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Effect of papillary muscle and trabeculae on left ventricular function analysis via computed tomography

A cross-sectional study

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Abstract

Deciding whether to include or exclude the papillary muscles and trabeculae to blood pool is essential, because quantifications of left ventricular (LV) functional parameters and myocardial mass are significantly affected. As a result, such inclusion or exclusion might produce different indices for diagnosis and therapy. Using cardiac computed tomography (CT), we obtained standard values of the portion of papillary muscle and trabeculae in normal adults, and to find out how the inclusion or exclusion of papillary muscle and trabeculae affect LV functional parameters depending on the patient group. Excluding the papillary muscles from the LV mass results in easier automated contour detection using CT. The percentage portions of papillary muscle and trabeculae to LV end-diastolic volume (EDV) and LV mass (LVM) were 11.9 ± 5.6% and 20.2 ± 4.3%, respectively, significantly affecting disease diagnosis. Imaging should be consistent at follow-up and include or exclude the papillary muscles and trabeculae to avoid introducing significant differences between measurements.

Abbreviations: BV = Threshold-based blood volume method, CMR = Cardiac MR, CT = computed tomography, DCMP = dilated cardiomyopathy, EF = ejection fraction, HCMP = hypertrophic cardiomyopathy, LV = left ventricle, LVEDV = LV end-diastolic volume, LVEDVI = LVEDV index, LVEF = LV ejection fraction, LVESV = LV end-systolic volume, LVESVI = LVESV index, LVM = LV mass, LVMI = LV mass index, MI = myocardial infarction, ST = standard method.

Keywords: adult, cardiac CT, left ventricular function, papillary muscles

1. Introduction

When quantifying left ventricular (LV) functional parameters and LV mass (LVM), the Simpson method includes the papillary muscles and trabeculae in the LV blood pool. By contrast, the threshold-based method automatically excludes the papillary muscles and trabeculae from the LV blood pool. Deciding whether to include or exclude the papillary muscles and trabeculae is essential because it significantly affects the quantification results. Inclusion or exclusion might produce different indices for diagnosis and therapy.

Cardiac magnetic resonance (CMR) imaging is the standard reference for measuring LV volume and ejection fraction (EF). However, its use is limited because of its high cost and limited availability. It is also unportable, has a long procedure time, is impractical for patients with claustrophobia, has reduced accuracy in cases of arrhythmias, and cannot image patients with implanted devices that are not MRI compatible (including some pacemakers or implanted defibrillators).[1,2]

Nowadays, cardiac computed tomography (CT) is increasingly used to evaluate coronary arteries and cardiovascular diseases. Compared to other modalities, including CMR and echocardiography, CT primary advantage is that it can provide a complete evaluation of the heart, including the cardiac anatomy, coronary arteries, and functional cardiac parameters, in a relatively short time.[3] Furthermore, it has shown a good correlation with CMR for assessing LV volumes and EF.[4]

This study aimed to obtain standard values of the portion of papillary muscles and trabeculae in normal adults and ascertain how including or excluding them in quantification methods may affect LV functional parameters depending on patient group.

2. Methods

2.1. Patient population

From September 2019 to March 2022, 288 normal controls were collected by balancing age and sex from cardiac CTs performed during a health check (Fig. 1A).

The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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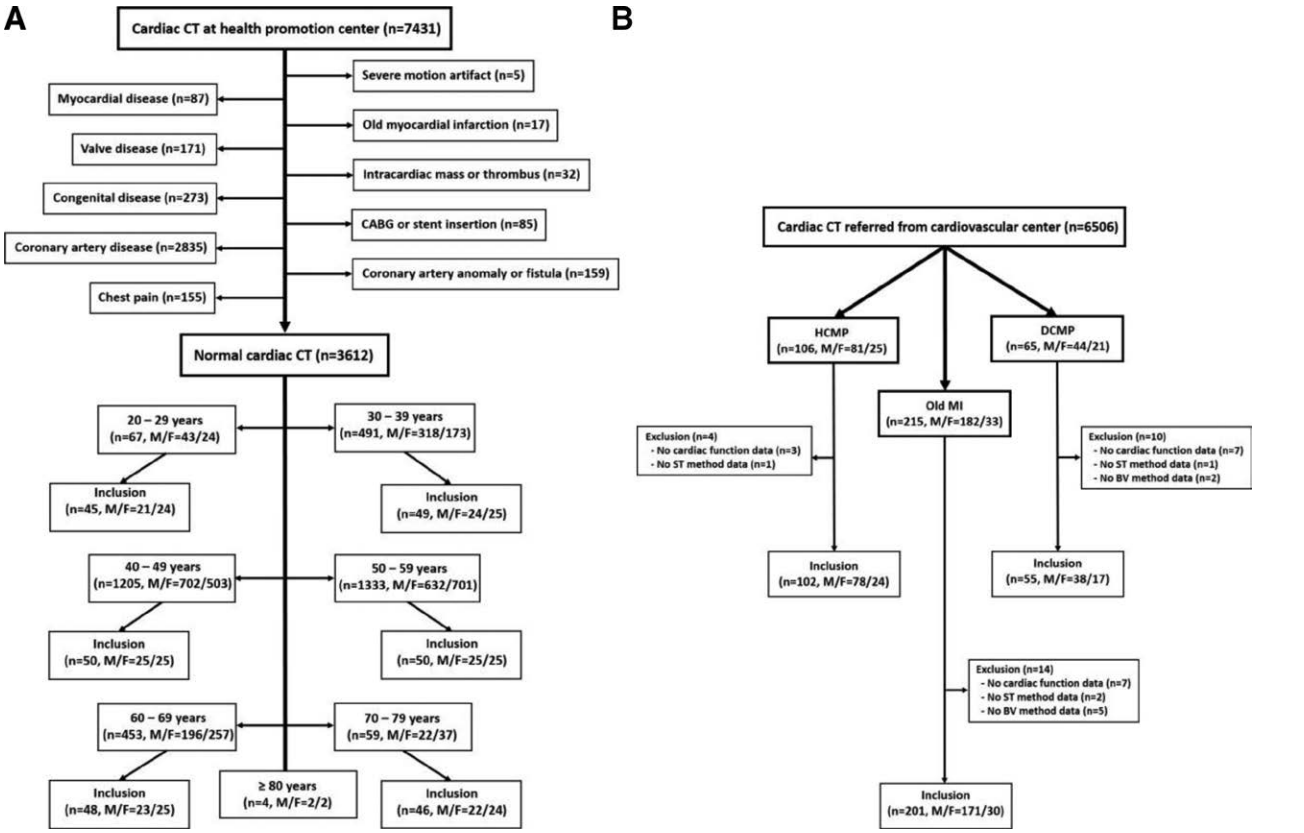

