methods**. The study enrolled 30 patients with median age of 62, diagnosed with arterial hypertension, who underwent a 12-lead electrocardiogram and transthoracic echocardiogram. The analysis included the assessment of correlation between the relevant electrocardiographic parameters and the left ventricular mass index, as well as calculation of their diagnostic capability including the area under the ROC curve. **Results**. Positive correlation of moderate intensity has been observed between the left ventricular mass index and Sokolow-Lyon (ρ=0.479), Cornell index (ρ=0.366), and Cornell product (ρ=0.423). Cornell product had the highest sensitivity (0.82), while the Romhilt-Estes criteria exhibited the highest specificity (0.85). Sokolow-Lyon yielded the highest area under the curve (0.733), followed by Cornell product (0.640), Cornell voltage (0.622), and Romhilt-Estes criteria (0.570). **Conclusion**. The Sokolow-Lyon criterion exhibited the best balance between sensitivity and specificity, the highest and significant area under the ROC curve and the strongest correlation with the left ventricular mass index.

Key words: Electrocardiography; Echocardiography; Hypertrophy, Left Ventricular; Hypertension; Diagnosis; Sensitivity and Specificity

Sažetak

Uvod. Hipertrofija leve komore definiše se kao uvećanje mase leve komore. Elektrokardiografija je široko rasprostranjena i jeftina metoda koja služi za inicijalni skrining ovog oboljenja, ali je ograničene senzitivnosti i specifičnosti. *Sokolow-Lyon* i *Cornell* kriterijumi i dalje se najviše koriste u dijagnostici ove bolesti, međutim, njihova osetljivost je niska. Nasuprot njima, *Romhilt-Estes* skor sistem obuhvata atrijalne abnormalnosti i faze repolarizacije, čime ovaj skor sistem postaje bolji dijagnostički alat. Cilj ovog rada bio je istraživanje međusobne povezanosti između elektrokardiografije i ehokardiografije u kontekstu dijagnoze hipertrofije leve komore. **Materijal i metode**. U studiju je bilo uključeno 30 bolesnika medijane godina 62, sa arterijskom hipertenzijom i ranije načinjenim 12-kanalnim elektrokardiogramom i transtorakalnim ehokardiogramom. Analiza je obuhvatala određivanje jačine povezanosti elektrokardiografskih parametara od interesa sa indeksom mase leve komore kao i određivanje njhovog dijagnostičkog kapaciteta uključujući izračunavanje površine ispod ROC krive. **Rezultati**. Primećena je jaka pozitivna korelacija između indeksa mase leve komore i *Sokolow-Lyon* kriterijuma (ρ = 0,479), *Cornell* indeksa (ρ = 0,366) kao i *Cornell* proizvoda (ρ = 0,423). Najveću senzitivnosti pokazao je *Cornell* proizvod (0,82) dok je najveću specifičnost imao *Romhilt-Estes* kriterijum (0,85). Analizirana površina ispod ROC krive bila je najveća za *Sokolow-Lyon* kriterijum (0,733), zatim *Cornell* proizvod (0,640), *Cornell* indeks (0,622) i na kraju *Romhilt-Estes* kriterijum (0,570). **Zaključak**. *Sokolow-Lyon* kriterijum pokazao je najbolji odnos između senzitivnosti i specifičnosti, najvišu i značajnu površinu ispod ROC krive kao i naizraženiju korelaciju sa indeksom mase leve komore.

Ključne reči: elektrokardiografija; ehokardiografija; hipertrofija leve komore; hipertenzija; dijagnoza; senzitivnost i specifičnost

Introduction

Left ventricular hypertrophy (LVH) is defined as an increase of the left ventricular mass either due to wall thickening or due to enlargement of the left ventricular cavity, or both, in response to a wide array of pathophysiological stressors [1–3]. This cardiac remodeling response is triggered by various pathophysiological stressors such as increased intraarterial pressure or intraventricular volume overload [2,4] and is prominently observed in hypertensive patients. The prevalence of LVH increases with the severity of hypertension, advancing age, and obesity. In general population, the prevalence of the LVH is between 15 and 20%

Corresponding Author: Dr Vladimir Đurović, UKCV - Klinika za nefrologiju i kliničku imunologiju, 21000 Novi Sad, Hajduk Veljkova 1-7, vladimir.djurovic@kcv.rs, aleksandra.vulin@mf.uns.ac.rs

