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Pegueró–Lo Presti criteria modified by body surface area for the electrocardiographic diagnosis of left ventricular hypertrophy in Thai patients

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Abstract

Background: Several electrocardiographic (ECG) criteria are used to diagnose left ventricular hypertrophy (LVH); however, they have low sensitivity.

Objective: To assess the sensitivity of LVH diagnosis using Pegueró–Lo Presti criteria modified by body surface area (BSA).

Methods: This study used retrospective data from 9,438 patients who attended the Central Chest Institute of Thailand from January 2017 to December 2017 with available echocardiography, and who were categorized into those with and without LVH to determine diagnostic accuracy. We randomly selected 317 patients after excluding others based on various conditions. The left ventricular mass of the 317 patients was estimated using echocardiography. Pegueró–Lo Presti criteria were modified by dividing original criteria by BSA. The accuracy of the modified criteria was compared with that of the original Pegueró–Lo Presti, Sokolow–Lyon, and Cornell voltage criteria. A McNemar test was used to determine the agreement of all ECG criteria examined with LV mass index. The area under a receiver operating characteristic curve (AUC) was used to assess the performance of the criteria.

Results: LVH was diagnosed in 164 of the 317 patients using echocardiography. The sensitivity of modified Pegueró–Lo Presti criteria was 50.6% (95% confidence interval [CI] 42.7% to 58.5%), and specificity was 88.2% (95% CI 82.0% to 92.9%), with an AUC of 0.67 (95% CI 0.61–0.73).

Conclusions: Pegueró–Lo Presti criteria modified by dividing them by BSA can improve sensitivity with acceptable specificity for the diagnosis of LVH compared with other ECG criteria examined, at least in selected Thai patients. The modified Pegueró–Lo Presti criteria have accuracy similar to that for the original criteria.

Keywords: hypertrophy; left ventricular; left ventricular dysfunction; point-of-care testing; predictive value of tests; sensitivity and specificity

Patients with left ventricular hypertrophy (LVH) are common in clinical practice, with a prevalence of 28%–62% in the elderly Thai population [1]. The prevalence of LVH is associated with hypertension, advanced age, obesity, ancestry, and sex [1, 2]. The regression of electrocardiographic (ECG)

LVH can reduce cardiovascular risk, whereas serial worsening imposes increased cardiovascular risk [3].

ECG criteria have been compared with echocardiographic criteria to diagnose LVH [4, 5]. When LVH is diagnosed using echocardiography, various methods are used to index

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LV mass, including the cube, truncated ellipsoid, area-length, and 3D-based formulas, which allow comparisons between individuals with different body sizes [6]. However, echocardiography is not recommended for routine screening for LVH because evidence for an improved cost-benefit ratio is lacking. An ECG is a simpler method with a lower cost for screening for LVH in the general population, especially in patients at risk for LVH. ECG criteria for diagnosis of LVH usually have high specificity, but low sensitivity [6], such as Sokolow-Lyon voltage criteria, which only have 22% sensitivity, but specificity as high as 100%. By contrast, Cornell voltage criteria have higher sensitivity (42%) and specificity (96%) [7]. Voltage-duration products calculated using the Cornell product (multiplying Cornell voltage by QRS duration) and 12-lead QRS sum (multiplying the 12-lead sum of voltage by QRS duration) improved the sensitivity to 37% (vs. Cornell voltage 28%) and 50% (vs. 12-lead voltage 43%), respectively [8, 9]. However, several factors influence the sensitivity for LVH diagnosis. The sensitivity is lower in female patients, those of younger age, those who smoke, and obese individuals [10, 11].

Previously accepted LVH ECG criteria have been used to screen patients at risk of LVH, such as those with hypertension or aortic stenosis. Nevertheless, the sensitivity of the aforementioned criteria for LVH screening remains low. The low sensitivity of these criteria means that even if no LVH is determined by ECG, LVH cannot be excluded. Because variation in body size may be a problem for the sensitivity of LVH ECG criteria, the inclusion of a factor for body surface area (BSA) is hypothesized to improve the ECG voltage criteria [6].

