Direct volumetry versus cylindrical approximation to assess left atrial volumetric changes before and after catheter ablation for atrial fibrillation using ECG-gated MDCT

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Purpose

In patients with atrial fibrillation (AF), left atrial (LA) enlargement is often observed because of increased LA load. Furthermore, LA reduction is often observed when they undergo catheter ablation with resultant sinus rhythm restoration (1). LA size is being recognized as a marker for cardiovascular risk (2-5), and therefore a precise method of evaluating LA volume is desirable (6).

Although LA volume is usually calculated with biplane trans-thoracic echocardiography using geometrical assumption of the atrial shape such as cylindrical approximation (7-13), that way of calculation of LA volume has been revealed to be inadequate for precise approximation compared with results of direct volumetry (9,10,12,14-16).

Recently, 64-slice (multi-detector) ECG-gated cardiac computed tomography (MDCT) has become widely available, enabling acquisition of detailed volumetric data of the heart. For the purpose of obtaining detailed information on LA and pulmonary vein anatomy before catheter ablation, and evaluating whether the pulmonary veins became stenosed or not after catheter ablation, we usually performed ECG-gated MDCT before and after catheter ablation. Using the same data, we could assess the LA volume using both direct volumetry and approximation method.

Direct volumetry needs laborious procedure and unfavorable for routine work, so we prefer approximation method. That is why we examine whether the approximation method is adequately precise when we evaluate temporal LA volumetric changes.

It is beneficial if we can assess LA volume precisely in easy-to-use approximation method, instead of messy direct volumetry.

However, to our knowledge, no report has examined the accuracy of cylindrical approximation, a frequently used one of geometrical assumption methods, by using cylindrical approximation before and after catheter ablation for atrial fibrillation and comparing the data with those of direct volumetry on 64-slice ECG-gated MDCT.

Although there is no established method of direct volumetry from three-dimensional LA volume, it has been reported that MDCT direct volumetry using threshold extraction of LA has higher reproducibility than the cylindrical approximation method (17).

The purpose of this study is to evaluate the accuracy of the cylindrical approximation method by means of calculating the percent LA volume reduction (%VR) compared with the direct volumetry as a golden standard for assessing temporal LA volumetric changes before and after catheter ablation for atrial fibrillation using ECG-gated MDCT.
Methods and Materials

Subjects

Between May 2006 and February 2010, 35 consecutive patients with atrial fibrillation (14 persistent atrial fibrillation and 21 paroxysmal atrial fibrillation; 27 men and 8 women; mean age, 56.68 years, range 29-71 years) underwent cardiac CT before and after catheter ablation for atrial fibrillation. This study was retrospectively evaluated in accordance with a protocol approved by the Tohoku University institutional review board, and the requirement for informed consent was waived.

CT scanning and image reconstruction

MDCT was performed with a 64-slice MDCT scanner (Aquilion 64, TOSHIBA, Tokyo, Japan; 5.2006-5.2007 and SOMATOM definition, SIEMENS, Forchheim, Germany; 5.2007-2.2010). Contrast-enhanced cardiac MDCT was performed during a single breath hold on helical mode with retrospective electrocardiographic gating.

Scan parameters were as follows: gantry rotation time 400 ms, detector collimation 0.5 mm, tube voltage 120 kV (Aquilion 64) and gantry rotation time 330 ms, detector collimation 0.6 mm, and tube voltage 120 kV (SOMATOM definition).

The scan delay was determined by test bolus injection of 12 mL contrast material with a flow rate of 3 mL/s followed by a 20 mL saline injection at the same rate. Repeated scanning at the level of the pulmonary trunk was performed to obtain a time-density curve in the descending aorta. The time to peak enhancement of the descending aorta was chosen as the delay time. For vessel enhancement, nonionic contrast material (iohexol 350 mg/mL, Daiichi-Sankyo, Tokyo, Japan) was injected at a flow rate of 0.07 mL/kg/s followed by a 30 mL saline chaser injected at the same flow rate. The injection duration of the contrast medium was equal to the scan duration plus 5 s. Beta-blockers were not given to decrease the heart rate.

