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REVIEW

Functional Tricuspid Regurgitation and Ring Annuloplasty Repair

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Abstract

Functional tricuspid regurgitation (TR) primarily arises from asymmetric dilation of the tricuspid annulus in the setting of right ventricular dysfunction and enlargement in response to left-sided myocardial and valvular abnormalities. Even if the TR is not severe at the time of mitral valve surgery, it can worsen and even appear late after successful mitral valve surgery, which portends a poor prognosis. Despite data demonstrating inferior outcomes in the presence of residual TR, surgical repair for functional TR remains underused. Acceptance of TR, in the presence of tricuspid annular dilation, may be unacceptable. Surgical repair should consist of placement of a rigid or semirigid annular ring, which has been shown to provide superior durability as compared with suture and flexible band techniques. Finally, percutaneous annuloplasty for correction of functional TR may allow treatment of patients with recurrent TR at high risk of reoperation.

Keywords: tricuspid valve; regurgitation; ring annuloplasty

Introduction

Functional tricuspid regurgitation (TR) is recognized as an important clinical condition for which surgical repair is being increasingly applied [1]. Functional TR primarily arises from left-sided heart failure due to myocardial or valvular dysfunction, leading to right ventricular (RV) enlargement and asymmetric tricuspid annular dilation. This leads to a vicious cycle of TR, volume overload, and then to worsening TR. Untreated TR can cause significant clinical symptoms, from decreased cardiac output and the development of right-sided heart failure, leading to congestive hepatopathy, ascites, peripheral edema, and excess mortality. Of importance is the development of significant TR years after mitral valve (MV) surgery, with a growing body of literature supporting the notion that acceptance of TR at the time of MV surgery (especially in the presence of tricuspid annular dilation) without intervention may no longer be acceptable. Since reoperations for recurrent TR are especially high-risk procedures, more aggressive treatment of TR at the time of initial surgery may be important [2, 3]. In brief, TR is not reliably alleviated after successful MV surgery. Therefore it is important to understand the surgical anatomy of the tricuspid valve (TV), the geometric distortions that result in functional TR, and therapies for functional TR.

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Anatomy of the Tricuspid Valve

The TV complex is analogous to the MV, as coordination of annular, leaflet, chordal, and papillary muscle and RV function are required for effective leaflet coaptation during systole. The relationship of these structures as seen from the surgical perspective is shown in Figure 1. The TV consists of three leaflets: anterior, posterior, and septal. The anterior and posterior tricuspid leaflets both arise from the annulus along the RV free wall. The anterior leaflet is the largest, followed by the posterior and septal leaflets, respectively. The septal leaflet arises from the tricuspid annulus directly above the interventricular septum. There are two named papillary muscles: anterior and posterior. Chordae tendinae tether the anterior and posterior leaflets to the anterior papillary muscle, and the posterior and septal leaflets to the posterior papillary muscle. There is no formal septal papillary muscle. Rather, the interventricular septum anchors chordae to the anterior and septal leaflets. In addition, there are accessory chordal attachments to the moderator band and RV free wall. These multiple and variable chordal attachments are important mediators of TR as they may impair proper leaflet coaptation in the setting of RV dysfunction and dilation [4]. The degree of TR can therefore be dynamic and directly affected by RV preload, afterload, and systolic function.

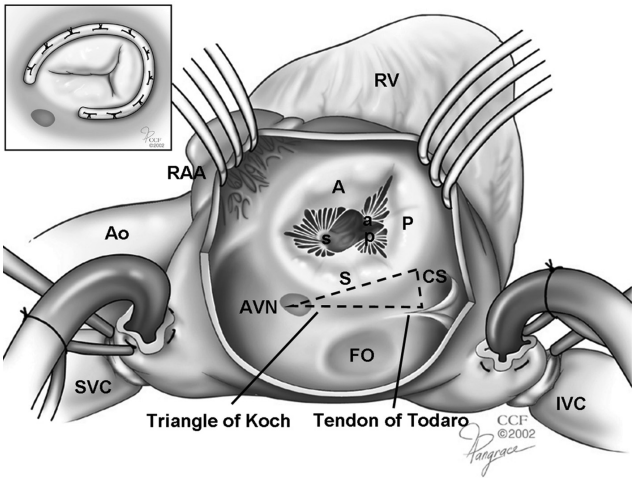

Figure 1 Tricuspid Valve Complex.
Anterior (A), posterior (P), and septal (S) leaflets. Anterior (a) and posterior (p) papillary muscles. The atrioventricular node (AVN) and bundle of His, coronary sinus ostium (CS), and the tendon of Todaro form the triangle of Koch. The inset shows ring annuloplasty restoring leaflet coaptation. Ao, Aorta; FO, fossa ovalis; IVC, inferior vena cava; RAA, right atrial appendage; RV, right ventricle; SVC, superior vena cava.

