A Comparison of Cornell and Sokolow–Lyon Electrocardiographic Criteria for Left Ventricular Hypertrophy in Korean Patients

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Background and Objectives: Electrocardiography (ECG) is a cost-effective and useful method for diagnosing left ventricular hypertrophy (LVH) in a large-scale study or in clinical practice. Among ECG criteria, the Cornell product (Cor P) and Sokolow-Lyon criteria were adopted by the European Society of Hypertension-European Society of Cardiology Guidelines but have different performances among races. The aim of this study was to compare the diagnostic performance of two voltage criteria in Korean patients.

Subjects and Methods: Electrocardiography and echocardiographic LV mass of 332 (159 male, 173 female) consecutive patients were analyzed. Cornell voltage criteria and the Cor P were compared with Sokolow-Lyon voltage (Sok V) and the Sokolow-Lyon product (Sok P). The sensitivities and specificities were estimated using a receiver-operating characteristics (ROC) curve in relation to the LVH diagnosis. The sensitivities and revised cut-off values were derived at specificity levels of 90, 95, and 100%.

Results: The Cornell-based criteria generally showed better performance than that of the Sok V criteria and Sok P in the area under the ROC curve analysis. The revised cut-off values for the Cornell voltage criteria (20 and 16 mm for males and females, respectively) showed an improved sensitivity (19.7 and 30.3% for males and females, respectively), with a high specificity of 95%.

Conclusion: The Cornell-based criteria had better performance than that of the Sokolow-Lyon criteria in both Korean men and women. However, revised cut-off values are needed to improve accuracy. (Korean Circ J 2012;42:606-613)

KEY WORDS: Electrocardiography; Echocardiography; Hypertrophy, left ventricular; Sensitivity and specificity.
The Institutional Review Board of Hanyang University Seoul Hospital approved this study protocol (IRB No. 2011-440). Informed consent was not required by the Board, because this was a retrospective study.

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Results

Demographic characteristics, electrocardiography measurements, and echocardiography values

Mean ages were 51.75±14.12 years for males and 54.63±13.17 years for females (p=0.055) and more males were included than females (11.3% vs. 4%, p=0.013) (Table 1). Mean body mass index (BMI) was not different (25.07±3.36 vs. 24.60±3.77 kg/m², p=0.237) and the distribution of BMI was similar (p=0.358), but mean BSA was significantly different (1.81±0.15 vs. 1.59±0.12 m², p<0.001) in males and females, respectively. No significant difference was observed in the prevalence of hypertension, diabetes mellitus, blood pressure, or heart rate between genders. Males had significantly higher mean ECG measurements than those of female for all criteria, including QRS duration, except the Cor P, for which females had significantly higher means (p<0.01). Mean LVM/BSA was higher in males than that in females (115.23±27.83 vs. 101.89±25.08 g/m², p<0.001).

Table 1. Demographic characteristics and comparisons of electrocardiographic measurements and echocardiographic values in males and females

|                  | Male (n=159) | Female (n=173) | p   |
|------------------|-------------|----------------|-----|
| Age (years)      | 51.75±14.12 | 54.63±13.17    | 0.055 |
| <35 years, n (%) | 18 (11.3)   | 7 (4)          | 0.013 |
| Height (cm)      | 168.38±7.01 | 156.02±5.81    | <0.001 |
| Weight (kg)      | 25.07±3.36  | 24.60±3.77     | 0.237 |
| BMI (kg/m²)      |             |                |     |
| Underweight (<18.5) (%) | 1 (0.6) | 4 (2.3) | 0.358 |
| Normal (18.5-24.9) (%) | 85 (53.3) | 105 (60.7) |     |
| Overweight (25-29.9) (%) | 64 (40.3) | 48 (27.7) |     |
| Obese (≥30) (%)  | 9 (5.7)     | 16 (9.2)       |     |
| BSA (m²)         | 1.81±0.15   | 1.59±0.12      | <0.001 |
| Hypertension, n (%) | 80 (50.3) | 86 (49.7) | 0.913 |
| Diabetes mellitus, n (%) | 22 (13.8) | 22 (12.7) | 0.872 |
| SBP (mm Hg)      | 130.77±18.07| 129.96±17.71   | 0.681 |
| DBP (mm Hg)      | 84.56±12.36 | 83.17±12.31    | 0.307 |
| HR (beats/min)   | 68.40±13.11 | 69.41±11.40    | 0.452 |
| Sok V (mm)       | 25.10±6.70  | 22.75±7.29     | 0.002 |
| Cor V (mm)       | 13.57±5.33  | 11.62±5.14     | 0.001 |
| QRS duration (ms)| 102.13±9.82 | 92.79±8.03     | <0.001 |
| Sok P (mm×ms)    | 2574.23±784.73 | 2116.93±731.27 | <0.001 |
| Cor P (mm×ms)    | 1400.79±605.48 | 1832.07±563.85 | <0.001 |
| LVM/BSA (g/m²)   | 115.23±27.83 | 101.89±25.08   | <0.001 |
| LVM/height² (g/m²²) | 51.47±14.87 | 49.16±14.07   | 0.147 |
| Prevalence of LVH |              |                |     |
| By LVM/BSA, n (%) | 71 (44.7) | 93 (53.8) | 0.101 |
| By LVM/height² (g/m²²) | 86 (54.1) | 99 (57.2) | 0.582 |

