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Original article

Diagnostic Accuracy of Computer-Assisted Electrocardiography in the Diagnosis of Left Ventricular Hypertrophy in Left Bundle Branch Block

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ABSTRACT

Introduction and objectives: Left ventricular hypertrophy has important prognostic implications. Although electrocardiography is the technique most often recommended in the diagnosis of hypertrophy, its diagnostic accuracy is hampered in the presence of a left bundle branch block.

Methods: In 1875 consecutive patients (56±16 years) undergoing studies to rule out heart disease and/or hypertension, 2-dimensional echocardiography and electrocardiography were performed simultaneously in an outpatient clinic. Digitized electrocardiograms were interpreted using an online computer-assisted platform (ELECTROPRES). Sensitivity, specificity, likelihood ratios, and predictive values of standard electrocardiographic criteria and of some diagnostic algorithms for left ventricular hypertrophy were determined and compared with the findings in patients with neither left bundle branch block nor myocardial infarction.

Results: Left bundle branch block was present in 233 (12%) patients. Left ventricular hypertrophy was detected more frequently in patients with left bundle branch block (60% vs 31%). In patients with left bundle branch block, sensitivities were low but similar to those observed in patients without it, and ranged from 6.4% to 70.9%, whereas specificities were high, ranging from 57.6% to 100%. Positive likelihood ratios ranged from 1.33 to 4.94, and negative likelihood ratios from 0.50 to 0.98. Diagnostic algorithms, voltage-duration products, and certain compound criteria had the best sensitivities.

Conclusions: Left ventricular hypertrophy can be diagnosed in the presence of left bundle branch block with an accuracy at least similar to that observed in patients without this conduction defect. Computer-assisted interpretation of the electrocardiogram may be useful in the diagnosis of left ventricular hypertrophy as it enables the implementation of more accurate algorithms.

Precisión diagnóstica del electrocardiograma asistido por ordenador al diagnosticar hipertrofia ventricular izquierda en el bloqueo de rama izquierda

Palabras clave:
Electrocardiografía
Hipertrofia
Bloqueo de rama izquierda
Interpretación asistida por ordenador

RESUMEN

Introducción y objetivos: La hipertrofia ventricular izquierda tiene implicaciones pronósticas. El electrocardiograma, la técnica recomendada con mayor frecuencia para su diagnóstico, está limitado en presencia de bloqueo de rama izquierda.

Métodos: Se ha realizado un electrocardiograma y un ecocardiograma a 1.875 pacientes consecutivos (media de edad, 56 ± 16 años) estudiados para descartar cardiopatía y/o hipertensión arterial, definiendo la hipertrofia ventricular izquierda mediante ecocardiografía. Los electrocardiogramas fueron interpretados por la plataforma digital asistida por ordenador ELECTROPRES. Se determinaron sensibilidad, especificidad, valores predictivos y razones de verosimilitud de los criterios electrocardiográficos clásicos y de algunos algoritmos diagnósticos de hipertrofia en los pacientes con bloqueo de rama izquierda, y se comparó esos valores con los obtenidos en los sujetos sin él.

Resultados: Se observó bloqueo de rama izquierda en 233 (12%) pacientes. La hipertrofia ventricular izquierda fue más frecuente en pacientes con bloqueo de rama izquierda (el 60 frente al 31%). En estos, las sensibilidades fueron bajas pero similares a las halladas en pacientes sin bloqueo (del 6,4 al 70,9%), mientras que las especificidades fueron altas (del 57,6 al 100%). Las razones de verosimilitud fueron:

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positivas (1,33-4,94) y negativas (0,50-0,98). Los algoritmos diagnósticos, los productos duración-voltaje y algunos criterios compuestos tuvieron las mejores sensibilidades.
Conclusiones: Se puede diagnosticar hipertrofia del ventrículo izquierdo en presencia de bloqueo de rama izquierda con una precisión diagnóstica al menos similar a la obtenida en los pacientes sin este trastorno de conducción. La interpretación del electrocardiograma asistida por ordenador puede ser útil al facilitar el uso de algoritmos diagnósticos más precisos.

Abbreviations

ECG: electrocardiogram
HES: ®Hannover ECG System®
LBBB: left bundle branch block
LV: left ventricular
LVH: left ventricular hypertrophy
VDP: voltage-duration product

INTRODUCTION

Left ventricular hypertrophy (LVH) increases the rates of morbidity and mortality in patients with hypertension[1–3] and therefore its detection is important for risk stratification. The electrocardiogram (ECG) is the most widely available technique for the diagnosis of LVH and thus clinical practice guidelines recommend its systematic use in hypertension.[4–7] However, left bundle branch block (LBBB) poses difficulties in the diagnosis of LVH by means of the ECG, although the available information on the effect of this conduction defect is contradictory and is based on small numbers of patients.[8–10]

While some authors have demonstrated that voltage criteria cannot be utilized for the diagnosis of LVH in LBBB[11] and recommend the use of complementary data,[12] others have found no significant limitations.[13–16] The sensitivity and specificity of the ECG in patients with LBBB can vary depending on the leads considered, and the precordial leads are those that have a reduced sensitivity.[17] Thus, it has been proposed that a set of criteria that combines precordial leads and limb leads, or the combination of QRS voltage and duration with left atrial enlargement,[14,18] may be more accurate in cases of LBBB.