CT scanning and image reconstruction

Axial image series were reconstructed at multiple cardiac phases in 0%-90% of the R-R interval in steps of 10% with a slice thickness of 0.5 mm (TOSHIBA), 0.75 mm (SIEMENS), and a reconstruction interval of 0.5 mm.

Measurement of LA parameters

The phase that provides the maximum anteroposterior diameter of LA was used for analysis. LA parameters were analyzed using the Volume Analysis software package on a workstation (Advantage Windows 4.3, GE Healthcare, Waukesha, Wisconsin, USA).
Before and after catheter ablation LA volume was measured by one radiologist and measurements were repeated by the same radiologist more than 1 week after the first measurement to evaluate intraobserver variability.

**Direct LA volumetry**

Following the method of Matsumoto (17), Using a combination of axial and multiplanar reformatted (MPR) images, LA was clamped at the mitral valve annulus, and was also clamped at the ostia of all the pulmonary veins (PVs) that joined LA at a plane perpendicular to their long axes, thus completely separating LA from the left ventricle and from PVs (Figure 1).

The contour of LA was determined using a combination of axial and multiplanar reformatted (MPR) images: LA was clamped at the mitral valve annulus, and was also clamped at the ostia of all the pulmonary veins (PVs) that joined LA at a plane perpendicular to their long axes. This completely separated LA from the left ventricle and from PVs (Figure 1), which consequently included the left atrial appendage.

To eliminate subjectivity in drawing the contours of LA and to obtain a constant measurement, we first determined the threshold value for LA by directly measuring the CT values within LA and its surrounding structures. The threshold value was obtained as follows:

1. From consecutive original axial slices, an original axial slice that provides the maximum anteroposterior diameter of LA was selected (Figure 2A).

2. An anteroposterior parasagittal line perpendicular to the long axis of LA (Figure 2A) was drawn to show a profile curve of the CT value (Figure 2B).

3. Average CT values in LA and its surrounding structures were measured, and the mean of the values was determined as the threshold value for extraction of LA (Figure 2B).

A total volume of voxels that have larger CT values than the threshold value was measured and normalized to the body surface area (BSA).

**Volumetry of cylindrical approximation method**

Following the cylindrical approximation method of Ho et. al (8), three orthogonal diameters of LA chamber were recorded (longitudinal, anteroposterior, and transverse). First, we selected an appropriate oblique axial MPR image so that the four main PVs might be best depicted. Second, the transverse diameter (T) was defined as the distance between the midpoints between the superior and inferior PVs on both sides (Figure 3A), and the anteroposterior diameter (width: W) was measured on the same image along the perpendicular line that crosses the transverse diameter at its center (Figure 3A). Finally, the longitudinal diameter (height: H) was measured on an oblique sagittal image that
was orthogonal to the transverse diameter line and passed the center of the transverse diameter (Figure 3B).

LA volume was calculated as follows (8):

\[
\text{LA Volume} = \# \times T \times W/2 \times H/2
\]

All the volumes were normalized to BSA.

**Calculation of the % LA volume reduction (%VR)**

The percent LA volume reduction (%VR) was calculated as follows:

\[
\%\text{VR} (\%) = \frac{(\text{LA volume before catheter ablation} - \text{LA volume after catheter ablation})}{\text{LA volume before catheter ablation}} \times 100
\]

We here refer to the first measurement of %VR using direct volumetry as D_%VR1 and the second as D_%VR2, while the first measurement of %VR using cylindrical approximation as A_%VR1 and the second as A_%VR2. We defined the mean value of D_%VR1 and D_%VR2 as D_%VR, and the mean value of A_%VR1 and A_%VR2 as A_%VR, respectively.

