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CARDIOVASCULAR IMAGING

ORIGINAL ARTICLE

Comparison of short and long axis methods in cardiac MR imaging and echocardiography for left ventricular function

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PURPOSE
The purpose of this study was to compare long axis and short axis methods in cardiac magnetic resonance imaging (MRI), and echocardiography for the evaluation of left ventricular function and mass.

MATERIALS AND METHODS
The study included 15 patients with a history of myocardial infarction and 5 patients with normal ventricular function who were examined with cardiac MRI and echocardiography. Left ventricular function and mass analyses calculated with Simpson's method from short axis images were compared to the results of horizontal long axis, vertical long axis, and combined axes methods. In addition, results obtained from echocardiography were compared to the short axis method in cardiac MRI.

RESULTS
In the patient group, there was no significant difference between ejection fraction calculated by modified Simpson's analysis in echocardiography and short axis imaging in cardiac MRI. In cardiac MRI, there was significant difference between ejection fractions assessed from both horizontal and vertical long axis images, and those assessed from short axis images. There was no significant difference in both patient and control groups between end-diastolic volume determined from short axis and end-diastolic volume determined by horizontal long axis, vertical long axis, and combined long axes. Significant difference between the patient and control groups was observed in end-diastolic volume calculated by modified Simpson's echocardiographic method.

CONCLUSION
The present study demonstrated that there were no significant advantages of simplified MRI techniques over modified Simpson's method echocardiography. Therefore, patients who cannot be evaluated by echocardiography optimally should be evaluated by short axis cine MRI sequence.

Key words: • magnetic resonance imaging • echocardiography • ventricular function, left

The incidence of cardiac failure continues to increase despite improvements in medical and interventional cardiology (1). In order to accurately diagnose, and assess the prognosis and the need for interventional treatment, it is important to evaluate ventricular mass and functions in a precise and reproducible way. In addition to being able to follow-up ventricular functions in these patients with serial imaging, it positively affects mortality and morbidity, providing clinicians the opportunity to overview and modify the ongoing treatment.

Although echocardiography is a widely available, inexpensive, and noninvasive method, it is operator-dependent and the acoustic window is limited in some patients. Even in patients for whom the acoustic window is sufficient, inferobasal segments of the myocardium are hard to evaluate. Moreover, although geometric assumptions used in the quantification of ventricular functions in echocardiography do not affect the results in normal ventricles, it is less accurate with ventricles that have undergone remodeling. Unlike echocardiography, short axis assessment in cardiac magnetic resonance imaging (MRI) is independent of geometric assumptions and information about the entire myocardium can be obtained; therefore, diagnostic accuracy with cardiac MRI is greater.

Currently, cardiac MRI has become the gold standard for evaluating cardiac functions. Ventricular end-systolic and end-diastolic volumes, ejection fraction, stroke volume, systolic and diastolic wall thickness, and systolic thickening are determined by 8–12-slice short axis images involving the entire ventricle, from the apex to mitral valve level. On the other hand, patients with deteriorated cardiac functions cannot tolerate an 8–12-slice breathhold period. Decreasing the slice number and shortening the breathhold period will improve patient compliance during the examination; however, a less complicated evaluation method for cardiac MRI, which will obtain equivalent or approximately equivalent results with short axis imaging, has not yet been demonstrated.

In this study, we evaluated the value of long axes methods in cardiac MRI (horizontal long axis, vertical long axis, and combined long axes) and echocardiography in the determination of left ventricular functions as compared to short axis methods.

Materials and methods

The study included 20 patients (3 females, 17 males) referred to our center for the evaluation of left ventricle systolic function. Patient age ranged between 29–80 years (mean, 55.4 years), height ranged between 150–187 cm (mean, 170 cm), weight varied between 53–104 kg (mean, 70.1 kg), and body surface area was between 1.47–2.2 m^2 (mean, 1.8 m^2). All the patients in the patient group had a history of myocardial infarction (MI). The control group included 5 volunteers whose systolic functions were normal.