Dilation of the tricuspid annulus is the primary mechanism leading to functional TR, and should then be the main target for surgical correction with annular prostheses. Tricuspid annular enlargement occurs primarily along the RV free wall, resulting in leaflet malcoaptation [5]. Conversely, the septal aspect of the tricuspid annulus, analogous to the intertrigonal portion of the mitral annulus, is relatively spared from annular dilation [6]. As a result, tricuspid annular sizing algorithms are traditionally based on the dimension of the base of the septal leaflet [7]. It has also been shown that the tricuspid annulus diameter is dynamic and can change markedly with loading conditions. During the cardiac cycle, there is normally a 19% reduction in annular circumference with atrial systole, and this highlights the critical need to understand the relationship between tricuspid disease and anatomy [8, 9].

The tricuspid annulus has a unique three-dimensional structure, and has important implications for the design of tricuspid annuloplasty rings. Fukuda et al. [8] performed a three-dimensional transthoracic echocardiographic study to better understand this shape and the movement of the tricuspid annulus in healthy individuals and diseased patients. They examined 15 healthy individuals and 16 patients with moderate-severe functional TR. Healthy individuals had a nonplanar, elliptical tricuspid annulus, with the posteroseptal portion being "lowest" (toward the RV apex) and the anteroseptal portion being "highest" (Figure 2). Patients with functional TR generally had a more planar annulus, which was dilated primarily in the septal-lateral direction, resulting in a more circular shape as compared with the elliptical "egg" shape seen in healthy individuals. Thus the data suggest that uniquely tailored nonplanar tricuspid rings could potentially improve ventricular function and reduce leaflet stress.

Lastly, the atrioventricular (AV) node and bundle of His are important structures that exist anteriorly along the septal aspect of the annulus. This region of the annulus is a surgical "no touch" zone, and sutures must not be placed in this region to avoid the development of AV conduction block. Open rings that do not contact the

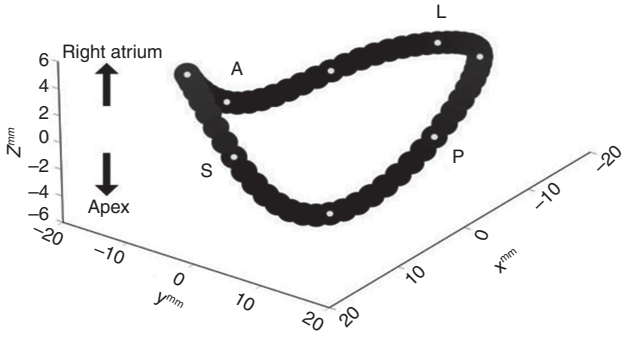

Figure 2 Three-Dimensional Shape of the Tricuspid Annulus.
Based on a three-dimensional transthoracic echocardiographic study in healthy individuals. Note that the annulus is not planar. A, anterior; L, lateral; P, posterior; S, septal (Reprinted with permission from Fukuda et al. [8] from Lippincott Williams & Wilkins.)

AV node are commonly used to reduce potential rhythm disturbances.

Current Surgical Approaches to Tricuspid Regurgitation

As with functional MV disease, the goal of surgical correction for functional TR should be the application of a rigid (or semirigid) annular ring to reduce annular diameter with the goal of leaflet coaptation. In addition, preemptive correction of TR should be increasingly applied, as surgical treatment of a left-sided cardiac abnormality does not always result in secondary reduction of TR [1]. As such, Dreyfus et al. [10] propose that at the time of MV repair, the presence of tricuspid annular dilation (≥70 mm measured intraoperatively in a flaccid heart, equivalent to a 40 mm diameter), even in the absence of significant TR, should be an indication for TV annuloplasty. Their findings also showed that TR increased by at least two grades in 45% of patients who received isolated MV repair without TV repair. This supports the notion that tricuspid dilation is an ongoing, progressive process that often warrants preemptive surgical treatment [10]. Furthermore, preoperative echocardiographic grading of TR is much clearer for those patients with mild or severe disease, but becomes much more difficult to quantify in the moderate disease category. Thus, as current guidelines suggest, any patient with greater than grade 2 TR, or a tricuspid annular diameter of 40 mm or more in any echocardiographic view, should be considered for repair of TR during any left-sided valve surgery.

