The Use of Romhilt-Estes Criteria in the Presumptive Electrocardiographic Diagnosis of Left Ventricular Hypertrophy in Comparison to Voltage-Based Criteria

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Abstract

Background

The ECG diagnosis of left ventricular hypertrophy (LVH) has been challenging for over a hundred years. ECG diagnosis of LVH has shown good specificity but lacks sensitivity. In addition, voltage-based criteria can be affected by multiple conditions such as obesity and chronic lung disease. Therefore, we sought to compare Romhilt-Estes (R-E) criteria with commonly used voltage-based criteria in presumptive ECG diagnosis of LVH.

Methods

This is a retrospective electronic medical record study from September 1, 2017, to September 1, 2018, of 499 consecutive ECGs from Boca Raton Regional Hospital. Different ECG criteria were used to identify the presence of LVH, including the Cornell criteria, modified Cornell criteria, Sokolow-Lyon criteria, and Romhilt-Estes criteria. The main study outcome was to compare the R-E criteria in presumptive ECG diagnosis of LVH to the voltage-based criteria (Cornell, modified Cornell, and Sokolow-Lyon).

Results

After analyzing the ECGs using the different ECG criteria, R-E criteria were positive with LVH present (score ≥ 5 points) in 162 patients. In contrast, Cornell criteria were positive in 42 patients (8.4%), modified Cornell criteria in 50 patients (10%), and Sokolow-Lyon criteria in 13 patients (2.6%). In addition, R-E criteria showed higher positivity of LVH diagnosis compared to the sum of three voltage-based criteria (32.7% versus 21% respectively, p<0.001).

Conclusion

We presume that R-E criteria can help better diagnose LVH by ECG compared to other commonly-used voltage-based criteria. However, further studies are needed using confirmatory imaging to confirm the accuracy of R-E criteria and compare it with other voltage based-criteria.

Introduction

Hypertension (HTN) is a major modifiable risk factor for cardiovascular disease. The left ventricle (LV) is a primary target for HTN end-organ damage [1]. Left ventricular hypertrophy (LVH) is growth in left ventricular mass caused by increased cardiomyocyte size, which can be physiological or pathological [2-5].

The ECG diagnosis of LVH has been a challenge for more than 100 years since it was first observed by Lewis in 1914 [6]. The original reference methods used in developing specific electrocardiographic criteria for the presence of LVH were either autopsy measurements or clinical assessments [7]. Although ECG diagnosis of LVH has shown good specificity (up to 98.8%), it did lack sensitivity (40%-60%) [8-10].

Romhilt-Estes (R-E) was first introduced in 1968 as an early effort to improve ECG's ability to detect and diagnose LVH before imaging methods [11]. R-E is mainly based on a point system that can help in the prediction of LVH, which is determined by six ECG features, and the presence of each feature has its own assigned points [12]. If the given ECG has a total score of 5 or less, it is considered unlikely to have LVH, 4 points are considered probable LVH, and a score of 5 or more is considered positive for LVH. The R-E score
has proven to be more specific in predicting LVH [12]. Voltage-based LVH criteria can be affected by multiple factors, including age, sex, obesity, and chronic lung disease, limiting the prediction of LVH [10,15,14]. Therefore, we sought to compare the R-E criteria to different voltage criteria (Sokolow-Lyon, Cornell, and modified Cornell criteria) in the presumptive diagnosis of LVH.

**Materials And Methods**

**Data source**

This was a retrospective study from September 1, 2017, to September 1, 2018. A total of 499 consecutive ECGs from Boca Raton Regional Hospital, a 400-bed tertiary hospital, were identified and analyzed. Therefore, this study was exempted by Institutional Review Board (IRB), as it was a retrospective study from medical records with de-identified data.

**Selection criteria**

Inclusion criteria are any patient with an ECG for any reason. Exclusion criteria are any patient under the age of 30 as LVH detection with voltage criteria has not been well established in this age group. ECGs with complete left bundle branch block or ventricular paced rhythm were also excluded from the study.

**Data extraction and analysis**

ECGs were read by three investigators (Gopika Dasari, Joel A. Casale, Navneet Kaur) independently who analyzed all the ECGs for LVH by either one of the voltage criteria (Cornell, modified Cornell, or Sokolow-Lyon), R-E criteria, or both. Charts were identified for any comorbid illnesses, including asthma, chronic obstructive pulmonary disease (COPD), coronary artery disease (CAD), congestive heart failure (CHF), and renal insufficiency/failure. Statistical significance was considered for a p-value<0.05.

