Diagnostic Accuracy of Left Ventricular Hypertrophy in Patients with Myocardial Infarction by Computer-Assisted Electrocardiography (ELECTROPRES)

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Background: Information is limited about the classification accuracy of electrocardiographic (ECG) criteria for left ventricular hypertrophy (LVH) in the presence of myocardial infarction (MI).

Methods: We evaluated LVH classification accuracy for a set of 16 ECG criteria and some combinations derived from them in 1642 patients (105 with MI) suspected of coronary heart disease with two-dimensional echocardiography evaluation and a standard 12-lead ECG recorded at the same time. Patients with left bundle branch block had previously been excluded. Measures of classification accuracy included sensitivity, specificity, likelihood ratios, and positive and negative predictive values.

Results: Diagnostic accuracy varied widely for different LVH criteria. The criteria with the best overall performance had highest sensitivity in the presence of MI and sensitivities of approximately 30% with relatively low specificities ranging from 72% to 78%. However, the classification accuracy for them was similar to that for patients without MI. The prevalence of LVH in patients with MI was higher (56%) than in those with no MI (31%). Classification accuracy of the best single previously published LVH criteria was comparable to that of the best combinations of any three of them.

Conclusions: The classification accuracy of LVH criteria in the presence of MI is comparable to that in patients without MI, in part possibly due to the higher LVH prevalence in the MI group. The presence of a well-validated computer database facilitates comparative evaluation of ECG-LVH criteria and derivation of optimal combinations of criteria for any given clinical application.

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Left ventricular hypertrophy (LVH) increases considerably cardiovascular morbidity and mortality in patients with arterial hypertension as well as in patients with myocardial infarction (MI).^{1–3} Electrocardiography (ECG) is the most available noninvasive technique for the diagnosis of LVH, and its use as a first-line screening tool is recommended by current guidelines to detect LVH

in all patients with hypertension.^{4–7} Several LVH electrocardiographical indices have been developed and in general they all present a fairly low sensitivity (usually <50%) and high specificity (85–90%).⁸ In patients with MI, the progressive development of left ventricular (LV) remodeling, with LV dysfunction and increased LV mass, leads to congestive heart failure and increases long-term

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mortality. Although the ECG can be used to assess infarction size, evaluate patency of infarct-related artery after reperfusion therapy, and to estimate prognosis, its ability to assess the presence of LVH, one of the landmarks of LV remodeling, has not been systematically studied. Subsequently, little is known about the effect of MI on ECG accuracy in the diagnosis of LVH. To our knowledge the only published work that has directly addressed this issue is a small study by Hanna et al.⁹ who retrospectively compared 49 patients with anterior wall MI with a historical cohort. In general, the ECG indices used presented both a lower sensitivity and specificity for anterior wall MI group when compared with the historical cohort.

The precise application of the ECG for the diagnosis of LVH is limited by difficulties in measuring manually QRS in the standard 12-lead ECG. Therefore, computer-assisted measurement and interpretation of digital ECG could be helpful to reduce inaccuracies and consequently to better assess the diagnostic ability of ECG for detecting LVH.¹⁰ Furthermore, computer-assisted ECG interpretation can facilitate diagnostic algorithm implementation. ELECTROPRES is an internet platform developed in Spain to provide computer-assisted detection of LVH by ECG which uses the validated HES[®] software for ECG interpretation.^{11,12} In order to improve the diagnostic performance of the platform, several diagnostic algorithms based on the combination of standard LVH ECG criteria have been developed to be applied besides standard ECG criteria of LVH. By using the ELECTROPRES internet platform we have recently demonstrated that the presence of left bundle branch block (LBBB) does not affect the diagnostic accuracy for the detection of LVH.¹³

The aim of this study is to investigate the diagnostic accuracy of standard ECG diagnostic criteria of LVH and different diagnostic algorithms as applied by ELECTROPRES in patients with MI whose digital ECG and two-dimensional (2D) echocardiography were performed simultaneously.

METHODS

Study Population

From January 2003 to August 2009, a cohort of 2090 patients (60.7% out of 3441 consecutive patients with echocardiogram) had a 2D echocardiogram and ECG performed during the same visit

to an outpatient cardiac clinic. Patients younger than 18 years old were excluded. Those with poor quality echocardiogram (215 patients) were also excluded, which left a sample of 1875 patients. Finally, patients with LBBB were excluded, leaving the 2 study groups: documented clinical history of MI (n = 105) and patients with neither LBBB nor MI (n = 1537). Figure 1 shows the steps followed for the inclusion of patients in the study.

