Evaluation of the electrocardiographic criteria for left ventricular hypertrophy

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ABSTRACT

Objective: Left ventricular hypertrophy (LVH) is an independent predictor of cardiovascular (CV) mortality.This study compared different criteria including Sokolow-Lyon and Cornell, in terms of voltage and voltage-QRS-duration products, as well as point-scoring systems such as the Romhilt-Estes, Perugia and Glasgow-Royal-Infirmary modified Romhilt-Estes score.

Methods: Patients undergoing echocardiography were recruited from the cardiology department in Glasgow Royal Infirmary. Echocardiographically derived left ventricular mass was indexed to body surface area and using sex dependent thresholds, LVH was determined. Electrocardiograms (ECG) were processed using The University of Glasgow Analysis Program, permitting different LVH criteria to be calculated and evaluated. Inclusion criteria for this study were that the patients had a technically adequate echocardiogram and ECG.

Results: The main analysis used 51 male and 76 female patients. At published thresholds, the Lewis index gave the greatest sensitivity of the voltage criteria (12%). However, adjusted to 95% specificity, the Cornell index produced the greatest sensitivity at 19%. The best voltage-duration product was the Cornell product that gave 15% sensitivity and 19% when adjusted to 95% specificity.The point scoring systems proved to be the most accurate with the Perugia score being 22% sensitive and the Glasgow Royal Infirmary modified Romhilt-Estes score 24 % sensitive, both at 95% specificity.

Conclusion: This study finds that ECG criteria for LVH that use only voltage are relatively poor predictors of LVH.This study also finds that the best criteria for assessing LVH are the point scoring criteria, in particular the Glasgow Royal Infirmary Modified Romhilt-Estes score.
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Key words: left ventricular hypertrophy, electrocardiography, echocardiography

Introduction

Enlargement of the left ventricle of the heart, known as left ventricular hypertrophy (LVH), can be caused physiologically, such as in a highly trained athlete, or pathologically in cases of hypertension; by valvular stenosis or incompetence; or inflammatory, genetic or infectious cardiomyopathies (1, 2). It has been established that LVH is a significant independent predictor of mortality (3). The prevalence of LVH in hypertensive patients has been estimated at 25% and 26% for males and females respectively; however, 14% and 20% respectively has been estimated for the normotensive population (5). However, other authors suggest that the prevalence of LVH in the entire population is 3% (6).

Despite the recent advances in accurate in vivo measurement of left ventricular (LV) mass using cardiac magnetic resonance imaging, echocardiography remains the current standard in establishing an individual patient's left ventricular (LV) size (9). It has been shown by the Framingham study that LVH determined by echocardiography is an independent risk factor for mortality (10). The most pronounced effect of LVH on the electrocardiogram (ECG) is an increase in amplitude of QRS complex voltage. In 1949 Sokolow and Lyon (11) developed criteria to determine the presence of LVH: If adding the amplitude of the S wave in lead V_1 to the R wave in lead V_5- or V_6 (whichever is greater) came to more than 35mm or 3.5mV then LVH was present. This criterion is widely used by clinicians today as it can be easily measured and assessed without complex calculations. In Sokolow and Lyon's paper (11), they found this criterion identified one third of patients potentially with LVH and did not identify any of their healthy volunteers. Other voltage-based criteria have emerged, including the Cornell voltage (12), based on findings on how the hypertrophied heart electrically orientates, which adds the amplitude of R wave in aVL to the S wave in V_3. There have been many more voltage-based criteria for the identification of LVH; however, factors such as body mass and subcutaneous fat can affect the voltages resulting in decreased sensitivity.

