Comparison of determinations of left atrial volume by the biplane area-length and Simpson’s methods using 64-slice computed tomography

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Abstract

Objectives: There is increasing evidence that left atrial (LA) size is an important predictor of adverse cardiovascular outcomes such as atrial fibrillation, stroke, and congestive heart failure. The aim of this study was to determine whether there is a difference in results of quantification of LA volume by the area-length and Simpson’s methods using multislice computed tomography (MSCT).

Methods and results: The study population consisted of 51 patients with sinus rhythm (sinus group) and 20 patients with atrial fibrillation (af group) clinically indicated for MSCT angiography for evaluation of coronary arteries. Maximum LA volume, obtained at end-systole from the phase immediately preceding mitral valve opening, was measured using the area-length and Simpson’s methods. In the sinus group, the mean LA volumes, indexed to body surface area, were $48.4 \pm 17.9 \text{ml/m}^2$ with the area-length method and $48.3 \pm 17.0 \text{ml/m}^2$ with the Simpson’s method. In the af group, the mean indexed LA volumes with the area-length method and the Simpson’s method were $91.5 \pm 47.5 \text{ml/m}^2$ and $90.3 \pm 45.9 \text{ml/m}^2$, respectively. LA volumes calculated by the area-length method exhibited a strong linear relationship and agreement with those calculated using Simpson’s method in both the groups (sinus group: $r = 0.99$, $P < 0.0001$, af group: $r = 0.99$, $P < 0.0001$).

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Introduction

There is increasing evidence that left atrial (LA) size is an important predictor of adverse cardiovascular outcomes such as atrial fibrillation [1], stroke [2], congestive heart failure [3], and cardiovascular death [4,5]. Thus far, in most research and clinical applications, two-dimensional (2-D) echocardiography has been used to assess LA volume. The American Society of Echocardiography has recommended quantification of LA size by biplane 2-D echocardiography using either the area-length method or the method of discs (Simpson's rule) [6]. Ujino et al demonstrated that with use of 2-D echocardiography, the results of biplane area-length measurement and that using Simpson’s methods were quite similar [7]. However, some studies have found that echocardiographic methods systematically underestimate LA volume compared with computed tomography (CT) [8] or magnetic resonance imaging (MRI) [9,10] because of the complexity of LA shape.

Recently, multislice computed tomography (MSCT) has attained spatial and temporal resolutions high enough to detect stenoses [11] and plaques [12] in the coronary arteries. In addition, using MSCT, short-axis LA images can be obtained perpendicular to the long-axis of the left ventricle and parallel to the mitral annulus, followed by calculation of LA volume using Simpson’s method. However, measurement of LA volume by Simpson’s method is relatively time-consuming. The area-length method has advantages over Simpson’s method in terms of time required for measurement of LA volume. For patients already indicated for coronary angiography by MSCT, it would be a clinically important advantage if the same MSCT data could be used to quickly gain additional information about cardiac function through analysis of LA volume.

To the best of our knowledge, no study has determined the relationship between area-length determination of LA volume and calculation by Simpson’s methods with MSCT. The aim of the present study was to determine whether there are differences in quantification of LA volume with the two methods using MSCT.

Methods

Patients

The study population consisted of 51 patients with sinus rhythm (sinus group) and 20 patients with atrial fibrillation (af group) clinically indicated for MSCT angiography for evaluation of the coronary arteries. The study included 51 patients suspected to have coronary artery disease (sinus group, 43; af group, 13), as well as 20 patients with proven coronary artery disease (sinus group, 8; af group, 7). All patients underwent contrast-enhanced MSCT in retrospective ECG-gated scanning mode.

The study was approved by the hospital ethics committee, and informed consent was obtained from all patients before the study.

MSCT image acquisition

Image acquisition was performed during a single breath-hold of the patient in the cranio-caudal direction using a 64-slice CT scanner (Somatom Sensation 64; Siemens Medical Solutions, Erlangen, Germany). Patients with a heart rate of >65 beats/min received 20–60 mg metoprolol orally 2 h before the MSCT scan (59/71; 83%). In addition, all patients received 0.6 mg nitroglycerin sublingually immediately before the MSCT scan. During the scan, the electrocardiographic (ECG) signal was digitally recorded.

