Original Research

Correlation Between Echocardiographic Left Ventricular Mass Index and Electrocardiographic Variables Used in Left Ventricular Hypertrophy Criteria in Chinese Hypertensive Patients

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Introduction: We investigated the association between echocardiographic (Echo) left ventricular mass (LVM) indexed to body surface area (LVM/BSA) or height$^{2.7}$ (LVM/H$^{2.7}$) and electrocardiographic (ECG) variables in 546 Chinese hypertensives.

Methods: The study group was stratified by gender and by BMI into obese (BMI ≥28 kg/m^2), overweight (BMI ≥24 kg/m^2 and BMI <28 kg/m^2), and healthy weight (BMI <24 kg/m^2) subgroups. Cornell voltage, Sokolow-Lyon voltage, maximum R amplitude in V_1-V_6, Gubner-Ungerleider voltage, and the products of these amplitude variables with QRS duration were measured.

Results: None of the ECG and Echo values showed a statistically significant difference between the obese and overweight subgroup; thus, we used only one cut-off point of BMI at 24 kg/m^2 for stratification of the hypertensive population. Cornell voltage, Cornell product and LVM/BSA were only affected by gender in our study. For hypertensives with BMI ≥24 kg/m^2, Cornell product was correlated with LVM/BSA and LVM/H$^{2.7}$ most significantly: correlation coefficients were approximately 0.45 for males and 0.40 for females and the correlation trended to be stronger as LVM/BSA or LVM/H$^{2.7}$ increased. However, a few ECG variables showed a weak correlation with LVM/BSA or LVM/H$^{2.7}$ in the hypertensives without left ventricular hypertrophy (LVH). A low sensitivity and high specificity of ECG criteria for the detection of LVH were also derived using receiver operating characteristic curves.

Conclusions: We conclude that Cornell product and Cornell voltage are the most convenient predictors for LVM/BSA with stratification only by gender. They are also the best parameters for predicting LVH in obese and overweight Chinese hypertensives, whereas estimation of LVM/BSA, LVM/H$^{2.7}$ by ECG is inaccurate in Chinese hypertensives without LVH. The cut-off point of BMI=24 kg/m^2 is suitable for stratification of body weight in further studies regarding Chinese hypertensives.

Left ventricular hypertrophy (LVH) is an important predictor of cardiovascular events.[1-3] In a previous study, we also reported that combined multiple indexes of either voltage or non-voltage ECG parameters were of prognostic significance for cardiovascular events.[4] Given the prognostic significance of LVH, the accurate measurement of left ventricular mass is crucial.

It is widely known that ECG measurements are affected by age, gender and body mass index (BMI). Along with the rapid growth of the Chinese economy, the lifespan has increased from 65 to 75 since the 1980s. It is evident that emphysema related to increasing age has an impact on the amplitude of surface cardiography.[5-8] At the same time, more and more Chinese seniors are suffering from hypertension as well as diabetes mellitus and metabolic syndrome. So far as we know, there are no data showing that the correlation reported previously is still applicable to modern Chinese hypertensives. We need to know whether the old ECG indexes may still accurately estimate left ventricular mass index (both as LVM indexed to body surface area, LVM/BSA, g/m^2, and LVM indexed to height$^{2.7}$, LVM/$H^{2.7}$, $g/m^{2.7}$), in this population. It has been reported that indexing left ventricular mass to height$^{2.7}$ can reduce the errors in estimating the impact of being overweight on the detection of LVH.[9] Is it true that the correlation between ECG variables and LVM/$H^{2.7}$ is better than that of LVM/BSA in Chinese hypertensives? In this retrospective study, we aimed to evaluate the relationship between LVM/BSA and LVM/$H^{2.7}$, measured by echocardiography (Echo), and 12-lead ECG variables in Chinese hypertensives stratified by gender and BMI into obese (BMI $\geq$28 kg/m^2), overweight (BMI $\geq$24 kg/m^2 and BMI <28 kg/m^2), and healthy weight (BMI <24 kg/m^2) subgroups, according to Chinese guidelines on the prevention and treatment of dyslipidaemia in adults.[10]

Methods

Patient population

Between 2004 and 2008, 546 consecutive Chinese hypertensives (325 men, age 22-92 years), diagnosed according to the hypertension guidelines of WHO 2004, were recruited from the inpatient department of the First Affiliated Hospital of Fujian Medical University. Exclusion criteria were patients with: a) chronic *cor pulmonale*; b) myocardial infarction; c) valvular heart disease; d) bundle branch blocks; e) pre-excitation syndrome; or f) atrial fibrillation or atrial flutter based on clinical history and examination according to relevant guidelines.[11-15]

Electrocardiography

All patients had a standard 12-lead ECG recorded at 25 mm/s and 1 mV/cm. Two independent observers who had no knowledge of the Echo parameters interpreted all the ECG tracings. The following ECG measurements were obtained based on inspection with a 4× magnifying lens:

- The QRS duration (ms)
- Sokolow-Lyon voltage (mv): sum of S-wave amplitude in lead V_1 and the higher R-wave amplitude in lead V_5 or V_6
- Cornell voltage (mV): sum of R-wave amplitude in lead aVL and S-wave amplitude in lead V_3
- Gubner-Ungerleider voltage (mV): sum of R-wave amplitude in lead I and S-wave amplitude in lead III
- Rmax voltage (mV): the highest R-wave amplitude from lead V_1 to lead V_6
- The voltage-duration product (mV × ms) for each of the voltage variables listed above was calculated by multiplying them by the QRS duration: Cornell product = Cornell voltage × QRS duration; Sokolow-Lyon product = Sokolow-Lyon voltage × QRS duration; and Rmax product = Rmax voltage × QRS duration.