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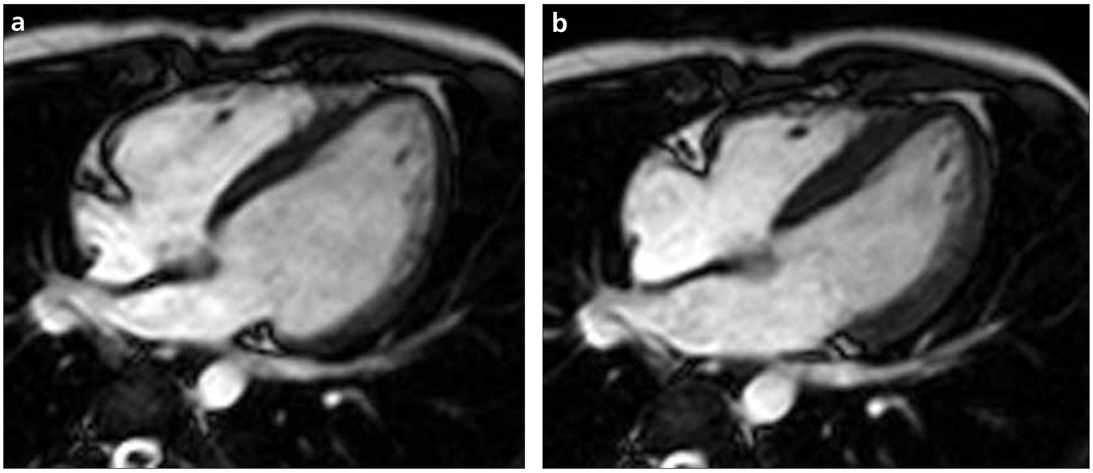

Figure 1. a, b. Horizontal long axis multi-segmented cine MR images taken during the end-diastolic phase **(a)** and the end-systolic phase **(b)**.

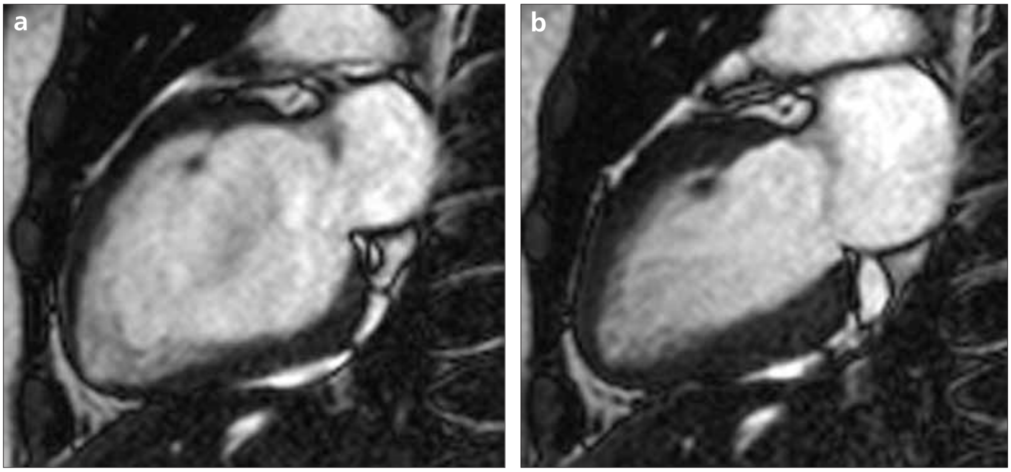

Figure 2. a, b. Vertical long axis multi-segmented cine MR images taken during the end-diastolic phase **(a)** and the end-systolic phase **(b)**.

