Tricuspid Valve Tethering Predicts Residual Tricuspid Regurgitation After Tricuspid Annuloplasty

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Background—Tricuspid valve (TV) annuloplasty is recommended for functional tricuspid regurgitation (TR), which is caused by TV annulus dilatation and tethering of the leaflets. However, the impact of TV deformations on the outcome of TV annuloplasty remains unknown. The goal of this study was to investigate the relationship between preoperative TV deformation and residual TR after TV annuloplasty.

Methods and Results—Two hundred sixteen patients with functional TR had 2D echocardiography before and after TV annuloplasty. Right ventricular fractional area change and left ventricular ejection fraction were determined with the apical views. Minimal TV annulus diameter was determined by frame-by-frame analysis. The distance of TV tethering was measured from the annulus plane to the coaptation point and tethering area by tracing the leaflets from the annulus plane. TR severity was determined by the ratio of the maximal jet area to the corresponding right atrial area. The severity of residual TR was associated with age, right and left ventricular dysfunction, tethering distance and area, and severity of preoperative TR (all P<0.05). TV annular dimension was not associated with outcome of TV annuloplasty. Multivariate analysis revealed that age, tethering distance, and severity of preoperative TR (all P<0.001) were independent parameters predicting residual TR. The sensitivity and specificity in predicting residual TR after surgery were 86% and 80% for tethering distances >0.76 cm and 82% and 84% for tethering areas >1.63 cm², respectively.

Conclusions—Severe TV tethering predicted residual TR after TV annuloplasty, whereas preoperative TV annular dimension was not associated with outcome of TV annuloplasty. (Circulation. 2005;111:975-979.)

Key Words: echocardiography ■ valves ■ valvoplasty

Functional tricuspid regurgitation (TR) often appears in conjunction with left-sided valve disease and left ventricular (LV) dysfunction despite the presence of a structurally normal tricuspid valve. Surgical management of functional TR at the time of correction of left-sided heart disease is recommended because, if significant TR remains, postoperative morbidity and mortality rise considerably.1–3 Tricuspid valve (TV) annuloplasty is now widely recommended as a safe and effective surgical procedure, although residual TR occurs in 10% to 20% of patients early after annuloplasty.4–6 Unfortunately, the mechanism and determinants of residual TR after TV annuloplasty have not been fully investigated and thus remain unknown.

Functional TR is thought to be caused by TV annulus dilatation and tethering of the tricuspid leaflet after right ventricular dilatation.7–9 TR severity also is related to both dilated TV annulus and leaflet tethering, which decrease the degree of leaflet overlap or coaptation at their tips.9 However, annuloplasty, performed to reduce the TV annulus, might not be sufficient to correct functional TR. Therefore, this study was designed to investigate the degree of association between preoperative TV deformations (TV annular dilatation and tethering) and residual TR after TV annuloplasty.

Methods

Study Population

The records of 345 consecutive patients who underwent left-sided heart surgery with TV annuloplasty at the Cleveland Clinic Foundation were reviewed for this study. The patients with LV assist devices (n=13), pacemaker wires across the TV (n=54), congenital heart disease (n=30), and inadequate visualization on echocardiography (n=32) were excluded. The final population of this study comprised 216 patients (77 men, 139 women; mean age, 67±13 years). These patients were examined by 2D transesophageal echocardiography at our institute before and after cardiac surgery. Postoperative echocardiography was performed at a mean follow-up of 5±4 days after cardiac surgery. Although no patients required reoperation during this short follow-up period, 1 patient had TV replacement for severe residual TR 9 days after follow-up echocardiography.

Distribution of Operative Techniques

The main left-sided lesions were mitral valve in 85 patients, aortic valve in 10 patients, both mitral and aortic valves in 33 patients, coronary artery disease in 6 patients, combined valve and coronary artery disease in 79 patients, and septal myectomy in 3 patients.
In 22 of 216 patients, TV annuloplasty was achieved by obliteration of the posterior leaflet as described by Kay et al. The remaining 194 patients underwent ring annuloplasty, including an annular ring developed by Carpenter et al, a flexible partial annular ring invented by McCarthy and Cosgrove, and a unique 3D ring recently developed by McCarthy et al. Annuloplasty type used depended on device availability and surgeon preference.