Figure 1. Flow diagram for selection of normal control group (A) and patent group (B). In our health promotion center, 7431 people underwent cardiac CT, of which 3612 cases were normal cardiac CT, except for cases with any cardiac diseases. Finally, 288 normal controls were selected by balancing age and sex. Medical records of 6506 patients who were referred from our cardiovascular center and underwent cardiac CT were evaluated to extract patients diagnosed with HCMP, DCMP, and old MI. Among them, the rest of the patients were included in the study, except for patients whose cardiac function test using CT was omitted. BV = blood volume, CABG = coronary artery bypass grafting, CT = computed tomography, DCMP = dilated cardiomyopathy, F = female, HCMP = hypertrophic cardiomyopathy, M = male, MI = myocardial infarction, ST = standard.

Among the patients who underwent cardiac CT during the same period, 102 hypertrophic cardiomyopathy (HCMP) patients, 55 dilated cardiomyopathy (DCMP) patients, and 201 old myocardial infarction (MI) patients were included in the patient group (Fig. 1B).

The study was approved by the Institutional Review Board of Ajou University Hospital (AJOUIRB-MDB-2022-160). All data were de-identified and used only for this retrospective study.

2.2. Cardiac CT acquisition

Image acquisition was performed using a dual-source 128-slice CT (Somatom IV line accessed in the vein. Definition FLASH, Siemens Healthcare, Forchheim, Germany) and a 192-slice CT (Somatom Force, Siemens Healthcare, Forchheim, Germany). If the patient heart rate exceeded 70 bpm, an oral beta-blocker (Betaloc Tab. 100mg, Yuhan, Seoul, Korea) was taken 1 hour before the examination to lower the heart rate, unless contraindicated. Intravenous line was accessed in the patient antecubital vein using 18G or larger catheters. The patient lay on the scanner table in the supine position with lifting both arms above the shoulders. The ECG lead was attached outside the scan range and the patient was educated about on how to hold his breath and exhale during scanning. To ensure a good assessment of the coronary arteries, all patients were given sublingual nitroglycerin (Nitroglycerin Sublingual Tab. 0.6 mg, Hana, Seoul, Korea) immediately before scanning, unless contraindicated. The cardiac CTs were acquired using the retrospective ECG-gating spiral scan protocol and the following parameters: a detector collimation of 128 × 0.6 mm or 192 × 0.6 mm, a 280 msec or 250 msec gantry rotation, a temporal resolution of 75 ms, a tube voltage of 100 to 120 kV (according to patient body mass index), and an effective tube current of 300 mAs. The prospective tube current modulation technique was used with a high-dose window of 65 to 80% of the R-R interval (if H-$R \geq 70$, then the window was between 35 to 80% of the R-R interval) and with the MinDose protocol (Siemens, Germany) for the remaining phases of the cardiac cycle. Contrast was administered at an injection rate of 4.5 mL/s using a dual-syringe power injector (Stellant D, MedRAD, Indianola, IA, USA). The split-bolus protocol injection was used to inject contrast medium according to body weight (1cc/kg): an injection of 60 to 80 mL pure, undiluted iodinated contrast material (Iomeron 400, Bracco, Milan, Italy for Somatom Definition FLASH or Omnipaque 350, GE Healthcare, Princeton, USA for Somatom Force) was followed by a constant volume of 40 mL a 60:40% saline-to-contrast medium mixture. Scanning was automatically initiated 6 seconds after a threshold of 100 HU was achieved in a region of interest in the ascending aorta. Patient table feed/pitch variables were adapted to the H-R (range, 0.17–0.38). Images were reconstructed at 10 to 100% of the R-R interval in 10% increments for LV functional analysis with the following parameters: slice thickness, 0.75 mm; reconstruction increment, 0.4 mm; and convolution kernel B36fASA (for Somatom Definition FLASH) or Bv40 (for Somatom Force).

2.3. Analysis of image data

LV function was automatically measured using workstation (Syngo.via imaging software, Siemens Healthcare, Cary, NC).