An ECG study by Peguero et al. [12] showed that the sum of the depth of the deepest S wave in any single lead and the depth of the S wave in lead V₄ ($S_D + SV_4$) could improve sensitivity to 62% for LVH diagnosis in a small cohort of American patients with a diagnosis of hypertensive crisis and an equal number with normal blood pressure at hospital admission, with a specificity of 90%. The LVH ECG criteria proposed by Peguero et al. [12] (Peguero-Lo Presti criteria) have higher sensitivity for LVH diagnosis than previously used ECG criteria. However, the Peguero-Lo Presti criteria and other previously accepted LVH ECG criteria do not include body weight, body mass index (BMI), or BSA. Moreover, there is limited sensitivity in Asian patients compared with patients of European ancestry, although modified sex-specific cut-offs may help to improve sensitivity while preserving specificity [13].

Patients with higher body weight, BMI, or BSA may have a smaller QRS. This is a common problem in the voltage ECG criteria for the diagnosis of LVH. Therefore, we modified the original Peguero-Lo Presti criteria by dividing by BSA and hypothesized that this would improve their sensitivity for LVH diagnosis in patients with Thai ancestry.

Methods

The present study was approved by the Human Research Ethics Committee of the Central Chest Institute of Thailand (approval No. 117/2561), was conducted in accordance with the principles outlined in the contemporary revision of the Declaration of Helsinki of 1964 (World Medical Association) incorporating the most recent (2013) and earlier amendments, and was reported according to the STARD 2015 list of essential items for reporting diagnostic accuracy studies [14]. This study of diagnostic accuracy used retrospective data from 9,438 patients who attended the Central Chest Institute of Thailand with available echocardiography, and electrocardiography (ECG) obtained from January 2017 to December 2017 and data were stored in the Institute database. Data from 4,026 patients (42.7%) were excluded because ECG showed right ventricular hypertrophy (RVH), complete left bundle branch block, complete right bundle branch block, left anterior fascicular block, left posterior fascicular block, ventricular paced rhythm, second degree atrioventricular block (AVB), complete AV block, patients with pulmonary hypertension, hypertrophic cardiomyopathy, moderate to large pericardial effusion, pneumothorax, pleural effusion, or myocardial infarction within 1 month before echocardiography or ECG recording, LV systolic dysfunction, and pregnancy. After web-based random sampling (<https://www.sealedenvelope.com/simple-randomiser/v1/lists>), data from 317 patients were included (**Figure 1**).

The LV mass of all 317 patients whose data were included in the present study was estimated using echocardiography and assessed using the cube formula specified by 2015 recommendations for cardiac chamber quantification by echocardiography in adults from the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI) [6]. Data from patients with a consensus of echocardiographic LVH by 2 cardiologists were included independently. The ECGs within 6 months of echocardiography were reviewed for all patients who were categorized as patients with and without LVH. The study by Peguero et al. [12] showed an average BSA 1.87 m² and an $S_D + SV_4 \geq 2.3$ mV for female patients and ≥ 2.8 mV for male patients diagnosed as LVH. Peguero-Lo Presti criteria were modified by dividing the criteria by BSA; so, $S_D + SV_4$ was indexed according to $BSA \geq 1.5$ mV/m² for male patients and ≥ 1.2 mV/m² for female patients and considered a diagnosis for LVH. Two cardiologists (WL and AP) assessed ECG criteria independently, including modified Peguero-Lo Presti criteria, Peguero-Lo Presti criteria, Cornell voltage criteria, and Sokolow-Lyon criteria for all patients. There was a high reproducibility as reflected by an intraclass correlation >0.90 for all ECG criteria.

Figure 1. Flow chart for sampling of patients whose data were included in the study. Randomized sampling was web-based (<https://www.sealedenvelope.com/simple-randomiser/v1/lists>). AVB, atrioventricular block; CXR, chest X-ray imaging; CRBB, complete right bundle branch block; CLBB, complete left bundle branch block; ECG, electrocardiography; HCM, hypertrophic cardiomyopathy; LV, left ventricular; LVH, left ventricular hypertrophy; LAFB, left anterior fascicular block; LPFB, left posterior fascicular block; MI, myocardial infarction; RV, right ventricular; RVH, right ventricular hypertrophy.

