**Original Article** | Cardiovascular Imaging

https://doi.org/10.3348/kjr.2017.18.4.664
pISSN 1229-6929 · eISSN 2005-8330
Korean J Radiol 2017;18(4):664-673

Korean Journal of Radiology

# Left Ventricular Functional Parameters and Geometric Patterns in Korean Adults on Coronary CT Angiography with a 320-Detector-Row CT Scanner

Eun-Ju Kang, MD, PhD[1], Ki-Nam Lee, MD, PhD[1], Won Jin Choi, MD[1], Young-Dae Kim, MD, PhD[2], Kyung Min Shin, MD, PhD[3], Jae-Kwang Lim, MD[3], Jongmin Lee, MD, PhD[3]

Departments of [1]Radiology and [2]Cardiology, College of Medicine, Dong-A University, Busan 49201, Korea; [3]Department of Radiology, Kyungpook National University, Daegu 41944, Korea

**Objective:** To assess the normal reference values of left ventricle (LV) functional parameters in Korean adults on coronary CT angiography (CCTA) with a 320-detector-row CT scanner, and to analyze sex-related differences and correlations with various clinical characteristics.

**Materials and Methods:** This study retrospectively enrolled 172 subjects (107 men and 65 women; age, 58 ± 10.9 years; body surface area [BSA], 1.75 ± 0.2 $m^2$) who underwent CCTA without any prior history of cardiac disease. The following parameters were measured by post-processing the CT data: LV volume, LV functional parameters (ejection fraction, stroke volume, cardiac output, etc.), LV myocardial mass, LV inner diameter, and LV myocardial thickness (including septal wall thickness [SWT], posterior wall thickness [PWT], and relative wall thickness [RWT = 2 x PWT / LV inner diameter]). All of the functional or volumetric parameters were normalized using the BSA. The general characteristics and co-morbidities for the enrolled subjects were recorded, and the correlations between these factors and the LV parameters were then evaluated.

**Results:** The LV myocardial thickness (SWT, 1.08 ± 0.18 cm vs. 0.90 ± 0.17 cm, $p$ < 0.001; PWT, 0.91 ± 0.15 cm vs. 0.78 ± 0.10 cm, $p$ < 0.001; RWT, 0.38 ± 0.08 cm vs. 0.33 ± 0.05 cm, $p$ < 0.001), LV volume (LV end-diastolic volume, 112.9 ± 26.1 mL vs. 98.2 ± 21.0 mL, $p$ < 0.001; LV end-systolic volume, 41.7 ± 14.7 mL vs. 33.7 ± 12.2 mL, $p$ = 0.001) and mass (145.0 ± 29.1 g vs. 107.9 ± 20.0 g, $p$ < 0.001) were significantly greater in men than in women. However, these differences were not significant after normalization using BSA, except for the LV mass (LV mass index, 79.6 ± 14.0 g/$m^2$ vs. 66.2 ± 11.0 g/$m^2$, $p$ < 0.001). The cardiac output and ejection fraction were not significantly different between the men and women (cardiac output, 4.3 ± 1.0 L/min vs. 4.2 ± 0.9 L/min, $p$ = 0.452; ejection fraction, 63.4 ± 7.7% vs. 66.4 ± 7.6%, $p$ = 0.079). Most of the LV parameters were positively correlated with BSA, body weight, and total Agatston score.

**Conclusion:** This study provides sex-related reference values and percentiles for LV on cardiac CT and should assist in interpreting results.

**Keywords:** *Computed tomography; Heart; Left ventricle; Normal value; Ventricular function; Ventricular volume; Korean*

Received September 14, 2016; accepted after revision January 29, 2017.
This study was supported by research funds from Dong-A University, a grant from the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (2015R1A2A2A03005433), and funding by a grant from Guerbet.
**Corresponding author:** Jongmin Lee, MD, PhD, Department of Radiology, Kyungpook National University, 130 Dongdeok-ro, Jung-gu, Daegu 41944, Korea.
• Tel: (8253) 420-5472 • Fax: (8253) 422-2677 • E-mail: jonglee@knu.ac.kr

Korean Journal of Radiology KJR

## INTRODUCTION

Coronary computed tomography angiography (CCTA) is a noninvasive imaging technique that is extensively used to evaluate the state of coronary arteries (1, 2), and CCTA can also provide three-dimensional volumetric information on the cardiac chambers, especially regarding the left ventricle (LV). For retrospective electrocardiography (ECG)-gated CCTA, images are obtained in multiple phases throughout one RR interval. Therefore, global, volumetric LV functional parameters can be measured simultaneously with the LV mass and volume (3, 4). The quantification of the LV function using CCTA has been validated in many prior studies through a comparison with cardiac magnetic resonance imaging (MRI), which is regarded as the standard reference for functional measurement of the LV (5-7). Although normal reference values for functional LV parameters in CCTA have been determined in several studies, most of these studies have been conducted in the United States or Europe, and the results do not necessarily extend to patients of Asian ethnicity (8, 9).

Several large-population trials reporting on echocardiography or cardiac MRI have shown significant differences in the LV parameters between subjects of different ethnicities (10, 11), and the normal reference values for the LV volume and other functional parameters when using CCTA have not been fully determined for patients of Asian ethnicity. Currently, a wide-detector CT scanner (320-detector-row CT scanner) allows for 16 cm z-axis coverage, which can acquire isophasic and isochronic CT data without stair-step artifacts. This wide detector CT scanner can be used to obtain volumetric and functional measurements of the cardiac chamber with greater accuracy, thus reflecting the actual physiological situation. The main purpose of our study was to assess the normal reference values of LV functional parameters in Korean adults for CCTA by using a 320-detector-row CT scanner. In addition, we also analyze sex-related differences and correlations between the reported LV parameters and various clinical characteristics.

