

Structural Challenges in Native Atrioventricular Valves Replacement



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KEYWORDS

• Atrioventricular valves • Mitral valve • Tricuspid valves • Valve replacement

KEY POINTS

- The anatomy of the atrioventricular valves is complex.
- The importance of preserving subvalvular mitral apparatus to maintain the geometry of the left ventricle is highlighted.
- Different suturing techniques of mitral valve replacement and the neo-left ventricular outflow tract after transcatheter mitral valve replacement are also discussed.
- This article provides important landmarks to remember while placing sutures during tricuspid valve replacement.

INTRODUCTION

Atrioventricular (AV) valve disease is a major burden in our Indian subcontinent. Mitral and aortic valves are the most commonly affected valves followed by the tricuspid and pulmonary valves. Our focus of interest is on the AV valves, that is, the mitral and tricuspid valves (TV). The main pathophysiology of the AV valves disease can be stenosis, that is, incomplete opening, or regurgitation, that is, incomplete closing. The main etiology of these is infective bacterial-induced rheumatic heart disease, which is prevalent in the low socioeconomic population, and degenerative valve disease, which is common in the high socioeconomic population.¹ Understanding the complexity of the AV valve anatomy is most important to treat the disease process.

MITRAL VALVULAR COMPLEX

Mitral valve complex is not a single structure; it involves a complex interaction between the

mitral valve leaflets (anterior mitral leaflet [AML], posterior mitral leaflet [PML]), mitral valve annulus, chords, papillary muscle (PM), and the left ventricle (LV)² (Fig. 1).

MITRAL ANNULUS

Mitral valve annulus is an essential structure between the left atrium (LA) and LV, which is a D-shaped orifice supporting the LV structures.³ Mitral annulus is not fully myocardial. There is a large area of fibrous continuity, that is, the aortomitral curtain which lies between the AML and the aortic valve in the roof of LV. The mitral annulus is as such not planar; when considered 3 dimensionally, it is a saddle-shaped structure with elevated septal and lateral segments and a depressed central segment (Fig. 2).

The relationship of mitral annulus to the surrounding structures (Fig. 3):

1. Posterolaterally—The left circumflex artery runs posteriorly which could be injured while taking deep stitches.

This article originally appeared in *Cardiology Clinics*, Volume 42 Issue 3, August 2024.

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Intervent Cardiol Clin 14 (2025) 381–393

<https://doi.org/10.1016/j.iccl.2024.09.008>

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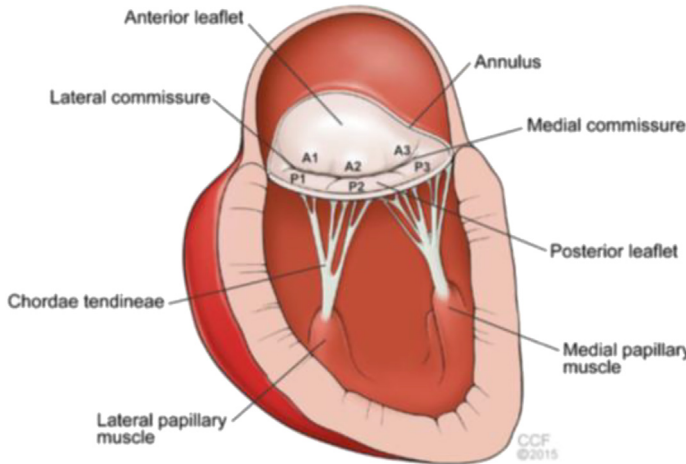


Fig. 1. Mitral valve complex. (Harb, S.C., Griffin, B.P. Mitral Valve Disease: a Comprehensive Review. *Curr Cardiol Rep* 19, 73 (2017). <https://doi.org/10.1007/s11886-017-0883-5>.)

- II. Posteromedially—The coronary sinus skirts the attachment of the posterior leaflet.
- III. Anteromedially—The bundle of His is located near the right trigone.
- IV. Anterolaterally—The noncoronary (NCC) and the left coronary (LCC) leaflets are in close relationship with the base AML, called aortomitral fibrous continuity. There is a 6-to-10 mm safety zone in this part.

Along the depressed anterior segment, AML is in continuity with the NCC leaflet and the LCC leaflet of the aortic leaflet known as the aortomitral curtain (Fig. 4A). The aortomitral curtain at either end is attached by the fibrous expansions to the LV—the right and left fibrous trigones. The right trigone is in line with the membranous septum. These all together form the central fibrous body (Fig. 4B). The AV conduction axis passes along the AV component

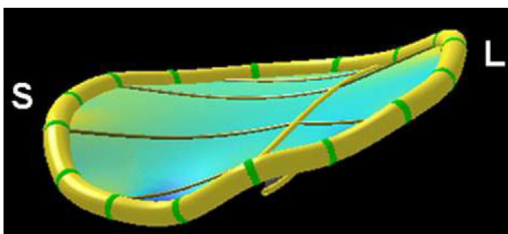


Fig. 2. Saddle-shaped mitral valve annulus reconstructed by 3-dimensional echocardiography. L, lateral segment; S, septal segment. (Nicolas M. Van Mieghem et al., Anatomy of the Mitral Valvular Complex and Its Implications for Transcatheter Interventions for Mitral Regurgitation, *Journal of the American College of Cardiology*, 56 (8), 2010, 617-626, <https://doi.org/10.1016/j.jacc.2010.04.030>.)

of the membranous septum. Hence, the aortic part is resistant to dilation when compared to the mural part which is supported by only the fibrous cords and in between, it's filled with adipose tissue which explains the disproportionate mitral annular dilation along the mural part.^{2,4} Circumferentially, the aortic part contributes one-third and the mural part occupies two-thirds of the annulus.