BMI: body mass index, BSA: body surface area, SBP: systolic blood pressure, DBP: diastolic blood pressure, HR: heart rate, Sok V: Sokolow-Lyon voltage, Cor V: Cornell voltage, Sok P: Sokolow-Lyon product, Cor P: Cornell product, LVM/BSA: left ventricular mass index by BSA, LVM/height²: left ventricular mass index by height², LVH: left ventricular hypertrophy

Table 2. Correlation coefficient (r) between electrocardiographic criteria and LVM/BSA and LVM/height² in males and females

|                  | LVM/BSA | LVM/height² |
|------------------|---------|-------------|
|                 | r       | p           | r       | p           |
| Male             |         |             |         |             |
| Sok V            | 0.284   | <0.001      | 0.269   | <0.01       |
| Cor V            | 0.391   | <0.001      | 0.376   | <0.001      |
| Sok P            | 0.316   | <0.001      | 0.270   | <0.01       |
| Cor P            | 0.394   | <0.001      | 0.361   | <0.001      |
| Female           |         |             |         |             |
| Sok V*           | 0.248   | <0.01       | 0.217*  | <0.01       |
| Cor V*           | 0.465   | <0.001      | 0.507*  | <0.001      |
| Sok P*           | 0.271   | <0.001      | 0.234*  | <0.01       |
| Cor P*           | 0.448   | <0.001      | 0.470*  | <0.001      |

*p<0.01 vs. Cor V, †p<0.01 vs. Cor P, LVM/BSA: left ventricular mass index by body surface area, LVM/height²: left ventricular mass index by height², Sok V: Sokolow-Lyon voltage, Cor V: Cornell voltage, Sok P: Sokolow-Lyon product, Cor P: Cornell product
but that of LVM/height$^{2.7}$ was not different (51.47±14.87 vs. 49.16±14.07 g/m$^{2.7}$, $p=0.147$). No difference in the prevalence of LVH by the two LVMI was observed between genders (LVM/BSA; $p=0.101$, LVM/height$^{2.7}$; $p=0.582$).

**Correlation between the four electrocardiography criteria and the two type indexed Left ventricular masses**

All four ECG criteria were significantly correlated with the two types of LVMI ($r$ values, 0.217-0.507, $p<0.01$) (Table 2). Cor V and Cor P had a higher correlation coefficient than that of Sok V and Sok P in both genders, but this result was significant only in females. The product of QRS duration and voltage tended to improve the correlation in Sok V, but this result was not significant.

**Comparison of the performance of the four electrocardiography criteria using receiver operating characteristic curves and conventional cut-off values**

Comparison of the AUC showed that the Cor V and Cor P had higher AUCs than those of Sok V or Sok P in both genders (Fig. 1). Cor V had the highest AUC in both genders (AUC in LVM/BSA: 0.648 in males and 0.735 in females, $p<0.001$; AUC in LVM/height$^{2.7}$: 0.687 in males and 0.782 in females, $p<0.001$).

In pairwise comparisons of AUC for each criterion, AUC of the Sok V and that of Cor V were considerably different for LVM/height$^{2.7}$ but not for LVM/BSA (males: difference between areas=0.042, $p=0.484$ for LVM/BSA; difference between areas=0.120, $p=0.041$ for LVM/height$^{2.7}$, females: difference between areas=0.098, $p=0.066$ for LVM/BSA; difference between areas=0.138, $p=0.007$ for LVM/height$^{2.7}$). However, the difference in AUC between the Sok P and Cor P.
was significant only in females for LVM/height\(^{2.7}\) (difference between areas=0.080, \(p=0.050\) for LVM/BSA; difference between areas=0.026, \(p=0.038\) in LVM/height\(^{2.7}\)). No significant difference was observed between Sok V and Sok P as well as between Cor V and Cor P except in female cases for LVM/height\(^{2.7}\) (difference between areas=0.026, \(p=0.038\) in LVM/height\(^{2.7}\)). The sensitivities for the conventional cut-off values were generally low, particularly in males using Cor V and Cor P (1.2-1.4% and 9.3-9.9%, respectively) and in females using Sok V and Sok P (7.1-7.5% and 8.1-8.6%, respectively) (Table 3). The test-negative likelihood ratio ranged from 0.82 to 0.99 due to the low sensitivities of the four LVH criteria.