Echocardiography

Two-dimensional guided M-mode recording was performed from the parasternal window according to the guidelines of the American Society of Echocardiography. The technician who recorded the echocardiographic parameters was unaware of the patients' ECG findings and blood pressure. The following parameters on the M-mode echocardiogram were evaluated:

- left ventricular end diastolic diameter (LVDd, cm)
- interventricular septal diastolic thickness (IVSTd, cm)
- left ventricular posterior wall diastolic thickness (LVPWTd, cm)

LVM was calculated according to Devereux's adjusted formula: $LVM = 0.8 \times 1.04 \times [(LVDd + LVPWTd + IVSTd)^3 - LVDd^3] + 0.6$ g.[16]

Left ventricular mass index was defined as LVM divided by body surface area (LVM/BSA, g/m^2) or by height$^{2.7}$ (LVM/$H^{2.7}$, $g/m^{2.7}$). BSA was calculated according to the formula: $BSA = 0.6 \times height (m) + 0.0128 \times weight (kg) - 0.1529$.

The inter- and intra-observer variabilities for echo measurements were 6.5 ± 2.5% and 4.5 ± 1.5%, respectively.[17]

Statistical analysis

SPSS for windows, version 10.0, was used for all statistical analysis. All measurements were expressed as mean ± SD. The significance of the differences between the mean values for men and women was evaluated using two-sided p-values from one-way analysis of variance (ANOVA). When ANOVA was performed, the Bonferroni correction was used to determine the differences among the obese subgroup, overweight subgroup and BMI <24 kg/m^2 subgroup. The Pearson correlation coefficient was also used to assess the strength of the relationship between LVM and various electrocardiographic measurements. The sensitivity and specificity for the detection of LVH at various cut-off points for ECG variables were determined by receiver operating characteristic (ROC) curves and areas under the curve (AUC). A p-value<0.05 was considered to be statistically significant.

Results

Demographic characteristic of hypertensive patients

The population characteristics are summarised in Table 1. All demographic and anthropometric variables except for age showed significant differences between men and women.

Differences in ECG and Echo parameters with stratification by gender

The gender differences in various ECG measurements and Echo values are shown in Table 1. Except for Gubner-Ungerleider voltage and LVM/H$^{2.7}$, most ECG measurements and Echo values were significantly greater in men.

Differences of ECG and Echo parameters with stratification by BMI

Table 2 shows the differences in ECG measurements and Echo values in Chinese hypertensives with stratification by BMI. None of the ECG and Echo values were significantly different between the overweight and obese subgroups. In consequence, we used only one cut-off point of BMI at 24 kg/m^2 for stratification of the hypertensive population. Cornell voltage, Cornell product and LVM/BSA were not significantly different between the two groups (Table 3)

Relation between LVM/BSA, LVM/H$^{2.7}$ and ECG measurements

The relationship between ECG measurements and Echo values is shown in Tables 4 and 5. The strongest correlation coefficients between LVM/BSA, LVM/H$^{2.7}$ and ECG measurements before stratification of the population by gender and BMI were found for the Cornell product: r=0.395 for LVM/BSA (p<0.001); r=0.373 for LVM/H$^{2.7}$ (p<0.001).

As some ECG and Echo values were significantly different between the BMI ≥24 kg/m^2 and BMI <24 kg/m^2 subgroups (Table 3), the correlation between ECG variables and Echo values was evaluated after stratification of the study population by gender and by BMI. Firstly, taking the BMI ≥24 kg/m^2 subgroup into consideration, we found that:

Table 1. Demographic characteristics of hypertensive patients and comparison of ECG variables and Echo parameters in Chinese hypertensives after stratification by gender.

	Male (n=325)	Female (n=221)
Age (years)‡	63.54 ± 13.09	65.02 ± 11.93
Height (m)*	1.675 ± 0.062	1.558 ± 0.056
Weight (kg)*	71.233 ± 10.982	60.863 ± 8.905
BSA (m^2)*	1.780 ± 0.163	1.576 ± 0.133
Rmax voltage (mV)*	2.307 ± 0.891	1.986 ± 0.676
Rmax product (mV × ms)*	220.726 ± 97.106	178.489 ± 69.306
Sokolow-Lyon voltage (mV)*	3.017 ± 1.201	2.683 ± 0.992
Sokolow-Lyon product (mV × ms)*	289.022 ± 131.486	241.495 ± 100.023
Cornell voltage (mV)*	1.696 ± 0.790	1.424 ± 0.601
Cornell product (mv × ms)*	163.680 ± 86.547	129.493 ± 62.343
Gubner-Ungerleider voltage (mV)‡	1.140 ± 0.557	1.087 ± 0.668
Gubner-Ungerleider product (mV × ms)†	109.094 ± 58.782	97.314 ± 60.175
LVM (g)*	200.984 ± 59.697	167.106 ± 46.387
LVM/BSA (g/m^2)†	113.126 ± 33.366	105.966 ± 27.690
LVM/H$^{2.7}$ (g/m$^{2.7}$)‡	49.976 ± 14.888	50.535 ± 13.817

*p<0.001, †p<0.05, ‡p>0.05. LVM – left ventricular mass; BSA – body surface area; LVM/BSA – left ventricular mass indexed to body surface area; LVM/H$^{2.7}$ – left ventricular mass indexed to height.$^{2.7}$

Table 2. Comparison of ECG variables and Echo parameters in Chinese hypertensives after stratification by BMI.