## MATERIALS AND METHODS

### Subjects

We retrospectively reviewed the medical charts of 911 patients who underwent CCTA for atypical chest pain or health screening in a single center from September 2011 to October 2015. Among these 911 patients, 387 CCTAs were produced using retrospective ECG-gating, through which data was available for subsequent functional cardiac analysis. The inclusion criteria were as follows: 1) the patients had no history of cardiac disease (coronary artery disease, myocardial infarction, cardiac surgery, etc.); 2) presented normal results on an ECG; and 3) were included based on the results of CCTA due to an Agatston score below the 25th age- and sex-matched percentile; without

**Table 1. General Characteristics of Enrolled Subjects**

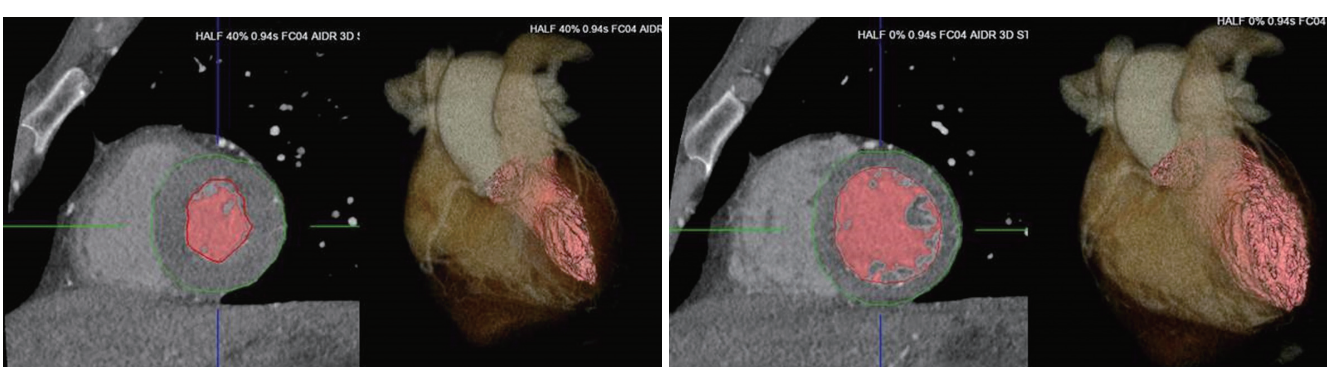
| | Total (n = 172) | Men (n = 107) | Women (n = 65) | *P* |
|---|---|---|---|---|
| Age (years)* | 58 ± 10.9 | 58 ± 9.7 | 59 ± 12.5 | 0.905 |
| Height (cm)* | 165.0 ± 8.5 | 169.8 ± 5.4 | 157.2 ± 6.6 | 0.000 |
| Weight (kg)* | 67.2 ± 11.5 | 70.8 ± 9.6 | 61.3 ± 12.1 | 0.000 |
| BMI (kg/m$^2$)* | 24.6 ± 34 | 24.5 ± 2.9 | 24.7 ± 4.2 | 0.746 |
| BSA (m$^2$)* | 1.75 ± 0.17 | 1.82 ± 0.4 | 1.63 ± 0.16 | 0.000 |
| Heart rate (bpm)* | 62.8 ± 10.9 | 61.3 ± 9.3 | 63.3 ± 9.7 | 0.324 |
| Agatston score | 8.2 ± 17.7 | 11.0 ± 20.6 | 4.0 ± 11.2 | 0.050 |
| Hypertension (%)† | 67 (39.0) | 42 (39.3) | 25 (38.5) | 0.880 |
| Diabetes (%)‡ | 23 (13.4) | 16 (15.0) | 7 (10.8) | 0.421 |
| Tchol (mg/dL)* | 189.3 ± 36.9 | 185.5 ± 38.1 | 195.5 ± 34.2 | 0.096 |
| LDL (mg/dL)* | 105.9 ± 32.4 | 108.0 ± 34.9 | 100.8 ± 25.8 | 0.434 |
| HDL (mg/dL)* | 57.8 ± 15.9 | 56.1 ± 15.8 | 61.7 ± 16.0 | 0.227 |
| Smoking (%) | 42 (24.4) | 36 (33.6) | 6 (9.2) | 0.000 |

Data are expressed as *Mean ± SD, †Patients were considered as having hypertension if their blood pressure (systolic/diastolic) was persistently higher than 140/90 mm Hg or patients were currently taking antihypertensive medication, ‡Patients were considered as having diabetes mellitus if their fasting glucose level was 126 mg/dL or more as assessed at least once or patients were currently taking oral hypoglycemic agents or insulin. BMI = body mass index, bpm = beats per minute, BSA = body surface area, HDL = high density lipoprotein, LDL = low density lipoprotein, Tchol = total cholesterol evidence of significant coronary arterial stenosis (> 50%) nor evidence of mitral/aortic valvular stenosis (including valve thickening, calcification, fusion of the cusps or leaflets) or valvular insufficiency (inadequate coaptation of valve cusps) (12). In total, 172 patients (107 men and 65 women; age, 58 ± 10.9 years; body surface area [BSA], 1.75 ± 0.17 $m^2$) who fulfilled the inclusion criteria were finally recruited. The general characteristics, co-morbidities (including hypertension and diabetes mellitus), lipid profiles, and history of smoking for all enrolled subjects were recorded and are summarized on Table 1. Our Institutional Ethics Committee approved this study, and written informed consent was waived.

