Tricuspid Valve Surgery Based on the Mechanisms of Functional Tricuspid Regurgitation

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Functional Tricuspid Regurgitation

The presence of functional tricuspid regurgitation (fTR) in any severity is common in patients with left-sided heart valvular disease. Singh JP et al. reported that the incidence of moderate or severe tricuspid regurgitation (TR) was 0.1%–0.5% in men and 0.5%–5.6% in women in the Framingham offspring data, though 82% of men and 85.7% of women had TR in any grade. However, the incidence of fTR accompanying a left-sided lesion is more frequent and varies in published reports because there are differences in the subject, definition of fTR and follow-up period among them. According to several reports, fTR with mitral regurgitation might be more frequent in patients with rheumatic pathology than in those with degenerative. In the study reported by Matsuyama K et al., 55% of patients (n = 175) who underwent mitral valve surgery and suffered from rheumatic etiology, 26% of them had preoperative grade 2 or more fTR. An understanding of the pathology of fTR should be based on the anatomical relationship called “tricuspid complex” consisting of the tricuspid annulus (TA), chordae tendineae, papillary muscles and the right ventricle (RV) as well as “mitral complex.” Development of the device and technique of echocardiography has revealed the mechanism of fTR. Although imperfect leaflet closure is the immediate cause of fTR, the three leaflets themselves are commonly normal. Inadequate coaptation of the leaflet is a consequence of geometric change caused by tricuspid annular dilation, right ventricular dilation, distortion of subvalvular apparatus, or a combination of these factors. Most cardiac surgeons have believed that dilation of the TA occurred in anterior and posterior portions because these attach to the free wall of the RV. The third portion, septal portion is attached to the right and left fibrous trigons, so that this portion has been considered to be similar to the anterior portion of the mitral annulus and spared from annular dilation, resulting from right-sided chamber dilation.

Why do we focus on the tricuspid valve (TV) now? More recently, the TV, often called “forgotten valve” attracts a great deal of attention among cardiac surgeons. The reason is that moderate or greater TR has been reported to be associated with a poor prognosis. Nath et al. reported that increasing TR severity was associated with a worse survival in men, regardless of left ventricular ejection fraction and pulmonary artery pressure. In addition, untreated, moderate or greater fTR at the time of mitral valve surgery has been reported to worsen and to affect both midterm survival and functional status, irrespective of grade of mitral regurgitation after surgery. The period when fTR was believed to disappear after successful left-sided valvular surgery was gone.

Methodology of Tricuspid Valve Surgery

Tricuspid annuloplasty (TAP) is a gold standard technique for fTR. Because tricuspid annular dilation leading to leaflet coaptation loss is a main cause for fTR, circumferential reduction of the annulus is a key to restore leaflet coaptation. With regard to reproducibility and durability, several clinical studies have demonstrated the superiority of artificial ring annuloplasty over suture-based annuloplasty. McCarthy et al. reported that the severity of TR after De Vega suture annuloplasty increased more rapidly than that after ring annuloplasty with the Carpentier-Edwards ring. The advantage of rigidity over flexibility with respect
to the material is still controversial. There are few prospective, randomized studies comparing the efficacy of TAP with a rigid ring versus that with a flexible ring against fTR, although several retrospective studies have demonstrated more excellent results with the rigid ring than with those of the flexible ring, especially with regard to preventing postoperative fTR progression in the long-term. The rigidity might contribute to preclude progressive tricuspid annular dilation, resulting from failed reverse remodeling of the RV. In contrast, Pfannmüller et al. have pointed out the risk of ring dehiscence responsible for reoperation after TAP with rigid ring. The authors have revealed that ring dehiscence only occurred in the region of the septal annulus. They have also speculated that greater force might exist on the sutures attached to a rigid ring than on those attached to a flexible ring, which could follow the systolic-diastole dynamic motion of the TA. In a detailed two-dimensional echocardiographic study by Tei et al., the dynamic, geometric changes of the TA during the cardiac cycle have been demonstrated. They were 19% of the circumference and 33% of the cross-sectional area in normal human subjects, and 10% and 18% in patients with fTR.

Although tricuspid valve replacement (TVR) is a promising option for the elimination of residual TR in patients with severe to torrential TR, TVR still remains a rare procedure. In particular, TVR is seldom performed in patients with fTR. One of the reasons for its rarity is high mortality and morbidity, relative to other valve surgeries. Vassileva et al. have reported that, regardless of the type of prosthesis, hospital mortality for TVR was significantly higher than that for tricuspid valve repair (13.6% vs. 9.5%), taken from the National Inpatient Sample database in the United States. The higher incidence of preoperative, chronic liver dysfunction and higher preoperative NYHA class has been suggested to affect the mortality and morbidity negatively over years. Considering that these preoperative parameters are supposed to be consequences of prolonged right heart failure, the establishment of guidelines, based on clinical and echocardiographic parameters, would contribute towards improving outcomes after TVR. Of note, TV surgery was a concomitant procedure in other cardiac operations in 80% of total tricuspid valve surgeries, whereas there was a trend toward an increasing rate of isolated TVR over time, with a corresponding decreasing rate of TVR as a concomitant procedure. Unfortunately, the reasons for this trend were not clear because detailed information of the etiology or pathology of the TV was not obtainable from this database.