First, a non-contrast ECG-gated scan was carried out to determine the calcium score. Then, for the coronary CT angiography, 65 to 85 ml of contrast medium (iopamiron 370, Bayer HealthCare, Berlin, Germany), depending on body weight, was injected through a dual-head injector at a rate of 4.0 ml/s into a cubital vein, followed by 30 ml of saline solution chaser. The scan delay was determined using the bolus tracking technique. The CT examination was performed with a tube voltage of 120 kV, an effective tube current-time product of 770 eff. mAs, collimation of 64 mm × 0.6 mm, a pitch of 0.2, and a gantry rotation time of 330 ms.
**Analysis of LA and left ventricular (LV) volumes**

Analysis of LA and LV volumes was performed offline on a workstation with the aid of a software package for analysis (syngo Circulation, Siemens). From the raw data of each scan, axial image series were reconstructed every 10% (0–90%) of the RR interval. A field of view of $180 \times 180 \text{mm}^2$, a $512 \times 512$ matrix, and a medium smooth convolution kernel (B25f) were applied. Using 3-D semi-automated software for cardiac evaluation (syngo Circulation), we analyzed the LV end-diastolic volume (EDV), end-systolic volume (ESV), ejection fraction, and LV mass. This software has been previously validated [13–15]. However, this automated software was not available for LA analysis.

Maximum LA volume, obtained at end-systole from the phase immediately preceding mitral valve opening, was measured manually using the area-length and Simpson’s methods and indexed to body surface area. Long-axis 2-chamber and 4-chamber views were prepared by manual segmentation.

For the biplane area-length method, maximal area was measured with a planimeter for 4- and 2-chamber views by tracing the endocardial border, excluding the confluence of the pulmonary veins and LA appendage, and the length was measured from the midline of the plane of the mitral annulus to the opposite superior aspect of the left atrium [6,7]. LA volume in this study was calculated as $0.85 \times 4$-chamber area $\times 2$-chamber area/average of the 2 lengths (Fig. 1). For Simpson’s method, a short-axis LA multislice image sequence, perpendicular to the long axis of the left ventricle and parallel to the mitral annulus, was acquired with a slice thickness of 2.0 mm. The LA endocardial border was traced manually, and the chamber area at each level was calculated. The area at each level from the plane of the mitral annulus to the opposite superior aspect of the left atrium was multiplied by slice thickness to obtain the volume imaged at that level, and the total atrial volume was obtained by summing the volumes from each level (Fig. 2). The borders of the left atrium were defined as for the biplane area-length method.

LA volume analysis was performed by a cardiologist with 3 years of experience in cardiac imaging. To assess interobserver and intraobserver variabilities, LA analysis using the area-length method was performed in 15 randomly selected patients with sinus rhythm by 2 independent observers and repeated by each observer 2 weeks later. Both observers were cardiologists with 3 years of experience in cardiac imaging, and blinded to each other’s results and to clinical findings.

**Echocardiography**

In a subset of 13 patients with sinus rhythm, 2-D echocardiography was also performed by a...
Fig. 2 Determination of LA volume by Simpson’s method of disc summation. The area at each level from the plane of the mitral annulus to the opposite superior aspect of the left atrium was multiplied by slice thickness to obtain the volume imaged at that level, and the total atrial volume was obtained by summing the volumes from each level.

second cardiologist blind to clinical history and MSCT findings, in order to validate LA volume by MDCT.

Standard apical 2- and 4-chamber views were obtained with the patient in the left lateral recumbent position using the 2.5 to 3.5 MHz transducers. According to standardized laboratory procedures, the transducer was angled to maximize cardiac chamber size and gain positions were adjusted to obtain the clearest outline of the endocardium.

For LA volume measurement, we selected the image at end-systole from the phase immediately preceding mitral valve opening. Both the area-length and Simpson’s methods were used to quantify the LA size by biplane 2-D echocardiography according to the recommendation of the American Society of Echocardiography [6]. As with MSCT, the confluence of the pulmonary veins and LA appendage were excluded.