MITRAL VALVE LEAFLETS

It is a bifoliate valve. The leaflets are described based on its location. The anterior one or the one which is in line with fibrous continuity of the 2 aortic leaflets is called the AML or the aortic leaflet. The opposite one is called the PML or the mural leaflet (Fig. 5).

AML has a wider surface area occupying two-thirds of the valve area but its attachment to the anterior annulus is short, which is only one-third of the annulus. AML is the one dividing the LV inflow and LV outflow tracts (LVOTs). PML is shallower contributing to one-third of the valve area with a wider attachment to the posterior annulus occupying two-thirds of the junctional circumference.⁵ The valve orifice area is 2.5 times lesser than the surface area of AML and PML for the leaflets to coapt well. Both the leaflets oppose each other in orthogonal planes, recognized as mitral smile (see Fig. 3A), with the end described as posteromedial and anterolateral commissures based on their anatomic location.

Both AML and PML are segmented into 3 sections each: A1 to A3 for AML and P1 to P3 for PML (see Fig. 5).

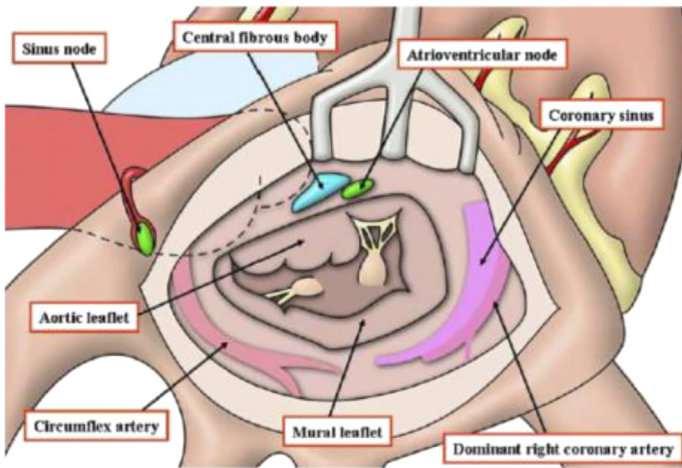


Fig. 3. Structures surrounding the mitral valve. (Nicolas M. Van Mieghem et al., Anatomy of the Mitral Valvular Complex and Its Implications for Transcatheter Interventions for Mitral Regurgitation, Journal of the American College of Cardiology, 56 (8), 2010, 617-626, <https://doi.org/10.1016/j.jacc.2010.04.030>.)

SUBVALVULAR APPARATUS: CHORDAE TENDINAE AND PAPILLARY MUSCLES

The mitral leaflets are attached to the LV via the chordae tendinae and the PMs. The chords originate from the papillary muscles, divide, and get attached to the undersurface of the mitral leaflets. The undersurface of mitral leaflets is divided into the clear zone, which is the basal part along the atrium, and the rough zone, which is the distal one where the cords insert. The chords are of 3 types: Tertiary chords or the basal chords originate directly from the LV and get inserted to the base of PML and the commissures, contributing to ventricular geometry. Secondary or the strut chords originate from PMs

and get inserted to the body of leaflets which prevents billowing and helps to distribute the load uniformly. Primary or the marginal chords are attached to the free margin of the leaflets, preventing from prolapse.⁶ Commissural chords get attached to the commissures (Fig. 6A).

There are 2 PMs which arise from the LV free wall with multiple heads in each. The anterolateral PM is supplied by the left circumflex and the diagonal arteries but the posteromedial PM has a single vascular supply either by circumflex or the right coronary artery based on the dominance. Because of this single vascular supply, posteromedial PM is prone for rupture due to myocardial infarction⁷ (Fig. 6B).

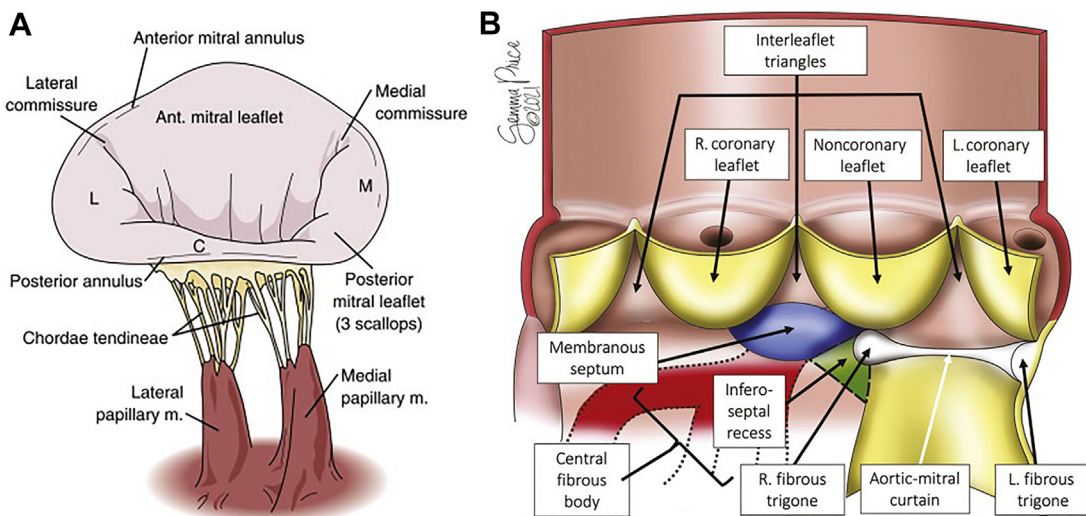


Fig. 4. Anterior mitral leaflet. Left coronary (LCC) leaflet of the aortic leaflet known as the aortomitral curtain (A) Central fibrous body (B). NCC, noncoronary; RCC, right coronary. ([A] Catherine M. Otto, Textbook of Clinical Echocardiography, 7th Edition, Elsevier Inc. 2024; and [B] With permission from Gemma Price.)