Recently, there has been greater investigation into the other ECG findings common to LVH. QRS duration has been demonstrated to be an accurate independent predictor of LVH in the absence of aberrant conduction or a bundle branch block (13). QRS duration when used with a voltage criterion such as Sokolow-Lyon's to produce a voltage-duration product has been shown to be even more sensitive and specific than either alone (14, 15). Other attempts have been made to use point scoring systems such as the Romhilt-Estes system (16), which allocates

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points for: high voltages in different leads; long QRS duration; abnormal P terminal force in lead V_1; left axis deviation; ST-T segment depression in leads $V_{5/6}$ and longer time from QRS onset to maximal QRS deflection. The Romhilt-Estes criterion has been demonstrated to have a relatively high sensitivity and specificity (14, 16, 17). Different authors have also attempted to create an electrocardiographic criterion that would give an estimate of LV mass, though these are thought to be clinically inaccurate and are scarcely used (18- 20).

Currently, The University of Glasgow (Uni-G) ECG Analysis program uses a modified version of the Romhilt-Estes criteria that gives a continuous score adjusted to a patient's age and sex (21).

This study was designed to identify the optimal electrocardiographic criteria in detection of left ventricular hypertrophy as determined by echocardiography in a randomly selected group of individuals who attended the Cardiology Department in Glasgow Royal Infirmary (GRI) to have an echocardiogram recorded. This study received ethical approval from the Glasgow Royal Infirmary Local Research Ethics Committee via the Central Office for Research Ethics Committee (COREC).

Methods

Patients

Patients were recruited in GRI Cardiology Department in early 2006. The inclusion criteria for this study were a technically adequate echocardiogram and a technically adequate ECG acquired either on the day of the echocardiogram or within the previous 31 days. Patients were included regardless of their indication for echocardiography, which included asymptomatic screening, cardiac murmur, hypertension, post myocardial infarction, cardiomyopathy and valvular heart disease.

Echocardiography

All patients underwent echocardiography which was performed using either a General Electric Vivid 3 with 3S probe (1.5-3.6MHz) or General Electric Vivid 7 with a M3S probe (1.5-3.0MHz). All echocardiograms were recorded by a skilled Cardiac Physiologist or Doctor. The LV was visualised with the patient lying in a modified left lateral decubitus position, with the ultrasound probe at the left parasternal window angled to visualise the heart in the long axis view. All the M-mode and 2D measurements were performed by the leading-edge-to-leading-edge method, as described by the American Society of Echocardiography (ASE) (22). Left ventricular measurements for this study were recorded as those at the onset of the QRS complex. They were: interventricular septum thickness at end diastole (IVSd), left ventricle internal diameter at end diastole (LVIDd) and left ventricular posterior wall thickness at end diastole (LVPWd). If a technically adequate LV study could not be performed, the patient was not included in this study. The left ventricular mass (LVM) was subsequently calculated using the validated formulae (22):

$$LVM_{ASE}\ (g) = 0.8 \times 1.04((IVSd + LVIDd + LVPWd)^3 - (LVIDd)^3) + 0.6$$

At the time of the echocardiogram recording, the patient's height and weight were also noted to establish body surface area (BSA) using the formulae (23):

$$BSA = 0.0001 \times (71.84) \times (Wt^{0.425}) \times (Ht^{0.725}),$$

where Wt is weight in kilograms and Ht is height in centimeteres. This allowed the LVM to be indexed to body surface area to minimise the influence of height and weight. However, this formula does not correct for male and female differences (24). The indexed LVM limits used to establish LVH were 116g/m^2 for males and 104g/m^2 for females as used in the LIFE trial and other previous studies (25, 26).

Table 1. Characteristics of patients recruited for comparison of electrocardiographic criteria for left ventricular hypertrophy divided into those included and those excluded because an ECG could not be obtained

Parameters	Patients with no ECG	Patients with ECG
Number	67	142
Age, years	59.1±16.2	60.3±18.5
Male gender, n(%)	34 (51)	59 (42)
Body mass index, kg/m^2	26.9±5.3	27.3±6.1
Echocardiographic left ventricular mass, g/m^2*	134.3±45.3	123.0±53.5
Number with left ventricular hypertrophy, n(%)	46 (69)	79 (56)

Values are represented as mean±SD or n (%)
• Mass determined using method of American Society of Echocardiography, indexed to body surface area with normal limits of 104 g/m2 for female and 116 g/m2 for male.
• ECG - electrocardiogram