Identification of LVH by different criteria is outlined in Table 1, and the R-E score is identified in Table 2.

| Different LVH criteria          |                             |
|--------------------------------|-----------------------------|
| Sokolow-Lyon criteria          | SV1 + RV5 or RV6 >35 mm     |
| Cornell criteria               | SV3 + RaVL >28 mm for men and >20 mm for women |
| Modified Cornell criteria      | R wave in aVL ≥11 mm        |
| Romhilt-Estes criteria         | unlikely if R-E score <4 points, likely if ≥4 points, and present if ≥ 5 points |

**TABLE 1: Different LVH criteria.**

mm: millimeter; R-E: Romhilt-Estes; LVH: Left ventricular hypertrophy.
TABLE 2: Romhilt-Estes score.

mV: millivolt; s: seconds; ms: millisecond.

| Romhilt–Estes score | 3 points |
|---------------------|----------|
| Amplitude: R or S wave in limb leads ≥ 2.0 mV or S wave in V1 or V2 ≥ 3.0 mV or R wave in V5 or V6 ≥ 3.0 mV | 3 points |
| ST-T segment pattern: ST-segment depression in opposite direction to QRS complex | 3 points |
| Without digitalis | 3 points |
| With digitalis | 1 point |
| Left atrial involvement: Terminal negativity of the P wave in lead V1 ≥ 0.01 mV and ≥ 0.04 s. | 3 points |
| Left axis deviation QRS axis ≥ − 30° | 2 points |
| QRS duration ≥ 90 ms. | 1 point |
| Intrinsicsoid deflection (Q-R interval) ≥ 50 ms in V5 or V6 | 1 point |

TABLE 3: Baseline characteristics.

COPD: Chronic obstructive pulmonary disease; CAD: Coronary artery disease; HTN: Hypertension; DM: Diabetes mellitus; CHF: Congestive heart failure.

Outcomes
The main study outcome was the ability of R-E criteria to better predict LVH compared to Cornell criteria, modified Cornell criteria, or Sokolow-Lyon criteria.

Results
Baseline characteristics
The baseline characteristics were identified in Table 3. The mean age was 71.1 (±16.4), with a mean BMI of 26.7 ± 5.7.
After analyzing ECGs using different ECG criteria, R-E criteria were positive, with LVH present (score ≥ 5 points) in 162 patients (32.7%) and likely (score=4 points) in 51 patients (10.3%) (Table 4). Cornell criteria were positive in 42 patients (8.4%), modified Cornell criteria in 50 patients (10%), and Sokolow-Lyon criteria in 13 patients (2.6%) (Table 5). We used LVH present of R-E criteria (score ≥ 5 points) to compare it with voltage-based criteria. R-E criteria showed a higher presumptive diagnosis of LVH than total voltage-based criteria (32.7% versus 21%, respectively, p<0.001).

|                | Unlikely (<4 points) | Likely (4 points) | Present (≥ 5 points) |
|----------------|----------------------|-------------------|----------------------|
| Number (n)     | 282                  | 51                | 162                  |
| %              | 57%                  | 10.30%            | 32.70%               |

**TABLE 4: Romhilt-Estes criteria results.**

| Criteria                  | Number (n) | Percentage (%) |
|---------------------------|------------|----------------|
| Cornell criteria          | 42         | 8.40%          |
| Modified Cornell criteria | 50         | 10%            |
| Sokolow-Lyon criteria     | 13         | 2.60%          |
| Romhilt-Estes criteria    | 162        | 32.70%         |

**TABLE 5: Different LVH criteria results.**

LVH: Left ventricular hypertrophy.

**Discussion**

In this retrospective study, 499 ECGs were analyzed. We compared the most commonly used ECG - LVH criteria, including Cornell, modified Cornell, and Sokolow-Lyon criteria, with the R-E criteria to see if there was an improved detection of LVH by R-E criteria. Our results suggest that R-E criteria could be a more reliable and sensitive method to diagnose LVH compared to traditional voltage-based criteria.

Although the introduction of non-invasive imaging methods (echocardiography, cardiac magnetic resonance) has shown better sensitivity and specificity [15], ECG still remains widely used as it is an inexpensive, convenient, and readily available way of determining the presence of LVH [15]. The most traditionally used ECG criterion in predicting LVH has been the QRS-based voltage criteria which commonly involves Sokolow-Lyon, Cornell, and modified Cornell criteria. However, detection of LVH by ECG can be affected by several factors, including obesity and chronic lung disease, limiting the sensitivity of voltage-based criteria in predicting LVH [10,13,14]. On the other hand, R-E criteria avoid these limitations since it utilizes multiple ECG components with a combination of non-amplitude and non-QRS elements [15].

To our knowledge, our study is the first study to compare the R-E criteria to other commonly used voltage-based criteria. R-E criteria show other benefits beyond diagnosing LVH. In 2015, Estes EH et al. found that rising levels of R-E score were associated with increased all-cause mortality. Only four components of the R-E criteria are predictive of increased mortality (P-terminal force, QRS amplitude, LV strain, and intrinsicoid deflection) [12]. Bacharova L et al. and Estes EH et al. emphasized the role of ECG as a strong predictor of future cardiovascular disease and mortality [15-16]. Another study illustrated that an R-E score > 4 is associated with an increased risk of cardiovascular disease, coronary heart disease, heart failure, and stroke [16]. It also demonstrated that each of the six individual components of the R-E criteria has a unique and independent ability to predict different cardiovascular disease outcomes [16]. According to a study by Darouian N et al., R-E criteria have also shown a benefit in expecting sudden cardiac arrest if the score was >5, independent of echocardiographic LVH and reduced LV ejection fraction [17].

