Background: Little is known about the impact of tricuspid annuloplasty (TAP) on annular dynamics. We assessed tricuspid annular dynamics using 3-D transesophageal echocardiography (3D-TEE) before and after TAP with different types of prosthetic ring.

Methods and Results: 3D-TEE of the tricuspid valve was acquired in 30 patients (TAP with rigid ring [RR], n=8; TAP with flexible ring [FR], n=10; control, n=12). Tricuspid annular dimensions (circumference, area, annular height, anteroposterior [AP], septolateral [SL] diameter) were measured throughout the cardiac cycle. All postoperative tricuspid annular dimension parameters were significantly reduced by TAP, while the AP/SL ratio was significantly increased (before, 0.96±0.16; after, 1.03±0.06; P<0.05). The difference in annular area between diastole and systole was significantly smaller in the TAP groups (11.6%) than in the control (27.9%, P<0.05). Annular height in the FR patients was significantly lower than in the RR group, while the postoperative AP/SL ratio was lower in the RR than the FR and control groups. Change in annular area was not seen in RR patients, while it was seen in the FR and control groups.

Conclusions: Annulus motion and shape differ according to the type of prosthetic ring used, although tricuspid regurgitation was well controlled by all types of ring utilized. The present results provide important information for selection of an appropriate prosthetic ring for TAP. (Circ J 2015; 79: 873–879)

Key Words: Annular geometry; Echocardiography; Surgery; Valvular disease

With recent advances in 3-D echocardiography (3DE), multiple studies have shown the technique to be feasible and accurate for assessing mitral valve surgery. 3DE has also enhanced understanding of mitral valve geometry and dynamics.1-2 As compared with the mitral valve, only a few studies have been carried out on the geometry or annular dynamics of the tricuspid valve.3-4 Tricuspid regurgitation (TR) was once largely ignored, and the importance of the tricuspid valve is often overlooked because of its unique and complex structure. Recent studies have found that this valve plays an important role in a number of clinical disease states, including left-sided valve disease and heart failure.7,8 Furthermore, development of functional TR is directly associated with increases in risk of morbidity and mortality.9,10 Therefore, functional TR has been gaining interest in regard to the configuration of the tricuspid valve as well as its treatment.

Although TR frequently improves after mitral intervention, its severity occasionally continues to worsen despite correction of the original insult.11-13 Even after treatment, TR often persists, which may be because of incomplete understanding of the tricuspid apparatus and alterations associated with different diseases. Therefore, it is important to obtain a better understanding of the physiological mechanisms underlying functional TR to suggest potential ways to improve therapy. Understanding of the anatomy of the tricuspid valve annulus and its dynamic changes during the cardiac cycle can also provide insight into the mechanism of TR. With the advent of 3DE, studies of tricuspid valve geometry in normal and functional TR patients are beginning to appear.3-6 In tricuspid annuloplasty (TAP), surgeons usually use various types of prosthetic ring to correct functional TR.14-17 Although previous investigations using 3DE have shown that the tricuspid annulus is non-planar and undergoes a complex series of conformational changes between systole and diastole,5 little is known about the impact of TAP using...
various kinds of prosthetic rings on tricuspid annular configuration or dynamics. Therefore, the purpose of this study was to assess tricuspid annular dynamics using 3-D transesophageal echocardiography (3D-TEE) before and after TAP with different types of prosthetic ring.

**Methods**

**Patient Selection**
We prospectively carried out 2-D transthoracic echocardiography (2D-TTE) and 3D-TEE in 30 patients who underwent heart valve surgery at Osaka University Graduate School of Medicine, and divided them into 3 groups: (1) TAP with a rigid prosthetic ring (MC annuloplasty system; Edwards Lifesciences, Irvine, CA, USA; n=8); (2) TAP with a flexible ring (TailorTM Ring; St. Jude Medical, St. Paul, MN, USA; n=10); and (3) those with normal tricuspid valve function but who underwent mitral valve surgery (control subjects, n=12). The indications for TAP included moderate or severe TR, mild TR with dilated tricuspid annulus, or pulmonary hypertension. Baseline patient characteristics are listed in Table 1. The degree of TR was defined based on the recommendations for evaluation of the severity of native valvular regurgitation with 2-D and Doppler echocardiography. Right ventricular dilatation and pulmonary hypertension were defined based on guidelines for the echocardiographic assessment of the right heart in adults from the American Society of Echocardiography. We defined normal tricuspid valve as TR grade <mild without dilated tricuspid annulus (tricuspid annulus diameter in 4-chamber view <40 mm).