Abbreviations

LVH – left ventricular hypertrophy
ECG – electrocardiography
DM – diabetes mellitus
BMI – body mass index
SL – Sokolow-Lyon
CI – Cornell index
CP – Cornell product
RE – Romhilt-Estes
LVM – left ventricular mass
LVMI – left ventricular mass index
LVIDd – left ventricular end-diastolic diameter
LVIDs – left ventricular end-systolic diameter
PLWd – posterior wall end-diastolic diameter
IVSd – interventricular septum end-diastolic diameter
LA – left atrium diameter
EF – ejection fraction
ROC – receiver operating characteristics
AUC – area under the curve
PPV – positive predictive value
NPV – negative predictive value

and it is similar in men and women, with rates being significantly higher in hypertensive patients [2]. As LVH evolves, it can independently serve as a risk factor for chronic heart failure, arrhythmias, and even sudden cardiac death [5], highlighting the critical need for accurate and timely detection of the condition.

Both electrocardiography (ECG) and echocardiography have emerged as indispensable tools in the comprehensive assessment of left ventricular hypertrophy. Echocardiography boasts superior diagnostic accuracy, especially in the early stages of the disease, however, it is also important to point out that it comes at the cost of being more expensive and time-consuming [6, 7]. Considering these factors, current available guidelines for arterial hypertension and appropriate utilization criteria for echocardiography do not endorse its universal application in patients with hypertension. Instead, they recommend employing echocardiography when the test results are likely to significantly impact the patient's management and treatment decisions [8–10]. ECG, on the other hand, is a relatively straightforward procedure since it poses as a complementary screening alternative that has low cost and wide dissemination, however, its diagnostic specificity and, especially, sensitivity are constrained [11]. The underlying assumption for the use of ECG is that the enlargement of the left ventricular mass leads to a more robust electrical field, resulting in heightened electrical forces directed posteriorly and leftward. Consequently, this augmentation leads to increased QRS amplitude in specific leads [12].

Traditionally, voltage criteria, such as Sokolow-Lyon (SL), Cornell voltage index (CI) and Cornell product (CP), as well as some scoring systems, one such being Romhilt-Estes (RE) criteria, are utilized in electrocardiography as a method for detecting left ventricular hypertrophy [11, 13–16], however, there is still an ongoing debate concerning their diagnostic value. The correlation between these two diagnostic modalities in detecting LVH has garnered increasing attention, as a more comprehensive understanding of their mutual relationship holds the potential to refine diagnostic accuracy and optimize patient care. By synthesizing the latest research findings, this paper aims to explore the interplay between ECG and echocardiography in the context of LVH diagnosis, particularly in hypertensive patients.

Material and Methods

We have conducted a cross-sectional retrospective study that included patients with diagnosed arterial hypertension [8] treated at the Institute of Cardiovascular Diseases of Vojvodina in Sremska Kamenica from 2017 to 2019.

Age, gender, presence of diabetes mellitus (DM), and body mass index (BMI) were recorded for each patient. All patients underwent a 2D echocardiography. Each patient underwent a standard 12-lead ECG recording at a speed of 25 mm/s and voltage gain of 10 mm = 1 mV. The SL voltage parameter, CI, CP, and RE were determined from each ECG report. Individual wave measurements were taken with a caliper to an accuracy of 0.1 mm. The SL voltage parameter was obtained by adding SV_1 and RV_5 (expressed in mm) with the cut-off value >35 mm. Cornell voltage index was obtained by adding SV_3 and RaVL (expressed in mm), while the CD was obtained by multiplying CI with the duration of the QRS complex (expressed in mm·ms). The cut-off value for the CI was sex-dependent (>28 mm for males and >20 mm for females), while the CP defined LVH when it was above 2440 mm·ms [8]. The RE criteria encompassed six categories, each scored with a specific number of points. Probable LVH was defined when the RE criteria score was 4 points, while definitive LVH was defined when the RE criteria score ranged from 5 to a maximum of 13 points [15, 16].

Moreover, the echocardiographic parameters were registered as follows: left ventricular mass (LVM), left ventricular mass index (LVMI), left ventricular end-diastolic diameter (LVIDd), left ventricular end-systolic diameter (LVIDs), posterior wall end-diastolic diameter (PLWd), interventricular septum end-diastolic diameter (IVSd), left atrium diameter (LA), and ejection fraction (EF). Myocardial hypertrophy was defined if the left ventricular mass index exceeded 115 g/m² for men and 95 g/m² for women [17].