**Statistical analysis**

Statistical analysis was performed with MedCalc version 10.4. All the data were expressed as mean ± 1.96SD. Intraobserver variability of each parameter was evaluated using the method of Bland and Altman. Coefficient of repeatability (CR) was calculated as 1.96 times the standard deviations of the differences to compare repeatability of approximation method and direct volumetry.

The correlation between %VR calculated with direct volumetry and approximation method was evaluated using Pearson’s correlation coefficient (r) and the method of Bland and Altman. Limits of agreement (LOA) was calculated and fixed bias and proportional bias were evaluated to compare two measurements.
Fig. 0: Figure 1. Images for clamping PVs. A: Axial image. B: Oblique coronal image. LA was clamped at the ostia (pink line in B) of all PVs that joined LA at a plane perpendicular to their long axes (blue line in A and B).

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Fig. 0: Figure 2. Images for extracting LA. A: Axial image that shows the maximum anteroposterior diameter of LA. B: A profile curve of the CT value. Draw an anteroposterior parasagittal line perpendicular to the long axis of LA (yellow line in A) to show the mean CT value in LA and its surrounding structures (B). It was defined as the threshold value for extraction of LA.

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Fig. 0: Figure 3. Images for three orthogonal diameters of LA chamber. A: Paraxial MPR image in which the four main PVs may be best depicted. B: Oblique sagittal image that was orthogonal to A. The transverse diameter (T) was defined as the distance between the midpoints between the superior and inferior PVs on both sides (A). The anteroposterior diameter (width: W) was the perpendicular line (L-M) that crosses the transverse diameter at its center (A). Longitudinal diameter (height: H) was measured on the center of the transverse diameter (B).
Results

LA margins were recognized well in all cases, thus allowing for segmentation of LA. There were no major complications. On average, CT examination was performed 4.1 (range, 1-28) days before catheter ablation and 203.9 (range, 161-300) days after catheter ablation. Before catheter ablation the selected phases that provided the maximum anteroposterior diameter of LA were 30% (18 cases), 40% (16 cases), 50% (1 case) and after catheter ablation were 30% (8 cases), 40% (25 cases), 50% (2 cases).

Reproducibility of the percent LA volume reduction (%VR)

LA volumes measured by each method and the mean value of the first and the second measurement and the percent LA volume reduction are shown in Table 1. Intraobserver variability (the mean of the difference ± 1.96SD) between D_%VR1 and D_%VR2 was 2.869 ± 10.405 %, and between A_%VR1 and A_%VR2 was #0.463 ± 26.942 %, respectively (Table 2). Coefficient of Repeatability was 10.405 % by direct volumetry, 26.942 % by approximation method. The Bland and Altman plot is shown in Figure 4.

Comparison of direct volumetry and approximation method

The mean difference ± 1.96 SD between D_%VR and A_%VR was 0.738 ± 27.890 %. Limits of agreement (LOA) showed rather wide range (-27.153 to 28.628 %)(Table 3). The Bland and Altman plot is shown in Figure 5-a. The correlation coefficient between D_%VR and A_%VR was r = 0.621 (95% CI 0.362 to 0.730, p=0.0001) (Figure 5-b). Fixed bias or proportional bias was not observed.
**Fig. 0:** Figure 4. Intraobserver reproducibility of the percent LA volume reduction (%VR). A: Bland and Altman plot of %VR using direct volumetry. B: Bland and Altman plot of %VR using approximation method. D_%VR1: %VR using first direct volumetry. D_%VR2: %VR using second direct volumetry. A_%VR1: %VR using first approximation measurement. A_%VR2: %VR using second approximation measurement. Intraobserver variability (the mean difference ± 1.96SD) between D_%VR1 and D_%VR2 was 2.869 ± 10.405 % and between A_%VR1 and A_%VR2 was -0.463 ± 26.942%.