The use of the ECG is also limited by difficulties when the QRS complex is measured manually, especially in LBBB. For this reason, computer-assisted ECG interpretation could be useful, as it reduces measurement errors.[19] Moreover, the computer enables the utilization of diagnostic algorithms. ELECTROPRES is a web-based platform developed in Spain to provide computer-assisted online help in the detection of LVH in the ECG using the Hannover ECG System® (HES®) software package.[20,21]

Our aim is to investigate the diagnostic accuracy of the standard ECG criteria for LVH and of several diagnostic algorithms, applied using the ELECTROPRES platform, in patients with or without LBBB.

METHODS

Study Population

Between January 2003 and August 2009, we studied a group of 2090 patients (60.7% of 3441 consecutive patients with an available echocardiogram) in whom electrocardiography and two-dimensional (2D) echocardiography had been performed simultaneously in the cardiology service of a hospital outpatient clinic. In the retrospective analysis, we excluded the patients under 18 years of age and those whose echocardiogram was of poor quality (215 patients; 10.3%), which left a final sample of 1875 patients. LBBB was detected in 233 (12%) of them; the diagnosis of LBBB was obtained following the standard ECG criteria (QRS width greater than 120 ms with a predominantly negative deflection in V1 and a predominantly positive deflection in V6), with no distinctions according to QRS width or QRS axis. These patients were compared with those in whom there was no ECG evidence of LBBB or myocardial infarction (n = 1561). Figure 1 shows the steps followed for the inclusion of patients in the study.[22]

The study protocol was approved in 2009 by the Ethics Committee of *Hospital Virgen de la Salud* in Toledo, Spain.

Electrocardiogram

All of the patients underwent a standard 12-lead ECG with a MAC 1200 ST electrocardiograph (GE Medical Systems). The recordings were stored in digital format in a GE CardioSoft database (v. 6.5, GE Healthcare) and exported in XML format to ELECTROPRES.

ELECTROPRES is an online system developed for the detection of LVH in the ECG using the HES® program, approved by the U.S. Food and Drug Administration, which has proved to be highly accurate.[20,21,23] In addition to the standard ECG criteria for LVH, the program utilizes 3 diagnostic algorithms composed of a combination of different standard criteria in such a way that they are considered to be diagnostic if one or more of the criteria included in them was met: algorithm A, comprising the criteria recommended by the guidelines for hypertension of the European Society of Cardiology (LVH according to the Sokolow-Lyon voltage criterion or the Cornell voltage-duration product [VDP]); algorithm B (LVH according to the Sokolow-Lyon voltage criterion, the Cornell voltage criterion, the Sokolow-Lyon voltage criterion, or

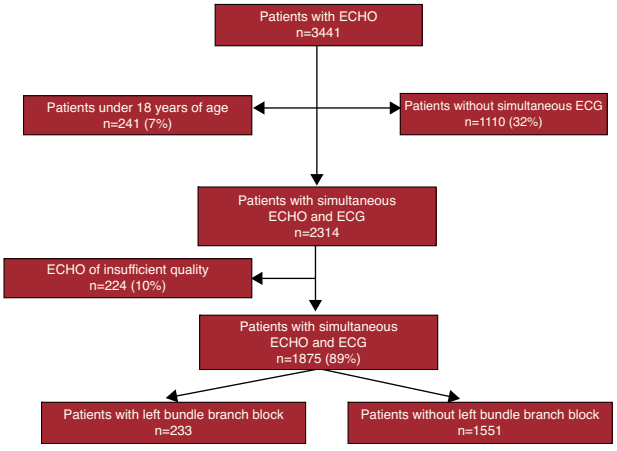

Figure 1. Flow chart depicting the steps for the inclusion of patients in the study. ECG, electrocardiogram; ECHO, echocardiogram.

Table 1
Electrocardiographic Criteria for Left Ventricular Hypertrophy

Criteria	Formula	Criteria for LVH
Sokolow-Lyon voltage (mV)	S (V1)+max (R_{V5} or R_{V6})	≥3.5 mV
Cornell voltage (mV)	$R_{aVL}+S_{V3}$	≥2.8 mV (men), ≥2 mV (women)
R6:R5	R_{V6}/R_{V5}	>1
R_{aVL} (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
12-Lead QRS (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	
Sokolow VDP (ms×mV)	S_{V1}+max ($R_{V5}\times R_{V6}$)×QRS duration	>367.4 mV ms (men), >322.4 mV ms (women)
Cornell VDP	Men: $R_{aVL}+S_{V3}$×QRS duration	>244 mV ms
	Women: ($R_{aVL}+S_{V3}$+0.6 mV)×QRS duration	
Gubner-Ungerleider VDP	Gubner×QRS duration	>207 mV ms
R_{aVL} VDP	R_{aVL}×QRS duration	>103 mV ms
12-Lead QRS VDP	12-Lead QRS area	>2348.8 mV ms (men), >1960.7 mV ms (women)
Dalfó	$R_{aVL}+S_{V3}$	>1.6 mV (men), >1.4 mV (women)
Perugia	*a)* $S_{V3}+R_{aVL}$>2.4 mV (men) or >2 mV (women), or	Any of those 3 variables
	b) Left ventricular pressure overload pattern, or	
	c) Romhilt-Estes score ≥5	
Romhilt-Estes (points)		>4 or >5 points

