Mitral Annulus Flattens in Ischemic Mitral Regurgitation: Geometric Differences Between Inferior and Anterior Myocardial Infarction

A Real-Time 3-Dimensional Echocardiographic Study

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Background—New surgical strategies to restore the saddle shape of the mitral annulus are expected to increase annuloplasty effectiveness. Preoperative and postoperative configuration of the curved annulus, however, is difficult to quantify with 2-dimensional echocardiography. We sought to investigate the geometric deformity in the mitral annulus in ischemic mitral regurgitation (MR), comparing inferior and anterior myocardial infarction (MI) with the use of a custom quantitation software system with transthoracic 3-dimensional echocardiography.

Methods and Results—We performed real-time 3-dimensional echocardiography in 23 patients with ischemic MR attributable to inferior MI or anterior MI and in 10 controls. Three-dimensional data were cropped into 18 radial planes, and we manually marked the annulus in mid systole. Three-dimensional annular images were reconstructed, and annular circumferences, areas, and heights were quantified. Annulus was significantly more dilated and flattened in ischemic MR than in controls and was further deformed in anterior MI as compared with inferior MI (control: circumference 9.9 ± 0.7 cm, area 9.6 ± 0.5 cm², height 5.0 ± 0.7 mm; inferior MI: circumference 11.5 ± 1.2 cm [P<0.01 compared with control], area 11.4 ± 2.0 cm² [P<0.05 compared with control], height 3.5 ± 1.6 mm [P<0.05 compared with control]; anterior MI: circumference 14.2 ± 2.4 cm [P<0.0001 compared with control, P<0.05 compared with inferior MI], area 13.7 ± 2.8 cm² [P<0.01 compared with control, P<0.05 compared with inferior MI], height 1.7 ± 1.5 mm [P<0.0001 compared with control, P<0.05 compared with inferior MI]).

Conclusions—Mitral annulus flattens in ischemic MR. Deformity of the mitral annulus was greater in anterior MI group than in the inferior MI group. (Circulation. 2005;112[suppl I]:I-458–I-462.)

Key Words: mitral valve • regurgitation • surgery • echocardiography

Saddle-shaped nonplanarity of the mitral annulus has been previously investigated by rotated 2-dimensional (2-D) or multiplane transesophageal echocardiography1,2 in human studies, and by marker radiography or sonomicrometry in animal studies.3,4 A recent computer-based simulation study has successfully demonstrated that the saddle-shape of the mitral annulus is a more subtle form to optimize mitral leaflet curvature, which minimizes peak mitral leaflet stress.5 Recently, new surgical strategies to restore the saddle shape of the mitral annulus, such as annuloplasty with non-planner saddle-shaped ring or semi-rigid ring and percutaneous annuloplasty,6–8 have been proposed, and these new techniques are expected to increase mitral valve repair effectiveness and durability. According to the previous reports, ischemic mitral regurgitation (MR) occurs in higher incidence in patients with inferior myocardial infarction (MI) compared with those with anterior MI, despite its less severe left ventricular (LV) remodeling, because of the greater displacement of posterior papillary muscle caused by localized inferior basal LV remodeling.9–11 Although there should be geometric heterogeneity in mitral annulus in various types of LV remodeling, the 3-dimensional (3-D) configuration of the curved mitral annulus is difficult to investigate using conventional 2-D echocardiography in the clinical setting. If we can provide preoperative 3-D configuration of the mitral annulus in each patient, it would be a guide to assist the surgeon in deciding the proper strategy in the annuloplasty.

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Methods

Patients
We prospectively studied 23 patients with significant ischemic MR (regurgitant orifice area >0.15 cm²) with prior inferior MI (11 patients, 7 men, age 65.3 ± 10.0 years) and anterior MI (12 patients, 9 men, age 71.5 ± 5.4 years). Inclusion criteria were technically adequate real-time 3-D echocardiographic image of the LV chamber and the mitral annulus to allow analysis, technically adequate color flow Doppler image to determine proximal isovelocity surface area (PISA), and normal sinus rhythm. Exclusion criteria were acute MI, structural mitral valve or subvalvular lesions, such as mitral valve prolapse or rheumatic disease, and other cardiac diseases, such as organic valvular, pericardial, congenital, or infiltrative heart disease. We initially included 33 patients (16 with inferior MI, 17 with anterior MI) in the study population. Ten patients were excluded from the study because of atrial fibrillation (2 with inferior MI, 3 with anterior), inadequate real-time 3-D echocardiographic image quality (2 with inferior MI, 1 with anterior), and mitral leaflet or/and annulus calcification (1 with inferior MI, 1 with anterior). Ten healthy subjects were also examined as controls (8 men, age 66.6 ± 5.7 years). All participants gave written, informed consent, and study protocol was approved by the Committee for the Protection of Human Subjects in Research at Kawasaki Medical School.