Ideally the repair should include the application of a rigid (or semirigid) ring for functional TR, which has been shown to offer the most durability over time in multiple series as compared with flexible bands or plication annuloplasty techniques. Proving this, McCarthy et al. [11] reported on 790 patients from 1990 to 1999 who underwent TV annuloplasty for functional TR during concomitant surgery using four tricuspid annular approaches: Carpentier-Edwards semirigid ring; Cosgrove-Edwards flexible band; the DeVega procedure; or Peri-Guard annuloplasty. During the 8-year follow-up period, regurgitation severity increased more rapidly over time with the DeVega and Peri-Guard procedures, while regurgitation severity was stablest across time with the Carpentier-Edwards ring [11]. In a separate series, Tang et al. [12] described 702 patients who underwent TV repair (largely in the setting of concomitant MV surgery), 493 of whom predominantly had a DeVega repair and 209 had an annuloplasty ring placed (54% Carpentier-Edwards, 25% Duran, and 21% Cosgrove-Edwards). At up to 21-year follow up (mean 5.9 years), the long-term survival, event-free survival, and freedom from recurrent TR were significantly better in the rigid ring group.

An additional important study was published by Navia et al. [13], who reported a cohort of 2277 patients who underwent TV procedures during primarily mitral and aortic operations. Here, a rigid tricuspid annular ring was used in 26% of patients, a flexible ring was used in 46%, DeVega annuloplasty was used in 5.7%, Peri-Guard annuloplasty was used in in 8.1%, a Kay (commissure) procedure was used in 11%, and an edge-to edge leaflet suture technique was used in 3.5%. At the 5-year follow-up, TR had increased only slightly for isolated rigid prosthesis annuloplasty (12%), but was progressively greater for all other annular procedures (flexible prosthesis 16%, DeVega annuloplasty 24%, Peri-Guard annuloplasty 44%, Kay procedure 19%). Taken together, these key studies highlight the superiority of annuloplasty ring placement in mitigating the risk of recurrent or progressive TR postoperatively (Figure 3).

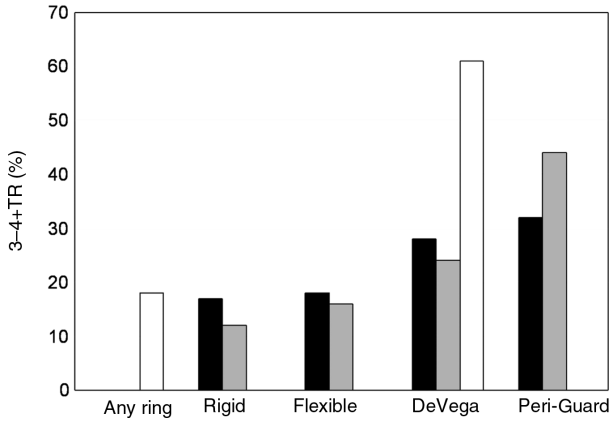

Figure 3 Recurrence of Tricuspid Regurgitation (TR) After Ring and Nonring Annuloplasty.
Reported rates for the recurrence of grade 3 or 4+ TR after initial tricuspid valve annuloplasty by technique. See the text for details. Dark bars, McCarthy et al. [11] 5-year follow-up; gray bars, Navia et al. [13] 5-year follow-up; open bars, Tang et al. [12] mean 5.9-year follow-up.

Surgical Techniques for Functional Tricuspid Regurgitation

Tricuspid Valve Replacement

In general, TV repair is favored over replacement to avoid the risk of thrombotic complications associated with bioprosthetic or mechanical valves. Additionally, TV repair appears to result in improved midterm survival (up to 10 years after surgery) as compared with replacement, although there is no significant difference in valve-related mortality or need for TV reoperation [2]. While the mechanisms for this difference are not fully understood, it is hypothesized that a large rigid prosthesis in a distorted, low-pressure cavity (right ventricle) may result in RV dysfunction and a perioperative low-output state.