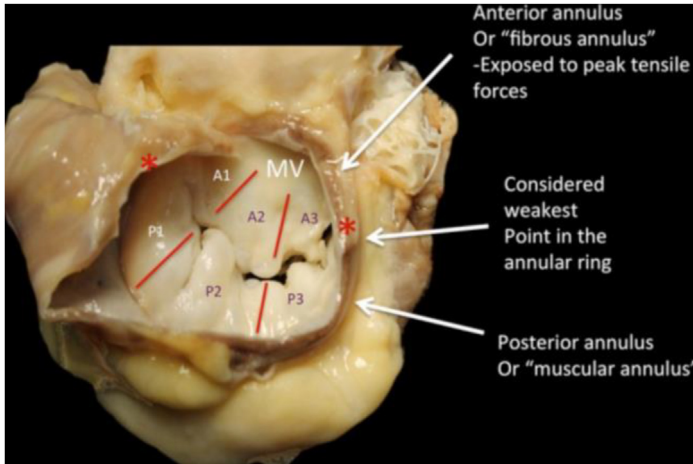


Fig. 5. Posterior mitral leaflet (PML) or the mural leaflet. (Pozzoli A, Zuber M, Reisman M, Maisano F and Tarassio M (2018) Comparative Anatomy of Mitral and Tricuspid Valve: What Can the Interventionist Learn From the Surgeon. *Front. Cardiovasc. Med.* 5:80. <https://doi.org/10.3389/fcvm.2018.00080>.)

LEFT VENTRICLE

PML is the one which is being supported by the LV via the basal chords. Hence, if there is LV dilation, this will change the orientation of the basal chords causing disturbances in leaflet coaptations causing valvular insufficiency.⁷

CHALLENGES IN MITRAL VALVE REPLACEMENT

Mitral valve replacement can be done either using mechanical or bioprosthetic valves.

Let us see the challenges faced step by step, both surgically and via transcatheter mitral valve replacement (TMVR).

SURGICAL CHALLENGES

Approach to the Mitral Valve

Usually it is trans-LA or trans-right atrium (RA)—transseptal.

Trans LA (**Fig. 7A**) is the classical approach used when the LA is enlarged. Sondergaard's groove is dissected and the LA is entered and the mitral valve is approached. When the LA is not enlarged, trans-RA-transseptal (**Fig. 7B**) approach is used. In the Dubost (**Fig. 7C**) approach, a horizontal incision is made over the RA, extended along the right upper lobe pulmonary vein, and the septum is entered.

In superior septal approach (**Fig. 7D**), the septal incision is extended superiorly. The main disadvantage of this approach is atrial

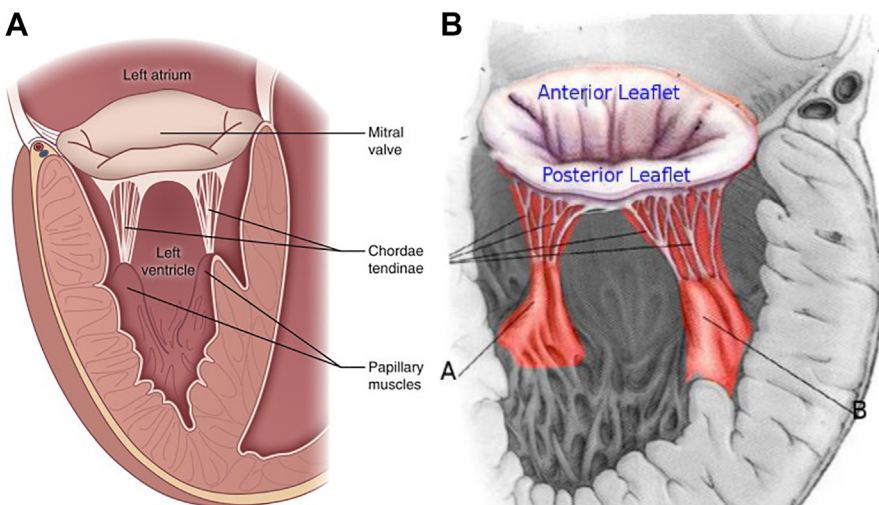


Fig. 6. (A) Types of chordae tendinae. (B) Papillary muscles. A, anterolateral papillary muscle; B, posteromedial papillary muscle. ([A] From Carpentier A, Adams DH, Filsoufi F. *Carpentier's Reconstructive Valve Surgery. From Valve Analysis to Valve Reconstruction.* 2010 Saunders Elsevier; and [B] From Filsoufi F, Carpentier A. <http://www.themitralvalve.org/mitralvalve/anatomy-subvalvular-apparatus>. Accessed August 11, 2020.)