### CT Acquisition and Analysis

All 172 CCTAs were performed using a 320-detector-row scanner (Aquilion ONE, Toshiba Medical Systems, Ottawa, Japan) with 320 x 0.5 mm collimation, 350-ms gantry rotation time, and 175-ms temporal resolution. For 55 examinations (31.9%), the tube voltage and current were modulated by the body mass index with the tube voltages set to either 100 kVp or 120 kVp and the tube current ranging from 400–550 mA. In the remaining 117 examinations (68.1%), the tube voltage and current were modulated using commercial software (Sure Exposure 3D®, Toshiba Medical Systems) with iterative reconstruction (AIDR 3D, Toshiba Medical Systems). The tube voltage was set to 120 kVp, and the tube current ranged from 130–250 mA. If the patient's heart rate exceeded 65 beats per minute (bpm), an oral beta blocking agent (30 mg propranolol hydrochloride, Pranol, Daewoong, Seoul, Korea) was administered 1 hour before CT, unless contraindicated. A bolus of 60–80 mL of nonionic contrast material (iobitridol, Xenetix® 350 mgI/mL, Guerbet, Paris, France) was intravenously administered at 4 mL/s, followed by 30 mL of a contrast-saline mixture (2:8 dilution) injected at 4 mL/s. The CT scans were initiated using automatic bolus triggering in the ascending aorta (the triggering level was 100 Hounsfield units) with a delay of 5 seconds. The CT images were produced with retrospective data acquisition using ECG-based tube current modulation and full tube current adapted according to the heart rate (70–80% to 30–80%). For some patients with rapid and irregular heart rates, the images were produced using multisegment reconstruction of 2 heartbeats according to the default value of the CT scanner. The axial images were reconstructed using images from the 75% cardiac phase or the automatically suggested 'best phase (ms)' to exclude coronary artery disease, while additional images to evaluate the LV functional parameters were reconstructed with increments of 10% from 0% to 90% of the RR interval. All data sets were transferred to a commercial software workstation (Vitrea FX, version 6.1, Vital images, Minnetonka, MN, USA) for post-processing.

Multi-planar reformation (MPR) images of each cardiac chamber (including short-axis, 4-chamber and 2-chamber views) were automatically generated by the software. The LV volumes were automatically calculated by thresholding the Hounsfield units in the volumetric dataset for all 10 phases of the reconstructive images, and the end-systolic and end-diastolic phases were defined as the smallest and largest LV volumes, respectively. The LV end-systolic volume (ESV, mL), end-diastolic volume (EDV, mL), stroke volume (SV [mL] = EDV - ESV), ejection fraction (EF [%] = SV x 100 / EDV), and cardiac output (CO [L/min] = heart rate x SV) were calculated (Fig. 1). The LV epicardial and endocardial contours were automatically indicated by the software with




A B

**Fig. 1. Measurements of left ventricular (LV) volume and myocardial mass.**
LV volumes were automatically calculated based on Hounsfield unit thresholding of volumetric dataset by using data from systolic **(A)** and diastolic **(B)** phases. LV myocardial mass was calculated on end-diastolic phase by using LV endocardial and epicardial contours that were semi automatically suggested by software.

Korean Journal of Radiology
KJR

the exclusion of papillary muscles. However, both contours could be modified by our experienced readers if considered necessary. These estimates were used to calculate the LV myocardial mass (g) ([epicardial volume - endocardial volume] x 1.04 g/mL) on the end-diastolic phase. All of the functional parameters, except EF, were normalized with BSA ($m^2$). An experienced radiologist measured the LV end-diastolic inner dimension (LVID, cm) on the 4-chamber MPR, LV wall thickness on the septum (septal wall thickness [SWT], cm) and posterior wall thickness (PWT, cm) on the short-axis MPR at the chorda level (Fig. 2); the relative wall thickness (RWT [cm] = 2 x PWT / LVID) was calculated as previously described (8, 13, 14). To assess the inter-observer variability, 20 randomly selected subjects were analyzed by two experienced radiologists. The products of the dose-length product were recorded using the CT system, and effective doses were calculated using a conversion coefficient for the chest (k = 0.014 mSv/[mGy·cm]) (15).

## Statistics

All estimated continuous variables were expressed using the mean ± standard deviation, and categorical variables were expressed in terms of frequency using percentages. The inter-observer agreement was analyzed using the intraclass coefficient. To compare the sex-related differences, independent *t* tests were performed for continuous variables according to the results produced by the Kolmogorov-Smirnov test and $\chi^2$ tests for categorical variables. The correlations between the LV parameters and the clinical characteristics with continuous variables (including age, height, weight, BSA, total cholesterol, etc.) were analyzed using Pearson's linear regression and $\chi^2$ tests for categorical variables (hypertension, diabetes mellitus, and smoking). A correlation coefficient of less than 0.20 is very weak, 0.20 to 0.39 is weak, 0.40 to 0.59 is moderate, 0.60 to 0.79 is strong and 0.80 or greater indicates a very strong correlation (16). SPSS version 21.0 (SPSS Inc.,

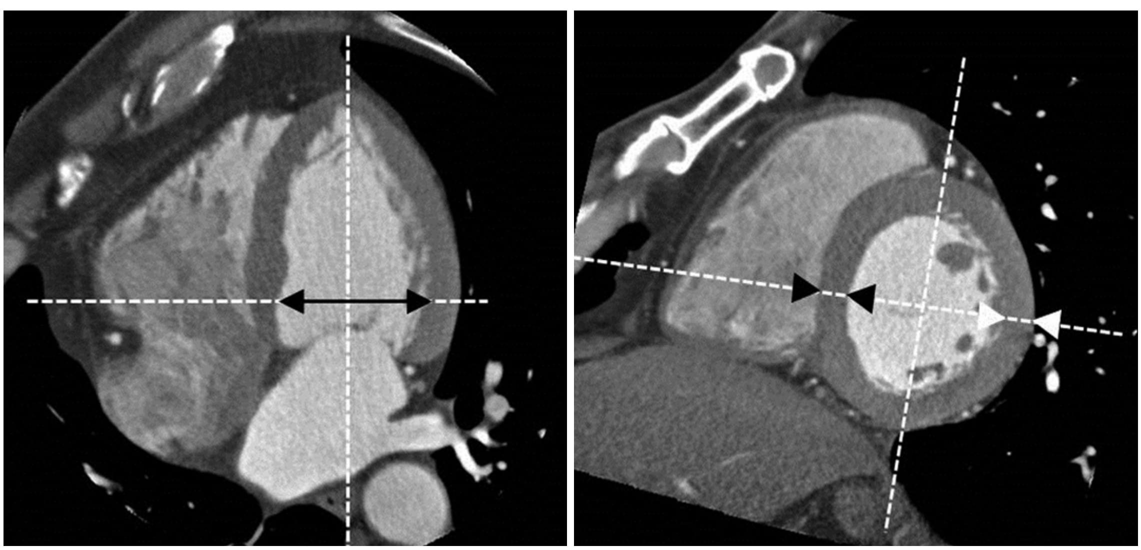

A B

**Fig. 2. Measurements of LV dimension and wall thickness at end-diastolic phase.**
**A.** LV inner dimension was measured on 4-chamber MPR at chorda level (black arrow). **B.** LV wall thickness on septum (SWT, black arrowheads) and posterior wall (PWT, white arrowheads) were measured on short-axis MPR at chorda level. LV = left ventricular, MPR = multiplanar reformation, PWT = posterior wall thickness, SWT = septal wall thickness