The normality of the continuous variables was assessed using the Kolmogorov-Smirnov test. Non-normally distributed continuous variables were reported as the median with the interquartile range (Q1-Q3). Continuous variables were compared between independent groups using the Wilcoxon rank-sum test, categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. Spearman's correlation coefficient was used to express the level of association between selected continuous variables. Discriminatory capacity, e.g., predictive strength of ECG criteria for the left ven-

tricle hypertrophy, was evaluated via the area under the receiver operating characteristic (ROC) curve area under the curve (AUC). The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), positive and negative likelihood ratio (PLR and NLR, respectively), were calculated for each predictor based on sensitivity and specificity. All statistical tests were two-tailed and the alpha level of 0.05 was set as a significance threshold. No imputations were used for the missing data. Statistical analyses were conducted using RStudio 2023.03.1+446 "Cherry Blossom" Release.

Results

Our study included 30 patients diagnosed with hypertension, with a median age of 62 (55-69) and female predominance of 56.7%. Female participants were significantly older with median age of 67 (61-72) compared to males with median age of 56 (36-61), p=0.017. Four participants (2 male and 2 female) had DM. The median BMI was 29 (27.3-32.2) kg/m^2, with no differences between genders (p=0.241). Five participants (16.7%) had a BMI below 24.9 kg/m^2, 12 (40%) patients fell into the BMI range of 25.0-29.9 kg/m^2, while 13 (43.3%) patients had a BMI over 30.0 kg/m^2. Patient baseline characteristics are presented in the **Table 1.**

After analysing the echocardiographic parameters, it was observed that the male gender exhibited significantly higher values for left ventricular mass, with a median of 359 (231-453) g compared to 173 (105-220) g in females, p<0.001. Similarly, the left ventricular mass index was notably higher in males, 160 (106-189) g/m^2, compared to 99 (69-111) g/m^2 in females, p=0.006. Despite these differences, the presence of LVH based on left ventricular mass index cut-off values showed no statistically significant difference between genders, with 9 (53%) females and 8 (62%) males having LVH (p=0.638). Additionally, the male population exhibited significantly higher LVIDd, LVIDs, and left atrium diameter, while no statistically significant differences were found in IVSd, PLWD, and EF. Complete echocardiographic parameters are presented in **Table 2.**

The ECG analysis showed that the SL criterion had a median of 24.90 (18.88-30.58) mm with no significant differences between genders. Among all patients, five (16.7%) participants had values above the appropriate cut-off, with no gender-based frequency differences. Regarding the CI criterion, males exhibited a significantly higher median value of

Table 1. Patients' characteristics at the baseline
Tabela 1. *Osnovne karakteristike bolesnika*

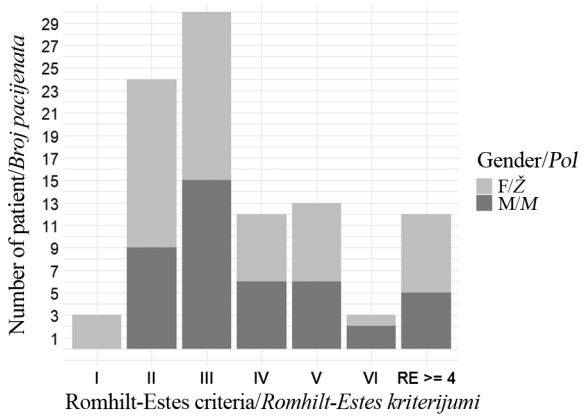
Characteristic *Karakteristika*	Total/*Ukupno*, No/*Br.* = 30	Female/*Žene*, No/*Br.* = 17	Male/*Muškarci*, No/*Br.* = 13	p/*p*
Age/*Starost*	62 (55-69)	67 (61-72)	56 (36-61)	0.017
BMI	29.0 (27.3-32.8)	28.4 (27.2-32.3)	31.7 (28.3-33.9)	0.241
< 24.9	5 (16.7)	4 (24)	1 (7.7)	
25.0-29.9	12 (40)	7 (41)	5 (38)	0.494
> 30	13 (40.3)	6 (35)	7 (54)	
Diabetes mellitus/*Dijabetes melitus*	4 (13)	2 (12)	2 (15)	1.000