	BMI <24 (n=196)	24≤ BMI <28 (n=251)	BMI ≥28 (n=99)
Rmax voltage (mV)	2.346 ± 0.884*†	2.148 ± 0.749	1.918 ± 0.822
Rmax product (mV × ms)	217.607 ± 92.074†	200.250 ± 81.537	184.528 ± 98.670
Sokolow-Lyon voltage (mV)	3.016 ± 1.200†	2.870 ± 1.064	2.647 ± 1.132
Sokolow-Lyon product (mV × ms)	279.826 ± 124.315	267.971 ± 116.149	254.502 ± 130.530
Cornell voltage (mV)	1.520 ± 0.723	1.613 ± 0.750	1.648 ± 0.695
Cornell product (mV × ms)	142.897 ± 77.891	151.693 ± 80.438	158.903 ± 79.322
Gubner-Ungerleider voltage (mV)	0.983 ± 0.530*†	1.154 ± 0.537	1.292 ± 0.815
Gubner-Ungerleider product (mV × ms)	91.627 ± 54.662*†	106.822 ± 52.679	123.137 ± 77.576
LVM (g)	176.262 ± 53.082*†	191.461 ± 60.034	198.446 ± 54.210
BSA (m^2)	1.584 ± 0.146*†	1.719 ± 0.137†	1.872 ± 0.187
LVM/BSA (g/m^2)	111.050 ± 31.495	111.279 ± 33.023	105.932 ± 26.311
LVM/$H^{2.7}$ ($g/m^{2.7}$)	47.247 ± 13.512*†	51.334 ± 15.282	53.181 ± 13.153

*$p<0.05$ compared with 24≤ BMI <28, †$p<0.05$ compared with BMI ≥28. BMI – body mass index (kg/m^2); LVM – left ventricular mass; LVM/BSA – left ventricular mass indexed to body surface area; LVM/$H^{2.7}$ – left ventricular mass indexed to height$^{2.7}$.

Table 3. Comparison of ECG variables and Echo parameters in Chinese hypertensives after stratification by BMI using a cut-off point of 24 kg/m^2.

	BMI <24 (n=196)	BMI ≥24 (n=350)
Rmax voltage (mV)*	2.346 ± 0.884	2.083 ± 0.776
Rmax product (mV × ms)†	217.607 ± 92.074	195.803 ± 86.870
Sokolow-Lyon voltage (mV)†	3.016 ± 1.200	2.807 ± 1.807
Sokolow-Lyon product (mV × ms)	279.826 ± 124.315	264.161 ± 120.354
Cornell voltage (mV)	1.520 ± 0.723	1.623 ± 0.734
Cornell product (mV × ms)	142.897 ± 77.891	153.732 ± 80.077
Gubner-Ungerleider voltage (mV)*	0.983 ± 0.530	1.195 ± 0.630
Gubner-Ungerleiderproduct (mV × ms)*	91.627 ± 58.782	111.437 ± 61.089
LVM (g)†	176.262 ± 53.082	193.437 ± 58.454
LVM/BSA (g/m^2)	111.050 ± 31.495	109.767 ± 31.327
LVM/$H^{2.7}$ ($g/m^{2.7}$)*	47.247 ± 13.512	51.857 ± 14.716
BSA (m^2)*	1.584 ± 0.146	1.762 ± 0.168

*$p<0.001$, †$p<0.05$. LVM – left ventricular mass; BSA – body surface area; LVM/BSA – left ventricular mass indexed to body surface area; LVM/$H^{2.7}$ – left ventricular mass indexed to height$^{2.7}$.

Table 4. Correlation coefficients (r) between ECG variables and LVM/BSA and LVM/$H^{2.7}$ after stratification by gender and BMI.

	Male				Female			
	BMI <24 (n=115)		BMI ≥24 (n=210)		BMI <24 (n=81)		BMI ≥24 (n=140)	
	LVM/BSA	LVM/$H^{2.7}$	LVM/BSA	LVM/$H^{2.7}$	LVM/BSA	LVM/$H^{2.7}$	LVM/BSA	LVM/$H^{2.7}$
Rmax voltage (mV)	0.269†	0.289†	0.318*	0.266*	0.347†	0.361†	0.257*	0.193†
Rmax product (mV × ms)	0.287†	0.309†	0.343*	0.297*	0.355†	0.360†	0.316*	0.262†
Sokolow-Lyon voltage mV)	0.317†	0.317†	0.393*	0.364*	0.343†	0.332†	0.338*	0.293*
Sokolow-Lyon product (mV × ms)	0.323*	0.328*	0.408*	0.380*	0.348†	0.332†	0.375*	0.338*
Cornell voltage (mV)	0.265†	0.251†	0.446*	0.451*	0.375†	0.353†	0.385*	0.379*
Cornell product (mV × ms)	0.267†	0.257†	0.448*	0.452*	0.354†	0.326†	0.404*	0.396*
Gubner-Ungerleider voltage (mV)	0.252†	0.260†	0.285*	0.304*	0.464*	0.471*	0.184†	0.214†
Gubner-Ungerleider product (mV × ms)	0.249†	0.260†	0.317*	0.303*	0.459*	0.461*	0.230†	0.258†

*$p<0.001$, †$p<0.05$. LVM/BSA – left ventricular mass indexed to body surface area (g/m^2); LVM/$H^{2.7}$ – left ventricular mass indexed to height$^{2.7}$ ($g/m^{2.7}$); BMI – body mass index (kg/m^2).

