Original Article

# Sensitivity and Specificity of Electrocardiographic Left Ventricular Hypertrophy (LVH) Criteria amongst Hypertensives in University of Abuja Teaching Hospital, Gwagwalada, Abuja

**Ngabea MA[1,2], Ojji DB[2], Sani MU[3], Umar H[4], Isezuo SA[4]**

[1]Department of Medicine, Maitama District Hospital, [2]Department of Medicine, University of Abuja Teaching Hospital, Gwagwalada, Abuja, [3]Department of Medicine, Aminu Kano Teaching Hospital, Kano, [4]Department of Medicine, Usmanu Danfodiyo University Teaching Hospital, Sokoto, Nigeria

## ABSTRACT

**Background:** Hypertension remains one of the important risk factors for cardiovascular diseases and a major global public health problem. Left ventricular hypertrophy is a recognised complication of systemic hypertension and strongly predicts cardiovascular morbidity and mortality. In Nigeria, few studies have tested the sensitivity and specificity of multiple electrocardiographic (ECG) criteria in the diagnosis of left ventricular hypertrophy (LVH) amongst hypertensives although it is a commonly used diagnostic method. This study sets out to determine the sensitivity and specificity various ECG criteria of LVH amongst patients with hypertension.

**Methodology:** One hundred and seventy-eight hypertensives were recruited consecutively into the study. They all had ECG done using standard methodology. They all had echocardiography done to assess the presence of echocardiographic LVH. ECG-LVH was determined using various ECG criteria.

**Results:** The various ECG criteria for the diagnosis of LVH were lower in sensitivities (23.5%–38.6%) compared to specificities (64.1%–72.9%). The Cornell voltage (CV) criterion had the combination of the highest sensitivity and specificity at 38.6% and 72.9%, respectively. The Massoleini criterion (MC) had similar values with CV criteria with sensitivity of 38.6% and specificity of 72.9%. The Romhilt criterion had a high specificity of 64.1% but low in sensitivity (23.5%). The sensitivity and specificity obtained for Sokolow–Lyon (SL) criterion were 28.9% and 64.0%, respectively. The corresponding values for Cornell product criterion were 34.6% and 69.4%, whereas those of Goldberger criterion were 34.4% and 68.0%. The prevalence of echocardiographic LVH was 32.4%.

**Conclusion:** CV, SL and MC ECG criteria had the best combination of sensitivities and specificities and therefore are good testing criteria for LVH in patients with hypertension.

**Key words:** Hypertension, left ventricular hypertrophy, sensitivity, specificity, University of Abuja Teaching Hospital

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## INTRODUCTION

Cardiovascular disease remains a leading global cause of morbidity and mortality.[1] It is predetermined by risk factors including hypertension and left ventricular hypertrophy (LVH) amongst others.[2] Hypertension is defined as persistent systolic blood pressure (BP) of >140 mmHg and/or diastolic BP of 90 mmHg or higher.[3]

LVH is a recognised complication of systemic hypertension and the best studied marker of hypertensive heart disease.[4] It refers to abnormal increase in the mass of left ventricular myocardium caused by a chronically increased workload on the heart which may be directly due to hypertension.[5] Increased workload on the heart causing LVH can also be caused by comorbid conditions such as obesity, chronic kidney disease and diabetes mellitus.

LVH is, however, a modifiable risk factor as treatment causes its regression, thereby decreasing the rate of adverse

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**Address for correspondence:** Dr. Ngabea MA , Department of Medicine, Maitama District Hospital, Abuja, Nigeria.
E-Mail: ngabea@yahoo.com

cardiovascular events and improving survival independent of degree of BP lowering, hence the need for its early diagnosis.[6] The prevalence of LVH amongst hypertensive varies widely between 20% and 50% depending on the population and tool applied for diagnosis.[7]

LVH strongly predicts cardiovascular morbidity and mortality in hypertensive patients and is also an independent risk factor for overall cardiovascular mortality and morbidity.[8] It is an important factor used for risk stratification of hypertensives[9] and is known to cause reduction in myocardial coronary reserve and predisposes to myocardial ischaemia and left ventricular dysfunction, thereby causing increased incidence of coronary heart disease amongst hypertensives.[10] It has been determined that there is a 4–8-fold increase in the chance of strokes after adjusting for an increase in BP amongst hypertensives with LVH compared to those without it. [11]

LVH can be diagnosed by ECG or echocardiography.[12] Although echocardiography is sensitive in diagnosing LVH, it is not yet widely available in many developing countries.[5] Although the sensitivity of various ECG criteria remains low, ranging from 7% to 35% in mild hypertension and 10%–50% in moderate/severe hypertension,[13] its specificity is high and thus is still widely used in Nigeria and many parts of the developing world for the diagnosis of LVH in hypertension, being a more affordable diagnostic tool.

This study determined the sensitivity and specificity of multiple ECG criteria in the diagnosis of LVH in the study population and, therefore, may help make ECG-LVH diagnosis easier and hasten detection of this important cardiovascular risk factor, thereby helping to attenuate the burden associated with it.

## METHODOLOGY

This was an observational cross-sectional study, in which a total of one hundred and seventy-eight eligible hypertensive subjects aged 18 years and above presenting at the cardiology clinic of the medical outpatient department of the University of Abuja Teaching Hospital (UATH) were consecutively recruited over a period of 6 months. Only individuals who granted written informed consent were included in the study.