The research protocol was approved by the Ethical Committee of Hospital Virgen de la Salud of Toledo (Spain).

Electrocardiography

All patients underwent a standard 12-lead ECG with a MAC 1200 ST electrocardiograph (GE Medical Systems, Pittsburgh, PA). All recordings were digitally stored in a GE Cardiosoft database (v. 6.5, GE Healthcare, Pittsburgh, PA) and exported in XML format to the ELECTROPRES platform for computerized measurement and analysis.

ELECTROPRES is an internet-based platform aimed at early detection of LVH by electrocardiography that uses the program Hannover ECG System (HES; Corscience, Erlangen, Germany) for ECG measurement and interpretation. The ECG analysis can be performed online although in this study this was done off-line. This software, approved by FDA, was developed in 1969, has undergone several updates, and has shown a high accuracy in ECG interpretation.¹⁴

Besides standard ECG criteria of LVH, ELECTROPRES also uses three diagnostic algorithms of LVH which were considered diagnostic if one or more criteria include in them was met: algorithm A, the European Society of Cardiology hypertension guidelines recommended criteria (LVH by Sokolow-Lyon voltage or by Cornell voltage-duration product [VDP]); algorithm B (LVH by Sokolow-Lyon voltage criterion, Cornell voltage criterion, Sokolow VDP or Cornell VDP); algorithm C (LVH by Sokolow-Lyon voltage, Cornell voltage, Gubner-Ungerleider, Lewis index, R-V6/R-V5, R wave in aVL, QRS 12 leads, Sokolow duration-voltage product, Cornell duration-voltage product, QRS 12 leads duration-voltage product, Gubner-Ungerleider duration-voltage product, or R in aVL duration-voltage product)¹⁵ (Table 1). Part of the electrocardiographic criteria, namely those of Sokolow-Lyon, Cornell, and Gubner-Ungerleider, the R in aVL, and the sum of the 12-lead QRS,

Figure 1. Flow chart depicting the steps for the inclusion of patients in the study. ECG = electrocardiogram; ECHO = echocardiogram; MI = myocardial infarction; LBBB = left bundle branch block.

were analyzed not only in the voltage, but in the VDP as well.

Echocardiography

At the time of the ECG recording all patients underwent a 2D echocardiogram performed with a Vivid 3 or Vivid 4 General Electric echocardiograph with a 2.5 MHz transducer by the same cardiologist (LRP). The images selected were those where visualization was optimal. Measurements were performed from long-axis parasternal views displayed on the screen over the 2D end-diastolic image, according to standard technique, assuring that the most perpendicular distance from the different structures were used. LV mass was calculated by the following equation:^{16, 17}

$$\text{LVM(g)} = 0.8(1.04 [\text{LVID} + \text{LVPW} + \text{IVS}]^3 - [\text{LVID}]^3) + 0.6,$$

where LVID: end-diastolic LV internal dimension, IVS: end-diastolic interventricular septum, LVPW: end-diastolic LV posterior wall thickness. LVH was

considered to be present when LVM index was $> 134 \text{ g/m}^2$ (men) or $> 110 \text{ g/m}^2$ (women).¹⁸

Statistical Analysis

We constructed a 2×2 table with the cutoff points for LVH and for each ECG criterion, calculating the sensitivity, specificity, positive and negative likelihood ratio, positive and negative predictive values, pretest odds and probability of a positive and negative test, and post-test odds and probability of a positive or negative test using the standard definitions. Chi-square test was used to test differences between ECG criteria and the ROC (receiver operated characteristic) curves to complete the analysis of the diagnostic accuracy of the different ECG criteria using standard methods.

In the 2-tailed tests, a $P < 0.05$ was considered to indicate statistical significance. Calculations were performed with the SPSS v. 17.0 statistical software package (IBM Inc, Armonk, NY).