**Table 2. Intraclass Correlation Coefficients of 20 Randomly Selected Subjects for Inter-Observer Variability**

| | Observer I | Observer II | ICC (95% CI) |
|---|---|---|---|
| LV EDV (mL) | 108.6 ± 22.8 | 107.8 ± 21.8 | 0.989 (0.972–0.996) |
| LV ESV (mL) | 40.5 ± 18.7 | 41.4 ± 17.5 | 0.912 (0.791–0.964) |
| LV mass (g) | 145.1 ± 55.1 | 144.5 ± 54.6 | 0.999 (0.998–1.000) |
| LV ID (cm) | 5.0 ± 0.51 | 5.0 ± 0.54 | 0.962 (0.906–0.985) |
| SWT (cm) | 1.00 ± 0.24 | 1.03 ± 0.27 | 0.942 (0.860–0.977) |
| PWT (cm) | 0.88 ± 0.16 | 0.88 ± 0.17 | 0.941 (0.857–0.976) |

Data are expressed as mean ± SD. CI = confidence interval, EDV = end-diastolic volume, ESV = end-systolic volume, ICC = intraclass correlation coefficients, ID = inner diameter, LV = left ventricle, PWT = posterior wall thickness, SWT = septal wall thickness

Chicago, IL, USA) was used for the statistical analyses, and $p$ values lower than 0.05 were considered to be statistically significant.

## RESULTS

All CCTAs were successfully performed without any complications, and the quality of the images was suitable to determine the presence or absence of coronary artery disease. The overall mean effective dose of CCTA for each subject (including calcium score CT) was 5.8 ± 1.6 mSv (range: 2.6–12.4 mSv). The inter-observer agreements for the LV dimension, LV volume, and mass were consistently excellent (intraclass correlation coefficient range: 0.912–0.999) (Table 2).

### Overall Values and Influence of Sex on LV Volume and Functional Parameters

The overall mean values and sex-related differences in terms of the LV dimension, volume, mass and functional parameters are summarized in Table 3. The LV inner diameter (ID) did not show any sex-related differences (LV ID, 4.8 ± 0.53 cm vs. 4.8 ± 0.57 cm, $p$ = 0.819). However, the measurements of the LV myocardial thickness (including SWT, PWT, and RWT) showed significantly higher values in men than in women (SWT, 1.08 ± 0.18 cm vs. 0.90 ± 0.17 cm, $p$ < 0.001; PWT, 0.91 ± 0.15 cm vs. 0.78 ± 0.10 cm, $p$ < 0.001; RWT, 0.38 ± 0.08 cm vs. 0.33 ± 0.05 cm, $p$ < 0.001). The absolute values of the LV volume (EDV, 112.9 ± 26.1 mL vs. 98.2 ± 21.0 mL, $p$ < 0.001; ESV, 41.7 ± 14.7 mL vs. 33.7 ± 12.2 mL, $p$ = 0.001), SV (71.4 ± 18.2 mL vs. 64.9 ± 15.1 mL, $p$ = 0.017), and mass (145.0 ± 29.1 g vs. 107.9 ± 20.0 g, $p$ < 0.001), were significantly higher in men than in women. However, the differences in the LV volume and SV were not significant after the values had been normalized using BSA. In contrast, a significant difference was still observed in the normalized LV mass (LV MI, 79.6 ± 14.0 g/m$^2$ vs. 66.2 ± 11.0 g/m$^2$, $p$ < 0.001). The CO (4.3 ± 1.0 L/min vs. 4.2 ± 0.9 L/min, $p$ = 0.452) and EF (63.4 ± 7.7% vs. 66.4 ± 7.6%, $p$ = 0.079) were not significantly different between men and women. The percentiles for the LV parameters are shown for men in Table 4 and for women in Table 5.

### Influence of the Subject's Body Frame on the LV Volume and Functional Parameters

The LV dimensions (LV ID, SWT, PWT, and RWT) were all positively correlated with BSA and body weight. However, although the parameters for the LV thickness (SWT, PWT, and RWT) were positively correlated with height, the LV ID showed no correlation ($r$ = 0.08, $p$ = 0.311) (Table 6).

**Table 3. Left Ventricular Dimension, Volume and Functional Parameters of Study Subjects**

| | Total (n = 172) | Men (n = 107) | Women (n = 65) | *P* |
|---|---|---|---|---|
| LV dimension (cm) | | | | |
| LV ID | 4.8 ± 0.52 | 4.8 ± 0.53 | 4.8 ± 0.57 | 0.819 |
| SWT | 1.01 ± 0.20 | 1.08 ± 0.18 | 0.90 ± 0.17 | 0.000 |
| PWT | 0.86 ± 0.15 | 0.91 ± 0.15 | 0.78 ± 0.10 | 0.000 |
| RWT | 0.36 ± 0.07 | 0.38 ± 0.08 | 0.33 ± 0.05 | 0.000 |
| LV volume | | | | |
| LV EDV (mL) | 107.3 ± 25.3 | 112.9 ± 26.1 | 98.2 ± 21.0 | 0.000 |
| LV EDVI (mL/m$^2$) | 61.4 ± 12.8 | 62.2 ± 13.9 | 60.3 ± 10.9 | 0.348 |
| LV ESV (mL) | 38.7 ± 14.3 | 41.7 ± 14.7 | 33.7 ± 12.2 | 0.001 |
| LV ESVI (mL/m$^2$) | 22.2 ± 8.1 | 23.0 ± 8.3 | 20.8 ± 7.5 | 0.085 |
| LV mass (g) | 130.9 ± 31.6 | 145.0 ± 29.1 | 107.9 ± 20.0 | 0.000 |
| LV MI (g/m$^2$) | 74.6 ± 14.4 | 79.6 ± 14.0 | 66.2 ± 11.0 | 0.000 |
| LV function | | | | |
| SV (mL) | 69.0 ± 17.3 | 71.4 ± 18.2 | 64.9 ± 15.1 | 0.017 |
| SI (mL/m$^2$) | 39.5 ± 8.8 | 39.3 ± 9.4 | 39.8 ± 7.7 | 0.695 |
| CO (L/min) | 4.3 ± 1.0 | 4.3 ± 1.0 | 4.2 ± 0.9 | 0.452 |
| CI (L/min/m$^2$) | 2.5 ± 0.5 | 2.4 ± 0.5 | 2.5 ± 0.5 | 0.542 |
| EF (%) | 64.5 ± 7.7 | 63.4 ± 7.7 | 66.4 ± 7.6 | 0.079 |