Table 2. Characteristics of patients included for comparison of electrocardiographic criteria for LVH divided into those with and without LVH determined by echocardiography, excluding those with a pacemaker or bundle branch block (15 total, 12 with LVH)

Parameters	Patients without LVH*	Patients with LVH*
Number	60	67
Age, years	55.7±19.6	61.8±17.6
Male gender, n(%)	18 (30)	33 (49)
Body mass index, kg/m^2	27.3±6.5	28±5.9
Echocardiographic left ventricular mass, g/m^2*	85.1±14.5	147.2±47.6
QRS complex duration, ms	88±9	93±13

Values are represented as mean±SD or n (%)
* Left ventricular mass is determined using method of American Society of Echocardiography, indexed to body surface area with normal limits of 104 g/m^2 for female and 116 g/m2 for male.
LVH- left ventricular hypertrophy

Electrocardiography

All ECGs were recorded using Burdick Eclipse 850i machines. The ECG datasets were transferred onto a research computer where The University of Glasgow (Uni-G) ECG Analysis program (21) was used to obtain a median waveform for each lead and numerical values (amplitude and duration) for each component of the ECG, i.e. QV_1, RV_1, SV_1, $R'V_1$ etc. These values were then fed into another program, developed by one of the IT support staff, on the research computer that calculated each electrocardiographic criterion for LVH.

The following voltage criteria were assessed: Sokolow-Lyon index (11), Cornell index (12), Gubner and Ungerleider index (27), Sum-of-12-lead amplitudes index (28), Lewis index (29), Framingham adjusted Cornell index (30). The following voltage-duration products, i.e. index $\times$ QRS duration, were assessed: Cornell product (14, 31), Sokolow-Lyon product (14) and Sum-of-12-lead product (14). The following scoring systems were assessed: Perugia score (32), Romhilt-Estes score (16) and the GRI modified Romhilt-Estes score (21). Four regression models that provide an estimate of LV mass were assessed: Rautaharju (2000) (18), Rautaharju (1988) (19), Huwez (1990) (20) and a voltage independent model, based on Sosnowski's model (33). Sosnowski's model gives a mass estimate in units ms^3/m^2; however this correlates with g/m^2 (33). Sosnowski's model is modified, as the Uni-G program only calculates intrinsicoid deflection for five of the ECG leads. The equations used with the limits adopted, are listed in Table 1.

Statistical Analysis

In testing sensitivity and specificity of ECG LVH criteria, a patient would be considered to truly have LVH if the echocardiographic derived LV mass, indexed to body surface area, was greater than $104g/m^2$ for women and $116g/m^2$ for men. Sensitivity

Table 3.Sensitivity and specificity of electrocardiographic criteria for left ventricular hypertrophy with 95% confidence intervals determined using published thresholds for abnormality against echocardiographic determined left ventricular hypertrophy