**Echocardiographic Measurements**

Two-dimensional transthoracic echocardiography was performed in a standard manner before and after cardiac surgery with several commercially available echocardiographic systems: Sonos 5500 (Philips Medical Systems), Sequoia 512 (Siemens), or Vivid 7 (GE Medical Systems). From the apical 4-chamber view, the following echocardiographic parameters were obtained. First, the right ventricular (RV) end-systolic and end-diastolic areas were measured by planimetry, tracing the endocardial outline of RV and the plane of TV. Then RV fractional area change was calculated: end-diastolic area minus end-systolic area divided by end-diastolic area times 100. Second, minimal TV annulus diameter was measured in the apical 4-chamber view as the distance between the points of reflection of the septal and mural endocardium on the anterior and septal tricuspid leaflets, respectively. The distance and area of TV tethering were measured by tracing between the atrial surface of the leaflets and the tricuspid annular plane at the time of maximal systolic closure (Figure 1). Third, TR severity was assessed by color Doppler flow mapping of spatial distribution of the regurgitant jet within the right atrium (RA). The TR jet area on color flow mapping and RA in the same frame was measured by planimetry, and the ratio of the maximal regurgitant area to RA area (%TR) was then obtained. According to previous studies, residual TR after TV annuloplasty was graded as mild if it occupied <20%, moderate if it was between 20% and 34%, and severe if it was >34% in follow-up echocardiography.

LV ejection fraction was also obtained by using Simpson’s rule methods from apical 4- and 2-chamber views. After recording of TV systolic velocity with continuous-wave Doppler, RV systolic pressure was calculated with the simplified Bernoulli equation.

**Statistical Analysis**

Values were expressed as mean±SD. Differences between proportions were assessed by χ² analysis. To compare the 3 subgroups of patients and 4 techniques of annuloplasty, we used 1-way ANOVA. We used logistic regression to correlate variables of interest. Multivariate stepwise regression analysis was performed to identify factors of severity of residual TR (measured continuously as %TR), and the significant variables for univariate analysis were entered into models. They were age, LV ejection fraction, RV fractional area change, distance and area of TV tethering, and preoperative %TR. Differences were considered significant at P<0.05. We also examined the sensitivity and specificity of various cutoff points for prediction of moderate or severe residual TR (≥20% TR) using receiver-operating characteristic curves.

Interobserver and intraobserver variabilities for measurement of TV annular diameter and distance and area of TV tethering were obtained by analysis of 10 random images by 2 independent blinded observers and by the same observer at 2 different time points. The results were analyzed by both least-squares-fit linear regression analysis and the Bland-Altman method.

**Results**

Clinical characteristic and echocardiographic results of this study are shown in Table 1. In univariate analysis, there were no significant relationships between residual TR and RA area, RV systolic pressure, or TV annular diameter (Table 1 and Figure 2A). Age, LV ejection fraction, RV fractional area change, distance and area of TV tethering, and preoperative %TR showed significant correlation with severity of residual TR after surgery (Table 1 and Figure 2). There was no significant difference in the occurrence of residual TR among patients with different types of TV annuloplasty (P=0.3). When these significant variables were entered into the multiple stepwise regression analysis (age, LV ejection fraction, RV fractional area change, distance and area of TV tethering, and preoperative %TR), age, TV tethering distance, and preoperative %TR emerged as independent predictors of residual TR (Table 1).

In 216 patients, severe TR was exhibited in 16 patients (7.4%), moderate TR in 33 (15%), and mild TR in 167 (77%) after cardiac surgery. Clinical and echocardiographic data among these 3 groups are given in Table 2. Using receiver-operating characteristic curves, we found the sensitivity and specificity in predicting moderate to severe TR after surgery to be 57% and 68% for preoperative %TR >43.6%, 86% and 80% for tethering distances >0.76 cm, and 82% and 84% for tethering areas >1.63 cm², respectively (Figure 3).