The sample size ($N$) was estimated using the formula: $N = Z^2PQ/D^2$, where $N$ = Sample size, $P$ = Prevalence of LVH in hypertension, $Z^2$ = Standard deviation at 95% confidence interval and $D$ = precision. $Z$ = Standard deviation at 95% =1.960, $P$ = Prevalence of LVH in hypertension from previous study = 35%, [14] $D$ = Precision = 5%, $Q$ = 1 − prevalence = 1 − 0.350 = 0.65. Therefore, $N = 1.96^2 \times 0.35 \times 0.65/2\ (0.05)^2$

A subject was considered hypertensive if the BP measured on two or three occasions of at least 5 min apart was consistently ≥140 mmHg systolic and/or ≥90 mmHg diastolic or on treatment for hypertension. Individuals with chronic renal failure, anaemia, valvular heart disease, pregnancy, diabetes and athletes were excluded.

Demographic data and anthropometric measurements were recorded. BP measurements were taken using the standard criteria. Blood samples of patients were taken for the determination of serum electrolytes, urea, creatinine, fasting blood sugar and fasting lipid profile.

Ethical approval for the study was obtained from the Research and Ethics Committee of the UATH, Gwagwalada, in December 2012.

### Electrocardiography

A standard (resting) 12-lead ECG was obtained in all the subjects according to the recommendations of the American Heart Association/American College of Cardiology/Heart Rhythm Society scientific statement.[15]

All ECG recordings were made using a commercially available Cardiofax (ECG 1550k) ECG machine by Nihon Kohden Corporation with a calibration of 25 mm/s (paper speed) and 1 mV/cm (gain). ECG tracings were read by the corresponding author using manual callipers, and the presence of LVH was assessed using Sokolow–Lyon (SL) voltage criteria,[16] Cornell voltage (CV) criteria,[17] Romhilt–Estes (RE) point score system,[18] Cornell product criteria,[19] Goldberger criteria (GC)[20] and Massoleini criteria (MC).[21]

1. SL criteria: This was measured as $SV_1 + RV_5$ or $V_6 \geq 35$ mm (3.5 mV) or $RaV_L$ >11 mm (1.1 mV). All subjects whose sum of the amplitude of the S wave in lead V1 and the R wave in lead V5 or V6 is >35 mm or R wave in lead AVL is >11 mm (1.1 mV) were considered to have LVH
2. CV criteria: This was defined as follows,
   a. $SV_3$+ RaVL ≥20 mm (2.0 mV) in women
   b. $SV_3$+ RaVL ≥28 mm (2.8 mV) in men

Each female hypertensive whose sum of the R wave in lead aVL and S wave in lead $V_3$ was equal to and or >20 mm and each male hypertensive whose sum >28 mm (2.8 mV) was considered to have LVH by ECG

3. RE point score system: These was determined as below,
   a. Voltage criteria (3 points each)
      i. Any R or S in limb leads ≥20 mm (2.0 mV)
      ii. $SV_1$, $SV_2$, $RV_5$ or $RV_6$ ≥30 mm (3.0 mV)
   b. ST-T waves change (3 points each, 1 point each if patient on digitalis)
   c. Left atrial abnormality (3 points)
      i. Terminal component of the *P* wave in $V_1$ >1 mm or 40 ms
      ii. Left axis deviation (2 points) considered as QRS axis of −30 or more negative
   d. Prolonged QRS duration >90 ms
   e. Delayed intrinsicoid deflection time in $V_5$ or $V_6$ ≥50 ms

   The above measurements were taken for each subject and the appropriate score assigned. Subjects were considered to have LVH by Romhilt criteria if they have a total score of ≥ 5.
4. Cornell product criteria: This was determined as below, $SV_3$ + RaVL (+8 in women) × QRS duration >2440 mm.

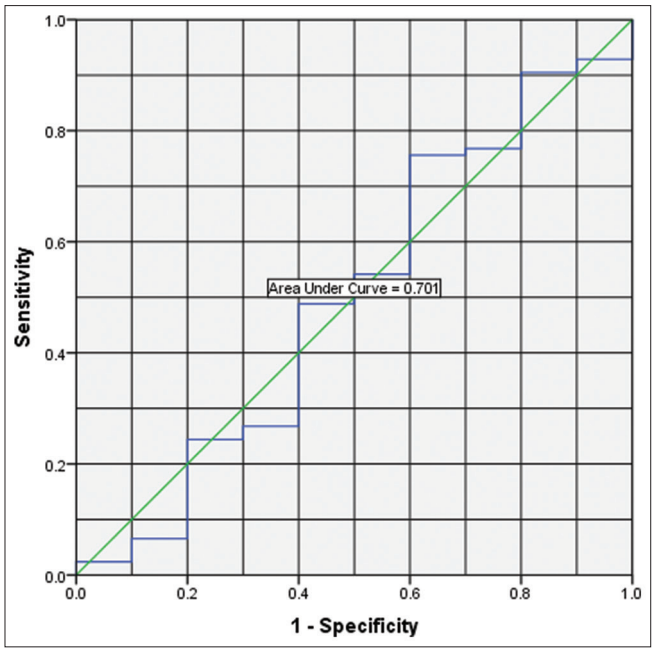


**Figure 1:** ROC curve showing the sensitivity and specificity of LVH by Sokolow–Lyon criteria. Area under the curve = 0.7010. This ROC value is >0.510, it therefore shows a combination of high sensitivity and specificity and therefore a positive predictor test. ROC: Receiver operating curves, LVH: Left ventricular hypertrophy