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**Fig. 0:** Figure 5. Comparison of direct volumetry and approximation method. a: Bland and Altman plot of D_%VR and A_%VR. b: Correlation between D_%VR and A_%VR. D_%VR: Average of D_%VR1 and D_%VR2. A_%VR: Average of A_%VR1 and A_%VR2. The mean difference ± 1.96SD between D_%VR and A_%VR was 0.738 ± 27.890 %. LOA was -27.153 to 28.628 %. The correlation coefficient between D_%VR and A_%VR (r) was 0.621 (95% CI 0.362 to 0.730, p=0.0001).
### Fig. 0: Table 1. LA volume and the percent LA volume reduction (%VR) using direct volumetry and cylindrical approximation method before and after catheter ablation.

<table>
<thead>
<tr>
<th>Method</th>
<th>Before CA mean (range)(mL)</th>
<th>After CA mean (range)(mL)</th>
<th>% LA volume reduction mean (range) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First direct volumetry</td>
<td>70.089 (41.617 to 155.396)</td>
<td>63.335 (37.402 to 118.124)</td>
<td>7.495 (-30.618 to 38.170)</td>
</tr>
<tr>
<td>Second direct volumetry</td>
<td>70.672 (42.236 to 148.369)</td>
<td>65.796 (38.382 to 120.633)</td>
<td>4.656 (-33.129 to 36.927)</td>
</tr>
<tr>
<td>Mean value of first and second direct volumetry</td>
<td>70.380 (42.965 to 151.882)</td>
<td>64.566 (37.892 to 119.3799)</td>
<td>6.098 (-31.875 to 37.541)</td>
</tr>
<tr>
<td>First approximation measurement</td>
<td>57.459 (24.370 to 127.720)</td>
<td>52.730 (23.902 to 102.850)</td>
<td>6.474 (-25.706 to 38.266)</td>
</tr>
<tr>
<td>Second approximation measurement</td>
<td>55.726 (23.159 to 133.226)</td>
<td>50.770 (17.078 to 95.585)</td>
<td>6.937 (-33.954 to 51.352)</td>
</tr>
<tr>
<td>Mean value of first and second approximation measurement</td>
<td>56.592 (23.764 to 130.473)</td>
<td>51.749 (20.490 to 99.218)</td>
<td>6.836 (-21.578 to 44.489)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>Intraobserver variability (the mean of the difference ± 1.96SD)</th>
<th>Coefficient of Repeatability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct volumetry (%)</td>
<td>2.869 ± 10.405</td>
<td>10.405</td>
</tr>
<tr>
<td>Approximation method (%)</td>
<td>-0.463 ± 26.942</td>
<td>26.942</td>
</tr>
</tbody>
</table>
Fig. 0: Table 2. Reproducibility of the percent LA volume reduction (%VR)

<table>
<thead>
<tr>
<th>D_%VR (range)</th>
<th>A_%VR (range)</th>
<th>Correlation coefficient between two methods (r)</th>
<th>The Mean difference (95%CI) (%)</th>
<th>Fixed bias proportional bias</th>
<th>Limits of agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.098 (-31.875 to 37.541)</td>
<td>6.836 (-21.578 to 44.489)</td>
<td>0.621 P=0.0001</td>
<td>0.738 (-4.150 to 5.626)</td>
<td>-</td>
<td>-27.153 to 28.628</td>
</tr>
</tbody>
</table>

Fig. 0: Table 3. Comparison of D_%VR and A_%VR. D_%VR: Average of first and second percent LA volume reduction by direct volumetry. A_%VR: Average of first and second percent LA volume reduction by cylindrical approximation method. LOA showed rather wide range. The correlation coefficient between D_%VR and A_%VR was rather weak (r= 0.621, 95%CI 0.362 to 0.730, p=0.0001)
Conclusion

The cylindrical approximation method showed lower reproducibility and larger measurement error than the direct volumetry in assessing temporal LA volumetric changes before and after catheter ablation for atrial fibrillation. Direct volumetry is more reliable than approximation method when assessing temporal LA volumetric changes before and after catheter ablation for atrial fibrillation.
References