Criteria	Threshold	Sensitivity, % (95% CI)		Specificity, % (95% CI)	
Voltage index					
Cornell	2.8 mV	7.5	(2.4-16.6)	100	(95.1-100)
Sokolow-Lyon	3.5 mV	6.0	(1.7-14.6)	95.0	(86.1-99.0)
Gubner and Ungerleider	2.2 mV	6.0	(1.7-14.6)	95.0	(86.1-99.0)
Sum-of-12-lead	17.9 mV	6.0	(1.7-14.6)	91.7	(81.6-97.2)
Lewis	1.9 mV	11.9	(5.3-22.2)	93.3	(83.8-98.2)
Framingham Adjusted Cornell	2.8 mV	44.8	(32.6-57.4)	50.0	(36.8-63.2)
Voltage-duration product					
Cornell	244 μVs	14.9	(7.4-25.7)	96.7	(88.5-99.6)
Sokolow-Lyon	371 μVs	6.0	(1.7-14.6)	98.3	(91.1-100)
Sum of 12 leads	1995 μVs	7.5	(2.4-16.6)	96.7	(88.5-99.6)
Point scoring systems					
GRI	4	23.9	(14.3-35.9)	95.0	(86.1-99.0)
GRI	5	17.9	(9.6-29.2)	96.7	(88.5-99.6)
GRI	6	13.4	(6.3-24)	100	(95.1-100)
Romhilt-Estes	4	11.9	(5.3-22.2)	96.7	(88.5-99.6)
Romhilt-Estes	5	4.5	(0.9-12.5)	100	(95.1-100)
Perugia	1	22.3	(13.1-34.2)	95.0	(86.1-99.0)
Regression models					
Rautaharju (2000)	116 /104 g/m^2*	100	(95.6-100)	1.7	(0.0-8.9)
Rautaharju (1988)	116 /104 g/m^2*	38.8	(27.1-51.5)	70.0	(56.8-81.2)
Huwez (1990)	116 /104 g/m^2*	44.8	(32.6-57.4)	55.0	(41.6-67.9)
Sosnowski (2006)	120 ms^3/m^2	25.4	(15.5-37.5)	80.0	(67.7-89.2)
Miscellaneous					
QRS duration	100 ms †	32.8	(21.8-45.4)	88.3	(77.4-95.2)
LV strain pattern ‡	-	11.9	(5.3-22.2)	98.3	(91.1-100)
P terminal force V1 ≤-4mVms	-	14.9	(7.4-25.7)	95.0	(86.1-99.0)
One of above three	-	41.7	(29.8-54.4)	86.7	(75.4-94.1)

* Echocardiographic threshold used for left ventricular hypertrophy: males 116g/m2 and females 104g/m2
† Value chosen arbitrarily
‡ Represents where there is ST depression >100μV and T wave inversion in lead V5
CI- confidence interval, GRI- Glasgow Royal Infirmary modified Romhilt-Estes scoring system,LV- left ventricle

and specificity were calculated using all study patients and separately for both sexes. The 95% confidence intervals were also calculated for sensitivity and specificity.

Microsoft Excel XP (Microsoft Corp) and Minitab (Minitab Ltd, Coventry England) Version 13 were used in all data handling and statistical analysis.

Results

Patients

In total, 142 patients were recruited with echocardiograms and ECGs. All the patient demographics are shown in Tables 1 and 2. Of the 142 patients with ECGs, 2 were excluded due the presence of a pacemaker. A further 13 patients had either a left or right bundle branch block and were excluded from the main analysis, which comprised 51 males and 76 females (Table 2). From the echocardiographic criteria, 67 (53%) patients were classified as having LVH while the remaining 60 (47%) did not.

General findings

The sensitivity and specificity of all the criteria at their published thresholds are listed in Table 3. All of the voltage criteria gave low sensitivities at varying specificities, with the Lewis voltage criteria providing the greatest sensitivity of 11.9% at 93% specificity. The Framingham-adjusted-Cornell voltage gave a specificity of 50% (95% CI (confidence interval) of 37% to 64%) and a sensitivity of 45%. The Sokolow-Lyon and Sum-of-12-lead voltage-duration products only showed a small improvement compared with their voltage index precursors. However, the Cornell voltage-duration product was twice as sensitive as the Cornell voltage index (15% versus 7.5%). The point scoring systems at recommended thresholds all gave specificities of at least 95%. The Romhilt-Estes gave sensitivities of 11% and 5% at scores of 4 and 5 respectively; the Perugia score gave a sensitivity of 22% and the GRI modified Romhilt-Estes score gave 24%, 18% and 13% at scores possible (4), probable (5) and definite (6), respectively. Some components of criteria were also analysed: presence of a LV strain pattern alone gave a sensitivity of 12% at specificity of 98% and left atrial enlargement gave a sensitivity of 15% at 95% specificity. QRS duration alone with a threshold of 100ms gave a sensitivity of 32% at a specificity of 88%. In using one of the three above, a sensitivity of 42% could be attained but at a specificity of 87%.

Patients with bundle branch blocks

The 13 patients that had a bundle branch block were also used to assess the ECG criteria for LVH, with 10 echocardiographically classified with LVH. The most significant result was the Cornell voltage duration product that correctly identified 4 of the 10 with LVH, and identified 0 of the 3 without LVH.