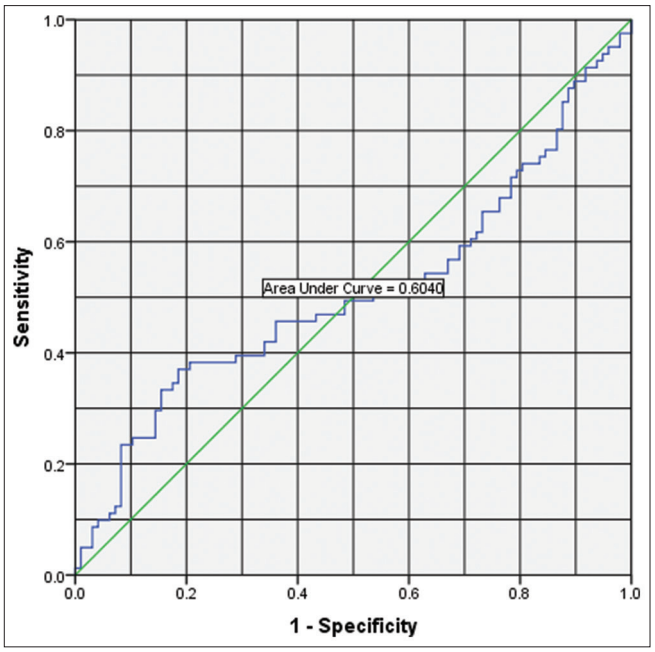


**Figure 2:** ROC curve showing the sensitivity and specificity of LVH by Cornell voltage criteria. Area under the curve = 0.6040. It shows a combination of high sensitivity and specificity with the ROC value >0.51. It is therefore a positive predictor criterion. ROC: Receiver operating curves, LVH: Left ventricular hypertrophy

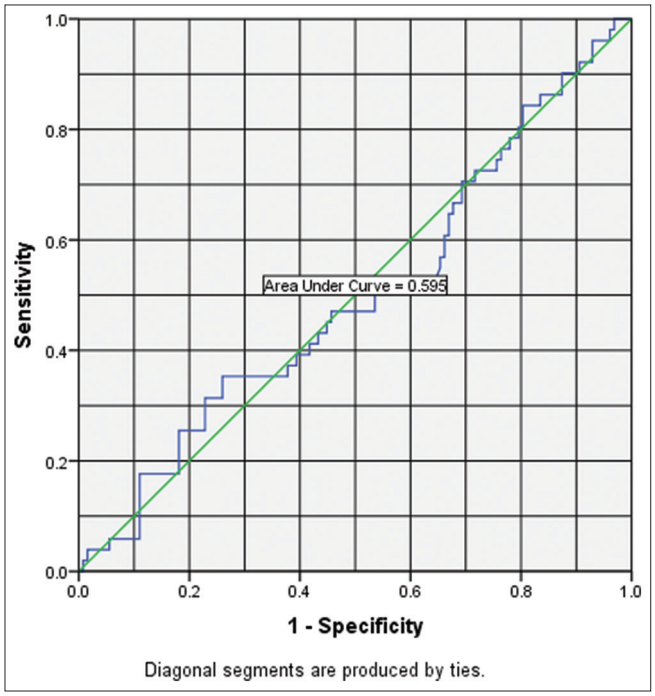


**Figure 3:** ROC curve showing the sensitivity and specificity of LVH by Romhilt criteria. Area under the curve = 0.5950. It is a positive predictor test because the area under the curve is >0.51, therefore this criterion also has a combination of high sensitivity and specificity. ROC: Receiver operating curves, LVH: Left ventricular hypertrophy

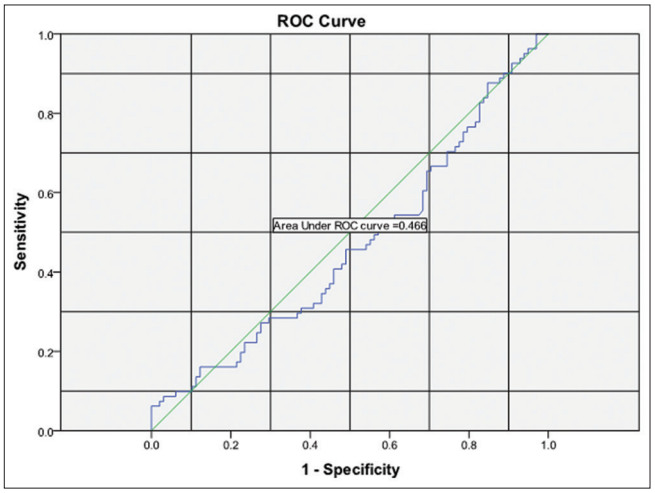


**Figure 4:** ROC curve showing the sensitivity and specificity of LVM by Cornell duration product. Area under the curve = 0.466. This shows a combination of low sensitivity and specificity with ROC value of 0.466 which is <0.51. It is a negative predictor test. ROC: Receiver operating curves, LVH: Left ventricular hypertrophy

Each female subject whose sum of Sin lead $V_3$ + R in aVL + 8 multiplied by QRS is >2440 mm was considered to have LVH, and for males, the sum of $SV_3$ + RaVL × QRS >2440 mm was considered to be positive for ECG-LVH

5. GC: This was defined as R in aVL ≥11 mm (1.1 mV). Each hypertensive subject whose R wave in aVL is >11 mm was considered to be positive for LVH
6. MC: This was defined as R in aVL ≥7.5 mm (0.75 mV). Each hypertensive subject whose R wave in lead aVL is ≥7.5 mm was considered to have LVH.