All patients were screened for claustrophobia, pacemaker, implanted cardioverter, defibrillator, non-MRI compatible surgical clips and prostheses; patients positive for any one or more of these were excluded. The patients with low cardiac performance who were not expected to tolerate the examination were also excluded. The time interval between evaluations by cardiac MRI and echocardiography ranged between 1–5 days and no changes in their treatments were made. The study was approved by the local ethics committee and written informed consent was obtained.

Cardiac magnetic resonance imaging

All the patients were evaluated with a 1.5 Tesla MRI system (Philips Intera Achieva; Philips Medical Systems, Best, the Netherlands). They were scanned in the supine position with ECG and breath follow-up pad. A 5-element phased array cardiac coil was used for signal collection. We used a cardiac gated multi-segmented cine steady-state free precession sequence (balanced turbo field echo). Multi-segmented cine imaging parameters were as follows: TR/TE, 3.1/1.56 ms; flip angle, 60°; FOV: 320–380 mm; matrix, 192 × 256; slice thickness, 8 mm; gap, 2 mm.

While each image was taken, the patients were required to hold their breath at the end of expiration. Low-resolution axial survey images were obtained first. Pseudovertical long axis images were acquired from the axial survey images. Horizontal long axis (4-chamber) images (Fig. 1) were planned according to the provided pseudovertical long axis images, and vertical long axis (2-chamber) images (Fig. 2) were planned according to these horizontal long axis images. Short axis images (Fig. 3) were planned according to horizontal long axis images. In total, 7–13 images of each patient's left ventricle were taken so as to include the entire ventricle. Mean MR scan time was 20–25 min.

All acquired MR images were sent to a workstation and were evaluated by 2 radiologists. Endocardial and epicardial borders were contoured manually, and functional analysis was performed with a dedicated software (ViewForum Cardiac Package Program, Version 3.4; Philips Medical Systems, Best, the Netherlands). On the short axis images, vertical long axis images, and horizontal long axis images, end-systolic and end-diastolic endocardial, and end-diastolic epicardial borders were contoured. The first image of the series was taken during the end-diastolic phase. The smallest and the largest ventricular cavity sizes at the midventricular level were used in order to determine the end-systolic and end-diastolic phases, respectively. Endocardial borders were contoured by differentiating hyperintensity of the blood in the cavity and the intermediate intensity of the myocardium. Since the papillary muscles would lengthen the time for analysis and would not

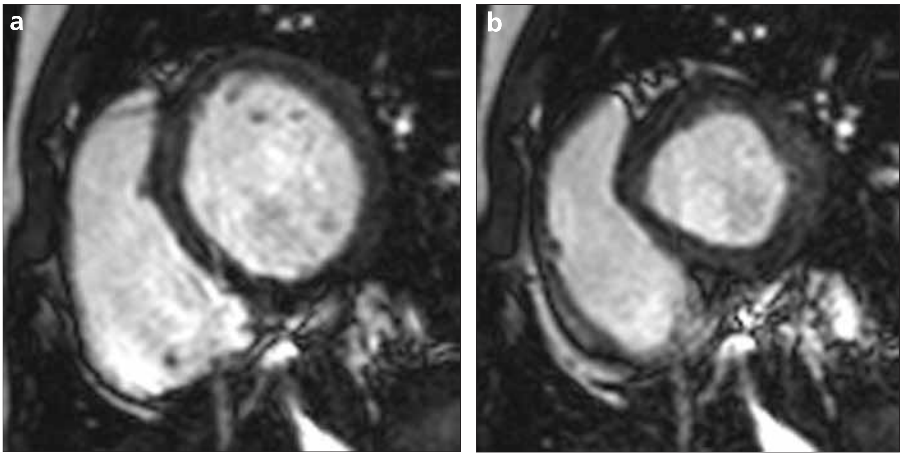

Figure 3. a, b. Short axis multi-segmented cine MR images taken during the end-diastolic phase **(a)** and the end-systolic phase **(b)**.