Statistical analysis

Results are expressed as the mean ± SD. Agreement in LA volume was determined by Pearson’s correlation coefficient determination and Bland–Altman analysis. Values of $P < 0.05$ were considered significant.
Table 1  Baseline clinical characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Sinus rhythm (n = 51)</th>
<th>Atrial fibrillation (n = 20)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>65 ± 11</td>
<td>64 ± 10</td>
<td>0.70</td>
</tr>
<tr>
<td>Male gender, n (%)</td>
<td>36 (71%)</td>
<td>15 (75%)</td>
<td>0.78</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>33 (65%)</td>
<td>9 (45%)</td>
<td>0.18</td>
</tr>
<tr>
<td>Hypercholesterolemia, n (%)</td>
<td>20 (39%)</td>
<td>8 (40%)</td>
<td>0.99</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>13 (25%)</td>
<td>6 (30%)</td>
<td>0.77</td>
</tr>
<tr>
<td>Smoking, n (%)</td>
<td>31 (61%)</td>
<td>10 (50%)</td>
<td>0.44</td>
</tr>
<tr>
<td>Obesity &gt;25 kg/m², n (%)</td>
<td>15 (29%)</td>
<td>6 (30%)</td>
<td>0.99</td>
</tr>
<tr>
<td>Body surface area, m²</td>
<td>1.64 ± 0.17</td>
<td>1.70 ± 0.19</td>
<td>0.22</td>
</tr>
<tr>
<td>Previous CABG, n (%)</td>
<td>7 (14%)</td>
<td>6 (30%)</td>
<td>0.17</td>
</tr>
<tr>
<td>Blood pressure after image acquisition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systole (mmHg)</td>
<td>136 ± 23</td>
<td>121 ± 24</td>
<td>0.02</td>
</tr>
<tr>
<td>Diastole (mmHg)</td>
<td>75 ± 12</td>
<td>76 ± 13</td>
<td>0.84</td>
</tr>
<tr>
<td>Heart rates during scanning (beats/min)</td>
<td>58 ± 10</td>
<td>69 ± 17</td>
<td>0.01</td>
</tr>
<tr>
<td>Left ventricular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-diastolic volume (ml)</td>
<td>131 ± 35</td>
<td>154 ± 46</td>
<td>0.08</td>
</tr>
<tr>
<td>End-dystolic volume index (ml/m²)</td>
<td>80 ± 20</td>
<td>93 ± 31</td>
<td>0.23</td>
</tr>
<tr>
<td>End-systolic volume (ml)</td>
<td>52 ± 24</td>
<td>95 ± 47</td>
<td>0.0001</td>
</tr>
<tr>
<td>End-systolic volume index (ml/m²)</td>
<td>32 ± 15</td>
<td>58 ± 31</td>
<td>0.0003</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>63 ± 11</td>
<td>41 ± 17</td>
<td>0.0001</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>154 ± 50</td>
<td>174 ± 48</td>
<td>0.09</td>
</tr>
<tr>
<td>Mass index (g/m²)</td>
<td>93 ± 25</td>
<td>104 ± 27</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Values are mean ± SD or n (percentages).
CABG, coronary artery bypass grafting.

Results

Patient characteristics

Clinical characteristics of all 71 patients are shown in Table 1. There were no statistically significant differences in age, male gender, presence of risk factors, diastolic blood pressure, LV EDV, and LV mass between the sinus and af groups. However, heart rates (P = 0.05) and LV ESV (P = 0.0001) were significantly higher and systolic blood pressure (P = 0.02) and ejection fraction (P = 0.0001) were significantly lower in the af group than those in the sinus group.

Correlation between LA volumes obtained with the area-length and Simpson’s methods with MSCT

In this study, both area-length and Simpson’s methods for measurement of LA volumes could be completed in all 71 patients. Table 2 shows absolute values of LA volumes, indexed to body surface area, with the area-length and Simpson’s methods in the sinus and af groups. In the sinus group (n = 51), the mean LA volumes, indexed to body surface area, were 48.4 ± 17.9 ml/m² with the area-length method and 48.3 ± 17.0 ml/m² with Simpson’s method. In the af group (n = 20), the mean indexed

Table 2  LA volumes using the area-length and Simpson’s methods.

<table>
<thead>
<tr>
<th></th>
<th>Area-length</th>
<th>Simpson</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinus rhythm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LA volumes (ml)</td>
<td>78.9 ± 28.5</td>
<td>78.8 ± 26.9</td>
<td>0.81</td>
</tr>
<tr>
<td>Indexed LA volumes (ml/m²)</td>
<td>48.4 ± 17.9</td>
<td>48.3 ± 17.0</td>
<td>0.89</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LA volumes (ml)</td>
<td>150.4 ± 67.3</td>
<td>148.7 ± 65.5</td>
<td>0.12</td>
</tr>
<tr>
<td>Indexed LA volumes (ml/m²)</td>
<td>91.5 ± 47.5</td>
<td>90.3 ± 45.9</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Values are mean ± SD.
LA, left atrial.
LA volumes with the area-length method and Simpson’s method were 91.5 ± 47.5 ml/m² and 90.3 ± 45.9 ml/m², respectively. As shown in Fig. 3, LA volumes calculated by the area-length method exhibited a strong linear relationship and agreement with those calculated with Simpson’s method in both groups [sinus group: \( r = 0.99, P < 0.0001 \) (Fig. 3(A and B)); af group: \( r = 0.99, P < 0.0001 \) (Fig. 3(C and D))].