Legend: BMI – Body Mass Index; Numerical data is presented as the median (Q1-Q3); categorical data is presented as n (%)
Legenda: BMI – *Indeks telesne mase; Numerički podaci su prikazani kao medijana (Q1-Q3); kategorijalni podaci su prikazani kao br. (%)*

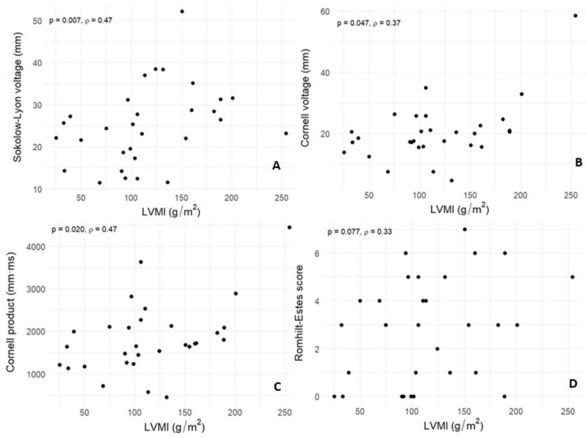
Table 2. Echocardiographic parameters
Tabela 2. *Ehokardiografski parametri*

Echocardiographic/*Parameter*	Total/*Ukupno*, No/*Br.* = 30	Female/*Žene*, No/*Br.* = 17	Male/*Muškarci*, No/*Br.* = 13	p/*p*
LVM (g)	222 (158-276)	173 (105-220)	359 (231-453)	< 0.001
LVMI (g/m^2)	106 (91-153)	99 (69-111)	160 (106-189)	0.006
LVIDd (cm)	4.90 (4.53-5.38)	4.70 (4.50-5.10)	5.30 (4.90-6.30)	0.025
LVIDs (cm)	3.20 (2.80-3.50)	3.00 (2.80-3.40)	3.40 (3.30-4.40)	0.034
IVSd (cm)	1.30 (1.20-1.40)	1.30 (1.20-1.40)	1.30 (1.30-1.40)	0.215
PLWd (cm)	1.30 (1.20-1.30)	1.20 (1.20-1.30)	1.30 (1.20-1.30)	0.151
LA (cm)	4.10 (3.42-4.40)	3.90 (3.30-4.30)	4.40 (3.90-4.70)	0.018
EF (%)	60 (54-64)	61 (57-64)	59 (52-64)	0.586

Legend: LVM – left ventricular mass; LVMI – left ventricular mass index; LVIDd – left ventricular end-diastolic diameter; LVIDs – left ventricular end-systolic; IVSd – interventricular septum end-diastolic diameter; PLWd – posterior wall end-diastolic diameter; LA – left atrium diameter; EF – ejection fraction; Data is presented as the median (Q1-Q3)
Legenda: LVM – masa leve komore; LVMI – indeks mase leve komore; LVIDd – enddijastolni dijametar leve komore; LVIDs – endsistolni dijametar leve komore; IVSd – enddijastolni dijametar interventrikularnog septuma; PLWd – enddijastolni dijametar zadnjeg zida; LA – dijametar leve pretkomore; EF – istisna frakcija; Podaci su prikazani kao medijana (Q1-Q3)



Graph 1. Romhilt-Estes criteria by gender
Grafikon 1. *Romhilt-Estes kriterijumi prema polu*

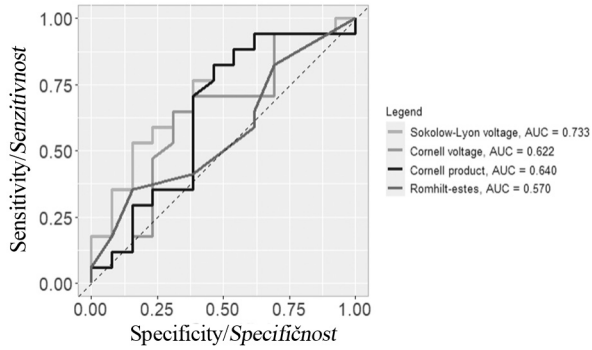


Graph 2. Scatter diagrams between left ventricular mass index and A. Sokolow-Lyon voltage. B. Cornell Voltage. C. Cornell product and D. Romhilt-Estes score
Grafikon 2. *Dijagram raspršenja između indeksa mase leve komore i A. Sokolow-Lyon voltažnog kriterijuma. B. Cornell voltažnog kriterijuma. C. Cornell proizvoda i D. Romhilt-Estes skora*