Echocardiographic Protocol
All the echocardiographic exams were performed by using SONOS 7500 (Philips Inc) with S3 probe for 2-D images, and X4 probe for real-time 3-D images.

Two-Dimensional Echocardiographic Study
All subjects underwent a standard 2-D echocardiographic examination. LV end-diastolic volume (EDV) and end-systolic volume (ESV) were measured by the biplane Simpson method. Ejection fraction (EF, %) was calculated by the equation 100×(EDV-ESV)/EDV. MR was evaluated by color Doppler echocardiography. Degree of MR was quantified by regurgitant orifice area using the PISA method.

Three-Dimensional Echocardiographic Study
Volumetric Image Acquisition
Using a real-time 3-D echocardiographic system, we obtained transthoracic volumetric images (full volume mode) with the apical view in all the subjects. The volumetric frame rate was 17 to 24 frames/s, with an imaging depth of 12 to 16 cm. Before acquiring the full volume image, we carefully adjusted the transducer position to be located at the apex in a biplane mode. All volumetric images were digitally stored on compact disk and transferred into a personal computer for offline analysis.

Quantification of Mitral Annular Nonplanarity by 3-D Echocardiography
We used our 3-D computer software that is based on MATLAB (MathWorks, Inc) to analyze the volumetric image. In a cross-sectional plane of the mitral annulus, we defined the center of the mitral annulus in the volumetric image to set the axis through the transducer position and the center of the annulus. We also determined the anterior-posterior axis and commissure-commissure axis in the volumetric image. The 3-D data were then automatically cropped into 18 radial planes spaced 10 degrees apart. We manually marked the mitral annulus in each cropped plane in mid-systole (the middle frame with systolic mitral leaflet closure). The mitral annulus was identified as the leaflet hinge points on the echocardiographic images. The anterior end of the mitral valve was marked at the level of the intertrigonal line. From these data, 3-D images of the mitral annulus were reconstructed (Figure 1). The reconstructed 3-D annulus image can be observed from any direction. Heights of the mitral annulus were quantified from the 3-D data to demonstrate the non-planarity. Annular circumferences and annular areas were quantified from the 3-D data as well. These data were compared in the 3 groups.

Statistical Analysis
Data are expressed as mean ± SD. Student t test was used for group comparisons. A value of P < 0.05 was considered significant.

Results
Geometric measurements of the LV chamber and mitral annulus in the 3 groups are summarized in the Table.

Basic Characteristics
There were no differences in age, sex, or body surface area among 3 groups. Compared with normal controls, EF was significantly lower and EDV and ESV were significantly larger in patients with ischemic MR with both inferior MI and anterior MI. LV dysfunction and LV remodeling were greater in patients with anterior MI than in those with inferior MI. There was no significant difference in regurgitant orifice area between those 2 groups of patients.

Mitral Annular Geometry
In healthy control subjects, configuration of the mitral annulus appeared as a non-planer saddle shape, with its high (farthest from apex) point located anteriorly near the aortic root and posteriorly near the posterior left ventricular wall, and its low points located at the anterior and posterior commissure sides (Figure 2). Compared with the normal controls, mitral annulus was significantly dilated in patients with ischemic MR, and more dilated in patients with anterior MI than in those with inferior MI. Annular height, which shows the nonplanarity of the annulus, was significantly shorter in both the anterior and inferior MI with ischemic MR groups compared with normal subjects. Annular height was significantly shorter in patients with anterior MI than in those with inferior MI.

Discussion
In the present study, we investigated the geometric differences in the mitral annular deformity in ischemic MR between the patients with inferior MI and anterior MI by using our custom 3-D quantitation software system with transthoracic real-time 3-D echocardiography. Using our custom 3-D analysis software system, we successfully demonstrated the curvature of mitral annulus and quantified its deformation directly from the 3-D data. In normal subjects, annular configuration appeared saddle-shaped, with its highest point near the aortic root anteriorly and near the posterior left ventricular wall posteriorly, and its low points located at the anterior and posterior commissure sides, as previously described.1,2 Mitral annulus was dilated and flattened in ischemic MR. The degree of geometric deformation of the annulus was significantly greater in the anterior MI group compared with the inferior MI group. On one hand, the degree of LV remodeling was also significantly greater in patients with anterior MI than in those with inferior MI in the present study population. These results would support the previous reports, which emphasize the importance of localized posteroinferior LV remodeling with papillary displacement as a mechanism of ischemic MR.9,10 There should be geometric heterogeneity in the mitral annulus in ischemic MR associated with variable clinical backgrounds, including the infarct region.
and infarct size. Three-dimensional echocardiography is a promising technique that can provide precise 3-D geometry, which is difficult to understand by conventional 2-D echocardiography.