- The correlation between most ECG variables and LVM/BSA, LVM/$H^{2.7}$ became stronger when the voltage-duration product was considered instead of the voltage amplitude alone.
- The correlation between Cornell voltage and Sokolow-Lyon voltage with LVM/BSA, LVM/$H^{2.7}$ had a higher r-value than for Rmax voltage and Gubner-Ungerleider voltage.
- Cornell product was considered to be a good predictor for LVM/BSA and LVM/$H^{2.7}$; the correlation coefficients were approximately 0.45 for men and 0.40 for women (Figure 1).

Secondly, in those patients with BMI <24 kg/m^2 (Table 4), the correlation between LVM/BSA, LVM/$H^{2.7}$ and ECG variables was weaker. The Sokolow-Lyon product might be a mild parameter for predicting LVM in male patients. The correlation coefficients were 0.323 for LVM/BSA and 0.328 for LVM/$H^{2.7}$ ($p<0.001$). But for the female patients, Gubner-Ungerleider voltage might be a moderate predictor; the correlation coefficients were 0.464 for LVM/BSA and 0.471 for LVM/$H^{2.7}$ ($p<0.001$).

The correlation between ECG variables and Echo measurements changed as LVM/BSA and LVM/$H^{2.7}$ increased. For the BMI ≥24 kg/m^2 hypertensives, the relationship tended to be stronger as LVM/BSA or