We assessed intraobserver variability by measuring twice, in a blinded fashion, 3 dimensions in 15

Table 1. Electrocardiographic Criteria for Left Ventricular Hypertrophy

Criteria	Formula	LVH Criteria
Sokolow-Lyon Voltage (mV)	$S(V1) + \max(R(V5) \text{ or } R(V6))$	≥ 3.5 mV
Cornell Voltage (mV)	$R(aVL) + S(V3)$	≥ 2.8 mV (men) ≥ 2.0 mV (women)
R6:R5	$R(V6) / R(V5)$	> 1
RaVL (mV)	$R(aVL)$	> 1.1 mV
Gubner-Ungerleider (mV)	$R(I) + S(III)$	> 2.5 mV
Lewis (mV)	$(R(I) + S(III)) - (R(III) + S(I))$	> 1.7 mV
QRS 12 (mV)	R wave + S wave (or Q wave, whichever is higher) in all 12 leads	> 19.530 mV (men) > 18.499 mV (women)
HES	Logistic regression equation	
VDP Sokolow (ms x mV)	$S(V1) + \max(R(V5) \text{ x } R(V6)) \text{ x QRS duration}$	> 367.4 mVms (men) > 322.4 mVms (women)
VDP Cornell	Males: $R(aVL) + S(V3) \text{ x QRS duration}$ Females: $(R(aVL) + S(V3) + 0.6 \text{ mV}) \text{ x QRS duration}$	> 244 mVms
VDP Gubner	Gubner x QRS duration	> 207 mVms
VDP RaVL	$R(aVL) \text{ x QRS duration}$	> 103 mVms
VDP QRS 12	QRS area in 12 leads	> 2348.8 mVms (men) > 1960.7 mVms (women)
Dalfó	$R(aVL) + S(V3)$	> 1.6 mV (men) > 1.4 mV (women)
Perugia	(a) $S(V3) + R(aVL) > 2.4$ mV male or > 2.0 mV females, or (b) Left ventricular strain pattern, or (c) Romhilt-Estes point score ≥ 5	Any of those 3 variables
Romhilt-Estes (points)		> 4 or > 5 points

ECG = electrocardiographic; LVH = left ventricular hypertrophy; HES = Hannover ECG System; VDP = voltage-duration product.

echocardiograms of randomly selected patients (a total of 42 measurements) within a 2-week interval. Variability was calculated as standard deviation of the differences between the first and second measurements made by the same observer, and expressed as a percentage of the mean value.

RESULTS

Baseline Characteristics

The baseline characteristics of the patients are shown in Table 2. The MI group consisted of 82 men (87.6%) and 13 women (12.4%), with a mean age of 64.9 ± 11.4 years. The most common diagnoses were hypertension ($n = 57$; 54.3%), diabetes mellitus ($n = 29$; 27.6%), and hypercholesterolemia ($n = 49$; 46.7%). The localization of the MI was anterior in 28 patients (26.6%), inferior in 58 patients (55.2%), anterior and inferior in 5 patients (4.8%), and in 14 patients (13.4%) the MI was localized to areas other than the LV or no Q wave was observed on the ECG.

In the group of patients with neither LBBB nor MI there were 849 men (55.2%) and 688 women (44.8%), with a mean age of 53.6 ± 15.5 years. Suspected or known heart disease ($n = 160$; 79.3%), essential hypertension ($n = 810$; 51.9%), and arrhythmia ($n = 160$; 68.7%) were the most frequent clinical diagnoses.

The patients with MI were older, more likely to be male, and had increased LV mass index, IVS end-diastolic thickness, LV end-diastolic diameter, and posterior wall end-diastolic thickness. A relatively low intraobserver variability in the echocardiographic measurements of 3% was observed.

Correlation between ECG Voltages and LV Mass

The correlation coefficients between LV mass index on echocardiography and each of the ECG indices are shown in Figure 2. In the MI group, the Perugia criterion presented the highest correlation with LV mass index ($r = 0.313$), followed by the Romhilt criterion ($r = 0.286$) and Cornell VDP criterion ($r = 0.255$). In the patients who did not

Table 2. Baseline Characteristics (Demographic, Echocardiographic, and Electrocardiographic) of the Population with Myocardial Infarction and without Myocardial Infarction or Left Bundle Branch Block