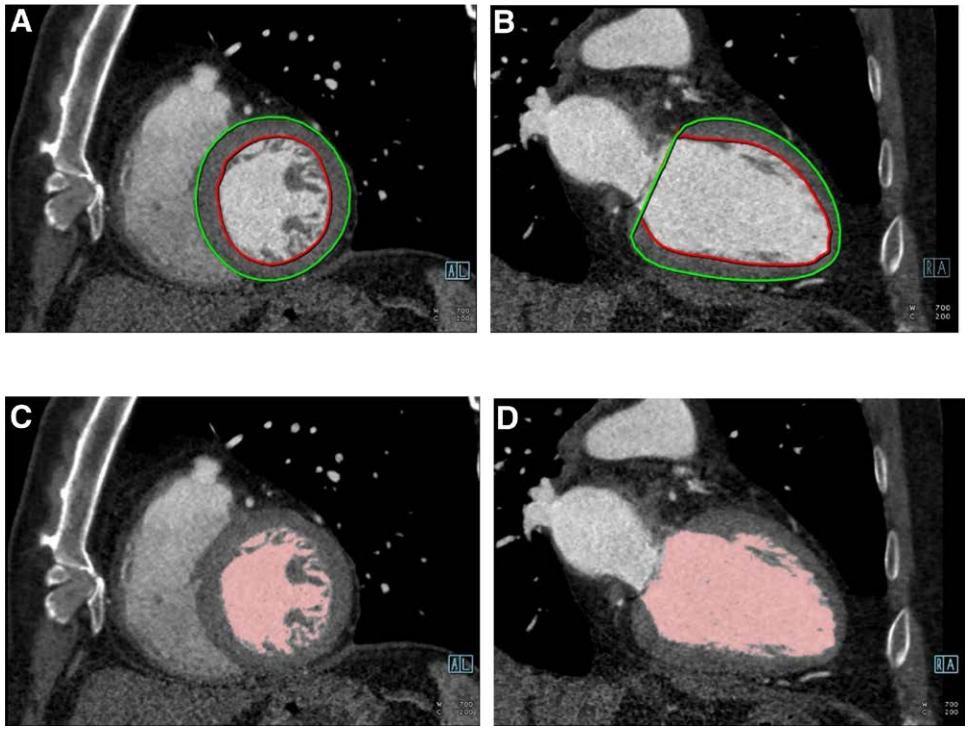

Figure 2. Representative example of 2 methods to measure LV function: (A and B) The standard (ST) Simpson method is based on automatic tracing of the endocardial (red line) and epicardial (green line) contours. The papillary muscle and trabeculae are not included in the left ventricular mass (LVM) but are included in the left ventricular volume. (C and D) The threshold-based blood volume (BV) method is based on attenuation differences between the LV blood pool and the myocardium. Because the attenuation values of the papillary muscle and trabeculae are below the threshold, they are not included in the left ventricular volume.

First, the standard (ST) method was performed using Simpson method, requiring automated planimetry of the LV blood pool in contiguous short-axis images along the length of the LV long axis (Fig. 2). Papillary muscles are generally included as part of the LV blood pool. Second, the threshold-based blood volume (BV) method was used based on attenuation differences between contrast in the LV blood pool and the myocardium (Fig. 2). This method did not include papillary muscles for the LV chamber volume. The indexed value of each parameter was derived by adjusting for the patient body surface area. We compared LV functional parameters and the LV mass index (LVMI) measured using both methods according to age and sex in the normal control group and according to disease entity in the patient group. Further analyses were performed in the LV hypertrophy group (LVMI > 115 g/m^2 in males and > 95 g/m^2 in females). The proportion of papillary muscle and trabeculae was calculated using parameters measured at the end-diastolic phase; the percentage of papillary muscle and trabeculae to the LV end-diastolic volume (LVEDV) was calculated using the LVEDV measured using the ST mode. The percentage of papillary muscle and trabeculae to LVM was calculated using LVM measured using the BV mode.

2.4. Statistical analysis

Data were collected using Microsoft Excel 2016 (Microsoft Corp., Redmond, WA) software. We used MedCalc (version 20.106; MedCalc Software, Mariakerke, Belgium) for all of the statistical analyses. Continuous variables are presented as the mean ± standard deviation (SD). Parameters were compared according to sex and age using an independent t-test and one-way ANOVA, respectively. We compared the parameters measured using both methods in each group using a paired t-test. Comparisons of categorical data to diagnose LV systolic dysfunction (LVEF < 50%) and LV enlargement (LVEDVI > 100 mL/m^2 in males and > 80 mL/m^2 in females) were performed using the χ^2 test.

Table 1

Basic characteristics of control group and patient group.

	Control group (n = 288)	Patient group (n = 358)	*P* value
Age (yr)	49.8 ± 16.3	63.0 ± 12.0	<.001
Sex (Male/Female)	140/148	290/72	<.001
BSA (m^2)	1.7 ± 0.2	1.8 ± 0.2	.012
Heart rate (bpm)	59.2 ± 7.1	73.6 ± 8.7	<.001
Systolic blood pressure (mm Hg)	104.7 ± 10.7	113.3 ± 25.1	.333
Diastolic blood pressure (mm Hg)	64.7 ± 9.5	74.2 ± 12.0	.065
Radiation dose of cardiac CT (mGycm)	356.6 ± 120.6	396.9 ± 222.0	.620

Values are means ± standard deviation or n.
BSA = body surface area.

3. Results

3.1. Normal control group

The basic patient characteristics are listed in Table 1 and compared with patient group. The differences in LV ejection fraction (LVEF), LVEDV, LVESV, and LVM between the 2 methods were 5.5 ± 4.1%, −8.6 ± 0.1% mL, −6.5 to 8.6 mL, and 14.1 ± 4.1 g in the control group (Table 2). Using the BV method, the LV blood pool volume decreased in end-systole and end-diastole. Therefore, LVEF using the BV method was higher than LVEF with the ST method. The papillary muscle and trabeculae proportions to LVEDV and LVM were 11.9 ± 5.6% and 20.2 ± 4.3%, respectively (Table 2). The ST method showed no statistically significant differences between males and females for LVEF, LVEDV index (LVEDVI), and LVESV index (LVESVI (Table 3). However, the LVMI in the male group was higher than in the female group for both methods (58.4 ± 6.5 vs 51.3 ± 6.0, $P < .001$ for the ST method, and 74.0 ± 8.5 vs 63.9 ± 8.2, $P < .001$ for the BV method) (Table 3). The papillary muscle

Table 2

Characteristics of control group and patient group.