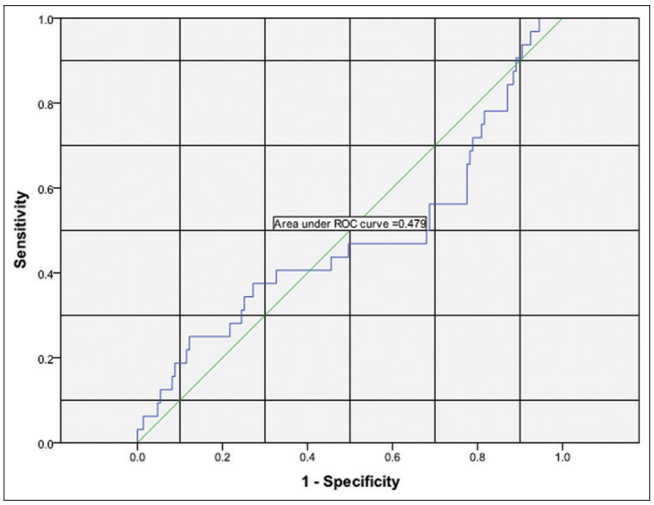


**Figure 5:** ROC curve showing the sensitivity and specificity of LVM by Goldberger criteria. Area under the curve = 0.479. This is a negative predictor criterion with a combination of low sensitivity and specificity with a ROC value of 0.479 which is lower than 0.510. ROC: Receiver operating curves, LVH: Left ventricular hypertrophy

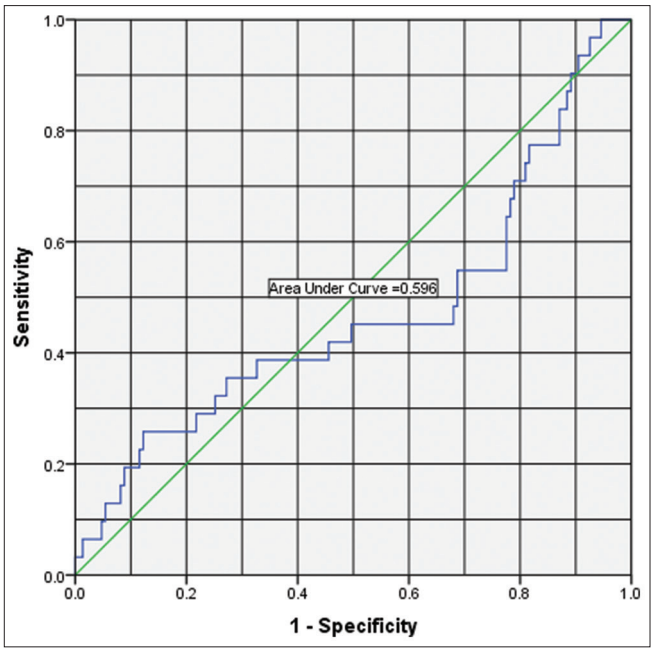


**Figure 6:** ROC curve showing the sensitivity and specificity of LVM by Massoleini criteria. Area under the curve = 0.5960. This depicts positive prediction and a combination of high sensitivity and specificity since the ROC value is 0.5960 which is > 0.51. ROC: Receiver operating curves, LVH: Left ventricular hypertrophy

### Echocardiography

Subjects had echocardiography done at the Cardiology Laboratory of UATH using a Vivid e General Electronics CE 0197, Rev 4, 2010 echocardiography machine. Complete echocardiographic examination was performed in the left lateral decubitus position by the corresponding author adhering to the recommendation of the American Society of Echocardiography (ASE),[22] using the leading edge to leading edge technique with ECG gating. M-mode images were derived from the 2D images. Measurements were averaged over three cardiac cycles. Left ventricular mass (LVM) was calculated according to the Devereux modified ASE cube formula.[23]

Echocardiographic LVH was calculated to serve as the reference standard for the determination of sensitivity, specificity and negative and positive predictive values of all the ECG criteria used in this study.

The partition value for LVH by echo was determined using an LVM/BSA value of 125 g/m² for both males and females.[24] A patient was deemed to have LVH by echo if his calculated LVM exceeds this cut-off point. LVM was indexed for body surface area (BSA) and height.

### Statistical analysis

Data management and analysis were performed using SPSS version 19.0 (IBM, India). The data were presented as means (±SD) for continuous variables and proportions for categorical variables. Echocardiographic LVH was used as the reference standard against which the performance of each of the various ECG criteria was compared for the measurement of their sensitivities, specificities, negative predictive values and positive predictive values. Sensitivity, specificity, positive predictive values and negative predictive values were calculated using the following formula: (1) Sensitivity = TP/TP + FN; (2) Specificity = TN/TN + FP; (3) Negative predictive value = TN/TN + FN; and (4) Positive predictive value = TP/TP + FP.[25] where True positive (TP)=LVH detected by both ECG and Echo, True Negative (TN)= LVH not detected by both ECG and Echo, False positive (FP)=LVH detected by ECG but not detected by Echo, False negative (FN)= LVH detected by Echo but not detected by ECG. Student's *t*-test was used to compare the means between the two groups. Receiver operating curves (ROCs) were constructed for each ECG criteria to evaluate test performance over a wide range of partition values. ECG criteria with ROC values between 0.51 and 1.00 were considered to be positive predictors, while those with ROC values <0.500 were considered to be negative predictors. $P < 0.05$ was considered statistically significant.