**Reproducibility of Echocardiographic Measurements**

Excellent correlation was observed in interobserver and intraobserver variabilities of echocardiographic measure-
ments. They were $r=0.80$ and $r=0.90$ for TV annular diameter, $r=0.91$ and $r=0.94$ for tethering distance, and $r=0.95$ and $r=0.94$ for tethering area, respectively. From the Bland-Altman method, interobserver and intraobserver variabilities were 0.19 and 0.15 cm for TV annular diameter, 0.07 and 0.06 cm for tethering distance, and 0.33 and 0.22 cm² for tethering area, respectively.

Discussion
The present study demonstrates that TV tethering was associated with residual functional TR after TV annuloplasty in a large number of patients undergoing left-sided heart surgery. More important is the finding that the distance and area of TV tethering permitted prediction of residual TR with relatively high accuracy.

Surgical Results Compared With Previous Studies
In this study, TR was assessed in 3 grades on the basis of the ratio of maximal regurgitant area to RA area, and residual TR was rated as severe in 7.4% and moderate in 15% of 216 patients. Reoperation for residual TR was performed in only 1 patient early after surgery (0.5%). These surgical results were compatible with previous studies. McCarthy et al reported that prevalence of 3+ or 4+ residual TR was 14% in 790 patients and reoperation risk was 4.2% per year at 30 days postoperatively. Onoda et al measured postoperative TR after Carpentier ring annuloplasty and observed moderate TR in 29% of 31 patients. Rivera et al reported that significant residual TR assessed by clinical findings or right ventriculography was observed in 22% of 81 patients.
also found that the incidence of significant TR was lower in patients with Carpentier ring (10%) than in those with De Vega nonring (43%) annuloplasty. In our study, the incidences of severe residual TR were 6.7% (13 of 194) and 14% (3 of 22) in patients with ring and nonring annuloplasty, respectively.

### Risk Factor of Tricuspid Valve Annuloplasty
Failure to correct significant TR at the time of left-sided lesions resulted in a poor late functional result, and reoperation carried a significant risk.\(^3\)\(^4\)\(^20\)\(^22\) Moreover, the lack of precise, easily applicable and reproducible diagnostic criteria to predict residual TR is a major limitation for selecting patients undergoing surgery for TR during left-sided heart disease. Previous studies identified several clinical (age, NYHA functional class, and nonring annuloplasty) and echocardiographic (LV dysfunction and severity of preoperative TR) factors associated with an increased risk of adverse clinical events after TV annuloplasty.\(^2\)\(^20\)\(^22\) McCarthy et al\(^4\) and Kuwaki et al\(^22\) also showed that higher preoperative TR was identified as a risk factor for residual TR after TV annuloplasty.

### Relationship Between Preoperative Tricuspid Valve Deformation and Residual Regurgitation
The TV annulus dilatation and leaflet tethering were important mechanisms in the development of functional TR.\(^7\)\(^9\) Annulus dilatation compromised leaflet closure or coaptation by limiting the amount of leaflet overlap. Changes in RV geometry presumably caused displacement of the papillary muscles, resulting in tethering of the TV leaflet. The ideal TV annuloplasty would resolve the deficiency in TV coaptation caused by both TV annular dilatation and leaflet tethering. However, the concept of current TV annuloplasty is to stabilize the area of the TV annulus that is primarily responsible for annular dilatation. Therefore, annuloplasty performed to reduce the TV annulus might not be sufficient to correct the tethering of TV. In the present study, TV tethering was identified as an independent predictor of residual TR early after TV annuloplasty. A similar finding of echocardiographic predictors has been described for mitral valve annuloplasty in patients with functional mitral regurgitation.\(^2\)\(^3\)\(^24\) Calafiore et al\(^23\) showed that mitral valve coaptation height (>11 mm) was a preoperative predictor for the failure of mitral annuloplasty in patients with functional mitral regurgitation. In contrast, the degree of TV annulus dilatation was not a preoperative risk factor for postoperative negative results in this study. Ring annuloplasty remodels the annulus, decreases tension on the suture line, increases leaflet coaptation, and prevents recurrent annular dilatation in most patients with functional TR. Our results, however, suggested that current annuloplasty techniques may reduce leaflet tethering to a certain level but might not be good enough in patients with severe leaflet tethering. Thus, on the basis of insights from our study on TV deformation, a future TV surgery addressing both leaflet tethering and annular dilation should