**Image Acquisition and Analysis**
All images were acquired using a Sonos 7500 device (Phillips Medical Systems, Bothell, WA, USA). 3D-TEE was performed using a X7-2t probe. We selected the angle at which the tricuspid valve was best visualized, which was usually 0°, so that full-volume images of the right ventricle could be optimally recorded. Electrocardiography-gated full volume images were acquired during 2 consecutive cardiac cycles. The volumetric frame rate was set at 17–30 Hz with an imaging depth of 12–16 cm. We ensured that the entire annulus throughout the cardiac cycle was included. After optimizing gain, recording was done and the images were stored on digital versatile discs for further offline analysis.

Tricuspid valve image analysis was conducted using commercially available software designed for assessing the mitral and tricuspid valves (RealView®; YD, Nara, Japan). Application of this novel system has been described for assessment of mitral annulus geometry in previous reports. Briefly, each apical 3D-TEE full-volume image was cropped into 18 apical 2-D planes spaced at 10° apart. A mid-systolic or mid-diastolic image was selected for assessment of tricuspid annulus geometry. First, marker points were placed on each annulus in each 2-D plane. Then, the system defined the annulus at that point. The system automatically reconstructed the tricuspid valve, because it is easy to detect the tricuspid annulus into the actual 3-D configuration, which could be viewed from various directions. Then, the system defined the AP axis as the line between the anteroseptal commissure and the center of the tricuspid annulus. The SL axis was defined as at right angles to the AP axis. For quantitative analysis, the annular shape was approximated in a planar quadrant configuration contour. Annular area and circumference, as well as annular height, defined as the distance between the lowest

### Table 1. Demographic Profile

<table>
<thead>
<tr>
<th>Group</th>
<th>Rigid ring (n=8)</th>
<th>Flexible ring (n=10)</th>
<th>Control (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>67±13 (47–79)</td>
<td>66±14 (27–78)</td>
<td>58±18 (42–80)</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>6/2</td>
<td>5/5</td>
<td>6/6</td>
</tr>
<tr>
<td>Disease</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MR+TR+AF:3</td>
<td>MR+TR+AF:3</td>
<td>MR+TR+AF:1</td>
<td></td>
</tr>
<tr>
<td>MR+TR+AF:3 (CAD:1)</td>
<td>MR+TR+AF:3 (DCM:1)</td>
<td>MR+TR+AF:1 (AF:1,CAD:1)</td>
<td></td>
</tr>
<tr>
<td>AS+TR:1</td>
<td>AS+TR:2</td>
<td>AS+TR:1</td>
<td></td>
</tr>
<tr>
<td>MR+TR:2 (DCM:1)</td>
<td>AS+MR+TR:1</td>
<td>IE, MR+TR:1</td>
<td></td>
</tr>
<tr>
<td>MR+AF:1</td>
<td>MR+AF:1</td>
<td>MR+AF:1</td>
<td></td>
</tr>
<tr>
<td>Concomitant operations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVR:5</td>
<td>MVR:4 (MAZE:1)</td>
<td>MVR:2</td>
<td></td>
</tr>
<tr>
<td>MVP:1</td>
<td>MVP:3 (MAZE:2)</td>
<td>MVP:9</td>
<td></td>
</tr>
<tr>
<td>MAP:1</td>
<td>AVR+MAP:1</td>
<td>AVR+MAP:1</td>
<td></td>
</tr>
<tr>
<td>MVR+AVR+MAZE:1</td>
<td>AVR+CABG:1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVR+MAP:1</td>
<td>AVR+MAZE:1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ring size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 28, n=6</td>
<td>No. 27, n=6</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>No. 30, n=1</td>
<td>No. 29, n=2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 32, n=1</td>
<td>No. 31, n=1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 33, n=1</td>
<td>No. 33, n=1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVDd (mm)</td>
<td>55.5±7.8</td>
<td>52.2±15.2</td>
<td>56.2±6.8</td>
</tr>
<tr>
<td>RV dilatation</td>
<td>2 (25)</td>
<td>2 (20)</td>
<td>0</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>63.5±11.9</td>
<td>64.4±7.8</td>
<td>66.0±8.9</td>
</tr>
</tbody>
</table>

Data given as n, (%) or mean±SD (range). AF, atrial fibrillation; AR, aortic regurgitation; AS, aortic stenosis; AVR, aortic valve replacement; CABG, coronary artery bypass grafting; CAD, coronary artery disease; DCM, dilated cardiomyopathy; IE, infective endocarditis; LVDd, left ventricular diastolic dimension; LVEF, left ventricular ejection fraction; MAP, mitral annuloplasty; MR, mitral regurgitation; MVR, mitral valve replacement; MVP, mitral valve repair; RV, right ventricular; TR, tricuspid regurgitation.
Tricuspid Annular Dynamics After Annuloplasty

Statistical Analysis
Data were analyzed using Statview 5.0 (SAS Institute, Cary, NC, USA). Results are expressed as mean±SD. Mann-Whitney U-test was used for comparison of continuous variables and Fisher’s exact test for comparisons of frequencies between the groups. Differences in echocardiographic measurements between mid-diastole and mid-systole, and annulus parameters before and after ring insertion were analyzed using paired t-test. Statistical significance was defined as P<0.05.