		Control group (n = 288)	HCMP (n = 102)	DCMP (n = 55)	Old MI (n = 201)
Age (yr)		49.8 ± 16.3	59.4 ± 12.9	59.8 ± 13.3	65.8 ± 10.5
BSA		1.7 ± 0.2	1.8 ± 0.2	1.7 ± 0.3	1.8 ± 0.2
ST mode	LVEF (%)	67.7 ± 6.8	71.2 ± 10.0	32.9 ± 7.1	53.6 ± 13.5
	LVEDVI (mL/m2)	72.8 ± 11.0	74.9 ± 15.9	139.2 ± 35.2	95.3 ± 28.1
	LVESVI (mL/2)	23.8 ± 7.2	22.1 ± 11.7	94.4 ± 30.9	46.7 ± 26.2
	LVMI (g/m2)	54.8 ± 7.2	97.1 ± 28.8	101.1 ± 27.0	69.9 ± 16.7
BV mode	LVEF (%)	73.2 ± 4.9	70.9 ± 10.6	38.7 ± 8.8	56.4 ± 12.7
	LVEDVI (mL/m2)	64.2 ± 10.9	58.0 ± 13.3	118.1 ± 30.4	80.6 ± 24.5
	LVESVI (mL/2)	17.3 ± 4.6	17.1 ± 9.2	73.8 ± 27.6	37.2 ± 21.7
	LVMI (g/m2)	68.8 ± 9.8	121.0 ± 33.0	131.1 ± 32.7	91.2 ± 22.0
Diff	LVEF (%)	5.5 ± 4.1	−0.3 ± 3.8	5.7 ± 4.1	2.8 ± 4.2
	LVEDVI (mL/m2)	−8.6 ± 3.9	−16.8 ± 6.3	−21.1 ± 8.7	−14.7 ± 7.4
	LVESVI (mL/m2)	−6.5 ± 3.3	−5.0 ± 3.3	−20.6 ± 6.3	−9.6 ± 6.0
	LVMI (g/m2)	14.1 ± 4.1	23.9 ± 7.7	30.1 ± 9.5	21.3 ± 7.3
% PM to LVEDV		11.9 ± 5.6	22.7 ± 7.1	15.0 ± 5.0	15.4 ± 5.8
% PM to LVM		20.2 ± 4.3	20.0 ± 4.7	23.0 ± 5.4	23.2 ± 4.3

BSA = body surface area, LVEF = left ventricular ejection fraction, LVEDVI = LV end-diastolic volume index, LVESVI = LV end-systolic volume index, LVMI = LV mass index, PM = papillary muscle and trabeculae, LVM = LV mass.

Table 3

Comparison of left ventricular functional parameter between male and female.

		Control group		
		Male (n = 140)	Female (n = 148)	*P* value
Age (yr)		49.8 ± 16.1	49.9 ± 16.6	.973
BSA		1.9 ± 0.2	1.6 ± 0.2	<.001
ST mode	LVEF (%)	67.0 ± 6.7	68.5 ± 6.9	.064
	LVEDVI (mL/m^2)	73.1 ± 12.4	72.5 ± 9.6	.638
	LVESVI (mL/ m^2)	24.5 ± 7.6	23.1 ± 6.7	.106
	LVMI (g/m^2)	58.4 ± 6.5	51.3 ± 6.0	<.001
BV mode	LVEF (%)	71.5 ± 4.8	74.8 ± 4.6	<.001
	LVEDVI (mL/m^2)	62.9 ± 12.1	65.4 ± 9.6	.057
	LVESVL (mL/ m^2)	18.0 ± 4.9	16.6 ± 4.3	.009
	LVMI (g/m^2)	74.0 ± 8.5	63.9 ± 8.2	<.001
Diff	LVEF (%)	4.5 ± 4.2	6.4 ± 3.8	<.001
	LVEDVI (mL/m^2)	−10.2 ± 3.4	−7.1 ± 3.7	<.001
	LVESVI (mL/m^2)	−6.5 ± 3.4	−7.1 ± 3.7	.128
	LVMI (g/m^2)	15.6 ± 3.7	12.7 ± 3.9	<.001
% PM to LV		14.1 ± 5.0	9.9 ± 5.3	<.001
% PM to LVM		20.0 ± 5.6	19.0 ± 5.7	.133

BSA = body surface area, LVEF = left ventricular ejection fraction, LVEDVI = LV end-diastolic volume index, LVESVI = LV end-systolic volume index, LVMI = LV mass index, PM = papillary muscle and trabeculae, LVM = LV mass.

Table 4

Left ventricular functional parameter according to age in control group.

Age group		Twenties	Thirties	Forties	Fifties	Sixties	Seventies	*P* value
ST mode	LVEF (%)	65.2 ± 4.8	65.9 ± 6.2	66.3 ± 7.1	69.1 ± 5.8	70.4 ± 6.9	69.5 ± 8.3	<.001*
	LVEDVI (mL/m^2)	75.9 ± 8.9	72.5 ± 8.6	71.7 ± 10.5	71.3 ± 10.7	73.5 ± 12.0	71.9 ± 14.5	.364
	LVESVI (mL/m^2)	26.6 ± 5.8	25.1 ± 6.9	24.4 ± 7.0	22.3 ± 6.3	22.1 ± 7.2	22.4 ± 8.7	.007*
	LVMI (g/m^2)	55.5 ± 8.9	54.7 ± 7.1	54.0 ± 7.1	54.4 ± 6.9	55.5 ± 5.7	54.6 ± 7.6	.897
BV mode	LVEF (%)	71.9 ± 3.5	72.6 ± 4.2	72.4 ± 4.9	73.8 ± 4.9	74.8 ± 5.1	73.7 ± 6.3	.042*
	LVEDVI (mL/m^2)	68.7 ± 8.1	64.5 ± 8.9	63.5 ± 10.9	62.1 ± 11.2	63.6 ± 11.9	63.0 ± 12.9	.064
	LVESVI (mL/m^2)	19.2 ± 3.5	18.0 ± 4.2	17.6 ± 4.5	16.2 ± 4.0	16.1 ± 4.8	16.7 ± 6.0	.006*
	LVMI (g/m^2)	67.3 ± 11.4	67.6 ± 9.3	67.6 ± 9.0	69.7 ± 9.4	71.3 ± 8.5	69.4 ± 10.9	.290
Diff	LVEF (%)	6.9 ± 3.7	6.7 ± 4.2	6.1 ± 3.9	4.7 ± 3.9	4.6 ± 4.2	4.2 ± 4.2	.002*
	LVEDVI (mL/m^2)	−7.2 ± 3.5	−8.0 ± 3.3	−8.2 ± 3.7	−9.2 ± 3.8	−10.0 ± 4.2	−8.9 ± 4.0	.008*
	LVESVI (mL/m^2)	−7.3 ± 3.3	−7.1 ± 3.4	−6.8 ± 3.2	−6.1 ± 2.8	−6.0 ± 3.2	−5.6 ± 3.5	.068
	LVMI (g/m^2)	11.9 ± 3.6	12.9 ± 3.2	13.6 ± 3.6	15.3 ± 4.0	15.8 ± 4.1	14.8 ± 4.4	<.001*
% PM to LVEDV		9.4 ± 4.5	11.1 ± 4.9	11.7 ± 5.7	13.2 ± 6.1	13.8 ± 6.4	12.3 ± 5.0	.002
% PM to LVM		17.2 ± 4.4	18.3 ± 5.0	18.7 ± 6.5	21.8 ± 4.1	20.4 ± 6.6	20.3 ± 6.0	.001

BSA = body surface area, BV = Threshold-based blood volume method, LVEF = left ventricular ejection fraction, LVEDVI = LV end-diastolic volume index, LVESVI = LV end-systolic volume index, LVMI = LV mass index, PM = papillary muscle and trabeculae, LVM = LV mass.

and trabeculae proportions to LVMM showed no statistical differences between males and females (20.0 ± 5.6 vs 19.0 ± 5.7, $P = .133$) (Table 3). LVEDVI and LVMI for both methods showed no statistically significant differences for age group. However, LVEF tended to increase while LVESVI decreased with age (Table 4).