Ischemic MR is known to occur in patients with systolic LV dysfunction due to ischemic heart disease with structurally normal mitral valve leaflets. It has been reported that the existence of ischemic MR is associated with excess mortality, and mitral valve repair using annuloplasty rings is recommended. In mitral annuloplasty, however, plane rings have been widely used for more than 20 years, despite the complex geometry of actual mitral annulus. Yamaura et al. reported that mitral annular configuration and dynamics are more physiological in patients with a flexible annuloplasty ring than in those with a rigid ring. Several animal studies have reported annulus deformation in regional ischemia or in chronic ischemic MR, and new

Figure 1. A 3-D volumetric image was automatically cropped into 18 equally spaced radial planes. We manually marked the mitral annulus in each cropped plane in mid-systole. From these data, 3-D images of the annulus were reconstructed for the quantitative measurements.

<table>
<thead>
<tr>
<th>Measurements of LV Chamber and Mitral Annulus</th>
<th>Controls (n=10)</th>
<th>Ischemic MR With Inferior MI (Inf) (n=11)</th>
<th>Ischemic MR With Anterior MI (Ant) (n=12)</th>
<th>P Value (Inf vs Ant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROA, cm²</td>
<td>0.25±0.11</td>
<td>0.28±0.16</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>LV chamber</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDVI, mL/m²</td>
<td>45.4±12.2</td>
<td>63.4±15.9‡</td>
<td>108.5±31.4*</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>ESVI, mL/m²</td>
<td>16.1±4.3</td>
<td>33.2±13.1§</td>
<td>73.8±28.8*</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>EF, %</td>
<td>64.9±3.2</td>
<td>50.1±6.9†</td>
<td>31.5±9.8*</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mitral annulus</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Circumference, cm</td>
<td>9.9±0.7</td>
<td>11.5±1.2§</td>
<td>14.2±2.4*</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Area, cm²</td>
<td>9.6±0.5</td>
<td>11.4±2.0†</td>
<td>13.7±2.8§</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Height, mm</td>
<td>5.0±0.7</td>
<td>3.5±1.6†</td>
<td>1.7±1.5*</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

ROA, regurgitant orifice area; EF, ejection fraction; EDVI, end-diastolic volume index; and ESVI, LV end-systolic volume index. Other abbreviations as in text.

*P<0.0001, †P<0.001, ‡P<0.01, §P<0.05 vs controls.
surgical strategies to restore the saddle shape of the mitral annulus have been proposed and investigated recently (ie, non-planner saddle-shaped annuloplasty ring or semi-rigid ring and catheter annuloplasty).\textsuperscript{6–8} The size of the mitral annulus is currently demonstrated by 2-D transthoracic or transesophageal echocardiography, despite its nonplanar, curved configuration, which was previously described as saddle shaped. Considering the concept of those new annuloplastic strategies that are expected to restore the saddle shape of the mitral annulus, precise 3-D quantitation is needed to provide the preoperative and postoperative geometric information. Furthermore, the heterogeneity of the annular deformity in ischemic MR patients with various types of LV remodeling should be taken into account in the clinical setting.

**Study Limitations**

Real-time 3-D echocardiography that is currently available in the clinical setting provides images with lower quality than conventional 2-D echocardiography. As the software system used in the present study requires identification of mitral annulus for the manual tracing, technically inadequate real-time 3-D echocardiographic images are not amenable for analysis. In the present study, we investigated only the annular geometry, although ischemic MR is a disease of the entire mitral complex. To understand 3-D geometric changes of the mitral apparatus comprehensively, further improvement of this system is required to the complete our understanding of the entire mitral complex geometry, including mitral annulus, mitral valve leaflet, papillary muscles, and LV. Furthermore, it would be especially interesting to compare the mitral annulus geometry in ischemic mitral regurgitation with a control group of patients with comparable LV dimensions but without significant MR. Further investigations using this technique including patients with and without MR would be needed. Finally, we estimated MR severity in the patients with 2 jets by the summation of 2 jets by PISA method, although this method has not been validated.

**Conclusions**

Mitral annulus flattens in ischemic MR. Geometric deformity of the mitral annulus was greater in patients with anterior MI than in those with inferior MI.

**Acknowledgments**

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**References**

10. Kumanohoso T, Otsuji Y, Yoshifuku S, Matsukida K, Koriyama C, Kisanuki A, Minagoe S, Levine RA, Tei C. Mechanism of higher incidence of ischemic mitral regurgitation in patients with inferior myo-


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