Variable	MI (n = 105)	Without LBBB or MI (n = 1537)	P
Age, years	64.9 ± 11.4	53.6 ± 15.5	<0.0010
Men, %	87.6	55.2	<0.0010
Hypertension, %	54.3	51.8	0.6867
Hypercholesterolemia %	46.7	26.8	<0.0010
Diabetes mellitus %	27.6	7.7	<0.0010
Body weight, kg	95.5 ± 107.1	85.5 ± 67.8	0.1498
Height, cm	168.7 ± 7.3	168.8 ± 9.2	0.9131
Body mass index	33.5 ± 37.4	30.3 ± 27.2	0.2533
LV mass index, g/m ²	102.5 ± 27	82.7 ± 41.4	<0.0010
IVS end-diastolic thickness, mm	11.7 ± 2	10.8 ± 2.7	<0.0010
LV end-diastolic diameter, mm	46.8 ± 6.8	43 ± 5.7	<0.0010
Posterior wall end-diastolic thickness, mm	10.3 ± 1.6	9.9 ± 2.8	0.1479
Sokolow-Lyon voltage, mV	1.65 ± 0.72	1.99 ± 0.73	<0.0010
Cornell voltage, mV	1.25 ± 0.66	1.13 ± 0.59	0.0455
R6:R5	0.94 ± 0.41	0.85 ± 0.19	<0.0010
R(aVL), mV	0.55 ± 0.33	0.51 ± 0.34	0.2426
Gubner-Ungerleider, mV	0.95 ± 0.58	1.1 ± 0.58	0.0104
Lewis, mV	0.62 ± 0.74	0.71 ± 0.8	0.2625
12-lead QRS, mV	11.9 ± 2.8	13.4 ± 3.7	<0.0010
Sokolow VDP, ms, mV	174.6 ± 88.5	193.3 ± 80.7	0.0225
Cornell VDP	145.9 ± 103.4	137.2 ± 70	0.2344
Gubner VDP	102.6 ± 69.6	107.3 ± 63.3	0.4645
R(aVL) VDP	59.7 ± 41.2	50.1 ± 36.6	0.0100
12-lead QRS VDP	1283.7 ± 490.9	1293.9 ± 438.9	0.4984
Dalfó	1.25 ± 0.66	1.13 ± 0.59	0.0455
Perugia	0.30 ± 0.46	0.08 ± 0.28	<0.0010
Romhilt-Estes, points	2.42 ± 2.10	1.19 (1.32)	<0.0010

Unless otherwise indicated, the data are expressed as the mean ± standard deviation. LBBB = left bundle branch block; MI = myocardial infarction; LV = left ventricular; R(aVL) = R wave in lead aVL; IVS = interventricular septal; VDP = voltage-duration product.

have MI or LBBB, the correlation with the LV mass index was highest for R in aVL VDP ($r = 0.695$) followed by R in aVL ($r = 0.664$). The Perugia criterion presented the closest correlation values between the MI and no MI or LBBB group ($r = 0.313$ and $r = 0.307$; respectively). Greatest differences between the two patient groups were observed in the R in aVL and the R in aVL VDP criterion.

Sensitivity, Specificity, and Likelihood Ratios

The prevalence of LVH as determined by echocardiography with the threshold values considered (LVM index was >134 g/m² in men or >110 g/m² in women) was 56.2% in the MI group and 30.7% in the no MI or LBBB group. Tables 3 and 4 show the sensitivity, specificity, predictive values, likelihood ratios, and posttest probabilities

of all electrocardiographic indices analyzed for the patients with MI and those with no MI no LBBB, respectively.

In general, in patients with MI sensitivities were low or intermediate and ranged from 0% for the Sokolow-Lyon voltage and 12-lead QRS voltage to 57.6% for algorithm C. Specificities were intermediate or high, ranging from 43.5% for algorithm C to 97.8% for Sokolow-Lyon voltage, HES, Gubner-Ungerleider, and total QRS. Positive likelihood ratios ranged from 0.0 for Sokolow-Lyon voltage to 2.34 for HES, and negative likelihood ratios ranged from 0.84 for Romhilt-Estes > 5 to 1.53 for RaVL. For the prevalence of LVH observed in this study, these likelihood ratios result in a negative test accuracy probability (NTA) of LVH that ranges from 0% for Sokolow-Lyon voltage to 75.0% for HES, and a positive test accuracy (PTA) of LVH that ranges from 54.4 for the algorithm B and RV6:RV5 to 57.7% for Dalfó.

Figure 2. Correlation coefficients between the left ventricular mass index as measured in the echocardiogram and the electrocardiographic criteria considered in this study in patients with MI and in those who did not have MI or LBBB. LV = left ventricular; ECG = electrocardiographic; MI = myocardial infarction; LBBB = left bundle branch block.