Data are expressed as mean ± SD. CI = cardiac index, CO = cardiac output, EDV = end-diastolic volume, EDVI = end-diastolic volume index, EF = ejection fraction, ESV = end-systolic volume, ESVI = end-systolic volume index, ID = inner diameter, LV = left ventricle, MI = mass index, PWT = posterior wall thickness, RWT = relative wall thickness, SI = stroke index, SV = stroke volume, SWT = septal wall thickness

Korean Journal of Radiology KJR

The LV volumetric parameters (LV EDV and LV ESV) were also positively correlated with height, weight, and BSA, but none of these parameters were correlated with height and weight after normalization with BSA. The LV mass showed a moderate to strong positive correlation with height ($r$ = 0.57), weight ($r$ = 0.57), and BSA ($r$ = 0.62), even after normalization with BSA (LV MI, $p$ < 0.001). The LV functional parameters (SV and CO) were both positively

**Table 4. Percentiles for Left Ventricular Parameters in Men**

| | 2.5th | 10th | 25th | 50th | 75th | 90th | 97.5th |
|---|---|---|---|---|---|---|---|
| LV dimension (cm) | | | | | | | |
| LV ID | 3.7 | 4.2 | 4.5 | 4.8 | 5.0 | 5.6 | 5.8 |
| SWT | 0.7 | 0.9 | 0.9 | 1.1 | 1.2 | 1.3 | 1.4 |
| PWT | 0.6 | 0.7 | 0.8 | 0.9 | 1 | 1.1 | 1.3 |
| RWT | 0.24 | 0.29 | 0.33 | 0.38 | 0.42 | 0.49 | 0.59 |
| LV volume | | | | | | | |
| LV EDV (mL) | 56 | 77 | 94 | 112 | 132 | 138 | 161 |
| LV EDVI (mL/m$^2$) | 31.1 | 44.0 | 53.2 | 63.5 | 72.0 | 78.9 | 87.5 |
| LV ESV (mL) | 19 | 25 | 32 | 40 | 51 | 56 | 71 |
| LV ESVI (mL/m$^2$) | 10.6 | 13.2 | 17.4 | 22.2 | 27.4 | 30.6 | 37.4 |
| LV mass (g) | 98 | 112 | 122 | 145 | 161 | 178 | 207 |
| LV MI (g/m$^2$) | 54.4 | 62.6 | 70.0 | 79.5 | 86.5 | 95.0 | 121.8 |
| LV function | | | | | | | |
| SV (mL) | 39 | 56 | 63 | 70 | 85 | 96 | 106 |
| SI (mL/m$^2$) | 22.9 | 26.3 | 31.8 | 39.0 | 47.2 | 51.8 | 57.0 |
| CO (L/min) | 2.4 | 3.2 | 3.6 | 4.2 | 5.0 | 5.8 | 6.3 |
| CI (L/min/m$^2$) | 1.4 | 1.8 | 2.0 | 2.4 | 2.7 | 3.1 | 3.5 |
| EF (%) | 47 | 54 | 58 | 64 | 69 | 73 | 77 |

CI = cardiac index, CO = cardiac output, EDV = end-diastolic volume, EDVI = end-diastolic volume index, EF = ejection fraction, ESV = end-systolic volume, ESVI = end-systolic volume index, ID = inner diameter, LV = left ventricle, MI = mass index, PWT = posterior wall thickness, RWT = relative wall thickness, SI = stroke index, SV = stroke volume, SWT = septal wall thickness

**Table 5. Percentiles for Left Ventricular Parameters in Women**

| | 2.5th | 10th | 25th | 50th | 75th | 90th | 97.5th |
|---|---|---|---|---|---|---|---|
| LV dimension (cm) | | | | | | | |
| LV ID | 3.8 | 4.2 | 4.5 | 4.8 | 5.0 | 5.3 | 6.0 |
| SWT | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | 1.1 | 1.3 |
| PWT | 0.6 | 0.6 | 0.7 | 0.8 | 0.8 | 0.9 | 1.0 |
| RWT | 0.21 | 0.26 | 0.29 | 0.32 | 0.36 | 0.39 | 0.44 |
| LV volume | | | | | | | |
| LV EDV (mL) | 63 | 74 | 83 | 98 | 109 | 123 | 139 |
| LV EDVI (mL/m$^2$) | 39.4 | 47.2 | 51.9 | 60.6 | 67.3 | 75.0 | 81.8 |
| LV ESV (mL) | 13 | 20 | 25 | 33 | 40 | 47 | 71 |
| LV ESVI (mL/m$^2$) | 8.1 | 11.4 | 15.3 | 20.6 | 25.0 | 31.3 | 35.5 |
| LV mass (g) | 76 | 80 | 93 | 107 | 117 | 133 | 154 |
| LV MI (g/m$^2$) | 48.9 | 53.5 | 57.2 | 65.9 | 71.9 | 81.3 | 87.5 |
| LV function | | | | | | | |
| SV (mL) | 36 | 49 | 54 | 63 | 74 | 84 | 99 |
| SI (mL/m$^2$) | 21.2 | 32.5 | 33.9 | 39.4 | 44.3 | 49.5 | 54.7 |
| CO (L/min) | 2.8 | 3.1 | 3.6 | 4.1 | 4.6 | 5.5 | 6.9 |
| CI (L/min/m$^2$) | 1.8 | 1.9 | 2.2 | 2.6 | 2.8 | 3.3 | 3.8 |
| EF (%) | 55 | 56 | 61 | 66 | 72 | 77 | 83 |