Our study is limited as it is a retrospective study in which we could only identify the available data. Additionally, we could not confirm our findings with further imaging using echocardiography or cardiac magnetic resonance. Therefore, further larger studies are needed to evaluate different ECG LVH criteria better.

**Conclusions**

This study suggests that using R-E criteria could improve the ability to diagnose LVH by ECG compared to using the more common voltage-based criteria. R-E criteria have also been shown to have other benefits.
such as the prediction of mortality, prediction of future cardiovascular disease, including CAD, heart failure, and stroke, and expecting sudden cardiac death. Additional studies, including a larger series of ECG reviews and confirmation of LVH by R-E criteria using imaging modalities such as echocardiography, are necessary to further test the utility of R-E criteria in diagnosing LVH by ECG.

**Additional Information**

**Disclosures**

**Human subjects:** Consent was obtained or waived by all participants in this study. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICJME uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

**References**

1. Yildiz M, Oktay AA, Stewart MH, Milani BV, Ventura HO, Lavie CJ: Left ventricular hypertrophy and hypertension. Prog Cardiovasc Dis. 2020, 63:10-21. 10.1016/j.pcad.2019.11.009
2. Bondue A: Left ventricular hypertrophy: how to identity the cause?. Rev Med Brux. 2018, 39:227-236.
3. Lazzaroni D, Rimoldi O, Camici PG: From left ventricular hypertrophy to dysfunction and failure . Circ J. 2016, 80:555-564. 10.1255/circj.CJ-16-0062
4. Bacharova L: Left ventricular hypertrophy: disagreements between increased left ventricular mass and ECG-LVH criteria: the effect of impaired electrical properties of myocardium. J Electrocardiol. 2014, 47:625-629. 10.1016/j.jelectrocard.2014.05.006
5. McMullen JR, Jennings GL: Differences between pathological and physiological cardiac hypertrophy: novel therapeutic strategies to treat heart failure. Clin Exp Pharmacol Physiol. 2007, 34:255-262. 10.1111/j.1440-1681.2007.04585.x
6. Lewis T: Heart, 1913-1914, Vol. 5: A Journal for the Study of the Circulation . Forgotten Books, 1914.
7. Budhwani N, Patel S, Deyver LM Jr: Electrocardiographic diagnosis of left ventricular hypertrophy: the effect of left ventricular wall thickness, size, and mass on the specific criteria for left ventricular hypertrophy. Am Heart J. 2005, 149:709-714. 10.1016/j.ahj.2004.07.040
8. Casale PN, Devereux RB, Klippet F, et al.: Electrocardiographic detection of left ventricular hypertrophy: development and prospective validation of improved criteria. J Am Coll Cardiol. 1985, 6:572-580. 10.1016/S0735-1097(85)80115-7
9. Romhilt DW, Bove KE, Norris RJ, Conyers E, Conradi S, Rowlands DT, Scott RC.: A critical appraisal of the electrocardiographic criteria for the diagnosis of left ventricular hypertrophy. Circulation. 1969, 40:185-195. 10.1161/01.cir.40.2.185
10. Levy D, Libab SB, Anderson KM, Christiansen IC, Kannel WB, Castelli WP.: Determinants of sensitivity and specificity of electrocardiographic criteria for left ventricular hypertrophy. Circulation. 1990, 81:815-820. 10.1161/01.cir.81.8.815
11. Romhilt DW, Estes EH: A point-score system for the ECG diagnosis of left ventricular hypertrophy. Am Heart J. 1968, 75:752-758. 10.1016/0002-8703(68)90055-5
12. Estes EH, Zhang ZM, Li Y, Terechzenko LG, Soliman EZ: The Romhilt-Estes left ventricular hypertrophy score and its components predict all-cause mortality in the general population. Am Heart J. 2015, 170:104-109. 10.1016/j.ahj.2015.04.004
13. Rodrigues IC, McIntyre B, Dastidar AG, et al.: The effect of obesity on electrocardiographic detection of hypertensive left ventricular hypertrophy: recalibration against cardiac magnetic resonance. J Hum Hypertens. 2016, 30:197-203. 10.1038/jhh.2015.58
14. Yang Y, Ahn JM, Kang DY, et al.: Implication of different ECG left ventricular hypertrophy in patients undergoing transcatheter aortic valve replacement. J Am Heart Assoc. 2022, 11:e023647. 10.1161/JAHA.121.023647
15. Bacharova L, Estes EH: Left ventricular hypertrophy by the surface ECG. J Electrocardiol. 2017, 50:906-908. 10.1016/j.jelectrocard.2017.06.006
16. Estes EH, Zhang ZM, Li Y, Terechzenko LG, Soliman EZ.: Individual components of the Romhilt-Estes left ventricular hypertrophy score differ in their prediction of cardiovascular events: the Atherosclerosis Risk in Communities (ARIC) study. Am Heart J. 2015, 170:1220-1226. 10.1016/j.ahj.2015.09.016
17. Darouian N, Aro AL, Narayanan K, et al.: The Romhilt-Estes electrocardiographic score predicts sudden cardiac arrest independent of left ventricular mass and ejection fraction. Ann Noninvasive Electrocardiol. 2017, 22:10.1111/anec.12424