Echocardiographic analysis

Transthoracic echocardiography had been performed using EPIQ 5 or 7, and IE33 cardiovascular ultrasound systems (Philips). Patients had lain in a partial left lateral decubitus position under stable hemodynamic conditions. Interventricular septum thickness, LV internal diameter, and

inferolateral wall thickness had been acquired at end-diastole using a parasternal approach, perpendicular to the LV long axis. LV mass was calculated using a linear method (cube formula), either in M-mode or 2D tracing, and indexed according to BSA. LVH was diagnosed if LV mass index was $>115 \text{ g/m}^2$ in male patients and $>95 \text{ g/m}^2$ in female patients [5].

ECG analysis

Standard 12-lead ECGs had been performed in all patients with normal calibration (10 mm/mV) and speed (25 mm/s). The ECG criteria used to diagnose LVH were:

1. Peguero–Lo Presti criteria using a summation of the amplitude of the deepest S wave in any single lead (S_D) and amplitude of S wave in V_4 (SV_4). LVH is diagnosed when $S_D + SV_4 \geq 2.8$ mV in male patients or ≥ 2.3 mV in female patients [12].
2. Modified Peguero–Lo Presti criteria using $S_D + SV_4$ from Peguero–Lo Presti criteria were indexed according to BSA. LVH was diagnosed when $S_D + SV_4$ were indexed according to $BSA \geq 1.5$ mV/m² in male patients or ≥ 1.2 mV/m² in female patients.
3. Sokolow–Lyon voltage criteria using a summation of the amplitude of the S wave in V_1 and the amplitude of R wave in V_5 or V_6 ($SV_1 + RV_5$ or RV_6) or the amplitude of the R wave in aVL (RaVL). LVH was diagnosed when $SV_1 + RV_5$ or $RV_6 \geq 3.5$ mV or $RaVL \geq 1.1$ mV [15, 16].
4. Cornell voltage criteria using a summation of the amplitude of the S wave in V_3 and the amplitude of the R wave in aVL ($SV_3 + RaVL$). LVH was diagnosed with $SV_3 + RaVL > 2.8$ mV in male patients or > 2.0 mV in female patients [7, 15, 17].

Statistical analysis

We specified 0.05 for a type I error and estimated 0.57 as a proportion for sensitivity (modified from Peguero et al. [12]). An acceptable error was considered as 18% of sensitivity. The estimated prevalence of LVH was 28% (from Chantra and Bhuthong [1]). We estimated a required sample size of 317 patients.

Categorical data are presented as frequency and percentage. Continuous variables are presented as mean $\pm$ standard deviation (SD). Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for all ECG criteria presented. A McNemar test was used to confirm the agreement of all ECG criteria presented against the LV mass index. The area under the receiver-operating characteristic curve (AUC) was used to assess the performance of the criteria. Cronbach α was used to determine interobserver variability between the 2 independent cardiologists. $P < 0.05$ was considered significant.

Results

The average age of patients whose data were included in the present study was 57.2 ± 16.5 years. Their average BSA was

1.7 ± 0.2 m². Nearly 50% had hypertension. About 20% of patients had atrial fibrillation and about 25% of patients had valvular heart disease. Of those, 164 patients had LVH and 153 patients did not. Compared with patients without LVH, more patients with LVH had advanced age, hypertension, diabetes mellitus, dyslipidemia, heart failure, and higher systolic blood pressure. The average left ventricular ejection fraction in patients with LVH was $66.1 \pm 7.5\%$ and $67.1 \pm 7.1\%$ in those without. The average LV mass index in patients with LVH was 141.6 ± 35.9 g/m² and it was 82.3 ± 17.3 g/m² in those without LVH. Demographic data indicating baseline characteristics of patients with and without LVH are shown in **Table 1**.

The sensitivity of modified Peguero–Lo Presti criteria was 50.6% (95% confidence interval [CI] 42.7% to 58.5%), specificity was 88.2% (95% CI 82.0% to 92.9%), PPV was 82.2% (95% CI 73.3% to 89.1%), and NPV was 62.5% (95% CI 55.7% to 69.0%). The modified Peguero–Lo Presti criteria had the best sensitivity and acceptable specificity compared with the original Peguero–Lo Presti criteria, Sokolow–Lyon voltage criteria, and Cornell voltage criteria (**Table 2** and **Figure 2**). Compared with the original Peguero–Lo Presti criteria, the modified Peguero–Lo Presti criteria had comparable accuracy with an AUC of 0.67 (95% CI 0.61–0.73; $P < 0.01$; **Table 2** and **Figure 3**).