In the no MI or LBBB group the sensitivities were overall low (between 3.5% for the Sokolow-Lyon voltage and 19% for the Lewis criterion), apart from the Dalfó (37.1%) and the algorithm C (53.1%). Specificities were high in all electrocardiographic indices, ranging from 70.7% for the research algorithm to 99.3% for the Cornell voltage. Positive likelihood ratios ranged from 1.28 for the Sokolov-Lyon voltage criteria to 8.73 for the Cornell voltage, and negative likelihood ratios ranged from 0.66 for the research algorithm to 0.99 for the Sokolow-Lyon voltage. For the prevalence of LVH observed in this study, these likelihood ratios give a negative post-test probability of LVH that ranges from 22.8% for the research algorithm to 30.6% for the Sokolow-Lyon voltage, and a positive posttest probability of LVH that ranges from 36.2% for the Sokolov-Lyon voltage criterion to 79.5% for the Cornell voltage.

When comparing sensitivity between the MI and the no MI or LBBB groups, the majority of the electrocardiographic indices showed no signif-

icant differences and when analyzing specificity between the same groups no significant differences were found (Table 5).

Finally, there were no statistically significant differences in sensitivity or specificity when the voltage and VDP criteria were compared.

DISCUSSION

The results of this study confirm the relatively low sensitivity and high specificity that has previously been reported for the different LVH electrocardiographical indices.⁸ We have recently demonstrated that the presence of LBBB does not affect the diagnostic accuracy of the ECG for the diagnosis of LVH using the computer-assisted internet platform ELECTROPRES.¹³ In this study, using the same platform and the same ECG criteria we have found that in the subgroup of patients with previous MI the sensitivity and specificity were similar to those observed in patients with no MI or

Table 3. Sensitivity (S), Specificity (Sp), Positive Test Accuracy (PTA), Negative Test Accuracy (NTA), Positive Likelihood Ratio (+LR), Negative Likelihood Ratio (–LR), Prevalence of Left Ventricular Hypertrophy (LVH), Negative Posttest Probability (–PPT), and Positive Posttest Probability (+PPT) of All Electrocardiographic Criteria Considered in Patients with Myocardial Infarction (n = 105)

Criteria	S (%) ± CI 95%	Sp (%) ± CI 95%	PTA (%) ± CI 95%	NTA (%) ± CI 95%	LR +	LR –	Incidence of LVH, %	PPT –	PPT +
Algorithm A	15.2 ± 9.2	89.1 ± 9.0	64.3 ± 25.1	45.1 ± 10.2	1.4	0.95	56.2	64.3	55.0
Algorithm B	17.0 ± 89.6	89.1 ± 9.0	66.7 ± 23.9	46.6 ± 10.3	1.56	0.93		66.7	54.4
Algorithm C	57.6 ± 12.6	43.5 ± 12.3	56.7 ± 12.5	44.4 ± 14.5	1.02	0.97		56.7	55.6
Sokolow-Lyon voltage	0.0 ± 0.0	97.8 ± 4.2	0.0 ± 0.0	43.3 ± 9.5	0.00	1.02		0.0	56.7
Cornell voltage	5.1 ± 5.6	95.7 ± 5.9	60.0 ± 42.9	44.0 ± 9.7	1.17	0.99		60.0	56.0
R6:R5	27.1 ± 11.3	78.3 ± 11.9	61.5 ± 18.7	45.6 ± 11.1	1.25	0.93		61.5	54.4
RaVL	3.4 ± 4.6	93.5 ± 7.1	40.0 ± 42.9	43.0 ± 9.7	0.52	1.53		40.0	57.0
Gubner-Ungerleider	1.7 ± 3.3	97.8 ± 4.2	50.0 ± 69.3	43.7 ± 9.6	0.78	1.00		50.0	56.3
Lewis	6.8 ± 6.4	91.3 ± 8.1	50.0 ± 34.7	43.3 ± 9.9	0.78	1.02		50.0	56.7
12-lead QRS	0.0 ± 0.0	97.8 ± 4.2	0.0 ± 10.0	43.3 ± 9.5	0.00	1.02		0.0	56.7
HES	5.1 ± 5.6	97.8 ± 4.2	75.0 ± 42.4	44.5 ± 9.7	2.34	0.97		75.0	55.4
Sokolow VDP	3.4 ± 4.6	95.7 ± 5.9	50.0 ± 49.0	43.6 ± 9.7	0.78	1.01		50.0	56.4
Cornell VDP	15.2 ± 9.2	89.1 ± 9.0	64.3 ± 25.1	45.1 ± 10.2	1.40	0.95		64.3	54.9
Gubner VDP	8.5 ± 7.1	89.1 ± 9.0	50.0 ± 31.0	43.1 ± 10.1	0.78	1.03		50.0	56.8
R(aVL) VDP	15.3 ± 9.2	87.0 ± 9.7	60.0 ± 24.8	44.4 ± 10.3	0.97	1.2		60.0	55.6
12-lead QRS VDP	11.9 ± 8.2	91.3 ± 8.1	63.6 ± 28.4	44.7 ± 10.0	0.97	1.41		66.6	55.3
Dalfó	23.7 ± 10.9	71.7 ± 13.0	51.9 ± 18.9	42.3 ± 10.9	0.84	1.06		51.9	57.7
Perugia	32.2 ± 11.9	71.7 ± 13.0	59.4 ± 17.0	45.2 ± 11.4	1.14	0.95		59.4	54.8
Romhilt-Estes > 4	10.2 ± 7.7	91.3 ± 8.1	60.0 ± 30.4	44.2 ± 10.1	0.98	1.19		60.0	55.8
Romhilt-Estes > 5	16.9 ± 9.6	80.4 ± 11.5	52.6 ± 22.4	43.1 ± 10.5	1.03	0.84		52.6	57.0