## RESULTS

A total of 102 female and 78 male subjects with hypertension were studied.

The demographic and clinical characteristics of female and female hypertensive subjects are summarised in Table I.

The female subjects with hypertension and male subjects did not differ significantly in age, 51.3 ± 11.2 years versus 52.7 ± 7.1 years, respectively ($P = 0.28$). There were significant differences between female subjects and male subjects in body mass index (BMI) (28.0 ± 6.3 kg/m² vs. 24.7 ± 3.9 kg/m², $P = 0.001$), BSA (1.8 ± 0.19 m² vs. 1.7 ± 0.16 m², $P = 0.001$), waist circumference (93.77 ± 10.81 cm vs. 91.2 ± 9.95 cm,

$P = 0.005$) and hip circumference (100.92 ± 11.83 cm vs. 102.6 ± 10.96 cm, $P = 0.005$).

### Electrocardiographic characteristics of the study population

The values of the various ECG parameters of the study population are summarised in Table II.

### Echocardiographic parameters of hypertensive female and male hypertensive subjects

The echocardiographic parameters of female and male hypertensive subjects are shown in Table III.

**Table I: Comparison of the clinical characteristics of female and male subjects**

| Parameter | Mean±SD | | *P* |
|---|---|---|---|
| | Females (*n*=102), *n* (%) | Males (*n*=76), *n* (%) | |
| Age (years) | 51.3 (11.2) | 52.7 (7.1) | 0.280 |
| Height (m) | 1.64 (0.08) | 1.61 (0.08) | 0.004 |
| Weight (kg) | 75.9 (16.3) | 64.8 (11.1) | 0.001 |
| BMI (kg/m$^2$) | 28.0 (6.3) | 24.7 (3.9) | 0.001 |
| BSA (m$^2$) | 1.8 (0.19) | 1.7 (0.16) | 0.001 |
| SBP (mmHg) | 143 (19.5) | 124.4 (4.8) | 0.001 |
| DBP (mmHg) | 88.3 (10.2) | 77.8 (7.6) | 0.001 |
| MAP (mmHg) | 109 (12.6) | 97 (8.3) | 0.001 |
| Pulse rate (b/min) | 78.9 (18) | 76.8 (17.4) | 0.023 |
| Waist circumference (cm) | 93.77 (10.81) | 91.2 (9.95) | 0.005 |
| Hip circumference (cm) | 100.92 (11.83) | 102.6 (10.97) | 0.005 |
| Waist/hip ratio | 0.93 (0.10) | 0.98 (0.12) | 0.024 |
| Male | 76 (42.7) | 39 (43.8) | |
| Females | 102 (57.3) | 50 (56.2) | |

BMI: Body mass index, BSA: Body surface area, SBP: Systolic blood pressure, DBP: Diastolic blood pressure, SD: Standard deviation, MAP: Mean arterial pressure

**Table II: Echocardiographic characteristics of the study population**

| Parameter | *n* | Mean±SD |
|---|---|---|
| P wave duration (ms) | 178 | 92.84±11.56 |
| QRS axis (degree) | 178 | 29.68±6.83 |
| QRS duration (ms) | 178 | 89.96±11.51 |
| RaVL (mV) | 178 | 0.75±0.35 |
| SV3 (mV) | 178 | 1.48±0.59 |
| SV1 (mV) | 178 | 1.52±0.67 |
| SV2 (mV) | 178 | 1.53±0.745 |
| RV5 (mV) | 178 | 1.89±0.83 |
| RV6 (mV) | 178 | 1.88±0.81 |
| Intrinsic deflection time V5 (ms) | 178 | 37.87±9.33 |
| Intrinsic deflection time V6 (ms) | 178 | 38.38±9.01 |
| ST depression V4-6 (mm) | 178 | 0.062±0.021 |
| T inversion V4-6 (mm) | 178 | 1.84±0.37 |

QRS: QRS wave, SV1: S wave in V1, SV2: S wave in lead V2, RV5: R wave in lead V5, RV6: R wave in lead V6. RaVL: R wave in lead aVL, SD: Standard deviation

### Sensitivity, specificity and negative and positive predictive values of the various electrocardiographic criteria

The sensitivities and specificities of the various ECG criteria in the diagnosis of LVH as obtained in this study for total volunteers are summarised in Table IV. Tables V and VI shows the sensitivities/specificities of the various ECG criteria for females and males subjects respectively while table VII shows the comparison of the specificity and sensitivities of male and female subjects.

The sensitivities and specificities obtained were 28.9%, 38.6%, 23.5%, 34.6%, 34.4% and 38.6% and 64.0%, 72.9%, 64.1%, 69.4%, 68.0% and 72.9% for the SL, Cornel voltage, RE, Cornel duration product, GC and MC, respectively.