Discussion

The present study shows that Peguero–Lo Presti criteria modified by BSA can improve their sensitivity for the diagnosis of LVH with specificity and accuracy compared with original Peguero–Lo Presti criteria. Moreover, the modified criteria had better sensitivity and similar specificity than previously accepted ECG criteria for LVH, such as Sokolow–Lyon voltage criteria or Cornell voltage criteria. Height and body weight are required to calculate BSA to interpret LVH voltage ECG criteria.

The sensitivity of all existing ECG criteria presented in the present study was lower than that found by previous studies [7, 12, 15]. There are several possible explanations underlying the observation that the sensitivity was lower than expected. First, previous studies recruited healthy patients for the control group, while the present study included data from diseased patients as controls were decreasing in sensitivity. Second, previous studies used a higher LV mass index for diagnosis of LVH, while this study used a lower LV mass index following the 2015 ASE–EACVI recommendations for cardiac chamber quantification by echocardiography in adults [6] and improved accuracy of echocardiographic LVH as reflected by an intraclass correlation > 0.90 in all ECG criteria. Finally, people of Asian ancestry, including Thais, may have a body size and

Table 1. Baseline characteristics of the patients with available echocardiography and with and without LVH

Demographic	Total n = 317 n (%) or mean $\pm$ SD	LVH n = 164 n (%) or mean $\pm$ SD	No LVH n = 153 n (%) or mean $\pm$ SD	P
Age (years)	57.2 $\pm$ 16.5	63.5 $\pm$ 13.2	50.4 $\pm$ 17.1	<0.01
Male sex	134 (42.3%)	59 (36%)	75 (49%)	0.02
Body weight (kg)	64.6 $\pm$ 15.2	64.6 $\pm$ 15.9	64.5 $\pm$ 14.5	0.98
Body surface area (m ²)	1.7 $\pm$ 0.2	1.7 $\pm$ 0.2	1.7 $\pm$ 0.2	0.37
Medical history				
Hypertension	151 (48)	97 (59)	54 (35)	<0.01
Diabetes mellitus	53 (17)	36 (22)	17 (11)	0.01
Dyslipidemia	158 (50)	101 (62)	57 (37)	<0.01
COPD	16 (5)	11 (7)	5 (3)	0.16
Heart failure	58 (18)	42 (26)	16 (11)	<0.01
Atrial fibrillation	57 (18)	29 (18)	28 (18)	0.89
Peripheral arterial disease	3 (1)	1 (1)	2 (1)	0.52
History of myocardial infarction	20 (6)	12 (7)	8 (5)	0.45
Valvular heart disease	76 (24)	46 (28)	30 (20)	0.08
• Aortic stenosis	8 (3)	7 (4)	1 (1)	0.04
• Aortic regurgitation	13 (4)	12 (7)	1 (1)	<0.01
• Mitral regurgitation	15 (5)	13 (8)	2 (1)	0.01
History of stroke or TIA	12 (4)	8 (5)	4 (3)	0.29
Chronic kidney disease	10 (3)	7 (4)	3 (2)	0.24
Prior PCI	22 (7)	15 (9)	7 (5)	0.11
Prior CABG	8 (3)	5 (3)	3 (2)	0.54
Echocardiographic parameters				
LVEF (%)	66.5 $\pm$ 7.3	66.1 $\pm$ 7.5	67.1 $\pm$ 7.1	0.18
LV mass index (g/m ²)	113.0 $\pm$ 41.1	141.6 $\pm$ 35.9	82.3 $\pm$ 17.3	<0.01
Relative wall thickness	0.6 $\pm$ 2.3	0.8 $\pm$ 3.2	0.5 $\pm$ 0.1	0.24
Medications				
• Beta-blockers	95 (30)	56 (34)	39 (26)	0.09
• ACEIs/ARBs	48 (15)	32 (20)	16 (11)	0.03
• Calcium channel blockers	71 (22)	48 (29)	23 (15)	<0.01
• Diuretics	44 (14)	33 (20)	11 (7)	<0.01
SBP (mmHg)	130.1 $\pm$ 20.1	135.2 $\pm$ 20.8	124.6 $\pm$ 17.7	<0.01
DBP (mmHg)	77.1 $\pm$ 13.3	78.1 $\pm$ 13.46	76.1 $\pm$ 13.0	0.20
Creatinine (mg/dL)	1.0 $\pm$ 0.7	1.1 $\pm$ 1.0	0.9 $\pm$ 0.3	0.23
eGFR (mL/min/m ²)	83.4 $\pm$ 24.4	74.5 $\pm$ 24.2	91.4 $\pm$ 21.9	<0.01