HES®, Hannover ECG System®; LVH, left ventricular hypertrophy; R_{aVL}, R wave in lead aVL; VDP, voltage-duration product.

the Cornell voltage criterion); and algorithm C (LVH according to the Sokolow-Lyon voltage criterion, the Cornell voltage criterion, the Gubner-Ungerleider criterion, the Lewis index, the RV6:RV5 ratio, the R wave in lead aVL [R_{aVL}], 12-lead QRS, the Sokolow-Lyon VDP, the Cornell VDP, the 12-lead QRS VDP, the Gubner-Ungerleider VDP, or the R_{aVL} VDP) (Table 1).[24,25] Some electrocardiographic criteria, such as those of Sokolow-Lyon, Cornell, and Gubner-Ungerleider, the R_{aVL}, and the sum of the 12-lead QRS, were studied not only in the voltage, but in the VDP as well.

Echocardiogram

Simultaneously with the ECG, the patients underwent a 2D color Doppler echocardiogram performed with a Vivid 4 echocardiograph from General Electric, equipped with a 2.5 MHz transducer, according to the standard technique. All the studies were carried out by the same cardiologist (LRP). Those images that allowed for optimal visualization were selected for reading. The measurements were made from long-axis parasternal views displayed on the screen over the 2D end-diastolic image, according to the standard technique, making sure to take the most perpendicular distance from the different structures. The left ventricular (LV) mass was calculated[26,27]:

$$\text{LV mass(g)} = 0.8(1.04[\text{LVEDD}+\text{LVPW}+\text{IVSd}]^3-[\text{LVEDD}]^3+0.6$$

Where LVEDD is the LV end-diastolic diameter; LVPWd, the LV posterior wall end-diastolic thickness; and IVSd, the interventricular septal end-diastolic thickness. LVH was considered to be present when the LV mass index was greater than 134 g/m^2 (men) or greater than 110 g/m^2 (women).[28]

Statistical Analysis

We constructed a 2×2 table with the cutoff points for LVH and for each ECG criterion, calculating the sensitivity, specificity, predictive values, likelihood ratios, pretest odds ratios and probability of a positive and negative test result, as well as posttest odds ratios and the probability of a positive and negative test result, according to the standard definitions. A χ^2 test was employed to analyze the differences between the ECG criteria and the ROC (receiver operating characteristic) curves to complete the analysis of the diagnostic accuracy of the different ECG criteria using standard methods. Likewise, we calculated the Pearson correlation coefficients between the LV mass index and the voltage of the different ECG criteria, with the exception of those of the R_{aVL}, the R_{aVL} VDP, Romhilt-Estes, and Perugia, for which the Spearman correlation coefficients were calculated as these variables did not follow a normal distribution.

In the 2-tailed tests, a *P* value less than .05 was considered to indicate statistical significance. The calculations were performed with the SPSS v. 17.0 statistical software package.

An estimation of the intraobserver variability was carried out by having an observer measure twice, in a masked fashion, 3 dimensions in 15 echocardiograms of randomly selected patients (a total of 45 measurements) with a 2-week interval. The standard deviation of the differences between the first and second measurements was calculated and was expressed as the percentage of the mean value.

RESULTS

Baseline Characteristics

Table 2 shows the baseline characteristics of the patients. The group of patients with LBBB is made up of 124 men (53.2%) and 109 women (46.8%), with a mean age of 67.1±12.6 years. The most common diagnoses were the suspicion or presence of heart disease (n=160; 79.3%), hypertension (n=145; 62.2%), and arrhythmias (supraventricular or ventricular premature complexes and atrial fibrillation) (n=160; 68.7%). Most of them (n=201; 86.3%) had or had

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

Variable	LBBB (n=233)	Without LBBB or MI (n=1561)	*P*
Age, years	67.1±12.6	53.6±15.5	<.0010
Men, %	53.2	55.2	.8872
Hypertension, %	62.3	51.8	.0030
Body weight, kg	86.7±83.4	85.5±67.8	.8072
Height, cm	165.7±9.3	168.8±9.2	.0010
Body mass index	31.3±27.6	30.3±27.2	.6014
LV mass index, g/m^2	100.2±31.7	82.7±41.4	<.0010
IVS end-diastolic thickness, mm	11.9±3.3	10.8±2.7	<.0010
LV end-diastolic diameter, mm	45.2±7.1	43±5.7	<.0010
Posterior wall end-diastolic thickness, mm	10.5±1.9	9.9±2.8	<.0010
Sokolow-Lyon voltage, mV	2.01±0.88	1.99±0.73	1
Cornell voltage, mV	1.48±0.79	1.13±0.59	<.0010
R6:R5	0.93±0.48	0.85±0.19	<.0010
R_{aVL}, mV	0.56±0.36	0.51±0.34	.0410
Gubner-Ungerleider, mV	1.11±0.65	1.10±0.58	.8092
Lewis, mV	0.79±0.84	0.71±0.80	<.0010
12-Lead QRS, mV	13.4±3.7	13.1±3.3	.2030
Sokolow VDP, ms, mV	212.8±116.1	193.3±80.7	.0140
Cornell VDP	194.3±127.8	137.2±70	<.0010
Gubner VDP	120.5±86.2	107.3±63.3	.0049
R_{aVL} VDP	61.5±47.5	50.1±36.6	.0030
12-Lead QRS VDP	1443.9±584.1	1293.9±438.9	.0020
Dalfó	1.48±0.79	1.13±0.59	<.0010
Perugia	0.30±0.46	0.08±0.28	<.0010
Romhilt-Estes, points	2.03±2.14	1.19±1.32	<.0010