affect the mass and cavity volume significantly, they were not included in the mass. While defining the epicardial borders, the septum was included in the left ventricle. Segments in which blood in the cavity was circumscribed by the myocardium by more than 50% were defined as basal segments and were included in the ventricular cavity. Atria were differentiated by their wall structure and by their dilatation in systole in cine images, and were excluded from the ventricular cavity. Ventricular outlets were not included in the ventricular cavity. Simpson's method and the long axis area-length method were used in the evaluation of the short axis and long axis images, respectively. In addition, cavity area and cavity length determined in vertical and horizontal long axes were combined by using the formula, $V = A \times B \times 0.85/L$, where V = volume, A = vertical long axis endocardial cavity area, B = horizontal long axis endocardial cavity area, and L = shorter cavity length.

Echocardiography

Echocardiographic evaluation was performed in the left lateral position using a Vingmed System Five GE ultrasound machine (Horten, Norway), with a 2.5 MHz transducer. Parasternal long and short axis, and apical 4-chamber images were acquired. Echocardiography of all patients was performed by the same cardiologist. Echocardiographic measurements were taken based on the criteria suggested by the American Echocardiography Association. Patients underwent M-mode and 2D echocardiographic evaluation, respectively. In M-mode evaluation (at the mitral valvular level perpendicular to the long axis of the ventricle), the left ventricle end-diastolic diameter, left ventricle end-systolic diameter, interventricular septum width, and posterior wall thickness from the parasternal long axis images were measured. The ejection fraction was calculated from these measurements. Epicardial borders were contoured in the end-diastolic and end-systolic images made from apical 4-chamber images. End-diastolic and end-systolic volumes, ejection fraction, and left ventricular mass were calculated according to modified Simpson's method.

Table 1. Comparison of the reference method to the functional analysis methods for determining left ventricular ejection fractions in the patient group

	Mean value (%)	Mean difference	SD	*P* value
SA[a]	28.97			
HLA	36.94	7.96	8.38	0.002
VLA	35.32	6.34	8.35	0.011
HLA+VLA	36.11	7.14	8.04	0.004
M-mode, echo	37.33	8.36	11.90	0.017
ECHO	31.06	2.09	16.10	0.622

[a] Short axis cardiac MRI is the reference analysis method.

SD: standard deviation; SA: short axis; HLA: horizontal long axis; VLA: vertical long axis; HLA+VLA: combined long axes analysis; M-mode: M-mode echocardiography; ECHO: modified Simpson's echocardiographic analysis from apical 4-chamber view.

Statistical analysis

The mean value and standard deviation were acquired for each parameter. Paired samples t-test was used for the patient group. $P < 0.05$ was considered statistically significant. The Statistical Package for Social Sciences (SPSS) Standard Version 11.5.0 for Windows was used as the statistical software program. Non-parametric two related samples test was used for the control group.

Results

In total, 6 patients were excluded from the study; 3 due to claustrophobia and 3 because they could not tolerate breathholding during scanning. However, all 6 of the patients could have been examined by echocardiography prior to cardiac MRI. Functional results of short axis images were taken as the gold standard for the left ventricle. In both the control and patient groups, there was no significant difference between ejection fractions calculated by Simpson's echocardiographic analysis and modified Simpson's short axis image analysis. Ejection fractions calculated using M-mode echocardiography were significantly different from short axis image analysis. In cardiac MRI there was significant difference when left ventricle short axis image analysis was compared to horizontal long axis, vertical long axis, and combined horizontal and vertical long axes. In the control group there was no significant difference in ejection fractions determined from horizontal long axis, vertical long axis, and combined long axes in comparison to short axis images (Table 1).