3.2. Patient group (DCMP, old MI and HCMP)

In patients with DCMP, and old MI patients, the LVEF measured using the BV method was higher than the LVEF measured using the ST method. However, LVEF measured using both methods was not statistically different ($P = .435$) in HCMP patients (Table 5) (Fig. 3). There were fewer diagnoses of LV systolic dysfunction and LV enlargement (35.9% vs 29.6%, $P < .001$ and 37.8% vs 22.7%, $P < .001$, respectively) using the BV than the ST method. The proportion of papillary muscle and trabeculae to LVM was not statistically different between the normal control group and the HCMP patients (20.2 ± 4.3 vs 20.0 ± 4.7, $P = .706$) and between the normal control group and the LV hypertrophy patients (20.2 ± 4.3 vs 19.5 ± 5.5, $P = .261$) (Table 6). However, the percentage portions of papillary muscle and trabeculae to LVM were higher in DCMP patients (23.0 ± 5.4, $P < .001$) (Fig. 4) and old MI patients (23.2 ± 4.3, $P < .001$) (Fig. 5) compared to the control group.

4. Discussion

Measuring LV volumes and LVM is essential because these parameters are significant prognostic factors of various cardiovascular diseases.[5–8] CMR imaging is considered the reference technique for cardiac functional analysis with higher accuracy and reproducibility than other modalities.[9] However, it is still being determined whether papillary muscle and trabeculation should be included in the cavity volume or the LVM.[8,10–12] The Society of Cardiovascular Magnetic Resonance task force on standardized protocols does not currently favor 1 method. However, it suggests that the inclusion or exclusion of papillary muscles in LVM should be the same as in normal reference ranges for comparison.[13]

Cardiac CT can be used in patients with contraindicated MR imaging.[3] Measuring LV functional parameters with cardiac CT is comparable to MRI.[14,15] However, there is no uniform measurement technique for LVM and LV function using cardiac CT.[16,17] Most comparison studies have used the Simpson method for both modalities.[3,18,19] De Jonge et al[17] compared the CT and MRI results, measured using 2 software packages with Simpson and threshold-based methods. They confirmed that a CT software algorithm based on the Hounsfield unit values of the LV blood pool showed a substantial overestimation in LVEF compared to MRI because papillary muscles and trabeculae were excluded from the LV blood pool, leading to an increased LVEF.[17] We also showed a higher LVEF using the BV method than the ST method because the volume of the LV blood pool decreased in end-systole and end-diastole with the BV method.

This study used CT to obtain standard values of the portion of papillary muscle and trabeculae in normal adults. The proportion of papillary muscle and trabeculae to LVM accounts for 20.2 ± 4.3% in the normal control group (Table 2). Previously, papillary muscle volume and trabecular volume were considered separately and were not combined. In a 100-participant subset of the Multi-Ethnic Study of Atherosclerosis CMR trial, Vogel-Claussen *et al*[16] found that papillary muscles made up 8.9 ± 0.1% of LVM. In addition, Jacquier et al[20] compared the percentage of trabecular mass with LVM in 16 controls (12 ± 5%). Our results are similar to the combination of the reported 8 to 9% LVM for papillary muscle and approximately 12% LVM for trabecular mass.

Table 5

Left ventricular functional parameter according to patient group.

	Control group (n = 288)			HCMP (n = 102)			DCMP (n = 55)			Old MI (n = 201)		
	ST	BV	*P* value	ST	BV	*P* value	ST	BV	*P* value	ST	BV	*P* value
LVEF (%)	67.7 ± 6.8	73.2 ± 4.9	<.001	71.2 ± 10.0	70.9 ± 10.6	.435	32.9 ± 7.1	38.7 ± 8.8	<.001	53.6 ± 13.5	56.4 ± 12.7	<.001
LVEDVI (mL/m^2)	72.8 ± 11.0	64.2 ± 10.9	<.001	74.9 ± 15.9	58.0 ± 13.3	<.001	139.2 ± 35.2	118.1 ± 30.4	<.001	95.3 ± 28.1	80.6 ± 24.5	<.001
LVESVI (mL/m^2)	23.8 ± 7.2	17.3 ± 4.6	<.001	22.1 ± 11.7	17.1 ± 9.2	<.001	94.4 ± 30.9	73.8 ± 27.6	<.001	46.7 ± 26.2	37.2 ± 21.7	<.001
LVMI (g/m^2)	54.8 ± 7.2	68.8 ± 9.8	<.001	97.1 ± 28.8	121.0 ± 33.0	<.001	101.1 ± 27.0	131.1 ± 32.7	<.001	69.9 ± 16.7	91.2 ± 22.0	<.001

BV = Threshold-based blood volume method, HCMP = hypertrophic cardiomyopathy, DCMP = dilated cardiomyopathy, MI = myocardial infarction, LVEF = Left ventricle ejection fraction, LVEDVI = LV end-diastolic volume index, LVESVI = LV end-systolic volume index, LVMI = LV mass index.