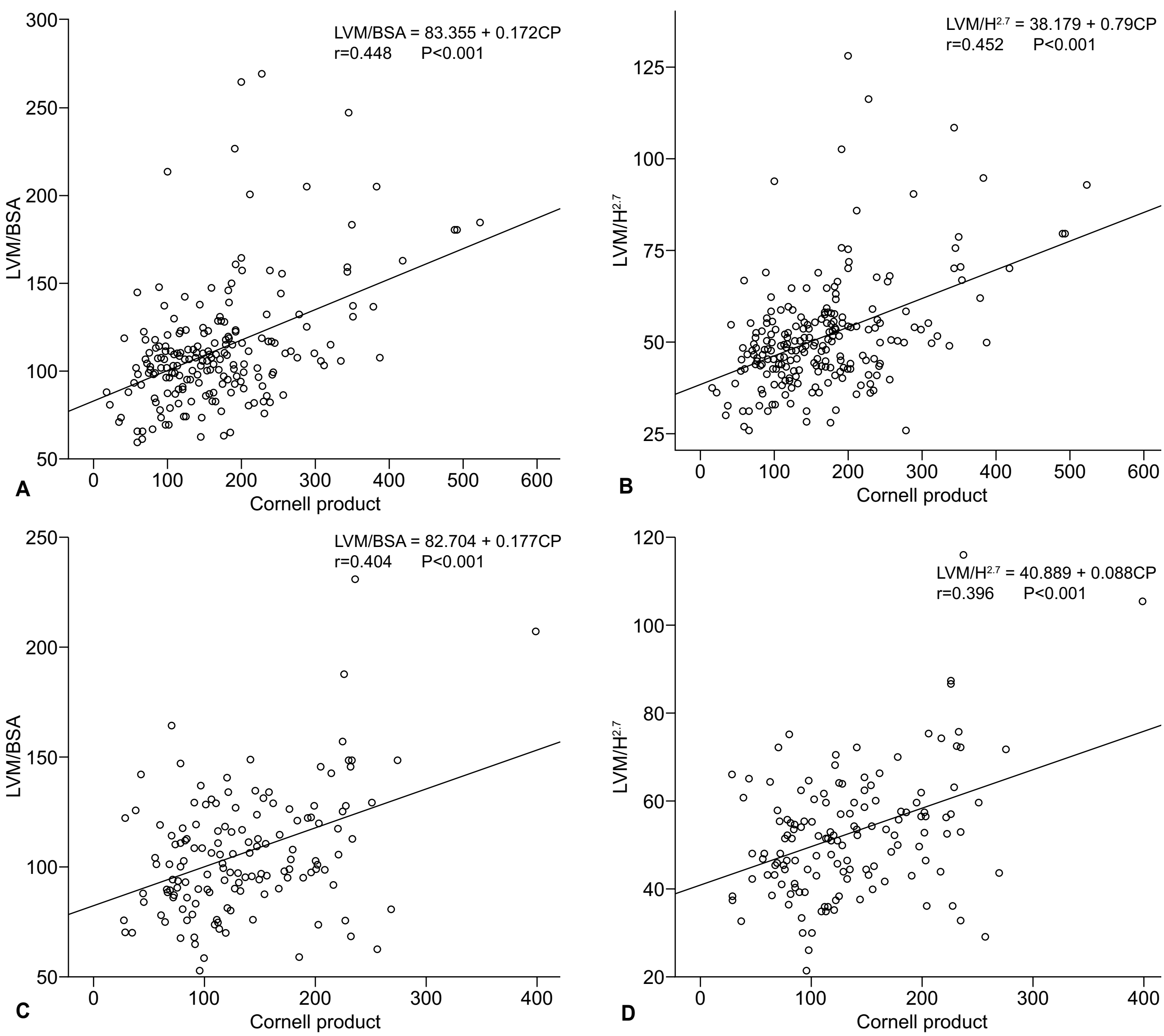

Figure 1. Scattergrams showing the correlation between Cornell product (mV × ms) and left ventricular mass indexed to body surface area (LVM/BSA, g/m^2) or height$^{2.7}$ (LVM/$H^{2.7}$, g/$m^{2.7}$) in hypertensives with BMI ≥24 kg/m^2 stratified by gender and body mass index: A, B in men; C, D in women. The solid line is the regression trend line.

Table 5. Correlation coefficients (r) between ECG variables and $LVM/H^{2.7}$ and LVM/BSA in 546 hypertensives.

	LVM/BSA	$LVM/H^{2.7}$
Cornell product (mV × ms)	0.395*	0.373*
Cornell voltage (mV)	0.392*	0.373*
Sokolow-Lyon product (mV × ms)	0.387*	0.328*
Sokolow-Lyon voltage (mV)	0.368*	0.308*
Rmax product (mV × ms)	0.339*	0.261*
Rmax voltage (mV)	0.311*	0.229*
Gubner-Ungerleider product (mV × ms)	0.291*	0.322*
Gubner-Ungerleider voltage (mV)	0.258*	0.299*

*$p<0.001$. $LVM/H^{2.7}$ – left ventricular mass indexed to $height^{2.7}$ ($g/m^{2.7}$); BMI – body mass index (kg/m^2).

$LVM/H^{2.7}$ increased (Table 6) ($p<0.05$). For those patients with LVM/BSA <70 g/m^2, LVM/BSA <80 g/m^2, LVM/BSA <90 g/m^2 and LVM/BSA <100 g/m^2, or with $LVM/H^{2.7}$<30 $g/m^{2.7}$ and $LVM/H^{2.7}$<40 $g/m^{2.7}$, a poor correlation was found between LVM/BSA, $LVM/H^{2.7}$ and ECG measurements. LVH was defined by following two criteria: a) LVM/BSA exceeded 125 g/m^2 in men or 110 g/m^2 in women;[18] and b) $LVM/H^{2.7}$ exceeded 51 $g/m^{2.7}$ in men or 47 $g/m^{2.7}$ in women.[19] For those patients without LVH, only Cornell voltage, Cornell product, Gubner-Ungerleider voltage and Gubner-Ungerleider product showed a weak correlation with Echo values; the correlation coefficients ranged from 0.166 to 0.258 for LVM/BSA when LVH was defined with the first criteria ($p<0.05$), and from 0.147 to 0.236 for $LVM/H^{2.7}$ ($p<0.05$) when the second criteria were used.

The diagnostic accuracy of ECG criteria at various cut-off points for the detection of LVH was analysed by ROC curves (Figure 2). As Cornell voltage, Cornell product and LVM/BSA were not affected by BMI, the sensitivity and specificity were determined using only stratification by gender when LVH was defined with the first criteria (Table 7). When LVH was defined with the second criteria, the diagnostic accuracy of various ECG parameters was assessed using stratification of the hypertensive population by gender and by BMI (Tables 8 & 9). The specificity for ECG criteria was about 90%, but the sensitivity ranged from only 20-40%.

Discussion

In this study, we evaluated the relationship between various ECG measurements and LVM/BSA and $LVM/H^{2.7}$ in Chinese hypertensives after stratification by gender and BMI. All variables except age, Gubner-Ungerleider voltage and $LVM/H^{2.7}$ were significantly different between men and women. This was in agreement with previous studies by Salton et al and Carlsson et al.[20,21] The lower voltages and LVM found in women might be due to the smaller body size of the women. Another reason for the differences in voltage amplitudes between men and women might be the larger distance between the precordial leads and myocardium in women as a result of mammary tissue. LaMonte et al reported that the QRS voltage increased after mastectomy.[22]

None of the ECG and Echo values were found to be significantly different between the obese and overweight patients. Thus, it would be appropriate to stratify the population by BMI at the cut-off point of 24 kg/m^2 in Chinese hypertensives for further study.

In our study, $LVM/H^{2.7}$ was not significantly different between male and female hypertensives. There were some advantages when LVM was indexed to $height^{2.7}$. Firstly, it eliminated the gender difference in the normalisation of LVM. This was in accordance with the study by de Simone et al, who also reported that indexation of LVM to BSA erroneously identi-

Table 6. Correlation coefficients (r) between LVM/BSA, $LVM/H^{2.7}$ and ECG measurements after stratification of LVM/BSA, $LVM/H^{2.7}$ in BMI≥24 kg/m^2 hypertensives.