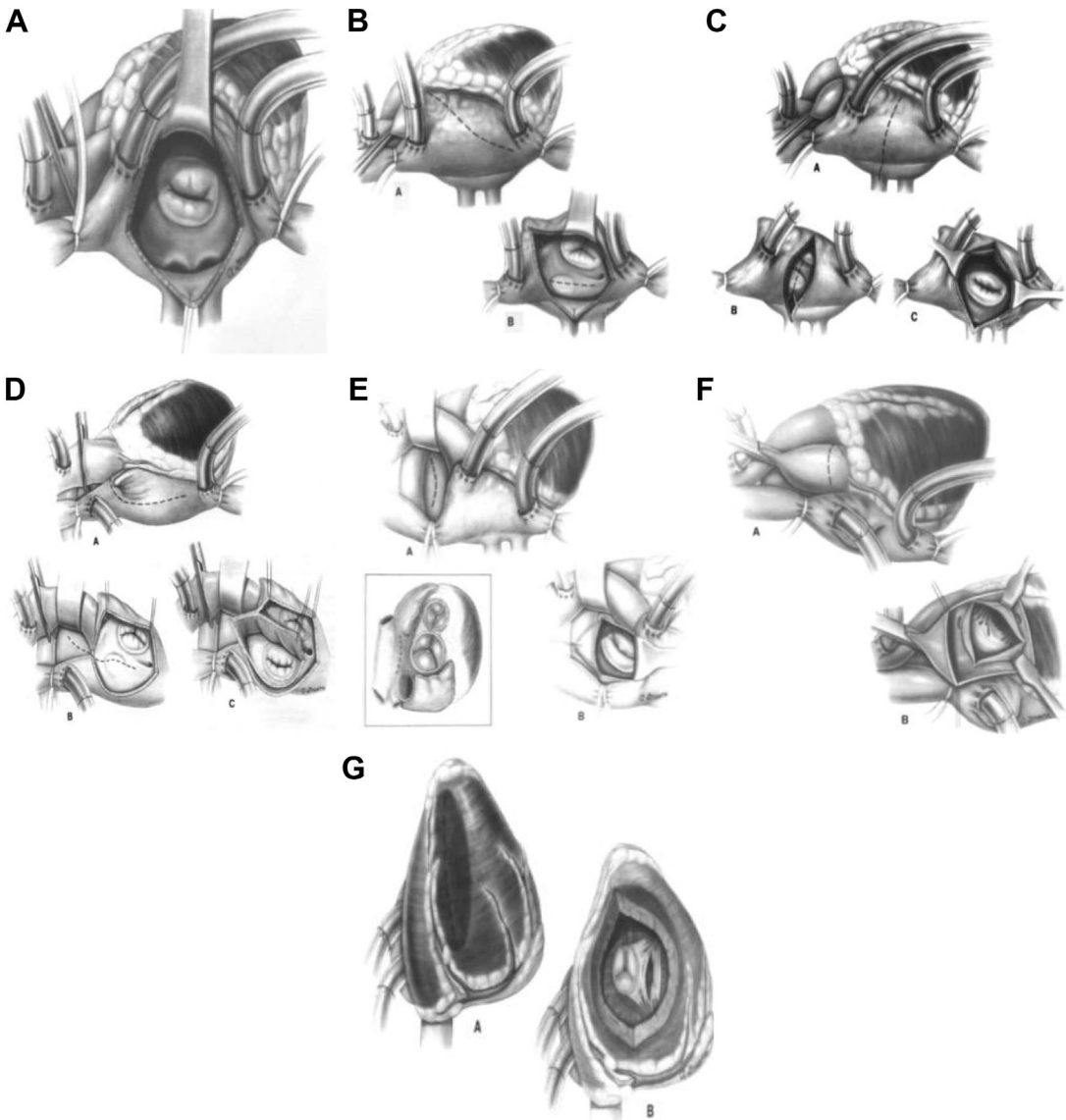


Fig. 7. Approach to the mitral and tricuspid valve. (A) Trans-left atrium (LA). (B) Transseptal approach. (C) Dubost approach. (D) Superior septal approach. (E) Superior approach. (F) Transaortic approach. (G) Trans-left ventricle. (A. Thomas Pezzella et al. *Operative Approaches to the Left Atrium and Mitral Valve: An Update, Operative Techniques in Thoracic and Cardiovascular Surgery*, 3 (2), 1998, 74-94, [https://doi.org/10.1016/S1522-2942\(07\)70078-8](https://doi.org/10.1016/S1522-2942(07)70078-8).)

arrhythmias since the vascularity to the sinoatrial (SA) node can be compromised because of the anatomic variation in the vascularity of the SA nodal artery. In the superior approach (Fig. 7E), the LA is entered via the roof of the LA between the aorta and the superior vena cava (SVC). The transaortic approach (Fig. 7F) is used in concomitant aortic procedures but the exposure is limited.

The trans-LV approach (Fig. 7G) is used in concomitant LV reconstruction procedures.

Mitral Leaflet and the Subvalvular Apparatus

Preservation of LV function is of utmost importance. As a result of the loss of annulo-ventricular continuity, chordal loss leads to deleterious effects; hence, the preservation of leaflets and the subvalvular apparatus gained popularity.⁸

The subvalvular apparatus acts like 2 bars holding the annulus. When these are not preserved, the LV geometry gets altered leading to LV dilation. There are various techniques to preserve the subvalvular apparatus (Fig. 8).



Fig. 8. Importance of subvalvular apparatus preservation.

In the PML preservation method, the AML is excised and the valve stitches are taken in such a way to buttress the PML. There are various methods of total chordal preservation. In this, caution is taken to avoid LVOT obstruction because of the preserved AML.

TECHNIQUES OF TOTAL CHORDAL PRESERVATION

Anterior Preservation

In David technique, the midpart of AML is excised and it is attached laterally. In Feikes technique, AML is incised in the middle and the incision is extended laterally and the AML is turned upside down and attached to the posterior annulus. In Khonsari technique, AML is excised and the chordal attachments are attached to the anterior annulus. In Rose and Oz method, an ellipse of

AML is removed and reattached to the anterior annulus using prolene (Fig. 9).⁸

Posterior Preservation

In Mikis technique, PML is split into 2 halves and is reattached to the commissures.⁸

Mitral Annular Sizing and Suturing Techniques of Mitral Valve Replacement

Once the valve is excised and the chords are preserved, we have to size the mitral annulus using the sizers provided by the valve makers to decide the appropriate valve size (Fig. 10). Always put a valve more than size 25 to avoid patient prosthesis mismatch.⁹⁻¹¹

The depth of suture pass should be not more than 2 to 3 mm from the cut edge through the annulus to avoid injury to the surrounding structures, namely the AV node, aortic valve,