### Discussion

Several Korean studies have investigated the performance of ECG criteria for LVH, and they have been conducted to improve ECG criteria for assessing LVH.\(^{18-21}\) But, the performance of the Cornell-based criteria has never been studied in Korea. Among various ECG criteria, voltage criteria are most convenient and they do not demand a PC-based analysis. Moreover, the Cornell-based criteria have

### Table 3. Sensitivities and specificities at conventional cut-off values for diagnosing echocardiographic LVH

|        | LVM/BSA |        | LVM/height\(^{2.7}\) |
|--------|---------|--------|-------------------|
|        | Sensitivity (%) | Specificity (%) | LR+ | LR- |
| Male   | | | | | |
| Sok V  | 11.3    | 95.5   | 2.48  | 0.93 |
| Cor V  | 1.4     | 100    | -     | 0.99 |
| Sok P  | 21.1    | 93.2   | 3.10  | 0.85 |
| Cor P  | 9.9     | 96.6   | 2.89  | 0.93 |
| Female | | | |
| Sok V  | 7.5     | 98.7   | 6.02  | 0.94 |
| Cor V  | 9.7     | 100    | -     | 0.90 |
| Sok P  | 8.6     | 98.7   | 6.88  | 0.93 |
| Cor P  | 19.4    | 95     | 3.87  | 0.85 |

LVM/BSA: left ventricular mass index by body surface area, LVM/height\(^{2.7}\): left ventricular mass index by height\(^{2.7}\), Sok V: Sokolow-Lyon voltage, Cor V: Cornell voltage, Sok P: Sokolow-Lyon product, Cor P: Cornell product, LR+: likelihood ratio of a positive test, LR-: likelihood ratio of a negative test

### Table 4. The sensitivities and revised cut-off values at specificity levels of 90, 95, and 100% for diagnosing echocardiographic left ventricular hypertrophy

|        | LVM/BSA |        | LVM/height\(^{2.7}\) |
|--------|---------|--------|-------------------|
|        | Sensitivity (%) | Cut-off value (mm or mm×ms) | Sensitivity (%) | Cut-off value (mm or mm×ms) |
| Male   | | | | | |
| Sok V  | 26.8    | 11.3   | 4.2   | 29.9  | 34.2  | 43.9 |
| Cor V  | 22.5    | 19.7   | 4.2   | 18.4  | 19.7  | 24.1 |
| Sok P  | 28.2    | 21.1   | 7     | 3106.5| 3385.5| 4565.6 |
| Cor P  | 23.9    | 16.9   | 4.2   | 1965.5| 2134  | 2819.7 |
| Female | | | | | | |
| Sok V  | 29     | 18.3   | 4.3   | 27.6  | 30   | 37.7 |
| Cor V  | 38.7    | 22.6   | 11.8  | 14.2  | 17   | 19.5 |
| Sok P  | 28     | 21.5   | 8.6   | 2603.7| 2735.4| 3468.4 |
| Cor P  | 35.5    | 29     | 10.8  | 2175  | 2270  | 2646 |

LVM/BSA: left ventricular mass index by body surface area, LVM/height\(^{2.7}\): left ventricular mass index by height\(^{2.7}\), Sok V: Sokolow-Lyon voltage, Cor V: Cornell voltage, Sok P: Sokolow-Lyon product, Cor P: Cornell product, LR+: likelihood ratio of a positive test, LR-: likelihood ratio of a negative test
been recently used and recommended in large-scale studies. Xie and Wang used the Cornell-based criteria to assess LVH in Chinese patients with hypertension, and their performance tended to be better than that of other criteria. Rodrigues et al. showed that Cor V had a closer association with LVM and better performance in the analysis of AUC of ROC than that of Sok V, as we demonstrated in this study. However, pairwise comparisons were not conducted in those studies. Comparing only the AUC may be insufficient to precisely determine ECG criteria performance. In this study, the difference between each AUC was analyzed to determine whether it was statistically significant and to measure the performance of the ECG criteria.