Discussion

This study has found that in this sample of the Glasgow population, with the exception of the Cornell criteria, voltage index and voltage-duration products are relatively poor predictors of LVH. Point scoring systems performed better, in particular the GRI score and the Perugia score identify about a fifth of the patients with LVH. QRS duration, LV strain and left atrial enlargement all independently demonstrated a relatively high sensitivity, exceeding that of most voltage and voltage-duration products. All regression models show a large distance between the upper and lower limits of agreement, which makes them all unsuitable for interchangeability with echocardiography for estimation of LV mass.

The Sokolow-Lyon (11) criteria have been evaluated to give sensitivities of 32% (11), 33% (12), 43% (14), while in this study their sensitivities were only 6% and 12% when adjusted. The Cornell voltage criteria have also been evaluated to give sensitivities of 41% (26), and 28% (14) but in this study, they exhibited only 8% and 19% sensitivity when adjusted. The Framingham adjusted Cornell index (30) gave a low specificity (and a low sensitivity when adjusted) suggesting that this criterion does not adjust well for the Glasgow population. Romhilt-Estes criteria at the probable LVH level (4 points) had previously been shown to have sensitivities of 54% (17) to 20% (14) with this study producing 12%. The results do not appear to be immediately comparable to other studies in the past.

Papers by Okin et al. (14, 15), utilising voltage-duration products and integrals found that the voltage, voltage-duration product and voltage-duration integral of 3 criteria (Sokolow-Lyon, Cornell and Sum-of-12-lead) were all superior to QRS duration alone: yet this study finds that despite a small improvement in each criterion when used as a voltage-duration product, it is not as sensitive as QRS duration alone. Caution must be exhibited when using QRS duration alone in a hospital population. Specificity in a healthy population is likely to be much lower given the normal range of QRS duration of 78-114 ms in 40-49- year old males (34). A recent study by Carlsson et al (13) concluded that QRS duration correlated as well as or better than any other ECG criteria for LVH but they did not compare with any point scoring systems.

Sex specific findings include a greater accuracy of Sokolow-Lyon criterion in males (35). Gasperin et al. (35) also found the Cornell index to be more sensitive in females. However, to adjust for sex they added the equivalent of 0.8 mV to the female Cornell voltage. It has been shown that a better sex-adjustment for the Cornell voltage is the addition of 0.6mV to females (31, 32). All the point scoring criteria performed better in males. However, analysis of some individual components found that LV strain was a better predictor in males but left atrial enlargement better in females. These suggest that despite previous voltage adjustments for age and sex (3, 36) other factors such as QRS duration, LV strain pattern and left atrial enlargement could be sex adjusted for better results in point scoring criteria.

Overall the findings from this study have demonstrated lower sensitivities than expected in comparison with other studies (11, 12, 14, 15, 17, 32, 35). The reasons for this may be the population or the methodology. However, the main purpose of the study was to assess the relative merits of different criteria and while reduced absolute values of sensitivity were found, it is often the case that criteria developed in one lab do not perform as well when evaluated elsewhere.

Clinical implications

Since LVH is a known independent risk factor of mortality, improved ECG detection may lead to more widely applied treatment; however, it has been found that despite various ECG criteria having greater sensitivities, their prognostic value in predicting CV mortality varies considerably (36). Hsieh et al (36) found that ECG criteria for LVH that utilised point scoring had a better power of predicting CV mortality than voltage or voltage-duration criteria. Given that the present study found that the GRI modified Romhilt-Estes score and Perugia score give the greatest sensitivity at a high specificity for a sample of the Glasgow population, by inference they should prove to be good indicators of LVH and CV mortality.