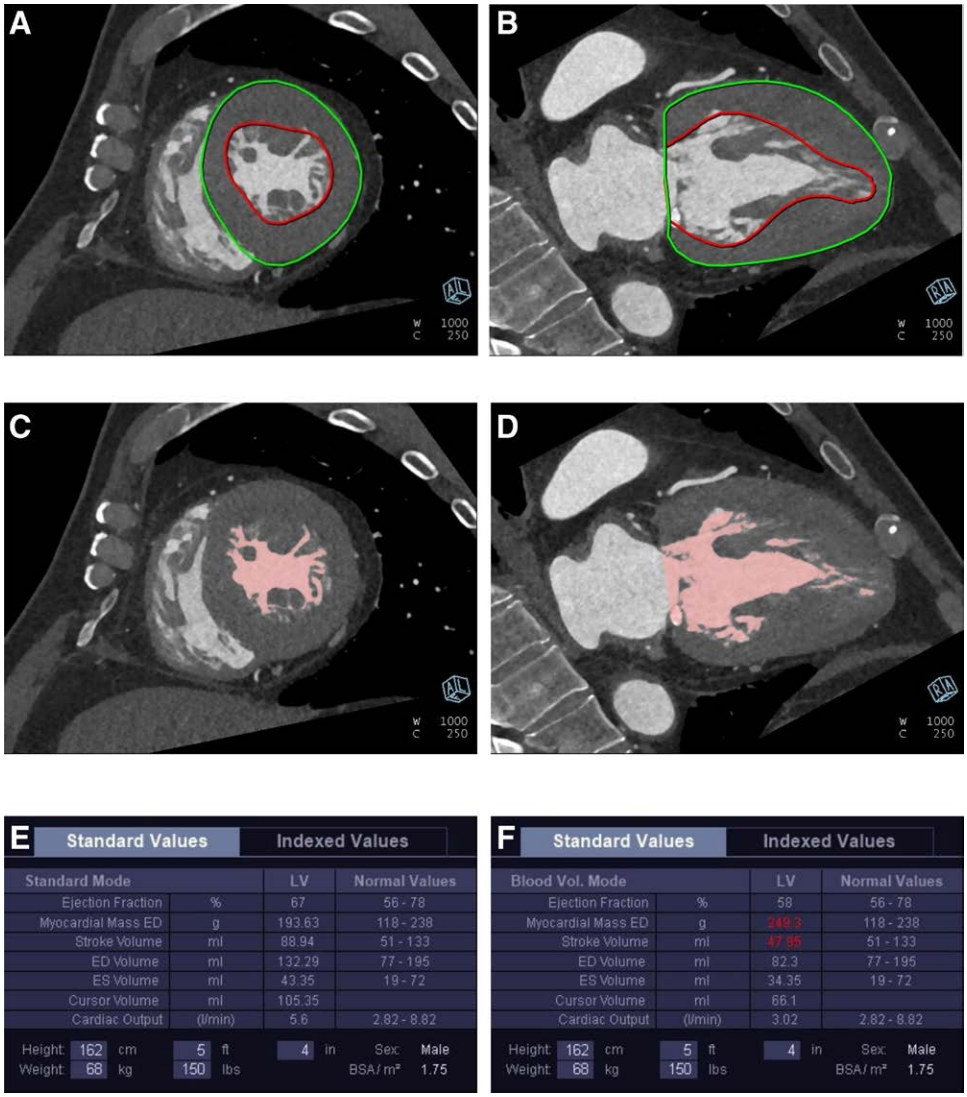

Figure 3. In case with hypertrophic cardiomyopathy (HCMP), LV function were measured by standard (ST) Simpson method (A, B and E) and threshold-based blood volume (BV) method (C, D and F). LV ejection fractions (LVEF) measured by both methods are within normal range (E and F). The LV myocardial mass (LVM) measured by BV method is higher (249 g vs 194 g) compared with LVM measured by ST method. The proportions of papillary muscle and trabeculae to LV end-diastolic volume (LVEDV) and LVM are 42.1% and 22.3%, respectively.

Table 6

Left ventricular functional parameter according to patient group.

	Control group (n = 288)			LV hypertrophy (n = 58)		
	ST	BV	*P* value	ST	BV	*P* value
LVEF (%)	67.7 ± 6.8	73.2 ± 4.9	<.001	50.4 ± 19.9	52.0 ± 19.0	.008
LVEDVI (mL/m²)	72.8 ± 11.0	64.2 ± 10.9	<.001	121.3 ± 51.7	97.9 ± 47.2	<.001
LVESVI (mL/m²)	23.8 ± 7.2	17.3 ± 4.6	<.001	67.4 ± 48.7	53.2 ± 40.8	<.001
LVMI (g/m²)	54.8 ± 7.2	68.8 ± 9.8	<.001	128.4 ± 23.6	159.6 ± 27.7	<.001

BV = Threshold-based blood volume method, LVEF = Left ventricle ejection fraction, LVEDVI = LV end-diastolic volume index, LVESVI = LV end-systolic volume index, LVMI = LV mass index.

With the ST method, LVEF, LVEDVI, and LVESVI were not significantly different between males and females. However, LVMI was higher in the male group than in the female group using both the ST and BV methods (Table 3). Our results are in agreement with a previous study that used cine MRI and found that normalization to body surface area removed the differences in LVEDV and LVESV while the LVM remained significantly different.[21] However, that study also reported a significant difference in LVEF between males and females. Meanwhile, Lorenz et al[22] found no significant differences in LVEF between the sexes in another cine MRI study. However, there were significant differences in the absolute and normalized LVEDV, LVESV, and LVM. We found that the proportion of papillary muscle and trabeculae to LVM was not statistically different between males and females. Our findings are also consistent with Vogel-Claussen et al,[16] which reported that the relative papillary