How Can We Eliminate Residual TR?

Cardiac surgeons who are unsatisfied with results of TAP for fTR have a keen interest in methods to eliminate residual or recurrent TR. Although residual TR occurs in 10%–20% of patients, early after TAP, the mechanisms have not been perfectly investigated, until recently. Fukuda and coworkers have deserved great credit for elucidating the important role of leaflet tethering in the TV. Leaflet tethering distance and area were measured in the apical 4-chamber view by tracing between the atrial surface of the leaflets and the tricuspid annular plane at the time of maximal systolic closure. Fukuda et al. have demonstrated the distance and area of the leaflet tethering enabled the prediction of residual TR with relatively high accuracy. With regard to recurrent TR, postoperative left ventricular function and increasing right ventricle pressure, that is to say, pulmonary hypertension has been supposed to be responsible for recurrent TR during midterm follow-up.

With the advent of the recently developed real-time, 3-dimensional echocardiography, the comprehension of the mechanism of fTR has assumed a new aspect. The tricuspid annulus (TA) is a nonplanar structure with a distinct bimodal shape having two high points and two low points. The highest point of the TA is in the antero-septal segment, which is close to the RV outflow and the aortic valve. The lowest point is the posteroseptal segment, which the coronary sinus starts. Interestingly, the TA loses the nonplanarity and becomes more circular by TR progression and “the more severe TR, the more planar the TA.” Song et al. have found that fTR severity was determined by the septal-lateral annulus and RV dilation, and tethering of the anterior and septal leaflets, associated with septal-lateral RV inlet dilation.

Taking into account 3-dimensional geometric change of the TA and RV in patients with fTR, several surgical techniques have emerged. To restore the nonplanarity of the TA, the new 3-dimensional designed rigid annuloplasty ring has been introduced. Although we have empirically bended manually planar semirigid ring in the operating room before, this ring is preconfigured to accommodate the saddle shape of the TA. A few studies in small cohorts have demonstrated supportive results of this ring, with low incidence of moderate to severe residual TR. Ghoreishi et al. have demonstrated that undersized TAP with this 3D ring (size 26 or 28) regulated with a lower incidence of residual TR and recurrent TR during a mean follow-up of 17 months. They, however,
have not referred to the incidence and fate of leaflet tethering.

Several surgical techniques have been introduced for relief from leaflet tethering and restrictive motion. The first technique is the leaflet augmentation with the autologous pericardial patch. This technique can increase the leaflet coaptation, whereas the tethering height remains unchanged. There are some technical differences in detail. Dreyfus et al. have augmented only the anterior leaflet with flesh pericardial patch, in contrast Choi et al. have enlarged both the anterior leaflet and a half of the posterior leaflet with a patch of glutaraldehyde-treated autologous pericardial patch or bovine pericardium. Although long-term follow-up would be required to substantiate the validity of the materials of the patch, the results during midterm follow-up were acceptable.

The second technique has been reported as "leaflet suspension" by Myers and coworkers. In this technique for children, in whom the valve replacement should be avoided, the free edge of the tethering leaflet responsible for residual regurgitation was anchored to the atrial side of the contralateral annulus with a 5-0 polypropylene suture.

Kappert et al. have introduced the third technique, right ventricular reduction for the patient with extremely dilated RV. This technique used as an adjunct procedure to TAP, which had failed to control severe TR with leaflet tethering. To approximate the anterior and posterior papillary muscle, two felt strip were placed lengthwise on the epicardial surface of the lateral wall of the RV and secured by three horizontal mattress sutures of 2-0 polypropylene. No residual, recurrent TR was observed during 1-year follow-up period. Although the authors have speculated that the reduction of the RV dimension led to reduce tethering force on the leaflets and achieve a sufficient coaptation, whether "Laplace’s law" is applicable to the RV, which is crescentic, was unclear.

The fourth technique is the so-called "clover technique," which consist of stitching together the central part of the free edges of the tricuspid leaflets. This technique, which was applied to treat post-traumatic TR at the beginning, has been employed for patients with fTR accompanied with prolapse/flail or severe tethering of multiple leaflets. For the concern that the tricuspid stenosis can possibly be provoked by this technique, it proved to be groundless, with no instance of tricuspid stenosis documented at rest and stress conditions.

**Conclusion**

Nowadays, the cardiac surgeons reaffirm that significant, moderate to severe TR should not be ignored at the time of left-sided valve surgery because not all TR will disappear after successful surgery. In addition, there is increasing evidence that residual or recurrent TR would have a negative impact on the outcome after tricuspid valve surgery. Considering the mechanism of fTR involves not only tricuspid annular dilation but also leaflet tethering resulting from the dislocation of the papillary muscles, we believe that applicable procedures adjunct to TAP should be used according to the precise and detailed preoperative assessment.

**References**