CI = cardiac index, CO = cardiac output, EDV = end-diastolic volume, EDVI = end-diastolic volume index, EF = ejection fraction, ESV = end-systolic volume, ESVI = end-systolic volume index, ID = inner diameter, LV = left ventricle, MI = mass index, PWT = posterior wall thickness, RWT = relative wall thickness, SI = stroke index, SV = stroke volume, SWT = septal wall thickness correlated with height, weight, and BSA, although neither were correlated height and weight after normalization with BSA. The cardiac index (CI) and EF showed no correlation with any of the parameters.

### Influence of Clinical Characteristics on LV Volume and Functional Parameters

The total Agatston score showed a weak positive correlation ($r$ = 0.16–0.26) with PWT, RWT, LV EDV, LV EDV index (LV EDVI), and both LV mass and LV MI. In contrast, the total Agatston score did not correlate with either LV ESV or other LV functional parameters (including SV, stroke index [SI], CO, CI, and EF). The total cholesterol was negatively correlated with LV ID, LV EDV, LV EDVI, SV, and SI, but the correlation coefficient was negligibly weak (absolute values of $r < 0.2$). Age, hypertension, diabetes and history of smoking did not show a correlation with any of the LV parameters.

## DISCUSSION

Measuring the LV mass and functional LV parameters plays an important role in both the diagnosis of cardiovascular disease and in the subsequent therapeutic determinations (17). Echocardiography has been extensively used in clinical practice as a primary, non-invasive tool to determine the functional LV parameters. However, operator dependency and a limited acoustic window may result in poor reproducibility in certain cases (18, 19). Cardiac MRI is now considered as the gold standard to assess the LV parameters, but its use is limited due to the relatively high cost, long scan times, and incompatibility for patients with claustrophobia or with ferromagnetic metal devices. Thus, CCTA may be an alternative method for functional LV assessment with a simultaneous evaluation of the coronary artery.

Chang et al. (20) used the steady-state free precession sequence on cardiac MRI to propose normal reference values for the right and left ventricular parameters in healthy Korean volunteers. Although the absolute and normalized index values for all LV volumes were larger when compared to those reported in our results, the LV mass and LV MI were significantly smaller than the values reported in our results (Table 7). These discrepancies may be due to the difference in the modality and differences in the measurement method, such as the exclusion or inclusion of the papillary muscle in the cardiac chamber. In addition, Chang et al. (20) used a sample with a wide

**Table 6. Influence of Clinical Characteristics on Left Ventricular Parameters**

| | Height | | Weight | | BSA | | Age | | Cholesterol | | Agatston Score | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *r* | *P* | *r* | *P* | *r* | *P* | *r* | *P* | *r* | *P* | *r* | *P* |
| LV dimension | | | | | | | | | | | | |
| LV ID | 0.08 | 0.311 | 0.26 | 0.001 | 0.23 | 0.003 | 0.131 | 0.087 | -0.18 | 0.023 | 0.12 | 0.155 |
| SWT | 0.38 | 0.000 | 0.55 | 0.000 | 0.52 | 0.000 | 0.146 | 0.056 | -0.06 | 0.466 | 0.15 | 0.059 |
| PWT | 0.38 | 0.000 | 0.36 | 0.000 | 0.39 | 0.000 | 0.035 | 0.648 | -0.10 | 0.203 | 0.26 | 0.001 |
| RWT | 0.29 | 0.000 | 0.18 | 0.019 | 0.23 | 0.003 | -0.054 | 0.484 | 0.01 | 0.851 | 0.16 | 0.050 |
| LV volume | | | | | | | | | | | | |
| LV EDV | 0.33 | 0.000 | 0.39 | 0.000 | 0.41 | 0.000 | -0.074 | 0.332 | -0.17 | 0.032 | 0.18 | 0.027 |
| LV EDVI | 0.01 | 0.917 | 0.01 | 0.884 | -0.00 | 0.953 | -0.079 | 0.302 | -0.18 | 0.024 | 0.17 | 0.035 |
| LV ESV | 0.26 | 0.001 | 0.18 | 0.017 | 0.23 | 0.003 | -0.133 | 0.083 | -0.10 | 0.233 | 0.06 | 0.458 |
| LV ESVI | 0.06 | 0.455 | -0.06 | 0.437 | -0.04 | 0.621 | -0.148 | 0.052 | -0.10 | 0.228 | 0.03 | 0.686 |
| LV mass | 0.57 | 0.000 | 0.57 | 0.000 | 0.62 | 0.000 | 0.059 | 0.444 | -0.11 | 0.159 | 0.21 | 0.010 |
| LV MI | 0.32 | 0.000 | 0.26 | 0.000 | 0.27 | 0.000 | 0.126 | 0.166 | -0.13 | 0.103 | 0.23 | 0.005 |
| LV function | | | | | | | | | | | | |
| SV | 0.27 | 0.000 | 0.41 | 0.000 | 0.41 | 0.000 | -0.009 | 0.906 | -0.18 | 0.024 | 0.20 | 0.012 |
| SI | -0.04 | 0.585 | 0.06 | 0.451 | 0.02 | 0.824 | 0.007 | 0.928 | -0.19 | 0.018 | 0.21 | 0.011 |
| CO | 0.18 | 0.020 | 0.30 | 0.000 | 0.30 | 0.000 | -0.031 | 0.688 | -0.02 | 0.764 | 0.12 | 0.144 |
| CI | -0.18 | 0.057 | -0.10 | 0.213 | -0.14 | 0.059 | -0.020 | 0.793 | -0.00 | 0.960 | 0.11 | 0.177 |
| EF | -0.11 | 0.145 | 0.04 | 0.611 | -0.00 | 0.991 | 0.152 | 0.056 | -0.03 | 0.747 | 0.08 | 0.316 |