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**TABLE 2. Comparison of Clinical and Echocardiographic Findings in Patients With Mild, Moderate, or Severe Residual TR**

<table>
<thead>
<tr>
<th>Postoperative TR</th>
<th>Mild (n=167)</th>
<th>Moderate (n=33)</th>
<th>Severe (n=16)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>69±12</td>
<td>62±17*</td>
<td>59±14*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Male gender, n (%)</td>
<td>60 (36)</td>
<td>13 (39)</td>
<td>4 (25)</td>
<td>0.6</td>
</tr>
<tr>
<td>LV ejection fraction, %</td>
<td>48.5±13.5</td>
<td>41.2±16.5*</td>
<td>41.5±15.5</td>
<td>0.009</td>
</tr>
<tr>
<td>RV fractional area change, %</td>
<td>31.2±11.8</td>
<td>25.6±11.0*</td>
<td>25.1±12.8*</td>
<td>0.01</td>
</tr>
<tr>
<td>RA area, cm²</td>
<td>25.3±8.8</td>
<td>25.6±8.7</td>
<td>27.1±6.9</td>
<td>0.7</td>
</tr>
<tr>
<td>RV systolic pressure, mm Hg</td>
<td>54.3±18.1</td>
<td>52.5±19.4</td>
<td>52.0±19.0</td>
<td>0.8</td>
</tr>
<tr>
<td>TV annulus diameter, cm</td>
<td>3.73±0.73</td>
<td>3.84±0.84</td>
<td>4.03±0.58</td>
<td>0.3</td>
</tr>
<tr>
<td>TV tethering distance, cm</td>
<td>0.53±0.33</td>
<td>1.07±0.39*</td>
<td>1.17±0.39*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>TV tethering area, cm²</td>
<td>1.01±0.86</td>
<td>2.33±1.26*</td>
<td>2.84±1.41*</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Preoperative %TR, %</td>
<td>38.2±14.6</td>
<td>39.6±13.6</td>
<td>55.2±14.8\†</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Data are presented as mean±SD when appropriate. *P<0.05 vs mild TR; †P<0.05 vs mild and moderate TR.

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**Figure 3.** Receiver-operating characteristic (ROC) curves of preoperative %TR and TV tethering distance and area. Best values separating patients with more than moderate TR were >43.6% for preoperative %TR, 0.76 cm for tethering distance, and 1.74 cm² for tethering area. Areas under curves were 0.62±0.05, 0.89±0.03, and 0.87±0.03, respectively.
be developed to overcome the limitations of annular resection alone in functional TR. Furthermore, assessment of preoperative TV tethering might be essential to define the surgical indication for TV replacement in patients with severe functional TR.

**Study Limitations**

Echocardiographic follow-up was performed at 5 ± 4 days after cardiac surgery. It was unknown whether residual TR led to subsequent worsening of heart failure in late follow-up and whether the durability of the annuloplasty technique for each ring was varied. Longer observation periods are required to validate the effectiveness and durability of this echocardiographic feature.

Because this echocardiographic study retrospectively focused on the comparison of TV deformations and early outcome after TV annuloplasty, patients with LV assist devices, pacemaker wires across the TV, and congenital heart disease were excluded. A strictly organized and randomized prospective protocol might provide more definitive results than this study. Also, further investigation is necessary to assess the safety and efficacy of TV annuloplasty in these patients.

A limitation of the 2D echocardiography was the inability to adequately characterize the posterior leaflet from apical 4-chamber view. In addition, assessment of RV function through the use of fractional area change may not be accurate enough to determine RV volume and function. Moreover, RV size and geometry are technically difficult to determine accurately with 2D echocardiography because of its anatomic complexity. Changes of ventricular geometry may cause the tethering of TV leaflet through the displacement of the papillary muscles, determining the outcome of tricuspid annuloplasty. Three-dimensional imaging techniques may have the potential to provide more accurate information for TV deformation and RV function and geometry.

**Conclusions**

The severity of preoperative TV leaflet tethering distance and area predicted significant residual TR after TV annuloplasty, whereas preoperative TV annular dimension was not associated with early outcome of TV annuloplasty.

**References**

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