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 \( >1.63 \) cm\(^2\), 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
pressure was calculated with the simplified Bernoulli equation.17

TV systolic velocity with continuous-wave Doppler, 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. They
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 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. McCarthy et al and Kuwaki et al 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. Anulus 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 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. The present study, TV tethering was 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. Calafiore et al 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 dilatation should...
be developed to overcome the limitations of annular reduction 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

Tricuspid Valve Tethering Predicts Residual Tricuspid Regurgitation After Tricuspid Annuloplasty

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