BSA = body surface area, CI = cardiac index, CO = cardiac output, EDV = end-diastolic volume, EDVI = end-diastolic volume index, EF = ejection fraction, ESV = end-systolic volume, ESVI = end-systolic volume index, ID = inner diameter, LV = left ventricle, MI = mass index, PWT = posterior wall thickness, RWT = relative wall thickness, SI = stroke index, SV = stroke volume, SWT = septal wall thickness

Korean Journal of Radiology
KJR

**Table 7. Summary Data from Previously Published Manuscripts and from Present Study**

| | Chang et al. (20) | Stolzmann et al. (8) | Present Study |
|---|---|---|---|
| Image modality | MR | CT | CT |
| Country | Korea | United States | Korea |
| Men | | | |
| LV EDV (mL) | 138 (133–144) | 144 (106–152) | 118 (93–143) |
| LV EDVI (mL/m$^2$) | 76 (72–78) | - | 65 (52–78) |
| LV ESV (mL) | 49 (45–52) | 47 (28–66) | 42 (26–58) |
| LV ESVI (mL/m$^2$) | 26 (25–28) | - | 23 (14-32) |
| LV mass (g) | 103 (99–107) | 167 (129–205) | 146 (114–178) |
| LV MI (g/m$^2$) | 57 (54–58) | 86 (68–104) | 79 (61–97) |
| EF (%) | 65 (64–67) | 66 (57–75) | 65 (57–73) |
| Women | | | |
| LV EDV (mL) | 114 (110–119) | 115 (108–122) | 98 (78–118) |
| LV EDVI (mL/m$^2$) | 76 (72–78) | - | 61 (51–71) |
| LV ESV (mL) | 39 (36–41) | 40 (28–52) | 32 (23–41) |
| LV ESVI (mL/m$^2$) | 26 (25–28) | - | 20 (15–25) |
| LV mass (g) | 72 (69–75) | 129 (100–158) | 104 (87–121) |
| LV MI (g/m$^2$) | 46 (44–47) | 68 (55–81) | 64 (55–73) |
| EF (%) | 66 (65–68) | 66 (59–73) | 68 (61–75) |

Data are expressed as mean (95% confidence interval). EDV = end-diastolic volume, EDVI = end-diastolic volume index, EF = ejection fraction, ESV = end-systolic volume, ESVI = end-systolic volume index, LV = left ventricle, MI = mass index

range of ages (20–70 years) and also included the same number of subjects from each age decade. In contrast, the present study included a large proportion of middle- to old-aged subjects whose details matched the clinical needs of this retrospective study. Since aging is associated with a smaller ventricular volume, the observed difference in age range may account for the difference in the LV volume (11, 20, 21). Stolzmann et al. (8) reported reference normal absolute values for LV from CCTA for a single center in the United States, and the mean values of LV EDV, LV ESV, and mass reported in that study were larger than our results for both sexes. In particular, the LV mass was significantly larger, even after normalization with BSA. The differences between the volumetric parameters they reported and those presented in this study are assumed to be associated with ethnic differences.

As in previous studies (8-11, 20, 21), we observed significant sex-related differences in LV thickness, volume, and mass. These sex-related differences were then eliminated in several of the parameters (LV EDV, LV ESV, and SV) after normalization with BSA. However, the LV mass was significantly larger in men, even after normalization (LV MI). Again, these results are broadly in agreement with those of prior studies. In our study, the mean Agatston score was also significantly higher in the male subjects than in the female subjects. Since the total Agatston score showed a weak positive correlation with LV MI ($r = 0.23$, $p = 0.005$), the Agatston score is speculated to act as a confounding factor.

Our study also comprised the same two-dimensional (2D) measurements of the LV (including LV ID, SWT, and PWT) that are usually reported via echocardiography (13, 14). These measurements are easy to perform in clinical practice using CCTA. The SWT and PWT values were positively correlated with the height, weight, and BSA of the subjects, while the LV ID was correlated with the weight and BSA only (no correlation with height). The LV ID is an axial 2D value that does not take into account the long length of the LV axis of each subject. We assume that the diameter of the long LV axis may be correlated with the subject height. The absolute values of our data (LV ID, SWT, PWT, and RWT) are similar to those obtained from previously published studies using CCTA, echocardiography, or MRI (8, 13, 21).

The influence of body habitus (height, weight, and BSA) of each subject on LV volume, SV and CO was consistent with our expectations. However, there was no significant correlation between co-morbidities (hypertension, total cholesterol, diabetes, and history of smoking) and LV parameters. Since high-risk patients may have been excluded as a result of our study design (i.e., such subjects did not meet the inclusion criteria), the actual relationship between the co-morbidities and the LV parameters cannot be defined with absolute certainty. As noted earlier, a significant correlation between the Agatston score and the LV parameters was observed. The Agatston score showed a positive correlation with the LV thickness, volume, and mass, and these results are consistent with a previously published study by Tong et al. (22) using echocardiography. The authors demonstrated that the calcium score and the extent of the left ventricular hypertrophy were significantly correlated. Finally, EF and CI showed no correlation with any of the clinical characteristics, suggesting that the systolic function is preserved with various statuses in each subject.

This study has some limitations that deserve consideration. First, the number of subjects that were included was relatively small, and this may influence the statistical significance. Second, this is a retrospective study based on medical charts of the subjects, so some bias may have occurred during data collection. Third, subjects with co-morbidities, such as hypertension, diabetes, hyperlipidemia, etc., were included in our study population. We considered these clinical characteristics to be relatively common diseases that are associated with the aging process. Therefore, a consideration of these factors may produce more reliable data that accurately represents the general population. Moreover, our results showed that the included co-morbidities had little influence on the LV parameters (demonstrated statistically negligible correlation coefficients). Fourth, the beta-adrenergic receptor blocker was selectively administered when the subject's heart rate was over 65 bpm, which may influence the functional LV parameters. Mo et al. (23) reported that propranolol will increase the LV ESV, contributing to a decreased EF, while LV EDV does not change statistically. However, administering the beta-blocker before CCTA acquisition is still common for patients with a fast heartbeat when evaluating coronary arteries. Therefore, we thought our study design properly reflects real LV parameters for CCTA in clinical practice. Fifth, most of our subjects did not have a prior echocardiography, and thus, the cardiac valvular statement is uncertain. However, we excluded mitral/aortic valvular abnormality based on the CCTA findings during the inclusion phase for the study population (12).