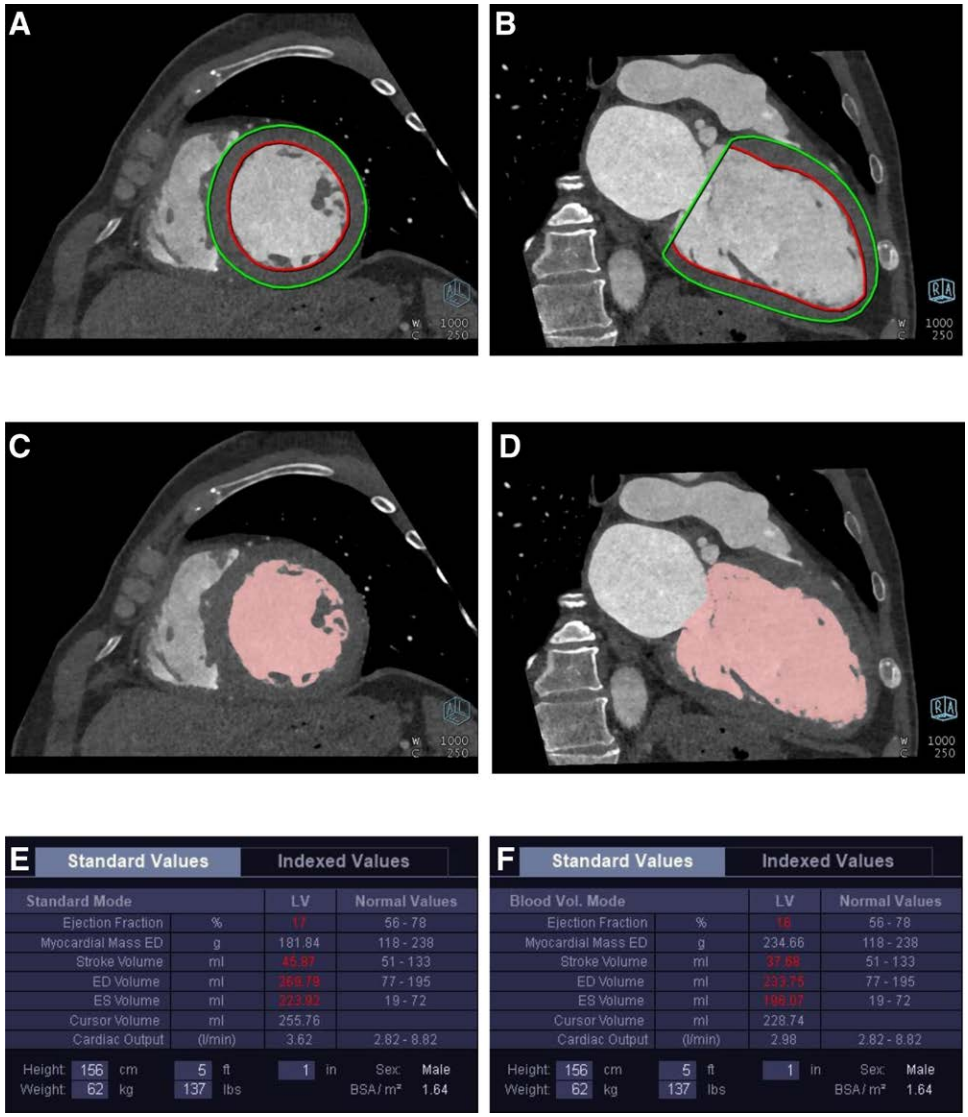

Figure 4. In case with dilated cardiomyopathy (DCMP), LV function were measured by standard (ST) Simpson method (A, B and E) and BV method (C, D and F). The LVEF decreased severely, and LVEDV increased markedly (E and F). The proportions of papillary muscle and trabeculae to LVEDV and LVM are 19.6% and 22.5%, respectively. BV = Threshold-based blood volume method.

muscle mass to the LVM was not significantly different between males and females, although the mean papillary muscle mass was significantly greater in males.

We observed an increase in LVEF, while LVESVI tended to decrease with age (Table 4). Similarly, in a large series of 464 clinically normal adults aged 16 to 88, Slotwiner et al[23] found a slight but significant increase in LVEF with age. However, Sandstede et al[21] found that the LVEF values hardly changed with age while there was a significant decrease in systolic and diastolic LV volumes. Merino et al[24] reported no differences in LVEDV, LVESV, or EF in 2 groups of young (aged 22 ± 1 years) and old (aged 70 ± 4 years) volunteers. In our study, LVEDVI and LVMI using both methods were not statistically different according to age. Meanwhile, in another study that used echocardiography to determine age-specific differences, Pearson et al[25] found that LVMI did not change with age. Using echocardiography, the Framingham study[26] also showed that LVM remained relatively stable in healthy men and women with advancing age. Considering our data along with those of other studies, we suggest using age-matched normal values to evaluate the LV volume and EF while LVM remains primarily age independent.

LVEF measured using the BV method was significantly higher in the control group, DCMP patients, and older MI patients but not in HCMP patients (Table 5). Our findings are in line with results from a previous CMR study of a normal group that reported that excluding the papillary muscles from the blood pool resulted in a significantly smaller LVEDV and LVESV and thus a higher LVEF.[8] The exclusion of these muscles might produce different indices for diagnosis and therapy.[3] We had fewer diagnoses for LV systolic dysfunction and LV enlargement (35.9% vs 29.6%, $P < .001$ and 37.8% vs 22.7%, $P < .001$, respectively) using the BV method than the ST method. Considering the difference in LVEF for the 2 methods, further research is needed as it can affect clinical decision-making based on the LVEF and LVM values and LV volume.

By contrast, in the HCMP patients in our study, LVEF determined by both methods did not significantly differ ($P = .435$). However, in LV hypertrophy patients, LVEF measured using the BV method was significantly larger than the LVEF using the ST method ($P = .008$) (Table 6). Our results are consistent with Park *et al*,[27] which assessed the effect of papillary muscles and trabeculae on LV measurements using cardiac MR in patients with