End-diastolic volume determined from horizontal long axis, vertical long axis, and combined long axes showed no significant difference from those determined from short axis in both the patient and control groups. On the other hand, end-diastolic volume calculated by modified Simpson's method

Table 2. Comparison of the reference method to the functional analysis methods for determining left ventricular end-diastolic volume in the patient group

	Mean value (ml)	Mean difference	SD	*P* value
SA[a]	249.100			
HLA	232.006	–17.09	41.55	0.130
VLA	261.366	12.26	37.79	0.220
HLA+VLA	250.313	1.21	31.77	0.880
ECHO	197.866	–51.23	69.24	0.01

[a] Short axis cardiac MRI is the reference analysis method.
SD: standard deviation; SA: short axis; HLA: horizontal long axis; VLA: vertical long axis; HLA+VLA: combined long axes analysis; ECHO: modified Simpson's echocardiographic analysis from apical 4-chamber view.

Table 3. Comparison of the reference method to the functional analysis methods for the determination of left ventricular end-systolic volume in the patient group

	Mean value (ml)	Mean difference	SD	*P* value
SA[a]	183.71			
HLA	158.17	–25.54	33.58	0.011
VLA	179.30	–4.41	27.29	0.541
HLA+VLA	170.58	–13.13	23.84	0.051
ECHO	148.13	–35.58	68.77	0.065

[a] Short axis cardiac MRI is the reference analysis method.
SD: standard deviation; SA: short axis; HLA: horizontal long axis; VLA: vertical long axis; HLA+VLA: combined long axes analysis; ECHO: modified Simpson's echocardiographic analysis from apical 4-chamber view.

Table 4. Comparison of the reference method to the functional analysis methods for the determination of left ventricular stroke volume in the patient group

	Mean value (ml)	Mean difference	SD	*P* value
SA[a]	64.70			
HLA	73.85	9.15	18.85	0.081
VLA	82.07	17.37	25.08	0.018
HLA+VLA	79.73	15.03	18.00	0.006
ECHO	49.73	-14.96	24.94	0.036

[a] Short axis cardiac MRI is the reference analysis method.
SD: standard deviation; SA: short axis; HLA: horizontal long axis; VLA: vertical long axis; HLA+VLA: combined long axes analysis; ECHO: modified Simpson's echocardiographic analysis from apical 4-chamber view.

Table 5. Comparison of the reference method to the functional analysis methods for the determination of left ventricular wall mass in the patient group

	Mean value (g)	Mean difference	SD	*P* value
SA[a]	122.89			
ECHO	213.47	–90.58	47.41	‹0.01

[a] Short axis cardiac MRI is the reference analysis method.
g: gram; SD: standard deviation; SA: short axis; ECHO: modified Simpson's echocardiographic analysis from apical 4-chamber view.

in echocardiography was significantly different from the volume determined by short axis, in both the patient and control groups (Table 2). In both patient and control groups, end-systolic volume determined by vertical long axis, combined long axes, and volume calculated by modified Simpson's echocardiographic method did not show significant difference compared to end-systolic volume determined by short axis images (Table 3).

As for the stroke volume, there was no significant difference between what was determined from horizontal long axis and shot axis images in both the patient and control groups. However, stroke volume determined by vertical long axis and combined long axes differed significantly from short axis analysis in the patient group. Stroke volume calculated by echocardiographic modified Simpson's method was significantly different between the patient and control groups (Table 4). Moreover, there was a significant difference in left ventricular mass determined from echocardiographic 4-chamber images and short axis cardiac MRI in both of the groups (Table 5).

Discussion

In order to determine the prognosis and treatment regimen for cardiac diseases, it is important to evaluate cardiac volumes and functions. Therefore, it is essential to determine how the results obtained by other imaging methods differ from those obtained by the gold standard method, cardiac MRI, and how we can improve the accuracy and patient compliance in cardiac MRI (2, 3).

Although echocardiography is the most widely used method in determining ventricular function, the technical disadvantages of echocardiography have led us to search for other non-invasive imaging methods that can answer clinical questions in a more reliable and rapid fashion (4). Functional analysis with cardiac MRI, by obtaining short axis images of the ventricles, is independent of geometric assumption and is now accepted as the gold standard (5–14).