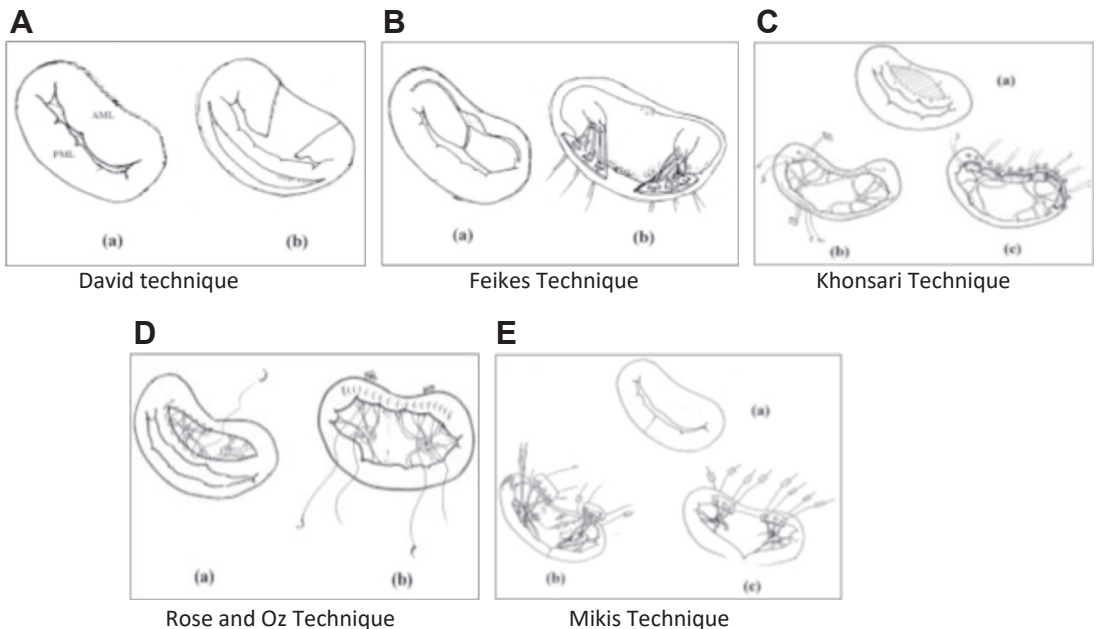


Fig. 9. (A) David technique. (B) Feikes technique. (C) Khonsari technique. (D) Rose and Oz technique. (E) Mikis technique.