The positive and negative predictive values were 44.8% and 47.1%, 55.2% and 58.9%, 20.7% and 67.8%, 48.3% and 56.2%, 19.0% and 82.6% and 38.6% and 72.9% for the SL, CV, Romhilt, Cornell duration product (CDP), GC and MC, respectively.

### Area under the receiver operating curves for the various electrocardiographic criteria

The areas under the various ROCs depicting the combinations of sensitivity and specificity of the various ECG criteria obtained in this study are summarised in Table VIII. The SL criterion had the highest value (0.7010). This was followed by CV and MC with values of 0.6040 and 0.5960, respectively. Other values for area under the curve were 0.5950, 0.4790 and 0.4660 for the Romhilt, GC and CDP criteria, respectively. Parameters with ROC values between 0.51 and 1.00 depict a positive prediction. SL, CV and MC with ROC values of 0.7010, 0.6040 and 0.5960, respectively, are positive predictors and good testing parameters. Figures 1-6 are graphs showing the Receiver operating curves ROCs for the Various ECG Criteria.

## DISCUSSION

Males and female hypertensive subjects were almost equal in percentage distribution in this study. This is important because gender has been shown to affect electrocardiographic LVH (ECG-LVH) cut-off values necessitating the use of different LVH partition values or cut-off points for males and females. Male and female subjects also had similar age distribution (51.3 ± 11.2 years vs. 52.7 ± 7.1 years).

The mean BMI and BSA for female hypertensive subjects were significantly higher than for male subjects. Obesity has been associated with increases in left ventricular thickness, left ventricular voltages and prevalence of ECG-LVH independent of the impact of BP levels.[26] Data from previous studies have also shown that the prevalence and sensitivity of ECG LVH detected by voltage based criteria like Sokolow-Lyon is lower in obese patients.[27] This is thought to be largely due to attenuating effects of increased distance of exploring electrodes from the left ventricle and attenuation of precordial QRS amplitudes by interposed tissue. This finding is likely to

have influenced the utility of ECG-LVH voltage criteria such as SL, MC and GC used in this study. However, Romhilt, CV and Cornell product criteria are less likely to be susceptible to this attenuating effect because these criteria are not strictly voltage based.

Most previous studies show that standard ECG criteria have low sensitivity and high specificity.[28] In a recent analysis by Pewsner *et al*., involving 21 studies,[28] the sensitivity of SL, CV, Cornell product and Romhilt criteria was 12%–52%, 7%–41%, 8%–32% and 8%–41%, respectively. The specificities for SL, CV, Cornell product and RE criteria were 53%–100%, 89%–100%, 83%–100% and 71%–100%, respectively. These trends are similar to the observation in the current study.

**Table III: Echocardiographic parameters of female and male subjects**

| Parameter | Mean±SD | | *P* |
|---|---|---|---|
| | Females (*n*=102) | Males (*n*=76) | |
| LVM (g) | | | |
| Male | 185.2 (63.7) | 173.2 (51.9) | 0.126 |
| Female | 173.8 (65.2) | 141 (32.1) | 0.0001 |
| All | 178.7 (64.7) | 154.9 (91.1) | 0.01 |
| LVM/BSA (g/m$^2$) | | | |
| Male | 99.4 (30.6) | 99.5 (33.2) | 0.715 |
| Female | 98.1 (40.1) | 85.3 (18.8) | 0.005 |
| All | 102.1 (36.2) | 91.4 (26.7) | 0.12 |
| LVM/HT (g/m) | | | |
| Male | 119.4 (36.4) | 104.2 (32.2) | 0.001 |
| Female | 109.6 (41.9) | 89.0 (19.1) | 0.001 |
| All | 118.8 (39.5) | 95.6 (26.8) | 0.005 |
| LVIDd (cm) | | | |
| Male | 4.63 (0.92) | 4.38 (0.78) | 0.04 |
| Female | 4.57 (0.83) | 4.28 (0.74) | 0.03 |
| All | 4.61 (0.89) | 4.33 (0.79) | 0.03 |
| IVSTd (cm) | | | |
| Male | 1.32 (0.21) | 1.13 (0.15) | 0.016 |
| Female | 1.27 (0.17) | 0.99 (0.13) | 0.354 |
| All | 1.28 (0.22) | 1.12 (0.14) | 0.02 |
| LVPWd (cm) | | | |
| Male | 1.22 (0.19) | 1.11 (0.12) | 0.010 |
| Female | 1.20 (0.13) | 1.09 (0.11) | 0.474 |
| All | 1.22 (0.21) | 1.10 (0.13) | 0.099 |

LVPWd: Left ventricular posterior wall in diastole, LVIDd: Left ventricular internal diameter in diastole, IVSDd: Inerterventricular septal diameter in diastole, SD: Standard error, LVM: Left ventricular mass, LVM/BSA: LVM indexed to body surface area, LVM/HT: LVM indexed to height

The CV and MC in this study exhibited the highest sensitivity of 38.6%, whereas the lowest sensitivity was seen with the RE criteria (23.5%). The CDP, GC and SL criteria exhibited 34.6%, 34.4% and 28.9%, respectively, as their sensitivities. The lowest specificity of 64% and the highest specificity of 72.9% were obtained with the SL and CV criteria, respectively. CDP, GC and Romhilt criteria had 69.4%, 68.0% and 64.1%, respectively, as their specificities. These values are consistent with the observation that ECG-LVH criteria always exhibit high specificities but low sensitivities.[28]

Furthermore, SL and the CV have the highest combination of sensitivities and specificities in the review by Pewsner *et al*.[28] Similarly, Dada *et al*. in Ibadan reported that SL and CV criteria exhibited the highest combination of sensitivities and specificities.[29] These are similar to the findings obtained in the current study.