ECG = electrocardiographic; MI = myocardial infarction.

Table 4. Sensitivity (S), Specificity (Sp), Positive Predictive Value (PPV), Negative Predictive Value (NPV), Positive Likelihood Ratio (+LR), Negative Likelihood Ratio (–LR), Prevalence of Left Ventricular Hypertrophy (LVH), Negative Posttest Probability (–PPT), and Positive Posttest Probability (+PPT) of All Electrocardiographic Criteria Considered in Patients with No Myocardial Infarction (MI) or Left Bundle Branch Block (LBBB) (n = 1561)

Criteria	S (%) (±CI 5%)	Sp (%) (±CI 5%)	PPV (%) (±CI 95%)	NPV (%) (±CI 95%)	LR +	LR –	Incidence of LVH (%)	PPT +	PPT –
Algorithm A	13.9 ± 3.1	95.7 ± 1.2	59.3 ± 9.1	71.5 ± 2.3	3.28	0.90	30.7	59.3	28.5
Algorithm B	14.8 ± 3.2	93.8 ± 1.4	51.5 ± 8.3	71.3 ± 2.4	2.39	0.91		51.5	28.7
Algorithm C	53.1 ± 4.5	70.7 ± 2.7	44.6 ± 4.1	77.3 ± 2.6	1.81	0.66		44.6	22.8
Sokolow-Lyon voltage	3.5 ± 1.6	96.2 ± 1.0	36.2 ± 13.7	69.4 ± 2.3	1.28	0.99		36.2	30.6
Cornell voltage	6.5 ± 2.2	99.3 ± 0.5	79.5 ± 12.7	70.5 ± 2.3	8.73	0.94		79.5	29.5
R6:R5	6.5 ± 2.2	95.5 ± 1.2	38.8 ± 10.7	69.7 ± 2.3	1.42	0.98		38.7	30.3
R(aVL)	10.0 ± 2.7	96.6 ± 1.1	56.5 ± 10.5	70.7 ± 2.3	2.92	0.93		56.5	29.3
Gubner-Ungerleider	5.2 ± 2.0	98.6 ± 0.7	62.5 ± 15.0	70.1 ± 2.3	3.75	0.96		62.5	29.9
Lewis	19.0 ± 3.5	93.4 ± 1.5	56.2 ± 7.7	72.3 ± 2.4	2.89	0.87		56.2	27.8
12-lead QRS	6.5 ± 2.2	96.0 ± 1.2	41.9 ± 11.2	69.8 ± 2.3	1.62	0.97		41.9	30.2
HES	9.2 ± 2.9	97.2 ± 1.0	59.5 ± 11.2	70.7 ± 2.3	3.30	0.93		59.5	29.3
Sokolow VDP	5.2 ± 2.1	96.9 ± 1.0	42.4 ± 12.6	69.7 ± 2.3	1.66	0.98		42.4	30.3
Cornell VDP	12.3 ± 2.9	97.4 ± 1.0	67.8 ± 9.8	71.4 ± 2.3	4.75	0.90		67.2	28.6
Gubner VDP	13.3 ± 3.0	95.6 ± 1.2	57.1 ± 9.2	71.3 ± 2.3	3.00	0.91		57.1	28.7
R(aVL) VDP	15.2 ± 3.2	95.1 ± 1.3	57.9 ± 8.6	71.6 ± 2.3	3.10	0.89		57.9	28.4
12-lead QRS VDP	12.7 ± 3.0	92.2 ± 1.6	42.1 ± 8.0	70.4 ± 2.4	1.64	0.95		42.1	29.6
Dalfó	37.1 ± 4.3	85.4 ± 2.1	53.0 ± 5.3	75.4 ± 2.4	2.54	0.74		54.0	24.7
Perugia	16.0 ± 3.3	95.1 ± 1.3	59.2 ± 8.5	71.8 ± 2.3	3.27	0.88		59.2	28.2
Romhilt-Estes > 4	6.0 ± 2.1	97.6 ± 0.9	52.7 ± 13.2	70.1 ± 2.3	2.51	0.96		52.7	30.0
Romhilt-Estes > 5	6.3 ± 2.2	98.7 ± 0.7	68.2 ± 13.8	70.3 ± 2.3	4.83	0.95		68.2	29.7