In this study there was no significant difference between the ejection fractions obtained by modified Simpson's method, using apical 4-chamber echocardiographic images, and the ejection fractions obtained by cardiac MRI, from short axis images, in both the patient and control groups. In contrast, previous studies reported significant difference between these 2 methods. The reason that our results were not consistent with those of previous studies could be that our study included a smaller number of patients and only a few of these patients had severe ventricular remodeling, such as an aneurysmatic left ventricle (15, 16). In 2-chamber and 4-chamber images, slices are taken from only one particular part of the left ventricle, and unless this part is the one that has undergone remodeling the results obtained may be misleading.

In the control group, there was no significant difference between the ejection fraction analyses made with M-mode echocardiography and with cardiac MRI, whereas there was significant difference in the patient group. In M-mode echocardiography, a ventricular sample is taken from only one segment and function is estimated from this one sample. Therefore, in remodeled ventricles that show signs of local dysfunction, different results have been obtained (17). Furthermore, slight deviations in ventricular diameter measurements in M-mode echocardiography lead to significantly different calculated results (18).

There was significant difference in both the patient and control groups between the end-diastolic volume measurements taken with echocardiographic area-length method and cardiac MRI short axis measurements. Limitations due to the acoustic window in echocardiography make it hard to evaluate the ventricle in diastole because of the dilatation of the ventricular cavity during this phase. Additionally, while performing echocardiography, it is more difficult to adjust the ultrasound beam so that it passes from the center of the ventricles during the diastolic period (19); therefore, accurate long axis images of the ventricles can not be obtained. In addition to this, the areas that have undergone remodeling can not be evaluated unless they are included in the view. All of this contributes to inaccuracy while evaluating end-diastolic volume by the area-length method.

There was no significant difference in both patient and control groups between the end-systolic volume measurements taken with the echocardiographic area-length method and cardiac MRI short axis measurements. Unlike the difficulties associated with evaluation during the diastolic period, contraction of the ventricles during systole makes evaluation easier and, therefore, more accurate.

When the myocardial mass of the left ventricle was analyzed using the cardiac MRI short axis method and echocardiography, significant difference between the two was noted. Two primary reasons for this were the challenge in defining the border of the epicardium and endocardium in echocardiography, and the geometric assumption used in this method.

End-diastolic volume obtained from cardiac MRI at horizontal long axis, vertical long axis, and combined long axes did not significantly differ from the results obtained with the short axis method. However, results were more approximate in the patient group. The mean difference between the measurements taken using the combination of both long axes images and the ones taken by using short axis images was only 1.2 ml. In the control group, volumes obtained using combination methods were 10.4 ml larger. This shows that the geometric model determined by using combined long axes images could be used in remodeled ventricles since it includes slices at least locally from pathologic myocardium segments.

There was no significant difference between the evaluation of left ventricle end-systolic volume using cardiac MRI short axis analysis and the evaluation by cardiac MRI vertical long axis and combined long axes analysis, and echocardiography, either in the control group or in the patient group. Horizontal long axis analysis of volume showed no significant difference in the control group, whereas there was significant difference in the patient group. Therefore, we concluded that as for the functional analysis of end-systolic volume, the geometric model formed by vertical long axis images would be more accurate.

Left ventricle ejection fraction values obtained by cardiac MRI at horizontal long axis, vertical long axis, and combined long axes in the patient group showed significant difference when compared to values obtained using short axis images. On the other hand, there was no significant difference in the control group. The assumed ellipsoid geometric model has led to different results in the ventricles, which have taken a spherical shape.

In conclusion, the present study demonstrated that there were no significant advantages of simplified cardiac MRI methods over modified Simpson's method echocardiography. Therefore, patients who cannot be evaluated by echocardiography, optimally should be evaluated using short axis cine MRI sequence.

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