	LVM/BSA					$LVM/H^{2.7}$		
	≥70	≥80	≥90	≥100	≥110	≥30	≥40	≥50
n	331	307	266	210	149	341	288	175
Rmax voltage (mV)	0.315*	0.330*	0.367*	0.366*	0.386*	0.221*	0.264*	0.348*
Rmax product (mV × ms)	0.344*	0.351*	0.383*	0.372*	0.388*	0.255*	0.280*	0.357*
Sokolow-Lyon voltage (mV)	0.390*	0.413*	0.448*	0.464*	0.475*	0.331*	0.382*	0.471*
Sokolow-Lyon product (mV × ms)	0.409*	0.423*	0.453*	0.455*	0.463*	0.350*	0.383*	0.464*
Cornell voltage (mV)	0.443*	0.431*	0.435*	0.438*	0.452*	0.431*	0.419*	0.436*
Cornell product (mV × ms)	0.446*	0.431*	0.434*	0.427*	0.444*	0.428*	0.408*	0.430*

*$p<0.05$. LVM/BSA – left ventricular mass indexed to body surface area (g/m^2); $LVM/H^{2.7}$ – left ventricular mass indexed to $height^{2.7}$ ($g/m^{2.7}$); BMI – body mass index (kg/m^2).

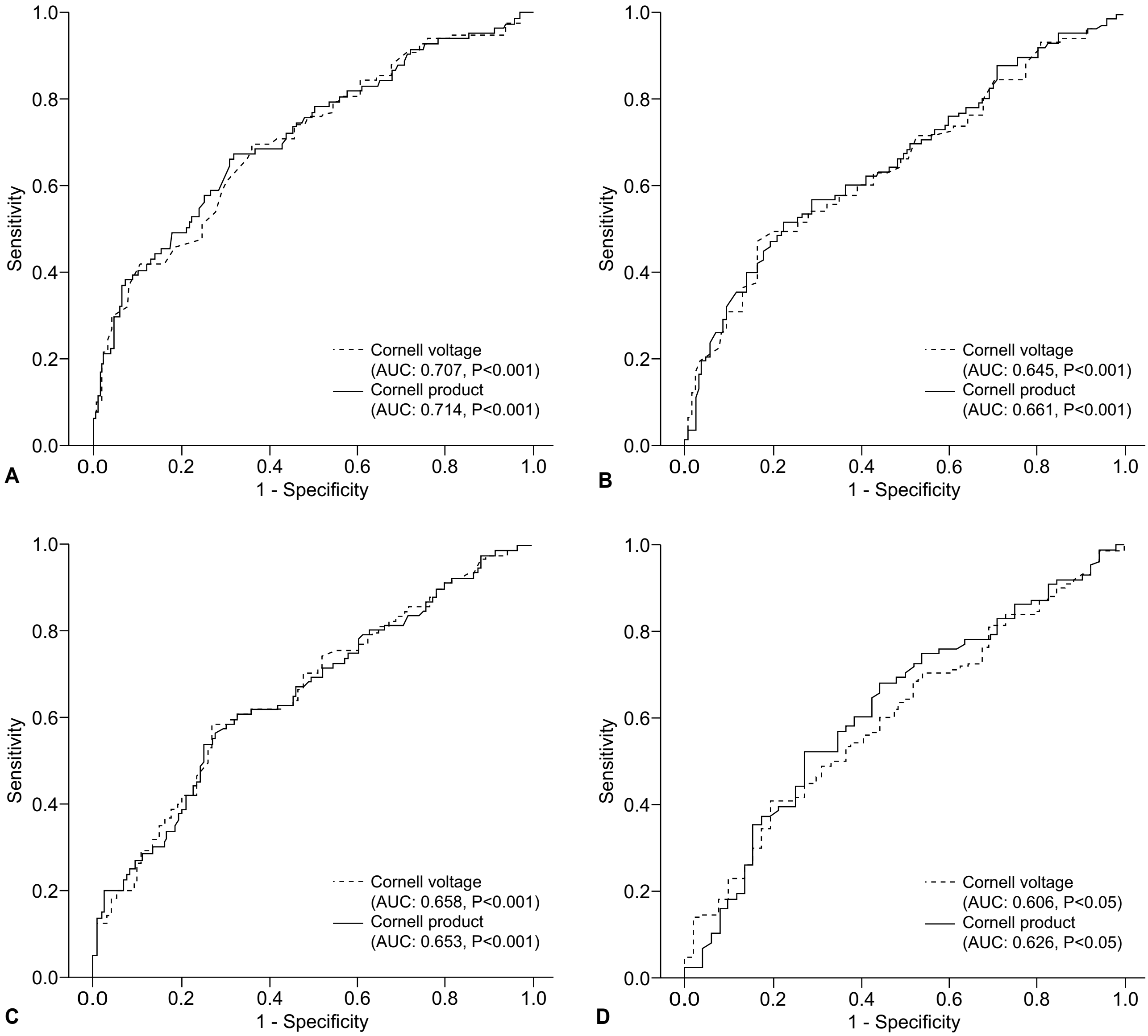

Figure 2. Receiver-operating characteristic curves with the continuous cut-off points of Cornell voltage and Cornell product for the detection of LVH in hypertensives with BMI ≥24 kg/m^2, using different criteria for the definition of LVH: A, LVM/BSA >125 g/m^2 in men and B, >110 g/m^2 in women; C, LVM/H$^{2.7}$ >51 g/m$^{2.7}$ in men and C, >47 g/m$^{2.7}$ in women. LVH – left ventricular hypertrophy; LVM/BSA – left ventricular mass indexed to body surface area; LVM/H$^{2.7}$ – left ventricular mass indexed to height$^{2.7}$.

fied LVM in overweight adults, whereas when LVM was indexed to height$^{2.7}$ the errors in normalisation of LVM for body size was reduced.[9] Secondly, some researchers also demonstrated that LVM/H$^{2.7}$ gave a more sensitive estimate of LVH than LVM/BSA.[23-26] Accordingly, we evaluated the relationship between LVM/H$^{2.7}$ and ECG measurements as well as that of LVM/BSA.