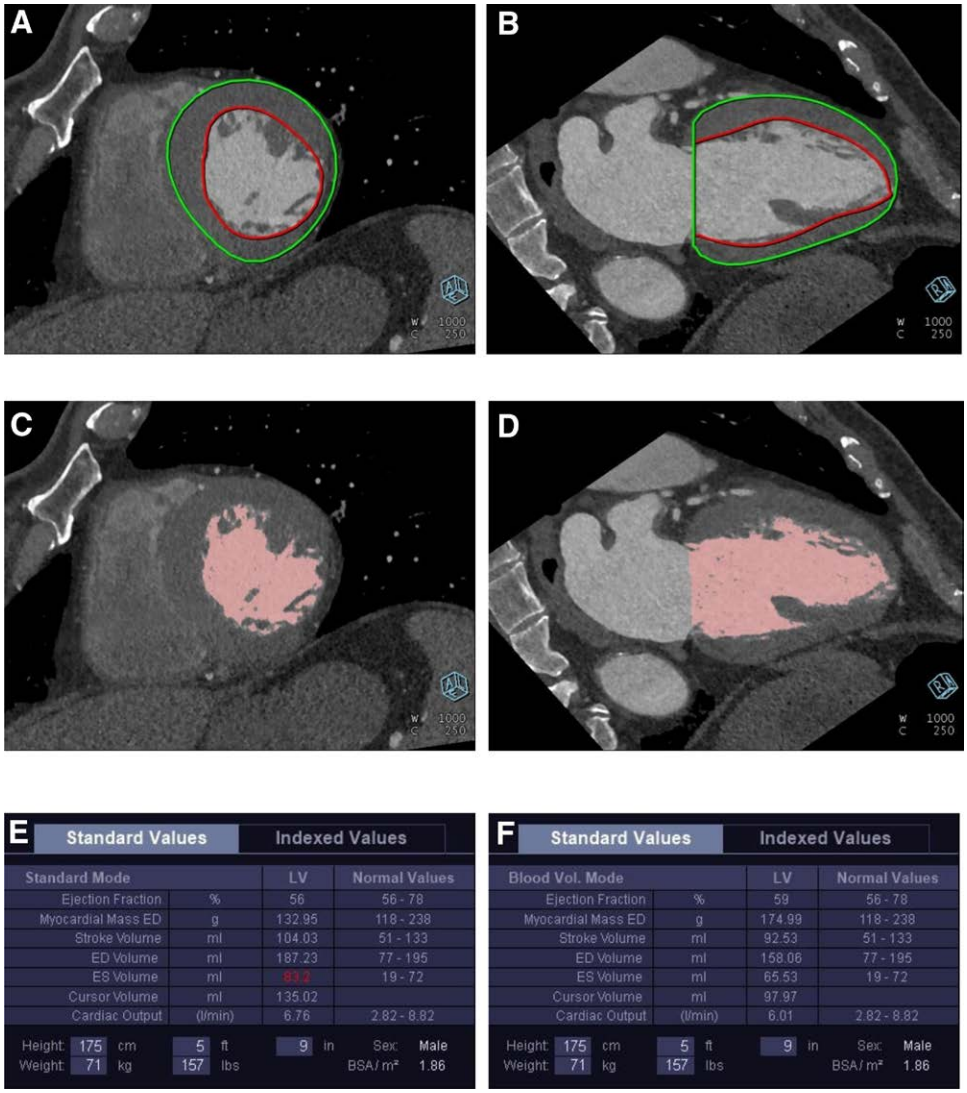

Figure 5. In case with old myocardial infarction (MI), LV function were measured by ST method (A, B and E) and BV method (C, D and F). Short axis view of LV myocardium (A and C) shows a decrease in wall thickness and fat deposition at left circumflex coronary artery territory. However, the LVLF was preserved within normal range (E and F). The proportions of papillary muscle and trabeculae to LVEDV and LVM are 22.5% and 24.0%, respectively. BV = Threshold-based blood volume method.

HCMP. They reported that HCMP patients showed a greater absolute difference of 16% for EF.[27] Our results showed no statistical differences in the proportion of papillary muscle and trabeculae to LVM between the normal control group and HCMP patients and between the normal control group and LV hypertrophy patients. However, in contrast to our findings, Kozor et al[28] reported that HCMP significantly increased the LV papillary muscle contribution to the total LVM compared to the normal control. These differences are due to the fact that deciding which endocardial trabeculae to exclude from the cavity volume is challenging and varies considerably, even when experienced observers perform the tracing; also, because of their small size, trabeculae are challenging to differentiate from the LV wall, which makes tracing complicated. Although several studies have used CMR to examine the characteristics of papillary muscles in HCMP,[27,28] to the best of our knowledge, none have used cardiac CT to examine papillary muscles in HCMP. Therefore, further studies using cardiac CT are needed in HCMP patients.

We investigated the effect of papillary muscle and trabeculae on LV functional parameters using CT and a large data set with a normal control and different patient groups. Our findings indicate that the BV and ST methods should not be used interchangeably because there is a significant difference in LVEF and LVM, which affect clinical decision-making. Radiologists should be aware of the marked discrepancy between the 2 methods during data analysis, particularly in patients with HCMP, and maintain a consistent method for longitudinal follow-ups.

This study had several limitations. First, we could not test for accuracy as we did not measure the LV parameters in vivo or using CMR, and it was impossible to obtain a standard for the true volume, function, and mass. However, in a previous study, cardiac CT had a good correlation with CMR for assessing LV volumes and EF.[4] Second, the high level of radiation is a significant disadvantage of using CT to determine cardiac functional parameters. It is particularly problematic in patients who require multiple follow-up CT examinations.[3] Third, the exact selection of end-diastolic and end-systolic phases could be missed because the image was reconstructed in 10% increments of the R–R interval. However, the optimal reconstruction interval of cardiac CT has not been established, although a 5% interval reconstruction may be more meticulous in selecting the cardiac phase. Finally, the BV method does not clearly demarcate the endocardial border between the myocardium and the blood pool. If the attenuation value of the segmented blood pool

between the trabeculae might not exceed the predefined threshold, it is not included in the blood pool.[3] This segmentation flaw might lead to an underestimation of the LV volume.

5. Conclusion

Excluding the papillary muscles from the LV mass results in easier automated contour detection using CT. The percentage portions of papillary muscle and trabeculae to LVEDV and LVM were 11.9 ± 5.6% and 20.2 ± 4.3%, respectively, significantly affecting disease diagnosis. Therefore, imaging should be consistent at follow-up and include or exclude the papillary muscles and trabeculae to avoid introducing significant differences between measurements.

Author contributions

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Methodology: Doo Kyoung Kang.
Resources: Doo Kyoung Kang.
Software: Doo Kyoung Kang.
Supervision: Doo Kyoung Kang.
Validation: Doo Kyoung Kang.
Visualization: Doo Kyoung Kang.
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