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

had paroxysmal or permanent atrial fibrillation, according to the medical record or the ECG.

In the group of patients without LBBB or myocardial infarction, there were 861 men (55.2%) and 700 women (44.8%), with a mean age of 53.6±15.5 years. The most common diagnoses were the suspicion or presence of heart disease (n=41; 2.6%), hypertension (n=810; 51.9%), and arrhythmias (supraventricular or ventricular premature complexes and atrial fibrillation) (n=138; 8.8%). Paroxysmal or permanent atrial fibrillation was observed in 138 (8.8%) of these patients.

The patients with LBBB were older, with a higher body mass index and a higher incidence of hypertension and atrial fibrillation.

The intraobserver variability in the echocardiographic measurements was 3%.

Correlation Between Electrocardiographic Voltages and Left Ventricular Mass

Figure 2 shows the correlation coefficients between LV mass and the ECG criteria. The 12-lead QRS VDP exhibited the highest correlation (r=0.391) with LV mass index, followed by the Cornell criterion (r=0.374) and the Dalfó criterion (r=0.374). In the patients who did not have LBBB or myocardial infarction, the correlation with the LV mass index was higher for the R_{aVL} VDP (r=0.695) and the R_{aVL} (r=0.664) and lower for the RV6:RV5 ratio (r=0.011). The greatest differences in the correlation with LV mass between the patients with and without LBBB were observed in the R_{aVL}, the R_{aVL} VDP, and the Lewis index.

Sensitivity, Specificity, and Likelihood Ratios

The incidence of LVH was 60.5%. Table 3 shows the diagnostic utility of all the ECG criteria in the patients with LBBB.

In general, in the patients with LBBB, the sensitivities were low or intermediate and ranged from 6.4% for the Gubner-Ungerleider voltage criterion to 70.9% for algorithm C. The specificities were high and ranged between 57.6% for algorithm C and 100% for the Gubner-Ungerleider voltage criterion. The positive likelihood ratios ranged from 1.33 for a Romhilt-Estes score over 4 to 4.89 for the Sokolow-Lyon voltage criterion, and the negative likelihood ratios from 0.50 for algorithm C to 0.98 for a Romhilt-Estes score over 4. In our population, these likelihood ratios produced a negative posttest probability of LVH ranging from 43.6% for algorithm C to 60.0% for a Romhilt-Estes score over 4, and a positive posttest probability of LVH ranging from 71.9% for algorithm C to 88.3% for algorithm A.

The incidence of LVH in the patients who did not have LBBB or myocardial infarction was 37.8%. Table 4 shows the diagnostic utility of all of the ECG criteria analyzed in the patients without LBBB. In general, the sensitivities were low and ranged from 3.5% for the Sokolow-Lyon voltage criterion to 53.1% for algorithm C. The specificities were high, between