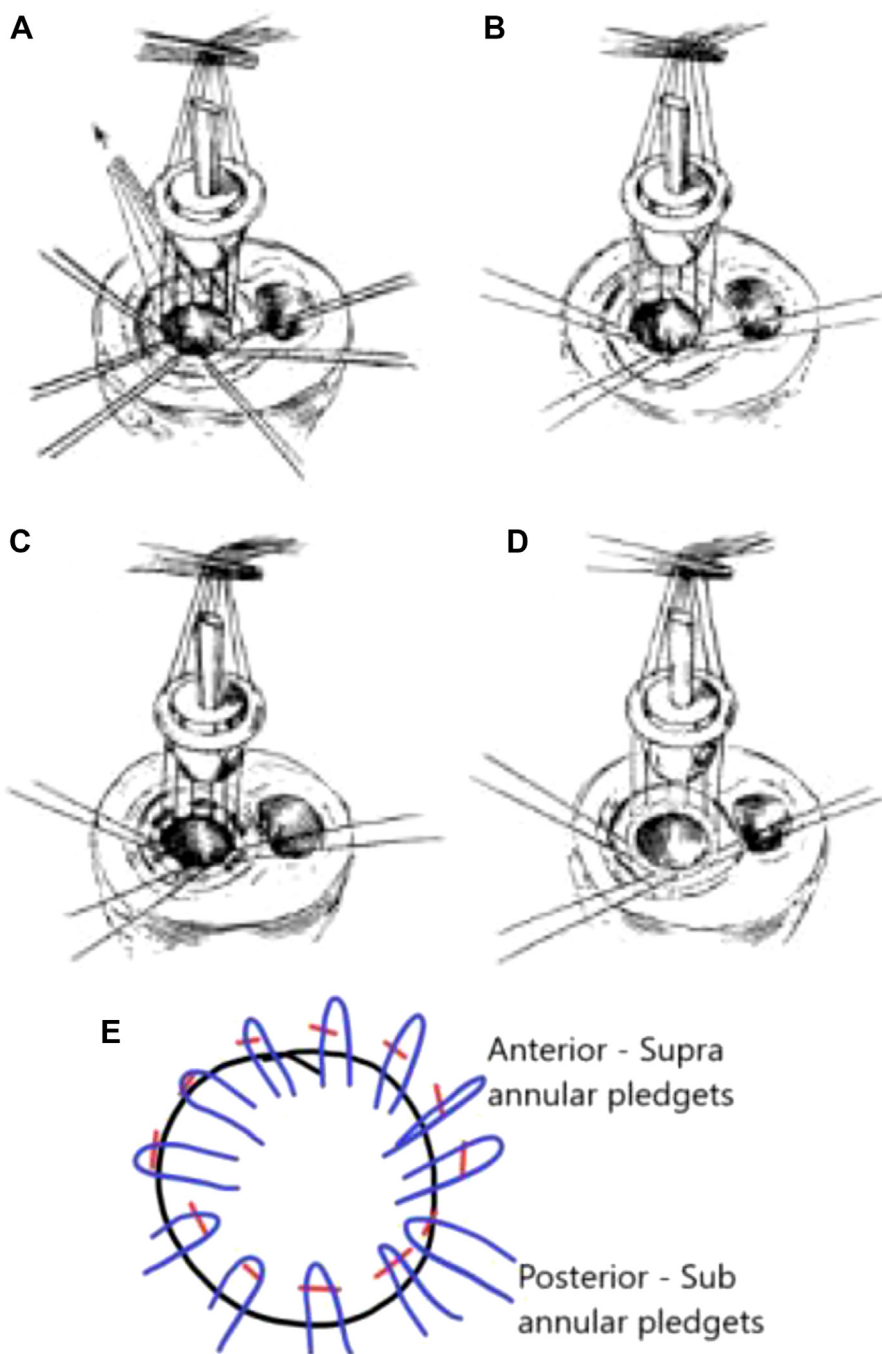


Fig. 10. Techniques of suture placement in mitral valve replacement. (A) This represents non-pledgetted interrupted simple technique of suture placement. Figure-of-8 suture placement is depicted in (B). Supraannular pledgetted horizontal method of suturing technique is depicted in (C). This is commonly used with mitral valve being placed annular. Subannular pledget placement with horizontal mattress suturing technique is shown on (D). In this, valve will be placed on LA side, which can be adopted in case of small annulus. Last one will be adopting both supraannular pledgets along the anterior annulus and subannular pledgets along the posterior annulus, which makes the valve lie tilted (E).¹² (Joseph R. Newton et al., Evaluation of suture techniques for mitral valve replacement, *The Journal of Thoracic and Cardiovascular Surgery*, 88 (2), 1984, 248-252, [https://doi.org/10.1016/S0022-5223\(19\)38359-X](https://doi.org/10.1016/S0022-5223(19)38359-X).)

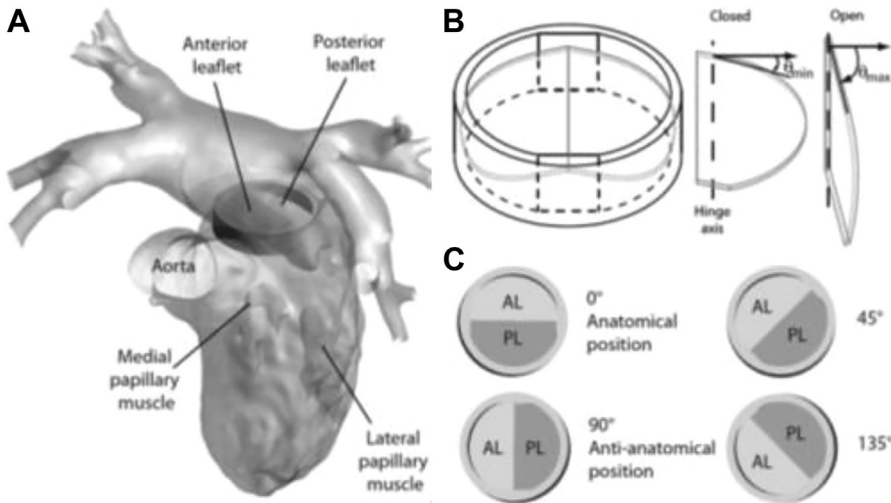


Fig. 11. (A) Depicts mechanical valve in the anatomic position. (B) Anatomic position with leaflets in open and closed positions. (C) Various orientations of placement of mechanical valve leaflets.

coronary sinus, and the left circumflex artery as depicted in **Fig. 2**.

Orientation of the Prosthetic Valves

While using mechanical valves, the orientation of the valves can be anatomic (the bileaflet valve corresponds to AML and PML) or anti-anatomic (perpendicular to AML and PML). If the disc does not open properly due to the underneath chordal structures, the design of the valves allows us to rotate the valve such that the disc opens fully (**Fig. 11**).¹³ Always make sure the disc opens properly without any obstruction.

In bioprosthetic valves, unlike aortic, only stented bioprosthetic valves are available. While placing the bioprosthetic valve, make sure that the struts lie along the right and left trigones, so that LVOT obstruction is avoided (**Fig. 12**).

Considerations in Transcatheter Mitral Valve Replacement

LA is approached via direct transatrial, transapical, transarterial retrograde, and transeptal routes¹⁴(**Fig. 13**). Transeptal is the most preferred route due its superior safety, ease of access, support, and the optimal stabilization the septum

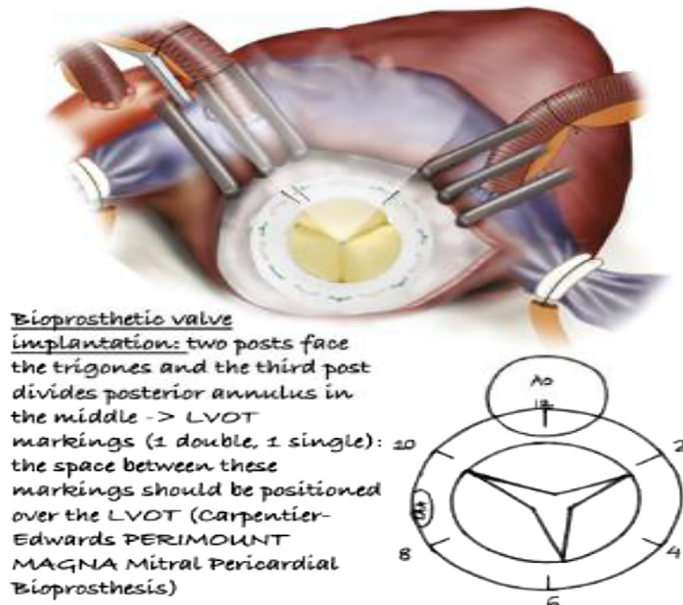


Fig. 12. Orientation of bioprosthetic mitral valve.

Bioprosthetic valve implantation: two posts face the trigones and the third post divides posterior annulus in the middle -> LVOT markings (1 double, 1 single): 10 the space between these markings should be positioned over the LVOT (Carpentier-Edwards PERIMOUNT MAGNA Mitral Pericardial Bioprosthesis)

provides. For easy access, the location of the puncture is most important. It will be very challenging and chances of an ascending aorta or posterior wall of LA will be common in case of more anterior or posterior puncture. When the LA is not enlarged, chances of injury to the left atrial appendage and pulmonary veins will increase in case of a wrong puncture. Hence, transesophageal echocardiography (TEE) is most important to decide the exact puncture site. The more posterior location of the mitral valve allows for easy access via TEE. The thickened mitral leaflets and the mitral annular calcification allow for the valve to hold when not in need of post-mitral replacement or repair. The subvalvular apparatus is prone to damage when the device enters laterally or medially. Always, it is preferable to place the device in the center which can be the chordae-free zone. For TMVR, balloon-expandable valves can only be used. After placing the valve, there is a chance of LVOT obstruction.