ACEIs, angiotensin converting enzyme inhibitors; ARBs, angiotensin receptor blockers; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; LVEF, left ventricular ejection fraction; LVH, left ventricular hypertrophy; PCI, percutaneous coronary intervention; SBP, systolic blood pressure; SD, standard deviation; TIA, transient ischemic attack.

shape that differs from those of European or other ancestries. Nevertheless, the specificity was similar to previous studies for all criteria presented.

We acknowledge that the present study has some limitations. The study design was retrospective and observational; so, a selection bias may exist. Nevertheless, we attempted to minimize the selection bias using web-based random sampling and analyzing each ECG and echocardiogram using a consensus by 2 cardiologists. A good intraclass correlation confirmed reproducibility. We excluded medical conditions, including

LV systolic dysfunction, RVH, and other conduction abnormalities. Therefore, the modified Peguero–Lo Presti criteria may be less accurate when applied to patients with the excluded conditions.

Conclusions

Peguero–Lo Presti criteria can be modified by dividing them by BSA to improve the sensitivity of the criteria with acceptable

Table 2. McNemar test and AUC for the electrocardiographic criteria against the echocardiographic LVH

Test	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	AUC	P AUC	*P McNemar
Peguero–Lo Presti LVH	29.9 (23.0–37.5)	90.9 (85.1–94.9)	77.8 (65.5–87.3)	54.7 (48.4–61.0)	0.67 (0.61–0.73)	<0.01	<0.01
Modified Peguero–Lo Presti LVH	50.6 (42.7–58.5)	88.2 (82.0–92.9)	82.2 (73.3–89.1)	62.5 (55.7–69.0)	0.67 (0.61–0.73)	<0.01	<0.01
Sokolow–Lyon LVH	18.3 (12.7–25.1)	88.9 (82.8–93.4)	63.8 (48.5–77.3)	50.4 (44.2–56.5)	0.59 (0.53–0.66)	0.06	<0.01
Cornell LVH	14.0 (9.1–20.3)	98.0 (94.4–99.6)	88.5 (69.8–97.6)	51.5 (45.6–57.4)	0.71 (0.65–0.76)	0.08	<0.01

AUC, area under the receiver-operating characteristic curve; CI, confidence interval; LVH, left ventricular hypertrophy; NPV, negative predictive value; PPV, positive predictive value. Values are presented as percentage (95% CI).

* $P < 0.05$ indicates lack of agreement.

Figure 2. Sensitivity and specificity of the ECG criteria against the echocardiographic LVH. Dark gray bars indicate sensitivity and open bars indicate specificity. Error bars indicate 95% confidence intervals. ECG, electrocardiographic; LVH, left ventricular hypertrophy.

specificity for the diagnosis of LVH compared with the original Peguero–Lo Presti criteria, Sokolow–Lyon voltage criteria, and Cornell voltage criteria. The modified criteria retain accuracy similar to that of the original Peguero–Lo Presti criteria.

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Figure 3. AUC of the ECG criteria against the echocardiographic LVH. Dashed blue line indicates Peguero–Lo Presti criteria (AUC 0.67), solid purple line indicates Peguero–Lo Presti criteria modified by BSA (AUC 0.67), short-dashed green line indicates Sokolow–Lyon voltage criteria (AUC 0.59), and long-dashed orange line indicates Cornell voltage criteria (AUC 0.71). The teal line is for reference. AUC, area under a receiver-operating characteristic curve; BSA, body surface area; ECG, electrocardiographic; LVH, left ventricular hypertrophy.

Conflicts of interest statement: The authors have each completed an International Committee of Medical Journal Editors Disclosure Form for Potential Conflicts of Interest. None of the authors has disclosed any potential or actual conflict of interest related to the published article.

Data sharing statement: Statistical summaries of the data generated and analyzed for the present study are included in this published article. Further details of the data are available from the corresponding author on reasonable request, after deidentification from any patient.

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