As shown in Tables 4 and 5, we found that the correlation between ECG variables and LVM/H$^{2.7}$ was similar to that of LVM/BSA. Before stratification of the population, when we examined the relationship between a number of ECG variables and LVM/BSA and LVM/H$^{2.7}$ the strongest correlation coefficient was found for the Cornell product. Carlsson et al and Tragardh et al demonstrated a better correlation between Cornell product and LVM/BSA measured by cardiac magnetic resonance, with correlation coefficients of 0.57 and 0.40, respectively.[21,27] In our study, the correlation coefficients were rather lower, r=0.395 for LVM/BSA and r=0.373 for LVM/H$^{2.7}$. The higher accuracy and reproducibility of LVM

Table 7. Sensitivity and specificity of Cornell voltage and Cornell product for the detection of LVH at various cut-off points. LVH was defined as LVM/BSA >125 g/m² in men or >110 g/m² in women.

	Male patients				Female patients		
Cornell voltage	AUC 0.707*				AUC 0.654*		
Cut-off point (mV)	2.34	2.52	2.80	2.92	1.83	2.00	2.11
Sensitivity (%)	40.2	31.7	28.0	24.4	36.6	30.1	24.7
Specificity (%)	90.1	92.6	95.9	96.7	86.7	91.4	92.2
Cornell product	AUC 0.714*				AUC 0.661*		
Cut-off point (mV)	237.0	243.3	244.0	256.8	189.2	201.1	202.0
Sensitivity (%)	39.0	37.8	36.6	31.7	32.3	25.8	24.7
Specificity (%)	91.4	93.0	93.4	93.8	90.6	93.0	93.7

*p<0.05. LVH – left ventricular hypertrophy; LVM/BSA – left ventricular mass indexed to body surface area (g/m²); AUC – area under the receiver-operating characteristic (ROC) curves.

measured by cardiac magnetic resonance rather than by M-mode echocardiography might explain the weak relationship in our study.[28,29] In our study, Cornell voltage and Cornell product, which were only affected by gender, might be the most convenient parameter for predicting LVH. The correlation between LVM/BSA, LVM/$H^{2.7}$ and ECG variables differed when the studied population was subdivided according to sex and BMI. Our study was the first one to stratify the study group by gender and BMI when evaluating the relationship between ECG measurements and LVM/BSA and LVM/$H^{2.7}$ in Chinese hypertensives.

Firstly, taking the BMI ≥24 kg/m² subgroup into consideration, we found that the Cornell product was the best predictor for the prediction of LVM/BSA and LVM/$H^{2.7}$, while the correlation coefficients for the voltage-duration product were greater than those for simple voltage criteria. This finding agrees with those of Carlsson et al and Okin et al.[21,30] Previous studies have shown that, during the process of hypertrophy, the factors inducing ventricular hypertrophy would impact myocardial conduction, resulting in a longer time for the depolarisation of the myocardium itself.[31-34] This may be a possible reason for the higher correlation when the voltage-duration product was applied. The correlation between Cornell voltage, Sokolow-Lyon voltage and LVM/BSA and LVM/$H^{2.7}$ was much better than that of Gubner-Ungerleider voltage and Rmax

Table 8. Sensitivity and specificity of ECG criteria for the detection of LVH at various cut-off points in male patients.

Definition of LVH	LVM/$H^{2.7}$ >51 g/$m^{2.7}$			LVM/BSA >125 g/m²		
BMI ≥24 kg/m²:						
Cornell voltage	AUC	0.658*		AUC	0.769*	
Cut-off point (mV)	2.64	2.80	2.89	2.64	2.80	2.89
Sensitivity (%)	19.8	16.5	15.4	36.6	34.1	31.7
Specificity (%)	94.1	95.8	96.6	94.1	96.4	97.0
Cornell product	AUC	0.653*		AUC	0.773*	
Cut-off point (mV × ms)	235.3	244.0	256.8	235.3	244.0	256.8
Sensitivity (%)	24.6	22.0	19.8	43.9	41.5	36.6
Specificity (%)	90.8	92.4	94.1	89.9	92.9	94.1
BMI <24 kg/m²:						
Sokolow-Lyon voltage	AUC	0.703*		AUC	0.703*	
Cut-off point (mV)	3.78	4.00	4.30	3.78	4.00	4.30
Sensitivity (%)	50.0	47.5	40.0	48.8	46.3	36.6
Specificity (%)	85.3	88.0	92.0	85.1	87.8	90.5
Sokolow-Lyon product	AUC	0.717*		AUC	0.719*	
Cut-off point (mV × ms)	384.6	390.4	438.2	384.6	390.4	438.2
Sensitivity (%)	50.0	45.0	32.5	48.8	43.9	31.7
Specificity (%)	89.3	90.7	93.3	89.2	90.5	93.2

*p<0.05. LVH – left ventricular hypertrophy; LVM/$H^{2.7}$ – left ventricular mass indexed to height$^{2.7}$ (g/$m^{2.7}$); AUC – area under the receiver-operating characteristic (ROC) curves.

voltage. Similarly, the stronger correlations between Cornell voltage, Sokolow-Lyon voltage and LVM/BSA have been reported previously. The r values for the correlations between Gubner-Ungerleider voltage and LVM/BSA were 0.32 and 0.36, respectively, lower than those of Cornell voltage and LVM/BSA (r=0.49 and 0.62, respectively).[21,35] Based on our data, it seems that Gubner-Ungerleider voltage and product were not sensitive parameters for the prediction of either LVM/BSA or LVM/$H^{2.7}$ for patients with BMI ≥24 kg/m^2.