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References

1. Kannel WB, Cobb J. Left ventricular hypertrophy and mortality-results from the Framingham Study. Cardiology 1992; 81: 291-8.
2. Maron BJ, Pelliccia A, Spirito P. Cardiac disease in young trained athletes. Insights into methods for distinguishing athlete's heart from structural heart disease, with particular emphasis on hypertrophic cardiomyopathy. Circulation 1995; 91: 1596-601.
3. Kannel WB, Gordon T, Offutt D. Left ventricular hypertrophy by electrocardiogram. Prevalence, incidence, and mortality in the Framingham study. Ann Intern Med 1969; 71: 89-105.
4. Konno T, Shimizu M, Ino H, Fujino N, Hayashi K, Uchiyama K, et al. Differences in diagnostic value of four electrocardiographic voltage criteria for hypertrophic cardiomyopathy in a genotyped population. Am J Cardiol 2005; 96: 1308-12.
5. Tingleff J, Munch M, Jakobsen TJ, Torp-Pedersen C, Olsen ME, Jensen KH, et al. Prevalence of left ventricular hypertrophy in a hypertensive population. Eur Heart J 1996; 17: 143-9.
6. Hammond IW, Devereux RB, Alderman MH, Lutas EM, Spitzer MC, Crowley JS, et al. The prevalence and correlates of echocardiographic left ventricular hypertrophy among employed patients with uncomplicated hypertension. J Am Coll Cardiol 1986; 7: 639-50.
7. Devereux RB, Wachtell K, Gerdts E, Boman K, Nieminen MS, Papademetriou V, et al. Prognostic significance of left ventricular mass change during treatment of hypertension. JAMA 2004; 292: 2350-6.
8. Lopez-Sendon J, Swedberg K, McMurray J, Tamargo J, Maggioni AP, Dargie H, et al; Task Force on ACE-inhibitors of the European Society of Cardiology; Expert consensus document on angiotensin converting enzyme inhibitors in cardiovascular disease. Eur Heart J 2004; 25: 1454-70.
9. Hillis, G.S. and Bloomfield, P. Basic transthoracic echocardiography BMJ 2005; 330: 1432-6.
10. Levy D, Garrison RJ, Savage DD, Kannel WB, Castelli WP. Prognostic implications of echocardiographically determined left ventricular mass in the Framingham Heart Study. N Engl J Med 1990; 322: 1561-6.
11. Sokolow M, Lyon TP. The ventricular complex in left ventricular hypertrophy as obtained by unipolar precordial and limb leads. Am Heart J 1949; 37: 161-86.
12. Casale PN, Devereux RB, Kligfield P, Eisenberg RR, Miller DH, Chaudhary BS, et al. Electrocardiographic detection of left ventricular hypertrophy: development and prospective validation of improved criteria. J Am Coll Cardiol 1985; 6: 572-80.
13. Carlsson MB, Tragardh E, Engblom H, Hedstrom E, Wagner G, Pahlm O, et al. Left ventricular mass by 12-lead electrocardiogram in healthy subjects: comparison to cardiac magnetic resonance imaging. J Electrocardiol 2006; 39: 67-72.
14. Okin PM, Roman MJ, Devereux RB, Kohsaka S. Electrocardiographic identification of increased left ventricular mass by simple voltage-duration products. J Am Coll Cardiol 1995; 25: 417-23.
15. Okin PM, Roman MJ, Devereux RB, Pickering TG, Borer JS, Kligfield P. Time-voltage QRS area of the 12-lead electrocardiogram detection of left ventricular hypertrophy. Hypertension 1998; 31: 937-42.
16. Romhilt DW, Estes EH Jr. A point-score system for the ECG diagnosis of left ventricular hypertrophy. Am Heart J 2006; 75: 752-8.
17. Romhilt DW, Bove KE, Norris RJ, Conyers E, Conradi S, Rowlands DT, et al. A critical appraisal of the electrocardiographic criteria for the diagnosis of left ventricular hypertrophy. Circulation 1969; 40: 185-95.
18. Rautaharju PM, Park LP, Gottdiener JS, Siscovick D, Boineau R, Smith V, et al. Race- and sex-specific ECG models for left ventricular mass in older populations. Factors influencing overestimation of left ventricular hypertrophy prevalence by ECG criteria in African-Americans. J Electrocardiol 2000; 33: 205-18.