The native LVOT is the region between the proposed place of implantation of the device and the basal to the mid-septum (Fig. 14). After placing the TMVR valve, AML pins in an open position and is displaced toward the septum, which is called the neo-LVOT (displaced AML, stent of TMVR, and the basal to midseptum). The Neo-LVOT can be measured during preoperative imaging. High-risk patients for Neo-LVOT obstruction have small ventricles, asymmetrical septal hypertrophy, perpendicular aortomitral angulation, and elongated anterior leaflet.¹⁵ When the LVOT area is less than 1.7 to 1.9 cm², the chance of neo-LVOT obstruction is less.¹⁵

TRICUSPID VALVE

TV is the apically positioned valve and it is the largest valve among the 4 valves. Like the mitral valve, TV also has following components: tricuspid annulus, leaflets, chords, and PMs.¹⁶

Tricuspid Annulus

There is no distinct tricuspid annulus. It is D shaped, with the C being formed by free wall of the RA and right ventricle and the straight part corresponds to the septal leaflet and the ventricular septum which is attached to the posteromedial trigone. That is why in secondary TR, TV annulus dilates more toward lateral and posterior sides than the septal side which is attached with the trigone (Fig. 15).¹⁷

TV annulus is surrounded by important structures (see Fig. 15):

- I. The noncoronary sinus of Valsalva, the area between the non-coronary and the right coronary aortic
- II. The bundle of His, which penetrates the central fibrous body at the apex of triangle of Koch
- III. The right coronary artery, which courses the right AV groove anteriorly

Anatomic Landmarks of the Triangle of Koch

The tendon of Todaro lies above the Eustachian valve and forms the lateral side of the triangle. The hinge point of the septal leaflet forms the medial side, and the coronary sinus forms the base of the triangle. The AV node lies at

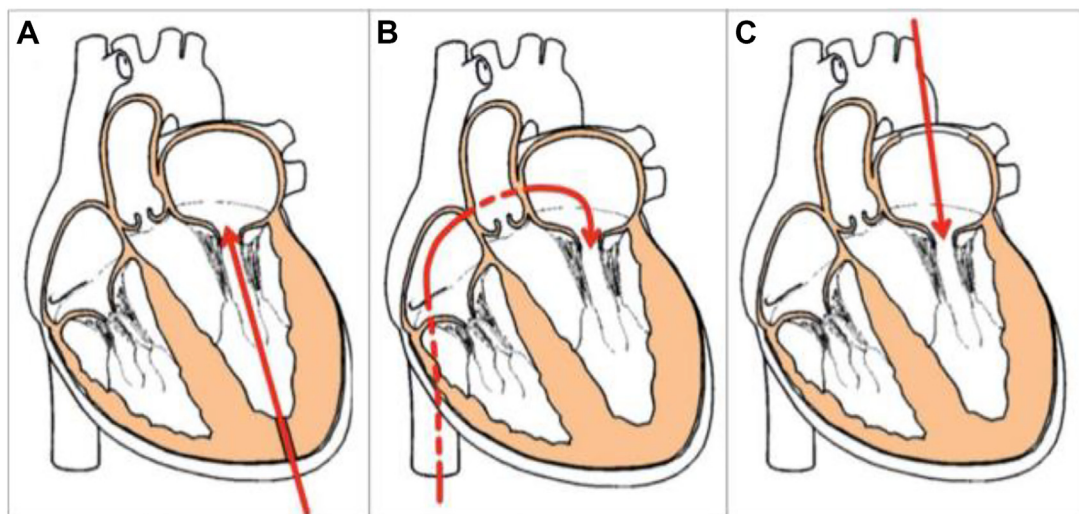


Fig. 13. Common approaches for transcatheter mitral valve replacement. (A) Transapical. (B) Transseptal. (C) Transatrial.

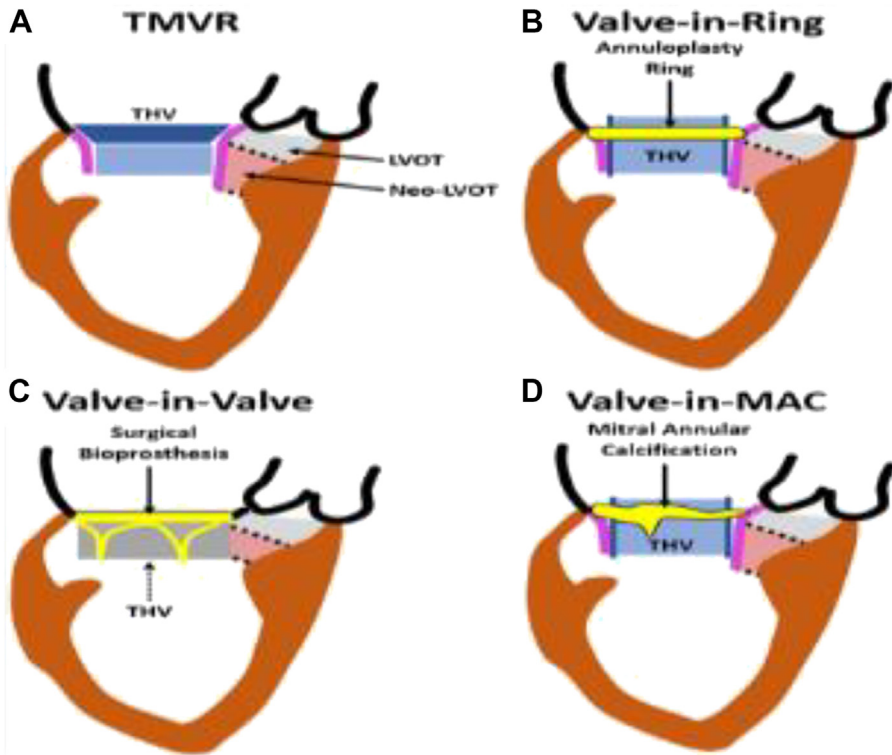


Fig. 14. Neo-left ventricular outflow tract. (A) Transcatheter mitral valve replacement (TMVR). (B) TMVR in ring (C) TMVR in valve (D) TMVR in mitral annular calcification (MAC).