Table 5. Comparisons between the Sensitivities and Specificities of the Two Groups of Patients: with Myocardial Infarction (MI) and No MI or Left Bundle Branch Block (LBBB)

Criteria	Sensitivity, %			Specificity, %		
	No LBBB or MI (n=1537)	MI (n=105)	P	No LBBB (n=1537)	MI (n=105)	P
Algorithm A	13.9 ± 3.1	15.2 ± 9.2	0.5337	95.7 ± 1.2	89.1 ± 9.0	0.8269
Algorithm B	14.8 ± 3.2	17.0 ± 89.6	1	93.8 ± 1.4	89.1 ± 9.0	0.8277
Algorithm C	53.1 ± 4.5	57.6 ± 12.6	0.0044	70.7 ± 2.7	43.5 ± 12.3	0.0755
Sokolow-Lyon voltage	3.5 ± 1.6	0.0 ± 0.0	0.2391	96.2 ± 1.0	97.8 ± 4.2	1
Cornell voltage	6.5 ± 2.2	5.1 ± 5.6	1	99.3 ± 0.5	95.7 ± 5.9	0.9145
R6:R5	6.5 ± 2.2	27.1 ± 11.3	<0.0010	95.5 ± 1.2	78.3 ± 11.9	0.4309
R(aVL)	10.0 ± 2.7	3.4 ± 4.6	0.1485	96.6 ± 1.1	93.5 ± 7.1	0.9141
Gubner-Ungerleider	5.2 ± 2.0	1.7 ± 3.3	0.3442	98.6 ± 0.7	97.8 ± 4.2	1
Lewis	19.0 ± 3.5	6.8 ± 6.4	0.0413	93.4 ± 1.5	91.3 ± 8.1	1
12-lead QRS	6.5 ± 2.2	0.0 ± 0.0	0.0379	96.0 ± 1.2	97.8 ± 4.2	1
HES	9.2 ± 2.9	5.1 ± 5.6	0.4597	97.2 ± 1.0	97.8 ± 4.2	1
Sokolow VDP	5.2 ± 2.1	3.4 ± 4.6	0.5429	96.9 ± 1.0	95.7 ± 5.9	1
Cornell VDP	12.3 ± 2.9	15.2 ± 9.2	0.7568	97.4 ± 1.0	89.1 ± 9.0	0.7431
Gubner VDP	13.3 ± 3.0	8.5 ± 7.1	0.4114	95.6 ± 1.2	89.1 ± 9.0	0.8269
R(aVL) VDP	15.2 ± 3.2	15.3 ± 9.2	1	95.1 ± 1.3	87.0 ± 9.7	0.7417
12-lead QRS VDP	12.7 ± 3.0	11.9 ± 8.2	1	92.2 ± 1.6	91.3 ± 8.1	1
Dalfó	37.1 ± 4.3	23.7 ± 10.9	0.1626	85.4 ± 2.1	71.7 ± 13.0	0.4909
Perugia	16.0 ± 3.3	32.2 ± 11.9	0.0267	95.1 ± 1.3	71.7 ± 13.0	0.2519
Romhilt-Estes > 4	6.0 ± 2.1	10.2 ± 7.7	0.2683	97.6 ± 0.9	91.3 ± 8.1	0.8279
Romhilt-Estes > 5	6.3 ± 2.2	16.9 ± 9.6	0.0185	98.7 ± 0.7	80.4 ± 11.5	0.3731

HES = Hannover ECG System; R(aVL) = R wave in lead aVL; VDP = voltage-duration product.