Interobserver and intraobserver variabilities of LA analysis for the area-length method were assessed in the sinus group. The intraobserver correlation coefficients and mean difference in LA volume were 0.99 and 0.5 ± 2.3 ml, respectively. The interobserver correlation coefficients and mean difference in LA volume were 0.99 and 0.0 ± 3.5 ml, respectively.

Correlation between LA volumes obtained with MSCT and echocardiography

In a subset of 13 patients with sinus rhythm, LA volume measurements were performed using both MDCT and echocardiography. With Simpson’s method, mean LA volumes, indexed to body surface area, were 43.9 ± 14.1 ml/m² by MSCT, and 39.7 ± 15.6 ml/m² by echocardiography. With the area-length method, on the other hand, indexed LA volumes were 43.0 ± 14.7 ml/m² by MSCT, and 40.9 ± 16.2 ml/m² by echocardiography. There was good correlation in each LA volume method (Simpson or area-length) between MSCT and echocardiography (Simpson’s method: \( r = 0.91, P < 0.0001 \), area-length method: \( r = 0.90, P < 0.0001 \)).
Discussion

The major findings of this study are that with MSCT, LA volumes calculated with the area-length method exhibited a strong linear relationship and agreement with those calculated with Simpson’s method, and that both of the methods assessed in this study exhibited highly satisfactory reproducibility.

Many findings have confirmed the relationship between increase in LA volume and the development of adverse cardiovascular outcomes in subjects without a history of atrial fibrillation or significant valvular disease [16]. However, accurate measurement of LA volume has been difficult, in part because of the oblique angle at which the heart lies within the chest, the continuous movement of the heart itself, and breathing, as well as the complexity of LA shape. Many previous studies examining the prognostic effects of LA volume have used 2-D transthoracic echocardiography with direct visualization of the myocardium and real-time imaging [1—4]. However, there are potential sources of error in 2-D planimetry of the left atrium using echocardiography. Apical imaging planes the atria in the far field of the ultrasound beam, resulting in a loss of lateral resolution with limited visualization of the LA endocardium. In the present study, validation of the MSCT method has been performed on a small number of patients by using transthoracic echocardiography. There was good correlation in LA volume assessment between MSCT and echocardiography, although measurement by MSCT overestimated LA volume compared with echocardiography. This finding is in agreement with previous reports [8].

The quantitative measurement of the LA size is typically required in patients with enlarged LA size complicated by paroxysmal or persistent atrial fibrillation. As fully established by previous studies, the LA shape is different from the small LA to the larger LA, where the larger LA is known to be more spherical. From that point, this study by MSCT included a small number of patients with atrial fibrillation to provide a new reliable standard for LA volume assessment in the wide range of clinical settings. The present results ensured the similar tight correlations in patients with larger LA size.

The current method of retrospective ECG-gated MSCT has already been accepted as an efficient noninvasive means of detection of coronary artery stenosis, with good sensitivity and specificity and a high negative predictive value [11,17]. Furthermore, MSCT data can be used to gain additional information on cardiac function and volumes [13]. Assessment of LA volume by Simpson’s method is often time-consuming and labor-intensive. The area-length method, on the other hand, is simple and reproducible. For patients already clinically indicated for MSCT coronary angiography for evaluation of the coronary arteries, if assessment of LA volume can be standardized and incorporated into routine diagnostic and prognostic paradigms, this simple method may prove to be highly effective in risk stratification and prevention strategies.

There are several limitations to the present study. First, only maximum LA volume was measured in the present study. However, various LA volumes can be used to describe LA phasic function, since cardiac MSCT with ECG-gated image acquisition yields images at different phases of the cardiac cycle. Second, we trimmed the LA appendage when we used Simpson’s method. To measure the accurate estimation of the LA size, the LA appendage should have been included. Third, nitroglycerin immediately before the MSCT scan might reduce the preload, which might affect the LA size. Finally, MSCT scans of the coronary arteries are still associated with a relatively high radiation dose and require iodinated contrast material. Furthermore, since MSCT cardiac study is not recommended in patients with atrial fibrillation by the current triggering system, MSCT could not be a new routine modality to accurately estimate the giant LA size. However, we believe that it is important to obtain as much relevant information using the same data set as acquired for noninvasive coronary angiography.

In conclusion, the area-length method is a simple and reproducible method for assessment of LA volume. Standardization of LA volume assessment using MSCT is clearly important for serial follow-up of outcome and meaningful communication of results of testing among institutions and physicians.

References