In the present study, we have provided the mean values for the LV dimension, volume, mass, and functional parameters for normal Korean adult subjects (including a consideration of sex-related difference). In addition, we have also separately provided the percentiles of all LV parameters for both sexes. This is the first study to date to attempt to determine the normal reference values of LV parameters on CCTA in an Asian population.

## REFERENCES

1. Raff GL, Gallagher MJ, O'Neill WW, Goldstein JA. Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. *J Am Coll Cardiol* 2005;46:552-557
2. Kim YJ, Yong HS, Kim SM, Kim JA, Yang DH, Hong YJ, et al. Korean guidelines for the appropriate use of cardiac CT. *Korean J Radiol* 2015;16:251-285
3. Lin FY, Min JK. Assessment of cardiac volumes by multidetector computed tomography. *J Cardiovasc Comput Tomogr* 2008;2:256-262
4. Mahnken AH, Bruners P, Schmidt B, Bornikoel C, Flohr T, Günther RW. Left ventricular function can reliably be assessed from dual-source CT using ECG-gated tube current modulation. *Invest Radiol* 2009;44:384-389
5. Juergens KU, Grude M, Maintz D, Fallenberg EM, Wichter T, Heindel W, et al. Multi-detector row CT of left ventricular function with dedicated analysis software versus MR imaging: initial experience. *Radiology* 2004;230:403-410
6. Raman SV, Shah M, McCarthy B, Garcia A, Ferketich AK. Multi-detector row cardiac computed tomography accurately quantifies right and left ventricular size and function compared with cardiac magnetic resonance. *Am Heart J* 2006;151:736-744
7. Asferg C, Usinger L, Kristensen TS, Abdulla J. Accuracy of multi-slice computed tomography for measurement of left ventricular ejection fraction compared with cardiac magnetic resonance imaging and two-dimensional transthoracic echocardiography: a systematic review and meta-analysis. *Eur J Radiol* 2012;81:e757-e762
8. Stolzmann P, Scheffel H, Leschka S, Schertler T, Frauenfelder T, Kaufmann PA, et al. Reference values for quantitative left ventricular and left atrial measurements in cardiac computed tomography. *Eur Radiol* 2008;18:1625-1634
9. Lin FY, Devereux RB, Roman MJ, Meng J, Jow VM, Jacobs A, et al. Cardiac chamber volumes, function, and mass as determined by 64-multidetector row computed tomography: mean values among healthy adults free of hypertension and obesity. *JACC Cardiovasc Imaging* 2008;1:782-786
10. Gardin JM, Wagenknecht LE, Anton-Culver H, Flack J, Gidding S, Kurosaki T, et al. Relationship of cardiovascular risk factors to echocardiographic left ventricular mass in healthy young black and white adult men and women. The CARDIA study. Coronary Artery Risk Development in Young Adults. *Circulation* 1995;92:380-387
11. Natori S, Lai S, Finn JP, Gomes AS, Hundley WG, Jerosch-Herold M, et al. Cardiovascular function in multi-ethnic study of atherosclerosis: normal values by age, sex, and ethnicity. *AJR Am J Roentgenol* 2006;186(6 Suppl 2):S357-S365

12. Chen JJ, Manning MA, Frazier AA, Jeudy J, White CS. CT angiography of the cardiac valves: normal, diseased, and postoperative appearances. *Radiographics* 2009;29:1393-1412
13. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, et al. Recommendations for chamber quantification. *Eur J Echocardiogr* 2006;7:79-108
14. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2015;16:233-270
15. Christner JA, Kofler JM, McCollough CH. Estimating effective dose for CT using dose-length product compared with using organ doses: consequences of adopting International Commission on Radiological Protection publication 103 or dual-energy scanning. *AJR Am J Roentgenol* 2010;194:881-889
16. Evans JD. *Straightforward statistics for the behavioral sciences*. Pacific Grove: Brooks/Cole Publishing, 1996
17. Nham E, Kim SM, Lee SC, Chang SA, Sung J, Cho SJ, et al. Association of cardiovascular disease risk factors with left ventricular mass, biventricular function, and the presence of silent myocardial infarction on cardiac MRI in an asymptomatic population. *Int J Cardiovasc Imaging* 2016;32 Suppl 1:173-181
18. Bernard Y, Meneveau N, Boucher S, Magnin D, Anguenot T, Schiele F, et al. Lack of agreement between left ventricular volumes and ejection fraction determined by two-dimensional echocardiography and contrast cineangiography in postinfarction patients. *Echocardiography* 2001;18:113-122
19. Picard MH, Popp RL, Weyman AE. Assessment of left ventricular function by echocardiography: a technique in evolution. *J Am Soc Echocardiogr* 2008;21:14-21
20. Chang SA, Choe YH, Jang SY, Kim SM, Lee SC, Oh JK. Assessment of left and right ventricular parameters in healthy Korean volunteers using cardiac magnetic resonance imaging: change in ventricular volume and function based on age, gender and body surface area. *Int J Cardiovasc Imaging* 2012;28 Suppl 2:141-147
21. Sandstede J, Lipke C, Beer M, Hofmann S, Pabst T, Kenn W, et al. Age- and gender-specific differences in left and right ventricular cardiac function and mass determined by cine magnetic resonance imaging. *Eur Radiol* 2000;10:438-442
22. Tong W, Lima JA, Lai H, Celentano DD, Dai S, Lai S. Relation of coronary artery calcium to left ventricular mass in African-Americans. *Am J Cardiol* 2004;93:490-492
23. Mo YH, Jaw FS, Wang YC, Jeng CM, Peng SF. Effects of propranolol on the left ventricular volume of normal subjects during CT coronary angiography. *Korean J Radiol* 2011;12:319-326