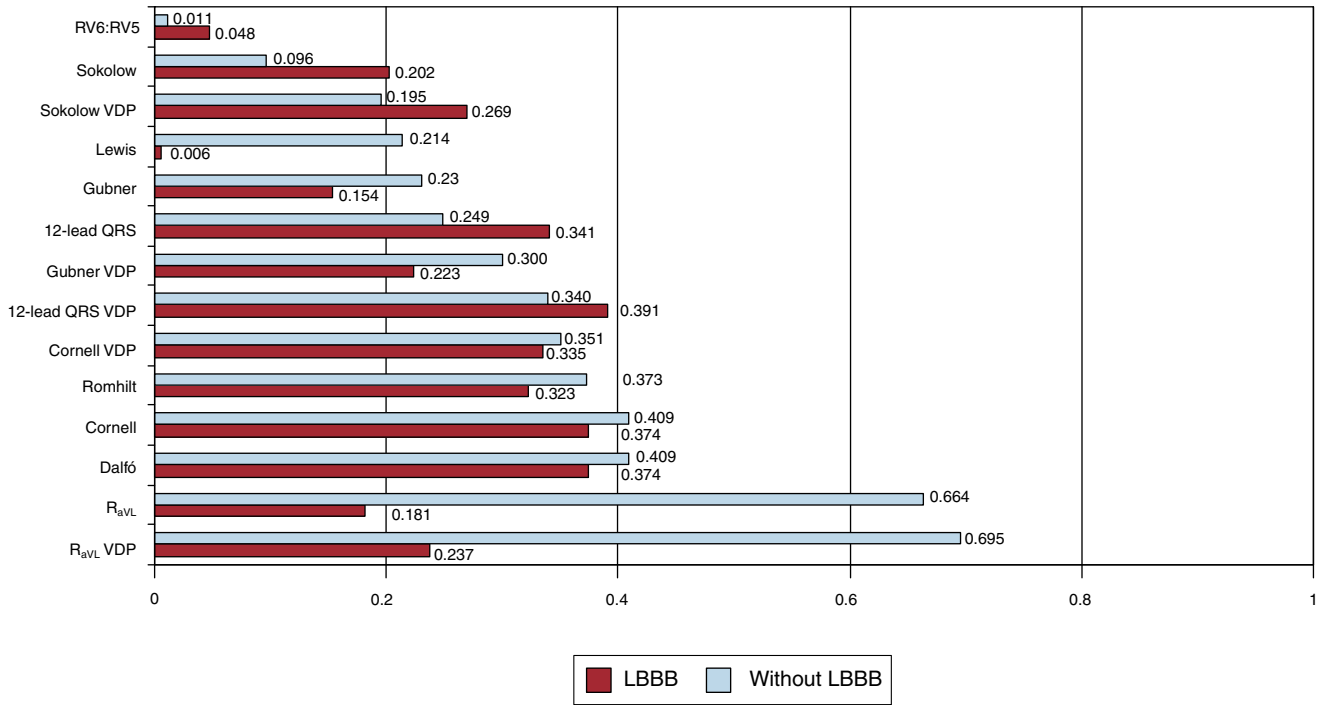

Figure 2. Correlation coefficients between the left ventricular mass index as measured in the echocardiogram and the electrocardiographic criteria considered in this study in patients with left bundle branch block and in those who did not have left bundle branch block or myocardial infarction. The correlation coefficients are shown at the end of each row. LBBB, left bundle branch block; R_{aVL}, R wave in lead aVL; VDP, voltage-duration product.

70.7% for algorithm C and 99.3% for the Cornell voltage criterion. The positive likelihood ratios ranged from 1.28 for the Sokolow-Lyon voltage criterion to 8.73 for the Cornell voltage criterion, and the negative likelihood ratios from 0.66 for algorithm C to 0.99 for the Sokolow-Lyon voltage criterion. In our population, these likelihood ratios resulted in a negative posttest probability ranging from 22.8% for algorithm C to 30.6% for the Sokolow-Lyon voltage criterion, and a positive posttest probability of LVH

Table 3
Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value, Positive Likelihood Ratio, Negative Likelihood Ratio, Incidence, Negative Posttest Probability, and Positive Posttest Probability of All the Electrocardiographic Criteria Considered in Patients With Left Bundle Branch Block (n=233)

Criteria	SEN (%)±95%CI	SPEC (%)±95%CI	PPV (%)±95%CI	NPV (%)±95%CI	LR+	LR–	Incidence, %	PTP–	PTP+
Algorithm A	37.6±8	92.4±5.4	88.3±8.1	49.1±7.5	4.94	0.68	60.5	50.9	88.3
Algorithm B	38.3±8	90.2±6.1	85.7±8.6	48.2±7.5	3.91	0.68		51.2	85.7
Algorithm C	70.9±7.5	57.6±10.1	71.9±7.5	56.4±10	1.67	0.50		43.6	71.9
Sokolow-Lyon voltage	10.6±5.1	97.8±3	88.2±15.3	41.7±6.6	4.89	0.91		58.3	88.2
Cornell voltage	19.1±6.5	95.7±4.2	87.1±11.8	43.6±6.8	4.40	0.85		56.4	87.1
R6:R5	21.3±6.8	87±6.9	71.4±13.7	41.9±7	1.63	0.91		58.1	71.4
R_{aVL}	8.5±4.6	97.8±3	85.7±18.3	41.1±6.5	3.91	0.94		58.9	85.7
Gubner-Ungerleider	6.4±4	100±0	100±0	41.1±6.4	Infinite	0.94		58.9	Infinite
Lewis	15.6±6	95.7±4.2	84.6±13.9	42.5±6.7	3.59	0.88		57.5	84.6
12-Lead QRS	10.6±5.1	96.7±3.6	83.3±17.2	41.4±6.6	3.26	0.92		58.6	83.3
HES®	25.5±7.2	89.1±6.4	78.3±11.9	43.9±7.1	2.35	0.84		56.2	78.3
Sokolow VDP	16.3±6.1	93.5±5.1	79.3±14.7	42.2±6.9	2.50	0.90		59.8	79.3
Cornell VDP	34±7.8	92.4±5.4	87.3±8.8	47.8±7.3	4.47	0.71		52.3	87.3
Gubner VDP	17.7±6.3	94.6±4.6	83.3±13.3	42.9±6.8	3.26	0.87		57.1	83.3
R_{aVL} VDP	24.1±7.1	93.5±5.1	85±11.1	44.6±7	3.70	0.81		55.4	85
12-Lead QRS VDP	29.8±7.6	91.3±5.8	84±10.2	45.9±7.2	3.34	0.77		54.1	84
Dalfó	55.3±8.2	79.4±8.3	80.4±7.9	53.7±8.4	2.68	0.56		46.3	80.4
Perugia	39.7±8.1	83.7±7.6	78.9±9.5	47.7±7.7	2.44	0.72		52.5	78.9
Romhilt-Estes >4	8.5±4.6	93.5±5.1	66.7±21.8	40±6.6	1.33	0.98		60	66.7
Romhilt-Estes >5	17.7±6.3	92.4±5.4	78.1±14.3	42.3±6.8	2.33	0.89		57.7	78.1