LBBB. In patients with MI, RV6:RV5 and Perugia criteria showed a modest but significant increase in sensitivities with a nonsignificant reduction in specificities; hence, these two criteria appear to perform better in patients with MI, whereas no significant differences were observed in the other indices between the two populations studied. Therefore, at least when assessed by a computer-assisted system, the presence of a previous MI nor LBBB does not seem to hamper the identification of LVH by different ECG criteria. This type of modern ECG evaluation offers several advantages such as fast and accurate blind measurement and simultaneous evaluation of several indices, as shown in this study. Nevertheless, although the combination of several LVH ECG criterion clearly improved sensitivity in our study this was at the expense of reduced specificity and our results therefore do not indicate a clear advantage for these algorithms over the old LVH criterion.

To the best of our knowledge, in patients with previous MI, very little is known with regards to the utility of ECG indices to predict LVH. A small retrospective study by Hanna et al.⁹ analyzed the accuracy of 5 LVH ECG indices (Cornell, R(aVL) > 1.1, R(I) ≥ 1.5, Sokolow-Lyon and R(V6):R(V5)

criterion) in patients with previous MI. They reported an overall worse sensitivity and specificity for the prediction of LVH in patients with MI, contrary to our findings. This difference may be due to a relatively small patient sample size and the use of a historical cohort as controls in the aforementioned study and our use of a computer-based diagnostic system, which may have helped to more accurately measure the QRS waves and reduce interobserver variability.

The study also found a significantly larger prevalence of LVH in the MI group (56.2%) than the no MI or LBBB group (30.7%). This seems logical since (a) LVH secondary to essential hypertension is well known to significantly increase cardiovascular morbidity and mortality¹⁻³ and (b) LVH may be the result of LV remodeling in patients with a previous MI. Furthermore this may, in part, explain the comparable classification accuracy of the ECG indices for LVH in MI patients and patients without MI by reasons of Bayesian considerations.

The electrocardiographical detection of LVH in the context of a past MI may therefore be of prognostic value, since an increase in the LV mass is indicative of LV remodeling which invariable translates into an elevated risk for developing

congestive heart failure and worsening the long-term prognosis. Nevertheless, the prognostic value of the ECG indices for LVH in patients with prior MI needs validation in further studies.

Despite our findings that the diagnostic performance of the LVH electrocardiographic indices is not significantly reduced in patients with previous MI its sensitivity is still low and this will invariably limit its use as a screening tool for LVH. Furthermore, being a more sensitive and specific diagnostic tool, echocardiography is nowadays regarded as the most useful tool for the detection of LVH. Nonetheless, many patients will undergo ECG testing for other reasons and it makes sense to use the information provided by this technique to assess the presence of LVH despite its limitations. In addition and in contrast to echocardiography, the low cost and readily availability of ECG testing constitute an important advantage.

Limitations of our study should be noted. We used 2D echocardiographic measurements, which can be less accurate than M mode echocardiography. Nevertheless, the technique used to measure was aimed to minimize errors in measurement and gave a prevalence of LVH similar to what has previously been reported in comparable samples.^{19,20} In addition, 2D echocardiographic measurements are commonly used in clinical practice, which increases its possibility of extrapolation of the results and is more representative of effectiveness of the method. In the study by Hanna et al.⁹ a reduced sensitivity was found in patients with anterior and lateral wall MI when compared to anterior wall MI only. In our study no distinction was made between the localization of the MI and it is therefore possible that a subgroup analysis could have revealed differences in the diagnostic accuracy depending on the LV region affected by the MI. Also, the relatively limited sample size of patients with MI and the large number of criteria evaluated, including multiple combinations, makes it possible that some of the observed classification accuracies could have been influenced by random chance. Validation of the results in other larger population is therefore warranted. Finally, since all electrocardiographic measurements have been carried out using a computer-assisted system that reduces measurement error, special care is necessary when a manual technique of measurement is used aimed at reproducing our findings.

In conclusion, our findings indicate that the presence of a previous MI does not limit the

diagnostic accuracy of the ECG in the detection of LVH in patients with known or suspected heart disease, at least when a computer-assisted internet platform is used. This type of diagnostic system constitutes an attractive approach since it allows to accurately and rapidly evaluate multiples LVH electrocardiographic indices in different clinical settings.

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