Secondly, in those patients with BMI<24 kg/m^2, the correlation between LVM/BSA, LVM/$H^{2.7}$ and ECG variables was weaker. Gubner-Ungerleider voltage is the sum of the R-wave amplitude in lead I and the S-wave amplitude in lead III. This parameter involves no precordial lead and thus is hardly affected by the distance between the precordial leads and myocardium, which might influence the voltage amplitude.[22] This might explain why Gubner-Ungerleider voltage might be a moderate predictor in female patients in this subgroup. But in male patients, the Sokolow-Lyon product was a mild parameter. At this stage we cannot explain why the correlation coefficient of the Cornell product was not as good as the Sokolow-Lyon product for predicting left ventricular mass.

As LVM/BSA or LVM/$H^{2.7}$ increased, the correlation between some ECG criteria and Echo measurements became stronger in the patients with BMI ≥24 kg/m^2. Little is known about why there is such a difference regarding the correlation of ECG parameters and LVM/BSA or LVM/$H^{2.7}$. It may be partially related to an especially hypertrophied pattern or pathophysiology in the patients with BMI ≥24 kg/m^2. For the patients without LVH, only a few ECG variables showed a weak correlation with LVM/BSA, which was in agreement with a previous study by Lenstrup et al.[36] We can deduce that ECG variables can be used to estimate LVM/BSA or LVM/$H^{2.7}$ only in hypertensives with increased left ventricular mass or LVH.

We found that, although the sensitivity was quite low (20-40%), the specificity for these ECG criteria was much higher (approximately 90%) in the detection of LVH, which was in accordance with previous studies.[37,38] Most of the values for area under the curve (AUC) were greater when the voltage-duration product was considered instead of the voltage amplitude alone. Moreover, the AUC value and sensitivity were higher when LVH was defined with the first criteria, especially in the BMI ≥24 kg/m^2 subgroup, though the correlation coefficients between ECG variables and LVM/$H^{2.7}$ were similar to that of LVM/BSA. We thus considered that the second criteria for LVH, 51 g/$m^{2.7}$ in men and 47 g/$m^{2.7}$ in women, might not be suitable for Chinese hypertensives, as the cut-off point was derived from the learning group, which was recruited in New York and Naples (Italy).[19] The determination of more accurate diagnostic criteria will require further study based on healthy Chinese subjects.

Table 9. Sensitivity and specificity of ECG criteria for the detection of LVH at various cut-off points in female patients.

Definition of LVH	LVM/$H^{2.7}$ >47 g/$m^{2.7}$			LVM/BSA >110 g/m^2		
BMI ≥24 kg/m^2:						
Cornell voltage	AUC	0.606*		AUC	0.623*	
Cut-off point (mV)	2.00	2.11	2.17	2.00	2.11	2.17
Sensitivity (%)	25.0	22.7	18.2	31.0	27.6	22.4
Specificity (%)	86.5	90.4	92.3	86.6	89.0	91.5
Cornell product	AUC	0.626*		AUC	0. 635*	
Cut-off point (mV × ms)	197.4	202.0	203.5	197.4	202.0	203.5
Sensitivity (%)	22.7	19.3	18.2	29.3	41.5	36.6
Specificity (%)	86.5	88.5	90.4	87.8	92.9	94.1
BMI <24 kg/m^2:						
Sokolow-Lyon voltage	AUC	0.676*		AUC	0.684*	
Cut-off point (mV)	1.25	1.47	1.66	1.25	1.47	1.66
Sensitivity (%)	29.7	24.3	21.6	28.6	22.9	20.0
Specificity (%)	86.4	88.6	93.2	84.8	87.0	91.3
Sokolow-Lyon product	AUC	0.669*		AUC	0.686*	
Cut-off point (mV × ms)	104.1	117.4	130.28	104.1	117.4	130.28
Sensitivity (%)	43.2	29.7	27.0	45.7	28.6	25.7
Specificity (%)	81.8	86.4	90.9	82.6	84.8	89.1

*$p<0.05$. LVH – left ventricular hypertrophy; LVM/$H^{2.7}$ – left ventricular mass indexed to $height^{2.7}$ (g/$m^{2.7}$); AUC – area under the receiver-operating characteristic (ROC) curves.

Conclusions

Firstly, Cornell product was found to be the best parameter for the prediction of LVM/BSA and LVM/$H^{2.7}$ in obese and overweight Chinese hypertensives. Secondly, Cornell voltage and Cornell product are the most convenient predictors for LVM/BSA, as they are affected only by gender. Thirdly, estimation of LVM/BSA and LVM/$H^{2.7}$ by ECG is inaccurate in Chinese hypertensives without LVH. Finally, the cutoff point of BMI=24 kg/m^2 is suitable for the stratification of body weight in further study regarding Chinese hypertensives.

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