95%CI, 95% confidence interval; HES®, Hannover ECG System®; LR–, negative likelihood ratio; LR+, positive likelihood ratio; NPV, negative predictive value; PPV, positive predictive value; PTP–, negative posttest probability; PTP+, positive posttest probability; R_{aVL}, R wave in lead aVL; SEN, sensitivity; SPEC, specificity; VDP, voltage-duration product.

Table 4
Sensitivity, Specificity, Positive Predictive Value, Negative Predictive Value, Positive Likelihood Ratio, Negative Likelihood Ratio, Incidence, Negative Posttest Probability, and Positive Posttest Probability of All the Electrocardiographic Criteria Considered in Patients Without Left Bundle Branch Block (n=1561)

Criteria	SEN (%)±95%CI	SPEC (%)±95%CI	PPV (%)±95%CI	NPV (%)±95%CI	LR+	LR–	Incidence, %	PTP–	PTP+
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	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±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	98.6±0.7	62.5±15	70.1±2.3	3.75	0.96		62.5	29.9
Lewis	19±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±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	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	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	67.8±9.8	71.4±2.3	4.75	0.90		67.2	28.6
Gubner VDP	13.3±3	95.6±0.2	57.1±9.2	71.3±2.3	3	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	92.2±1.6	42.1±8	70.4±2.4	1.64	0.95		42.1	29.6
Dalfó	37.1±4.3	85.4±2.1	53±5.3	75.4±2.4	2.54	0.74		54	24.7
Perugia	16±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±2.1	97.6±0.9	52.7±13.2	70.1±2.3	2.51	0.96		52.7	30
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

95%CI, 95% confidence interval; HES®, Hannover ECG System®; LR–, negative likelihood ratio; LR+, positive likelihood ratio; NPV, negative predictive value; PPV, positive predictive value; PTP–, negative posttest probability; PTP+, positive posttest probability; R_{aVL}, R wave in lead aVL; SEN, sensitivity; SPEC, specificity; VDP, voltage-duration product.

from 36.2% for the Sokolow-Lyon voltage criterion to 79.5% for the Cornell voltage criterion.

All of the ECG criteria, except for the R_{aVL}, were significantly more sensitive in the patients with LBBB (Table 5). On the other hand, only 3 ECG criteria (RV6:RV5, Perugia, and a Rohmhilt-Estes score over 5) were significantly less specific in the patients with LBBB.

Comparison of the Voltage Criteria With the Voltage-Duration Product Criteria

The ECG criteria for the VDP had a slightly higher sensitivity and a somewhat lower specificity than the voltage criteria, although the diagnostic accuracy did not improve significantly (Fig. 3).

Table 5
Comparisons Between the Sensitivities and Specificities of the Two Groups of Patients (With and Without Left Bundle Branch Block)

	Sensitivity, %			Specificity, %		
Criteria	Without LBBB (n=1561)	LBBB (n=233)	*P*	Without LBBB (n=1561)	LBBB (n=233)	*P*
Algorithm A	13.9±3.1	37.6±8	.0002	95.7±1.2	92.4±5.4	.3717
Algorithm B	14.8±3.2	38.3±8	.0004	93.8±1.4	90.2±6.1	.4343
Algorithm C	53.1±4.5	70.9±7.5	.0133	70.7±2.7	57.6±10.1	.0762
Sokolow-Lyon voltage	3.5±1.6	10.6±5.1	.0172	96.2±1	97.8±3	.6785
Cornell voltage	6.5±2.2	19.1±6.5	.0207	99.3±0.5	95.7±4.2	.3650
R6:R5	6.5±2.2	21.3±6.8	.0081	95.5±1.2	87±6.9	.0425
R_{aVL}	10±2.7	8.5±0.6	.8094	96.6±1.1	97.8±3	.6506
Gubner-Ungerleider	5.2±2	6.4±4	.7564	98.6±0.7	100±0	.3161
Lewis	19±3.5	15.6±6	.5723	93.4±1.5	95.7±4.2	.5356
12-Lead QRS	6.5±2.2	10.6±5.1	.4585	96±1.2	96.7±3.6	.7004
HES®	9.2±2.9	25.5±7.2	.0029	97.2±1	89.1±6.4	.0524
Sokolow VDP	5.2±2.1	16.3±6.1	.0211	96.9±1	93.5±0.1	.4951
Cornell VDP	12.3±2.9	34±7.8	.0004	97.4±1	92.4±5.4	.2147
Gubner VDP	13.3±3	17.7±6.3	.4345	95.6±1.2	94.6±0.6	.7330
R_{aVL} VDP	15.2±3.2	24.1±7.1	.1534	95.1±1.3	93.5±5.1	.7564
12-Lead QRS VDP	12.7±3	29.8±0.6	.0059	92.2±0.6	91.3±5.8	.7998
Dalfó	37.1±4.3	55.3±8.2	.0159	85.4±0.1	79.4±8.3	.3574
Perugia	16±3.3	39.7±8.1	.0003	95.1±1.3	83.7±7.6	.0211
Romhilt-Estes >4	6±2.1	8.5±4.6	.5913	97.6±0.9	93.5±5.1	.2790
Romhilt-Estes >5	6.3±0.2	17.7±63	.0157	98.7±0.7	92.4±5.4	.0407