SL and the CV/MC have been observed in this study to combine the best sensitivity and specificity for routine evaluation of LVH in the hypertensive population studied. The MC was noticed to have exhibited exactly the same values of sensitivity and specificity with the CV criteria in this study. This can be attributed to the fact the single voltage amplitude index of the MC is a subcomponent of the CV criteria.

The sensitivity and specificity values of the various ECG criteria obtained in this study were similar to the findings from previous studies of African hypertensives as obtained by Dada *et al*. and Kizer *et al*.[29,30] These results are generally consistent with the observation that in blacks, ECG criteria for LVH usually show increased sensitivity with a reduction in specificity when compared to Caucasians.[31]

Although the Cornell product criterion, being also sex specific, was expected to exhibit similar sensitivity and specificity compared to the CV criterion, QRS duration has been noted to be shorter in blacks generally.[32] This might have affected the predictive values of ECG product criteria in blacks and also in this study. In their initial paper propounding the Cornell product ECG criteria, Okin *et al*. obtained a sensitivity of 37% and specificity of 96% for the Cornell product criteria, which

**Table IV: Sensitivity, specificity, negative and positive predictive values of various electrocardiographic criteria in diagnosis of left ventricular hypertrophy for total volunteers**

| ECG criteria | Sensitivity (%) (95% CI) | Specificity (%) (95% CI) | PPV (%) (95% CI) | NPV (%) (95% CI) |
|---|---|---|---|---|
| SL | 28.9 (19.8-9.4) | 64.0 (53.2-74.0) | 44.8 (31.8-58.5) | 50.1 (38.0-58.5) |
| CV | 38.6 (28.1-49.9) | 72.9 (62.9-81.5) | 55.2 (41.5-68.3) | 58.9 (48.5-6 6.7) |
| RE | 23.5 (12.8-37.5) | 64.1 (55.1-72.4) | 20.7 (11.2-33.4) | 67.8 (58.7-76.0) |
| CDP | 34.6 (24.4-46.0) | 69.4 (59.3-78.3) | 48.3 (35.0-61.8) | 56.2 (46.9-65.2) |
| GC | 34.4 (18.6-53.2) | 68.0 (59.8-75.5) | 19.0 (9.9-31.4) | 82.6 (74.7-88.9) |
| MC | 38.6 (28.1-49.9) | 72.9 (62.9-81.5) | 55.2 (41.5-68.3) | 58.9 (48.5-6 6.7) |

CI: Confidence interval, ECG: Electrocardiographic, PPV: Positive predictive value, NPV: Negative predictive value, SL: Sokolow-Lyon criteria, CV: Cornell voltage criteria, RE: Romhilt-Estes criteria, CDP: Cornell duration product criteria, GC: Goldberger criteria, MC: Massoleini criteria

**Table V: Sensitivity, specificity, negative and positive predictive values of various electrocardiographic criteria in diagnosis of left ventricular hypertrophy for females**

| ECG criteria | Sensitivity (%) (95% CI) | Specificity (%) (95% CI) | PPV (%) (95% CI) | NPV (%) (95% CI) |
|---|---|---|---|---|
| SL | 27.6 (18.8-39.4) | 63.0 (52.2-73.0) | 44.8 (31.8-58.5) | 50.1 (38.0-58.5) |
| CV | 37.6 (26.1-47.9) | 71.8 (61.9-80.5) | 55.2 (41.5-68.3) | 58.9 (48.5-6 6.7) |
| RE | 25.5 (14.8-38.5) | 63.7 (54.1-71.4) | 20.7 (11.2-33.4) | 67.8 (58.7-76.0) |
| CDP | 32.6 (24.4-47.0) | 68.3 (58.3-76.3) | 48.3 (35.0-61.8) | 56.2 (46.9-65.2) |
| GC | 32.4 (17.5-52.3) | 67.2 (57.8-74.6) | 19.0 (9.9-31.4) | 82.6 (74.7-88.9) |
| MC | 37.6 (26.1-47.9) | 71.8 (61.9-80.5) | 55.2 (41.5-68.3) | 58.9 (48.5-6 6.7) |

CI: Confidence interval, ECG: Electrocardiographic, PPV: Positive predictive value, NPV: Negative predictive value, SL: Sokolow-Lyon criteria, CV: Cornell voltage criteria, RE: Romhilt-Estes criteria, CDP: Cornell duration product criteria, GC: Goldberger criteria, MC: Massoleini criteria