20.90 (18.45 vs. 25.65) mm vs. 17.10 (15.40-26.65) mm, p=0.035. Additionally, nine patients, with no significant gender-based frequency differences, had values indicative of left ventricular hypertrophy. The CP also yielded significant results, with males having a higher median value of 1992.80 (1716.0-2821.50) mm·ms vs. 1540.0 (1205.60-1674.40) mm·ms, p=0.012. Of note is that five patients showed CP values exceeding 2440 mm·ms, with no significant gender-based frequency differences. Four patients (13.3%) met the RE criterion with a score of 4, while eight patients (26.7%) had a score over 4, as illustrated in **Graph 1**.

Correlation analysis revealed that there was a significant moderate positive correlation between LVMI and SL voltage (ρ=0.47, p=0.007), CI (ρ=0.37, p=0.047), as well as CP (ρ=0.42, p=0.020). On the other hand, although the RE score correlated moderately positive with LVMI, the correlation was not statistically significant (ρ=0.33, p=0.077) **(Graph 2)**.

The CP demonstrated the highest sensitivity of 0.82, followed by SL (0.76), CI (0.65) and lastly the RE criteria (0.35). On the other hand, the RE score achieved the highest specificity of 0.85, while CP exhibited the lowest specificity of 0.54, which resulted in the lowest NPV **(Table 3).** Analysis of the ROC curves demonstrated that the SL criterion exhibited the highest AUC of 0.733, closely followed by the CP with an AUC of 0.640, the CI criterion with an AUC of 0.622, and lastly, the RE score with an AUC of 0.570 **(Graph 3).**



Graph 3. ROC curves for the electrocardiographic criteria
Grafikon 3. *ROC krive za elektrokardiografske kriterijume*

Discussion

Various electrocardiographic criteria were compared in this study to diagnose left ventricular hypertrophy, with echocardiographic findings of the left ventricular mass index serving as the reference diagnostic method in patients with arterial hypertension. Left ventricular hypertrophy represents an asymptomatic organ damage developing under the influence of arterial hypertension and posing high risk of adverse cardiovascular events for the patients [8].

Our study included 30 patients with the median age of 62 years, mostly overweight and obese individuals with 80.3% having a BMI that exceeds the obesity cut-off of 24.9 [18]. This observation is in line with previous research indicating higher prevalence of left ventricular hypertrophy in obese populations [19]. Diabetes has also been closely associated with the development of the LVH [20, 21]. We identified four individuals (13%) with diabetes mellitus, reinforcing the relevance of considering DM as a potential risk factor in the context of left ventricular hypertrophy.

The correlation analysis revealed that LVMI exhibited the strongest positive correlation with SL (ρ=0.47), followed by a slightly weaker but still statistically significant positive correlation with CP (ρ=0.37) and CI index (ρ=0.42). On the other hand, the RE criteria showed the weakest association with LVMI in our study. Such variations in results among different studies that explore the relationship between ECG and left ventricular hypertrophy have been attributed to the daily fluctuations in ECG voltage within the same patient, as reported by previous research [22, 23].

Table 3. Diagnostic performance of the EKG criteria
Tabela 3. *Dijagnostički kapacitet EKG kriterijuma*

ECG parameter/*EKG parametar*	Sensitivity/*Senzitivnost*	Specificity/*Specifičnost*	PPV	NPV	PLR	NLR	AUC
Sokolow-Lyon	0.76	0.62	0.72	0.67	2.00	0.39	0.733
Cornell voltage	0.65	0.69	0.73	0.60	2.10	0.51	0.622
Cornell product	0.82	0.54	0.70	0.70	1.78	0.33	0.640
Romhilt-Estes	0.35	0.85	0.75	0.50	2.33	0.76	0.570

Legend: PPV – Positive predictive value; NPV – Negative predictive value; PLR – Positive likelihood ratio; NLR – Negative likelihood ratio; AUC – Površina ispod krive
Legenda: PPV – Pozitivna prediktivna vrednost; NPV – Negativna prediktivna vrednost; PLR – Odnos verovatnoće pozitivnog rezultata; NLR – Odnos verovatnoće negativnog rezultata; AUC – Površina ispod krive