HES®, Hannover ECG System®; LBBB, left bundle branch block; R_{aVL}, R wave in lead aVL; VDP, voltage-duration product.

AUC

Variables	AUC	Standard error[a]	Asymptotic significance[b]	Asymptotic 95%CI	
				Lower limit	Upper limit
ECG_dCornell	0.699	0.034	<0.001	0.631	0.766
ECG_dCornellVDP	0.717	0.034	<0.001	0.651	0.783
ECG_dSokolow	0.515	0.038	0.699	0.441	0.589
ECG_dSokolowVDP	0.565	0.037	0.094	0.491	0.638
ECG_dSum12-leadQRS	0.652	0.036	<0.001	0.582	0.723
ECG_dSum12-leadQRSVDP	0.685	0.035	<0.001	0.617	0.754
ECG_dRaVL	0.632	0.037	0.001	0.560	0.704
ECG_dR$_{aVL}$VDP	0.651	0.036	<0.001	0.581	0.722
ECG_dLewis	0.575	0.038	0.052	0.502	0.649
ECG_dGubner	0.586	0.037	0.026	0.513	0.660
ECG_dGubnerVDP	0.621	0.037	0.002	0.549	0.693
ECG_dDalfó	0.699	0.034	<0.001	0.631	0.766
ECG_dRV6RV5	0.501	0.038	0.987	0.426	0.575

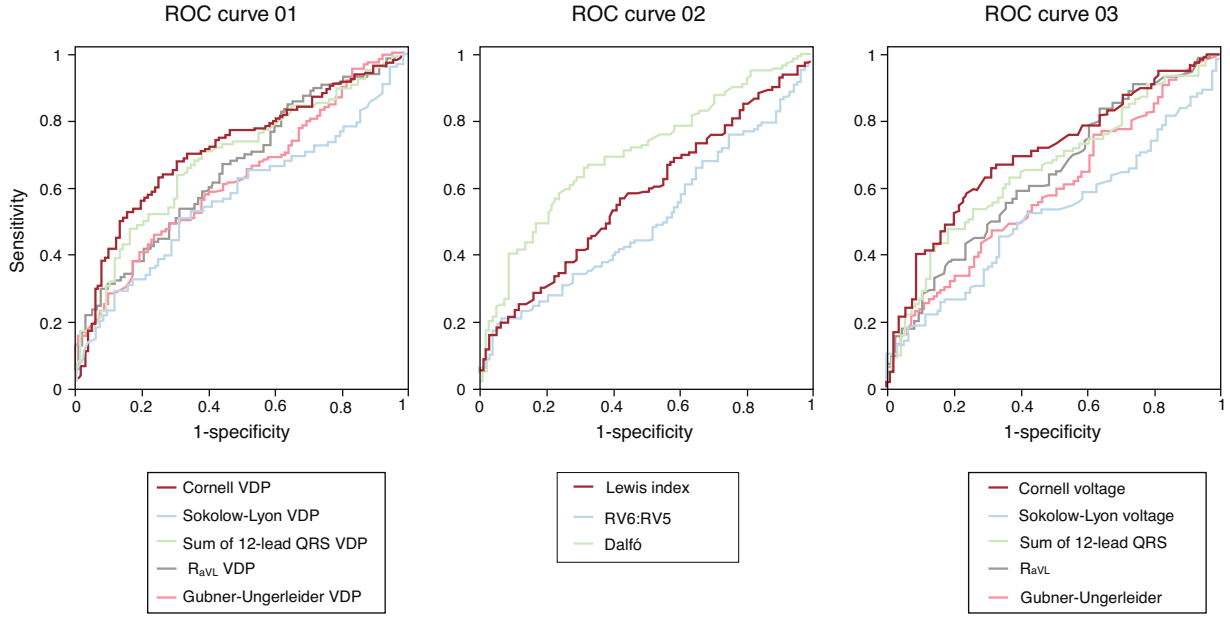

Figure 3. Receiver operating characteristic curves of all the electrocardiographic criteria, excluding those of Perugia and Romhilt-Estes, which are expressed as scores rather than continuous variables. AUC, area under the curve; 95%CI, 95% confidence interval; ECG, electrocardiogram; LBBB, left bundle branch block; R_{aVL}, R wave in lead aVL; ROC, receiver operating characteristic; VDP, voltage-duration product.