**Table VI: Sensitivity, specificity, negative and positive predictive values of various electrocardiographic criteria in diagnosis of left ventricular hypertrophy for males**

| ECG criteria | Sensitivity (%) (95% CI) | Specificity (%) (95% CI) | PPV (%) (95% CI) | NPV (%) (95% CI) |
|---|---|---|---|---|
| SL | 30.9 (20.8-41.4) | 65.2 (55.2-76.0) | 44.8 (31.8-58.5) | 50.1 (38.0-58.5) |
| CV | 39.6 (29.2-50.9) | 73.8 (64.7-82.5) | 55.2 (41.5-68.3) | 58.9 (48.5-6 6.7) |
| RE | 25.2 (14.8-38.5) | 65.4 (56.4-73.4) | 20.7 (11.2-33.4) | 67.8 (58.7-76.0) |
| CDP | 36.4 (26.4-48.0) | 69.4 (60.3-79.5) | 48.3 (35.0-61.8) | 56.2 (46.9-65.2) |
| GC | 35.8 (19.6-55.2) | 69.0 (60.8-76.5) | 19.0 (9.9-31.4) | 82.6 (74.7-88.9) |
| MC | 39.6 (29.2-50.9) | 73.8 (64.7-82.5) | 55.2 (41.5-68.3) | 58.9 (48.5-6 6.7) |

CI: Confidence interval, ECG: Electrocardiographic, PPV: Positive predictive value, NPV: Negative predictive value, SL: Sokolow-Lyon criteria, CV: Cornell voltage criteria, RE: Romhilt-Estes criteria, CDP: Cornell duration product criteria, GC: Goldberger criteria, MC: Massoleini criteria

**Table VII: Comparison of sensitivity and specificity between male and female patients**

| ECG criteria | Specificity (%) (95% CI) | | *P* | Sensitivity (%) (95% CI) | |
|---|---|---|---|---|---|
| | Male | Female | | Male | Female |
| SL | 65.2 (55.2-76.0) | 63.0 (52.2-73.0) | 0.01 | 30.9 (20.8-41.4) | 27.6 (18.8-39.4) |
| CV | 73.8 (64.7-82.5) | 71.8 (61.9-80.5) | 0.02 | 39.6 (29.2-50.9) | 37.6 (26.1-47.9) |
| RE | 65.4 (56.4-73.4) | 63.7 (54.1-71.4) | 0.23 | 25.2 (14.8-38.5) | 25.5 (14.8-38.5) |
| CDP | 69.4 (60.3-79.5) | 68.3 (58.3-76.3) | 0.09 | 36.4 (26.4-48.0) | 32.6 (25.4-47.0) |
| GC | 69.0 (60.8-76.5) | 67.2 (57.8-74.6) | 0.35 | 35.8 (19.6-55.2) | 32.4 (17.5-52.3) |
| MC | 73.8 (64.7-82.5) | 71.8 (61.9-80.5) | 0.04 | 39.6 (29.2-50.4) | 37.6 (26.1-47.9) |

CI: Confidence interval, ECG: Electrocardiographic, SL: Sokolow-Lyon criteria, CV: Cornell voltage criteria, RE: Romhilt-Estes criteria, CDP: Cornell duration product criteria, GC: Goldberger criteria, MC: Massoleini criteria

**Table VIII: Area under the receiver operating curve curves with 95% confidence intervals**

| | ROC area | SE | 95% CI |
|---|---|---|---|
| Massoleini | 0.5960 | 0.0512 | 0.496-0.728 |
| SL | 0.7010 | 0.0685 | 0.536-0.894 |
| CV | 0.6040 | 0.0596 | 0.506-0.745 |
| RE | 0.5950 | 0.0573 | 0.491-0.652 |
| Goldberger | 0.4790 | 0.063 | 0.356-0.603 |
| CDP | 0.4660 | 0.044 | 0.380-0.552 |

ROC: Receiver operating curve, SE: Standard error, CI: Confidence interval, SL: Sokolow-Lyon criteria, CV: Cornell voltage criteria, RE: Romhilt-Estes criteria, CDP: Cornell duration product criteria

was an improvement from that of the CV criteria at 28% and 96%.[33] However, in this study, the accuracy of the Cornell product is lower and this may be accounted for by the fact that QRS duration has been noted to be shorter in blacks generally.[32]

The RE criteria have been shown consistently to exhibit high specificity, which may be up to 100% in some studies but generally low sensitivity.[29,34] A similar pattern was observed in the current study. Subjects in this study exhibited less ST-T deviations compared to Caucasians. This may account for the observed relatively lower specificity value in the current study as ST-T changes are major component of the Romhilt criteria.

The CV, MC and the SL criteria showed a good combination of sensitivities and specificities and high negative predictive values in this study. Negative predictive values were 58.9%, 55.2% and 50.1% for the CV, MC and SL criteria, respectively. The combination of sensitivities and negative predictive values of the SL, CV and MC as obtained in this study are all above 50% and thus these criteria have exhibited good performance in the current study, though further data are needed to confirm these observations.

Gender differences in the partition values, sensitivities and specificities of ECG criteria for LVH have been established by several studies.[35-37] In the current study, a statistically significant difference in sensitivities and specificities were similarly observed for CV, SL and MC. It was also observed by Alfakih *et al*.[36] that the CDP exhibited high sensitivity in both males and females in their work, but this was not the case in the current study. This may be attributable to the fact that this is a study on black hypertensives. Voltage-based criteria have been shown to be more sensitive in black hypertensives.

The combination of sensitivities and specificities as for CV criteria as obtained in this study is similar to the findings of Ogunlade,[38] further confirming its clinical utility in black hypertensives.

## CONCLUSION

Data from the this study have shown that the Cornell voltage and Sokolow-Lyon criteria had the best combination of sensitivities and specificities thus are recommended for ECG LVH diagnosis in poor resource setting like Nigeria. However more data are needed to validate these findings.

### Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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### Conflicts of interest

There are no conflicts of interest.

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