Reproducibility of the parameters was assessed in a randomly chosen subgroup of 10 patients. Bland-Altman analysis was performed and results are presented as mean difference±2SD. This analysis was performed using MedCalc for Windows, version 14 (MedCalc Software, Ostend, Belgium). Two sequentially collected images were analyzed by a single observer to determine intraobserver repeatability, and the same 3D-TEE image was analyzed by 2 independent observers to determine interobserver comparison.
Table 2. Change in Tricuspid Annulus Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before TAP</th>
<th>After TAP</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annular area (cm²)</td>
<td>14.1±0.1</td>
<td>7.6±2.1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Annular circumference (mm)</td>
<td>134.9±15.0</td>
<td>98.9±13.9</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>AP distance (mm)</td>
<td>41.1±6.4</td>
<td>31.2±4.7</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>SL distance (mm)</td>
<td>43.2±5.1</td>
<td>38.2±4.3</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>AP/SL ratio</td>
<td>0.96±0.16</td>
<td>1.03±0.06</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Annular height (mm)</td>
<td>3.4±1.8</td>
<td>3.8±1.6</td>
<td>NS</td>
</tr>
</tbody>
</table>

AP, anteroposterior; SL, septolateral; TAP, tricuspid annuloplasty.

Results

Patient Characteristics
The mean age of the TAP groups (rigid, flexible) was 66±13 years and 61% were male; were slightly different to the control group (Table 1). There were no significant differences regarding mean age and gender between the rigid and flexible groups, or for degree of TR. Also, the TAP patients had similar left ventricular ejection fraction. The ring sizes used differed according to each patient’s native valve size, although there was no significant difference in mean size. Concomitant left-sided heart operations did not differ among the groups. There were no significant differences among the groups for the other baseline characteristics.

Annular Changes Before and After TAP
Full-volume data were obtained in all patients. In the TR patients, the SL diameter of the tricuspid annulus was significantly greater than the AP diameter. Mean annular area, annular circumference, AP diameter, and SL diameter were all significantly reduced after TAP (Table 2). Furthermore, the shape of the tricuspid annulus was remodeled and the AP diameter became similar to the SL diameter, thus the AP/SL ratio was significantly increased. In contrast, mean annular height did not differ between before and after TAP. Preoperative TR was significantly reduced after insertion of the annuloplasty ring (Figure 2). There were no significant differences between the rigid and flexible groups with regard to the postoperative degree of TR. As compared with the control group, overall tricuspid annular dynamics (diameter changes between diastole and systole) were significantly reduced after TAP.

Annular Post-TAP Geometry and Dynamics
In the control group, the AP diameter of the tricuspid valve annulus was similar to the SL diameter. In those who underwent TAP with a rigid ring, the AP diameter was significantly greater than the SL diameter, while the AP diameter was similar to the SL diameter in patients with a flexible ring. As a result, the AP/SL ratio was significantly greater in the rigid group as compared with the other groups. With regard to the planarity of the tricuspid valve annulus, the annular height of the tricuspid annulus in patients with a flexible ring after TAP was significantly lower than that in the other groups. There was no significant difference in tenting height between the rigid ring and control groups (Figure 3).

Figure 4 shows the change in each annulus parameter between mid-diastole and mid-systole in all groups. In patients with a rigid ring, there was hardly any change in annular area between mid-diastole and mid-systole. In contrast, each parameter of the annulus in mid-diastole was significantly greater than that in mid-systole in both the flexible ring and control groups. This ratio of change in the flexible ring was slightly lower than that in the control group, although it did not reach statistical significance. The change ratios for the AP and the SL diameters were similar in all groups. The dynamic diastolic to systolic change in AP and SL diameters was not seen in the rigid ring group, while it was seen in the flexible ring and control groups.

Intra- and Interobserver Variability
The results of intraobserver Bland-Altman analysis are as follows: annular area, –0.02±1.65 cm²; annular circumference, –0.49±12.13 mm; AP distance, 0.08±8.60 mm; SL distance, –0.23±4.67 mm; annular height, 0.25±4.50 mm. Bland-Altman analysis for interobserver comparisons are as follows: annular area, 0.06±1.30 cm²; annular circumference, –0.07±16.5 mm; AP distance, 0.03±3.13 mm; SL distance, –0.26±3.30 mm; annular height, –0.37±1.83 mm.