DISCUSSION

This study demonstrates that the presence of LBBB does not limit the accuracy of the ECG in the diagnosis of LVH, at least not when the interpretation of the ECG is computer-assisted. The computer can improve the use of the ECG in the diagnosis of LVH as it enables an accurate measurement and the simultaneous evaluation of different criteria.

The incidence of LVH is higher in the patients with LBBB (60.5% vs 35.1%), which indicates that the increase in LV mass contributes to the development of LBBB secondary to ventricular fibrosis and/or damage to the conduction tissue. This may explain the high incidence of atrial fibrillation observed. The prevalence of LVH found in different studies has depended on the clinical scenario considered and the criteria utilized, and has been reported to be between 15% and 73% in studies using the same criteria for LVH that we did.[29] The presence of LBBB has been considered to be an indicator of the presence of LVH,[30] which could explain its high incidence in our LBBB patients, a circumstance similar to that reported by other authors.[10,14,31]

The ECG is utilized for the diagnosis of LVH despite its low sensitivity.[32–34] Although its high specificity could indicate that it is a "SpPIn" (specific, positive, in) technique in the diagnosis of LVH, meaning that its positivity would establish the definitive

diagnosis, its low sensitivity limits its utility.[35] Moreover, the presence of LBBB appears to further restrict the diagnostic accuracy of ECG for LVH.[10–13] As a consequence of all these factors, some authors have concluded that electrocardiographic criteria are inadequate for the diagnosis of LVH and have pointed out the need to develop more efficient algorithms.[20]

Despite these limitations, an ECG is performed in many patients for different reasons. Thus, it would seem reasonable to employ this technique to evaluate the presence of LVH. In addition, its low cost and availability, as well as the significant prognostic information it provides,[3,36,37] are also important reasons for proposing ECG as a frontline diagnostic technique in hypertension.[4,5] The ECG provides information on the LV mass and chamber remodeling, in addition to a simple increase in voltage.[38] Echocardiography is considered to be the most useful tool for the diagnosis of LVH in hypertension, although its higher cost and the fact that it is not as widely available limit its use.[39]

Our data indicate that the ECG criteria for LVH exhibit a high specificity but a low sensitivity for the detection of the majority of the patients with LVH when they have LBBB. However, some criteria and algorithms can reach a sensitivity of 40% to 70%, which enables the detection of a significant number of cases of LVH. It should be pointed out that certain ECG criteria, such as the Gubner-Ungerleider voltage, have a high positive likelihood ratio, which makes it possible to establish the diagnosis of LVH when they are positive. In contrast, the lowest likelihood ratios found do not enable us to rule out the presence of LVH, although they reduce the posttest probability to 41% in this population, in which the incidence of LVH is 61%.

Although there are differences in the correlation between the ECG criteria and the LV mass index, the diagnostic accuracy of the ECG does not change significantly in LBBB. On the other hand, the compound criteria show a significant increase in sensitivity in patients with LBBB, although no change is observed in specificity, a circumstance that could be due to the fact that these criteria lend fuller consideration to the vector changes observed in LBBB.

Different criteria have been proposed to overcome the limitation of the ECG in the diagnosis of LVH. Among them, VDP have been clinically validated. Some authors have observed that these criteria have a higher sensitivity,[40] a finding that has not been confirmed by others[41]; moreover, there is no information concerning their utility in LBBB. We found that the VDP resulted in a slight increase in sensitivity, with a minor decrease in specificity. Further research will be required to improve the accuracy of the ECG for the diagnosis of LVH and, in addition to the cardiac electrical signal, certain epidemiological characteristics should probably be taken into account as well.[42]

The use of the computer in the interpretation of the ECG makes it possible to obtain greater accuracy in the measurement of the QRS complexes in LBBB, an improvement that is difficult to achieve manually due to QRS slurring. In the clinical setting, the variability in the measurement of ECG voltage is high, with poor agreement in the diagnosis of LVH.[14] Web-based computer-assisted diagnosis is feasible and is especially useful in primary care.[43] Computer-assisted methods have been shown to have a diagnostic capability similar to that of the most competent cardiologists.[15,16,21,43,44] Our data demonstrate that the use of the computer can help to overcome the traditional limitations of the ECG.

Echocardiographic measurements are obtained from the 2D image, a method that may be less accurate than that based on the M-mode recording. Nevertheless, the technique employed was optimized to minimize errors and, in fact, we obtained an incidence of LVH comparable to that observed in other similar samples.[29–31] Moreover, this technique is routinely used in the clinical setting, a circumstance that increases the possibility of extrapolating the results.

CONCLUSIONS

The presence of LBBB does not limit the diagnostic accuracy of the ECG for the diagnosis of LVH, at least not when a computer-assisted diagnostic system is employed. This allows the implementation of more efficient algorithms. Among the criteria considered, the Gubner-Ungerleider voltage is that which has exhibited the highest positive likelihood ratio for the diagnosis of LVH in the presence of LBBB.

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CONFLICT OF INTERESTS

None declared.

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