The main finding of this study was that Cor V performed better than Sok V in the correlation with the two LVMIs, the AUC of the ROC in both genders, and in pairwise comparisons of LVM/height. Another interesting finding was that with revised cut-off values under a fixed specificity of 95%, the Cor V also showed better sensitivity than that of any other criteria.

Noble et al. analyzed vector cardiographic changes induced by LVH to explain such better performance of Cor V. The increased LVM orients the electric forces horizontally (corresponding to the RaVL) and posteriorly (corresponding to the SV 3). Furthermore, the V 3 lead is closer to the LV and is probably less influenced by variations in the distance between the myocardium and the leads. Considering this better performance of the Cor V with revised gender-specific cut-off values, we can postulate that gender-specific criteria are still useful in Korean subjects even though reliable cut-off values are not yet available. Revised gender-specific cut-off values are also strongly supported by the finding that Cor V sensitivity at conventional cut-off values was too low to be applied to Koreans. However, further studies are needed to confirm the clinical usefulness of gender-specific cut-off values in Korean subjects.

We observed gender differences in the performance of the ECG criteria. Although Cor V had better performance than that of Sok V in both genders, the sensitivity of Cor V in females was stronger than that in males. Previous studies have shown that gender may influence ECG criteria sensitivity and this could affect the ECG performance for LVH. Barrios et al. suggested that there are pathophysiologival differences between genders regarding establishing and developing LVH. In the LIFE study, there were more female patients with ECG-LVH by Cor P than that of males.

In contrast with LVM/BSA, mean LVM/height in our study was not significantly different between genders, which was consistent with a previous study. A better correlation between the Cornell-based criteria and the two types of LVM, regardless of gender, was also found in a previous study. We expect that LVM/height to be a similar clinical value for Korean subjects. Further study may be needed to determine whether index-specific cut-off values are clinically useful to predict LVH.

Revised cut-off values of the Cor V (20 mm in males and 16 mm in females) improved the sensitivity in both genders by up to 30.3%. This tendency was also found in a previous study. However, revised Cor V cut-off values in males were lower than those in previous studies, and although the mean Cor V values were significantly different in males and females, the differences were not apparent (13.57±5.33 vs. 11.62±5.14 mm, p=0.001). These findings suggest that a gender difference in the cut-off values for Koreans may be smaller than that of conventional cut-off values. But, because conventional Cor V cut-off values were obtained from a sample of young normotensive individuals in whom the magnitude of ECG voltage was significantly different between genders, relatively older subjects in our study may have biased the cut-off values. Theoretically, the compositional changes in myocardial fibrosis, which are potentially complicated by hypertension, may have reduced the correlation between electrical voltage and LVM. Therefore, further study in representative young subjects showing clear differences between genders is needed to set reasonable gender-specific cut-off values.

Some limitations were noteworthy in this study. Because we used data from patients, generalizing our findings may be limited to a patient population in which the prevalence of hypertension and diabetes mellitus is somewhat different from that of the general population. The age distribution may have been different from that of the general population (there were fewer young females than young males). However, test characteristics such as sensitivity and the likelihood ratios are indispensable in situations such as hypertension, diabetes, and the elderly in real world situations. A small number of obese patients also participated in this study, and obesity may affect LVH. Therefore, we used LVM/height as LVM besides LVM/BSA, which is obesity-independent. Additionally, as some of the patients were previously on pharmacological treatment, this may have affected the results. Therefore, this study may not be sufficient to generalize to all Koreans. Although the Cor V sensitivities improved with the revised cut-off values, they were not satisfactory because of the low sensitivity of the voltage criteria. The accuracy of ECG criteria for diagnosing LVH is not enough. A scoring system such as the Romhilt-Estes or Perugia scores may improve sensitivity, but they could diminish specificity and may not be useful for a large population. Furthermore, none of the more sophisticated indices is clearly superior to the voltage criteria. Therefore, the ECG criteria cannot be considered a “SpPin” (specific, positive, in) test for the diagnosis of LVH in patients with hypertension and the clinician should assess the cost effectiveness of different diagnostic strategies.

In conclusion, the gender-specific Cor V had better overall performance in Korean subjects. Because conventional Cor V cut-off
values may not be appropriate for the total Korean population, we suggest revised CorV cut-off values of 20 mm for males and 16 mm for females. A further examination of the general population may be necessary to acquire more accurate cut-off values.

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