19. Rautaharju PM, LaCroix AZ, Savage DD, Haynes SG, Madans JH, Wolf HK, et al. Electrocardiographic estimate of left ventricular mass versus radiographic cardiac size and the risk of cardiovascular disease mortality in the epidemiologic follow-up study of the First National Health and Nutrition Examination Survey. Am J Cardiol 1988; 62: 59-66.
20. Huwez FU. Electrocardiography of the left ventricle in coronary artery disease and hypertrophy (PhD dissertation). Glasgow: Glasgow Univ. 1990.
21. Macfarlane PW. Physician's Guide, University of Glasgow ECG analysis program., Glasgow: Glasgow University Press; 2006.
22. Devereux RB, Alonso DR, Lutas EM, Gottlieb GJ, Campo E, Sachs I, et al. Echocardiographic assessment of left ventricular hypertrophy: comparison to necropsy findings. Am J Cardiol 1986; 57: 450-8.
23. Dubois D, Dubois EF. A formula to estimate approximate surface area if height and weight be known. Arch Int Med 1916; 17: 863- 71.
24. Wachtell K, Bella JN, Liebson PR, Gerdts E, Dahlof B, Aalto T, et al. Impact of different partition values on prevalences of left ventricular hypertrophy and concentric geometry in a large hypertensive population: the LIFE study. Hypertension 2000; 35: 6-12.
25. Crow RS, Hannan P, Granditis G, Leinig C. Is the echocardiogram an appropriate ECG validity standard for the detection and change in left ventricular size? J Electrocardiol 2005; 29: 248-56.
26. Devereux RB, Dahlof B, Levy D, Pfeffer MA. Comparison of enalapril versus nifedipine to decrease left ventricular hypertrophy in systemic hypertension (the PRESERVE trial). Am J Cardiol 1996; 78: 61-5.
27. Gubner R, Ungerleider H. Electrocardiographic criteria for left ventricular hypertrophy. Factors determining the evolution of the electrocardiographic patterns in hypertrophy and bundle branch block. Arch Intern Med 1943; 72: 196-209.
28. Siegel RJ, Roberts WC. Electrocardiographic observations in severe aortic valve stenosis: correlative necropsy study to clinical, hemodynamic, and ECG variables demonstrating relation of 12-lead QRS amplitude to peak systolic transaortic pressure gradient. Am Heart J 1982; 103: 210-21.
29. Lewis T. Observations upon ventricular hypertrophy with especial reference to preponderance of one or another chamber. Heart 1914; 5: 367-403.
30. Norman JEJ, Levy D, Campbell G, Bailey JJ. Improved detection of echocardiographic left ventricular hypertrophy using a new electrocardiographic algorithm. J Am Coll Cardiol 1993; 21: 1680-6.
31. Okin PM, Devereux RB, Jern S, Kjeldsen SE, Julius S, Nieminen MS, et al. Regression of electrocardiographic left ventricular hypertrophy during antihypertensive treatment and the prediction of major cardiovascular events. JAMA 2004; 292: 2343-9.
32. Schillaci G, Verdecchia P, Borgioni C, Ciucci A, Guerrieri M, Zampi I, et al. Improved electrocardiographic diagnosis of left ventricular hypertrophy. Am J Cardiol 1994; 74: 714-9.
33. Sosnowski M, Korzenioowska B, Tendera M. Left ventricular mass and hypertrophy assessment by means of the QRS complex voltage-independent measurements. Int J Cardiol 2006; 106: 382-9.
34. Macfarlane, P. Normal limits. In: Macfarlane P, Lawrie T, editors. Comprehensive Electrocardiology: Theory And Practice In Health and Disease. 1st ed. Oxford; Pergamon press: 1989. p. 1441.
35. Gasperin CA, Germiniani H, Facin CR, Moraes A, Leinig C. An analysis of electrocardiographic criteria for determining left ventricular hypertrophy. Arq Bras Cardiol 2002; 78: 72-83.
36. Hsieh BP, Pham MX, Froelicher VF. Prognostic value of electrocardiographic criteria for left ventricular hypertrophy. Am Heart J 2005; 150: 161-7.