The SL criterion demonstrated relatively balanced sensitivity (0.76) and specificity (0.62), positive predictive value (PPV) and negative predictive value (NPV) predictive values (0.72 and 0.67, respectively), suggesting its potential for correctly identifying true positive and true negative cases. The CI criterion showed similar results (sensitivity 0.65, specificity 0.69, PPV 0.73, NPV 0.60), while its QRS duration product exhibited higher sensitivity of 0.82 with significantly lower specificity of 0.54, while PPV and NPV were identical, 0.70. On the other hand, the RE criterion displayed the lowest sensitivity (0.35) and NPV (0.50) but notably the highest specificity (0.85) and PPV (0.75), suggesting it might be more appropriate at correctly identifying true negatives. The wide range of sensitivity and specificity suggests the presence of both false negative and false positive results. Various studies had been conducted reporting sensitivity and specificity values that are different than the ones in our study. For instance, a study conducted in 2022 [11] reported much lower sensitivity of all analysed ECG criteria (SL 0.05, CI and RE 0.22), while, on the other hand, specificity rates were much higher, reaching up to 1 for SL criterion, 0.952 and 0.738 for CI and RE, respectively. A systemic review from 2007 performed on 21 studies [13] found that the median sensitivity for SL criterion was 0.21 (range 0.04 to 0.52), while the median specificity was 0.89 (range from 0.53 to 1). CI and CP exhibited the same median specificity of 0.96 (range 0.89 to 1 and 0.90 to 1, respectively), and the sensitivity was notably lower: 0.15 (range 0.02 to 0.41) and 0.115 (range 0 to 0.39) for CI and CP, respectively. Moreover, the RE criterion demonstrated the highest specificity with a median of 0.99 (range 0.71 to 1) and a relatively low sensitivity, median of 0.12 (range 0 to 0.41). Not all results in our study correspond although there is an alignment with certain aspects of the findings from the 2007 systemic review. This variation could be attributed to the relatively small sample size examined in our study. Regarding the observed wide range of sensitivity values, Narayanan and colleagues [24] attribute the presence of false negative results to electrical remodeling of the heart. They suggest that extracardiac factors such as the distribution of adipose tissue in the chest area and chronic obstructive pulmonary disease lead to a decrease in the ECG voltage recorded on the surface of the chest. Additionally, the same authors state that pathological changes in hypertrophied myocardium can lead to relative voltage deficit, resulting in a lack of expected increase in QRS amplitude.

The results from numerous authors who have studied the diagnostic capabilities of specific electrocardiographic criteria for diagnosing LVH are not consistent in regard to which criterion has the best diagnostic potential. Wei Zhang et al. [17] compared SL, CI and CP criteria in relation to echocardiographic diagnosis of LVH using LVMI as the reference. They concluded that the Cornell criteria had the highest AUC, indicating that it might be a more reliable diagnostic test for LVH. Their findings were consistent with the results of Hsieh et al. and Xie et al. [25, 26], where it was demonstrated that voltage criteria modified by the duration of the QRS complex, such as the CI product, were superior in diagnosing LVH defined according to LVMI. Moreover, these criteria were also identified as better predictors of cardiovascular mortality. Our study demonstrated that the SL voltage criterion was a significantly better diagnostic method, as indicated by the highest AUC value of 0.733, followed by CP (0.640), CI (0.622) and lastly the RE criterion (0.570).

Conclusion

In our patient cohort, the Sokolow-Lyon voltage criterion exhibited the best trade-off between specificity and sensitivity, substantial ROC curve area and a moderately strong correlation with the left ventricular mass index diagnosed. Although weaker than Sokolow-Lyon, the Cornell voltage index and Cornell product also displayed positive correlations with the left ventricular mass index. Notably, there was not any statistically significant correlation between echocardiographic left ventricular hypertrophy diagnosis and Romhilt-Estes electrocardiographic criteria in our study. However, the value of these criteria was seen in their high sensitivity, the highest negative likelihood ratio and negative predictive value.

To make an early and more accessible left ventricular hypertrophy diagnosis, further research is necessary to identify even more precise electrocardiographic criteria as the primary and routine diagnostic tool in hypertensive patients.

The study had several limitations. Its design was retrospective and it included a relatively small number of participants. There was a presence of selection bias and the potential for confounding variables.

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Rad je primljen 28. VIII 2023.
Recenziran 13. X 2023.
Prihvaćen za štampu 13. X 2023.
BIBLID.0025-8105:(2023):LXXVI:5-6:156-161.