Tricuspid Valve Repair

Although ring annuloplasty for functional TR is not technically demanding, careful respect should be shown to surrounding structures. A traditional approach has been to place stitches from the 10 o'clock position to the 6 o'clock position, thus avoiding the AV node and the triangle of Koch (Figure 2, inset). Furthermore, and especially in the treatment of functional TR, numerous annular stitches should be used. This helps address the fundamental disease in which the tricuspid annulus is usually underdeveloped as compared with the mitral annulus, and the distracting force from the geometric distortion of the right ventricle must be counteracted with sufficient sutures. Within the circumference of the tricuspid annulus, these annuloplasty sutures should be taken parallel with and travel in the annulus. A common source of failure of TV annuloplasty is the dehiscence of the ring from inadvertent application of the stitches to the atrial wall or to the leaflet tissue.

Ring Sizing in Functional Tricuspid Regurgitation

While most would agree that rigid TV annuloplasty offers the best solution for functional TR, controversy exists regarding size selection for the TV annuloplasty; some have suggested oversizing the TV annuloplasty for fear of subsequent tricuspid stenosis.

One approach is to use criteria that are triggered by an annular diameter of greater than 40 mm, with a general guideline for sizing being to "undersize" by at least two ring sizes. Huffman et al. [14] examined patients who underwent MV repair with a rigid complete annuloplasty ring and who simultaneously underwent TV repair with the same-size TV annuloplasty ring. Their data suggests that the same-size ring can be used for TV repair as was used for MV repair, without development of significant tricuspid stenosis or negative effects on right-sided heart function. Specifically, there was no obvious worsening of RV function, with most patients having normal to only moderately decreased function, in line with their preoperative right-sided heart function. These findings were confirmed by three large clinical trials by Mukherjee et al. [15] (United States), Desai et al. [16] (United States), and Bertrand et al. [17] (Europe), which showed that the right ventricle gets better when functional TR is repaired. Moreover, the "same size" approach seemed to prevent the recurrence of significant TR. Additionally, Gammie et al. [18] showed that the application of a renormalizing tricuspid ring (26–28 mm) results in very little recurrent TR and no tricuspid stenosis.

Following ring annuloplasty, there are less commonly used surgical techniques for the treatment of

functional TR. Posterior annular bicuspidalization is performed by the placing of a pledget-supported mattress suture from the anteroposterior commissure to the posteroseptal commissure along the posterior annulus. Deloche et al. [5] showed that focal posterior TV annuloplasty can be effective in selected cases. Nevertheless, other approaches include anterior leaflet augmentation patching (Dreyfus) or edge-to-edge (Alfieri-type) repairs as described by Castedo et al. [19, 20] and partial purse-string suture techniques to reduce the anterior and posterior portions of the annulus (DeVega-style techniques) [21].

While operating times (cross clamp/bypass) are potentially longer with the addition of TV repair during left-sided surgical procedures, Dreyfus et al. [10] showed no additional increase in 30-day mortality with a TV repair added [10]. Furthermore, across all degrees of TR, Badhwar et al. [22] examined 88,473 patients and found that there is no increased mortality when concomitant TV repair and an MV operation are performed. What is more, Calafiore et al. [23] demonstrated decreased 30-day mortality, with less recurrent TR and better 5-year survival with the addition of a TV repair in a small retrospective series of 110 patients undergoing MV surgery.

Current Guidelines for the Management of Functional Tricuspid Regurgitation

The American College of Cardiology/American Heart Association 2014 practice guidelines for the surgical treatment of patients with functional TR give a class I indication for TV repair in any patient with severe TR undergoing MV surgery [24]. In patients with less than severe TR, a class IIb recommendation is given for patients undergoing MV surgery if there is pulmonary hypertension or any tricuspid annular dilation greater than 40 mm. The European Society of Cardiology 2012 guidelines take a more aggressive stance, with a class IIa recommendation for TV repair in patients with moderate functional TR and a dilated tricuspid annulus (>40 mm) in a patient undergoing left-sided surgery [25].