Discussion
The present study has described the structure of the tricuspid annulus, and its dynamics between mid-diastole and mid-systole before and after TAP using 3D-TEE and commercially available software. We found that the postoperative tricuspid annulus had different shapes and motion according to the type of prosthetic ring used. To the best of our knowledge, the current study is one of the first to assess change of these annular parameters before and after TAP. The present findings provide several novel in-
Tricuspid Annular Dynamics After Annuloplasty

The geometry of the tricuspid annulus and mechanism of TR have received focus in recent studies. The tricuspid annulus is normally saddle-shaped and non-planar, a configuration that is compatible with the present control group. The AP/SL ratio of the tricuspid annulus, however, was slightly different from that reported in other studies. Ton-Nu et al noted that the tricuspid annulus area was ellipsoid in shape, with the SL distance greater than the AP distance. In contrast, the present AP diameter was similar to SL diameter, which may have been due to differences in the control group. Previous studies selected control groups from healthy normal subjects, while the present control group consisted of patients who had left-sided valve surgery and normal tricuspid valve function, in order to eliminate the effect of left-sided valve surgery on postoperative tricuspid annulus.

As for the effect of TAP with a prosthetic ring, 3DE has provided little information regarding annulus changes. In the present study, each parameter of the tricuspid annulus was significantly reduced after implantation of a prosthetic ring, including both the SL and AP diameters. 3D-TEE was useful to confirm the effects of TAP. In addition, the present results provide interesting information regarding the different types of prosthetic ring used. There are 2 types of prosthetic ring commercially available for TAP: rigid and flexible. The MC3 annuloplasty system uses a rigid ring with a 2-D shape, which allows the shape to be adapted to the saddle configuration of the tricuspid annulus during implantation. In contrast, the Tailor ring has flexibility in every direction without a fixed 2-D shape.

In the current study, the rigid ring group had the same annular height after TAP as that in the control group, while the flexible ring group had a lower annular height. When a rigid ring is used, the shape of the tricuspid annulus becomes fixed. In contrast, patients with a flexible ring had a configuration similar to that in the control group. The effects of these differences on postoperative TR, however, are unknown, because TR was well regulated after TAP in all of the present patients.

As for the dynamic changes between diastole and systole of the tricuspid annular parameters, data are scarce, especially for patients who underwent TAP. Previous reports have focused on the geometry of the tricuspid annulus at a single point. Fukuda et al demonstrated an early to mid-systolic reduction in the tricuspid annular area before a late systolic increase, while others have noted that the maximum area occurred in mid-diastole. In the present study, we adopted the area change between the mid-diastolic and mid-systolic phases as a parameter of annular dynamics. The percent change in tricuspid annular area in the control group was 30.2±7.5%, which is similar to previous studies that showed changes ranging from 20% to 39% during the cardiac cycle. We also noted differences in tricuspid annulus dynamics between the 2 types of prosthetic ring. In the rigid ring group, as expected, this annular change was nearly eliminated. In contrast, the annular dynamics were retained to some extent even after TAP, suggesting that the annulus dynamics are preserved by the flexible ring configuration.
There are several potential limitations in this study. First, it is important to consider the variations in etiology underlying left-sided heart disease that might affect results in patients with functional TR. To overcome this as much as possible, we chose patients who underwent left-sided heart valve surgery as the control group. Even though slight heterogenous characteristics exist in left-sided heart disease, differences in annular motion and shape were still able to be measured. From this point of view, the present results are considered to provide important information.

Study Limitations

There are several potential limitations in this study. First, it is important to consider the variations in etiology underlying left-sided heart disease that might affect results in patients with functional TR. To overcome this as much as possible, we chose patients who underwent left-sided heart valve surgery as the control group. Even though slight heterogenous characteristics exist in left-sided heart disease, differences in annular motion and shape were still able to be measured. From this point of view, the present results are considered to provide important information.

The main aim of the present study was to evaluate changes in annular shape, thus we did...
not examine this relationship. Third, it was sometimes difficult to obtain clear images of each leaflet due to image quality. Thus, the analyst must carefully observe in order to discriminate the leaflets and annulus in the images during offline analysis. The relatively small number of patients in this study represents another limitation. Finally, we did not detect a direct relationship between type of prosthetic ring used and the effect of TAP. Although we examined several different parameters between the groups, we could not find clinical meaning for the noted differences. The relationships between the various parameters examined in this study and long-term results of TAP with a prosthetic ring should be clarified. Additional long-term follow-up and comprehensive analysis that includes both atrial and ventricular functions are needed.

Conclusions

Using 3D-TEE and custom software, we demonstrated that annulus motion and shape differ according to the type of prosthetic ring used, although TR was well controlled by all types of ring utilized. We consider that postoperative 3D-TEE is useful for assessing tricuspid annular dynamics before and after TAP. The present results could provide important information for selection of an appropriate prosthetic ring in TAP.

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Disclosures

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References