Despite the American College of Cardiology/American Heart Association and European Society of Cardiology guidelines, which support surgical repair of TR at the time of MV surgery in many patients, TV repair currently appears underused. The current surgical volume of TV repair with or without concomitant MV surgery (Society of Thoracic Surgeons National Cardiac Database) averages approximately 5000 operations per year This represents only approximately one-tenth of the more than 60,000 MV operations performed yearly in the United States [18]. This can be due in part to the currently debated decision making on whether or not concomitant TV repair should be performed during MV surgery. Data presented by David et al. [26] on 1171 patients from 1985 through 2005 suggest that TR does not increase with time and that unless it is preoperatively graded as severe, there should be intervention while MV repair is being performed. This conclusion is drawn from near 15-year follow-up data showing only 9% of patients had isolated TR.

Although there are few prospective mortality or functional data to specifically address this question, there are clear consequences of allowing TR to progress to severe (and potentially cause worsening right-sided heart failure). Thus it would seem logical that earlier intervention for TR, especially in the presence of ongoing right atrial and RV enlargement, would be beneficial. Attempting to shed light on this debate, Chikwe et al. [27] reported on 645 patients who had MV repairs and underwent functional TV repair because of grade 2+ or greater TR and/or a dilated annulus (>40 mm). The results showed the addition of TV annuloplasty was independently associated with less TR and better RV function. There was no increase in operative mortality, but a survival benefit was not shown in this retrospective study. Likewise, 1-year data from Ward et al. [28] showed that performing concomitant TV repair with a triad annuloplasty correlated with reduced TR, stable RV dimensions, and reduction of symptoms. However, a randomized trial comparing acceptance of TR versus earlier intervention may be required to further answer the greatly debated question of the benefits of early intervention for TR.

New Directions in Tricuspid Valve Repair

During TV surgery, a surgeon must be comfortable with complex decision making, including cannulation site selection, placement of the right atrial incision, caval snaring, use of active venous suction, the management of intravenous pacing wires, and the handling of TV repair both during cardioplegic arrest and on the beating heart. Additionally, a surgeon must understand the intraoperative evaluation of the quality of a TV repair in terms of assessment while the patient is under anesthesia and the impact on residual or recurrent TR. Unfortunately, concomitant TV surgery remains underused at the time of MV surgery for a variety of reasons, including the lack of randomized mortality data to support aggressive treatment, and the unfounded fear of the additional operating time required to perform TV annuloplasty. Techniques that reduce the morbidity and time required to perform TV annuloplasty could be helpful. In addition, reoperations for recurrent TR are especially high risk, with up to 35% in-hospital mortality, and are therefore not routinely offered to patients [3]. One such technique is minimally invasive TV surgery, which was described by Lee et al. [29]. They reported a series of 141 consecutive patients undergoing TV operation using a minithoracotomy without cross-clamping. This was done with a beating heart or by allowing the heart to fibrillate. The repair rate was 61%, and 30-day mortality was low at 2.1%. Secondly, new percutaneous approaches for treating TV disease are on the horizon. The MitraClip (Abbott, Minneapolis, MN, USA) has been used to achieve a percutaneous Alfieri-type edge-to-edge repair of the TV. Lastly, percutaneous annular rings that can be delivered to the MV or TV are also under development, as is a new TV stent, the GATE (NaviGate Cardiac Structures, Laguna Hills, CA, USA). Additionally, at the forefront of tricuspid interventions, there have been several case series describing successful off-label use of transcatheter aortic and pulmonic prostheses for tricuspid valve-in-valve replacement with promising initial results.

In conclusion, concomitant surgical repair of TR at the time of MV surgery should be considered, as this approach has been shown to result in improved perioperative outcomes, functional class, and potentially survival. Any TR with annular dilation cannot simply be ignored when one is performing corrective surgical procedures for mitral regurgitation, as TR does not reliably disappear after successful MV surgery, and reoperations for recurrent TR carry high mortality rates. Furthermore, the addition of TV repair has been shown not to increase operative mortality when MV repair is performed. Consequently, aggressive application of TV repair based solely on tricuspid annular dilation is becoming more common. The application of a rigid or semirigid ring appears to have improved durability, or at least freedom from recurrence of significant TR. All suture-based or other nonring approaches should be avoided. With this understanding, use of TV annuloplasty for functional TR can be maximized.

Conflict of Interest

The authors declare no conflict of interest.

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