the apex of the triangle in the membranous septum (Fig. 16).¹⁸

TRICUSPID LEAFLETS

The TV comprises 3 leaflets: the anterior, the posterior, and the septal, which are separated by 3 commissures. The septal leaflet is

characteristic of the TV, with either direct chordal attachment to the septum or through the so-called Lancisi conal PM. The TV leaflets are thinner, more translucent, and more fragile compared to the mitral valve leaflets. The anterior tricuspid leaflet (ATL) is the largest one, followed by the posterior tricuspid leaflet (PTL) and the septal tricuspid leaflet (STL). Attachments of

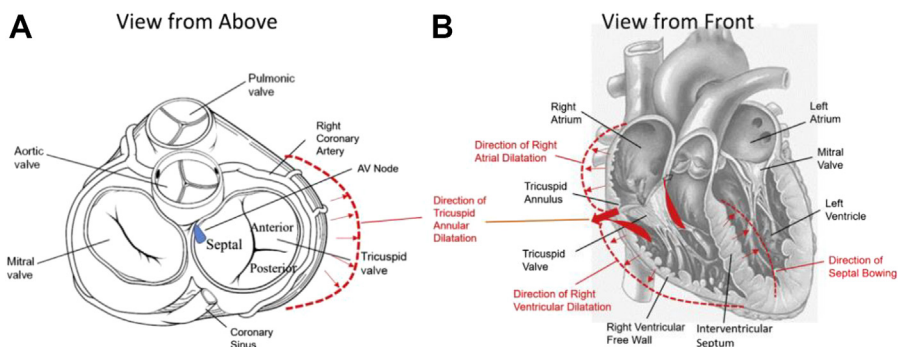


Fig. 15. Illustrating the complex tricuspid valve anatomy in detail with the important neighboring structures and the direction of dilation in various settings. The tendon of Todaro (blue line) lies above the Eustachian valve and forms the lateral side of the triangle. The hinge point of the septal leaflet (orange line) forms the medial side, and the coronary sinus (CS) forms the base of the triangle (yellow line). The atrioventricular node lies at the apex of the triangle in the membranous septum (asterisk). (Abdellaziz Dahou et al., Anatomy and Physiology of the Tricuspid Valve, JACC: Cardiovascular Imaging, 12 (3), 2019, 458-468, <https://doi.org/10.1016/j.jcmg.2018.07.032>.)

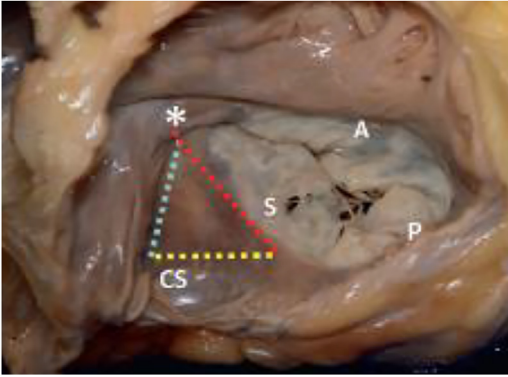


Fig. 16. Anatomic landmarks of the triangle of Koch.

leaflets are ATL to the right ventricular outflow tract (RVOT), PTL to the muscular wall of RV, and STL to the septum. There are 3 commissures of the TV and these separate the 3 leaflets (see **Figs. 15** and **16**).^{17,19}

Papillary Muscles

There are 3 tricuspid PMs, which supports the tricuspid valve, namely—anterior, posterior, and septal PMs. The anterior PM, supporting ATL and PTL, is the largest one. The moderator band joins this muscle. The posterior PM supports PTL and STL. The septal PM attaches STL to the septum (**Fig. 17**).

Surgical Considerations in Tricuspid Valve Replacement

Bioprosthetic valves used for the mitral position are the valve of choice in the tricuspid position. Since a larger size valve is implanted when

compared to the size of the patient, the durability of the valve is greater and has low or normal RV pressure. These would contribute to low stress on the prosthetic valve. Valve-in-valve implantation is also possible. When there is RV dysfunction, mechanical valve should be avoided due to abnormal valve disc motion.

For replacement, if there is excess leaflet toward the RVOT, it should be excised or can be buttressed while placing sutures.

Three commonly used suturing techniques are²⁰

1. Everting 2/0 pledgeted sutures from the atrial to the ventricular side of the valve
2. Noneverting 2/0 pledgeted sutures from the ventricular to the atrial side of the valve
3. Single continuous 2 or 3/0 polypropylene sutures

As depicted in **Fig. 13**, the area of importance is along the septal leaflet. It is better to avoid this area. Hence, the suture can be through the septal leaflet as depicted in **Fig. 18A**. The suture line can be deviated from the atrial side of the AV node and membranous septum inferiorly to avoid injury to the conduction system and cephalad to the AV groove anteriorly to avoid injury to the right coronary artery. If there is enough space, the coronary sinus can be left to drain into RA if not to LA. Like mitral position, the struts of the bioprosthetic valve should be between the membranous septum and conduction tissue. Always tie the sutures with the heart beating closed to detect any disturbances in AV conduction.²⁰

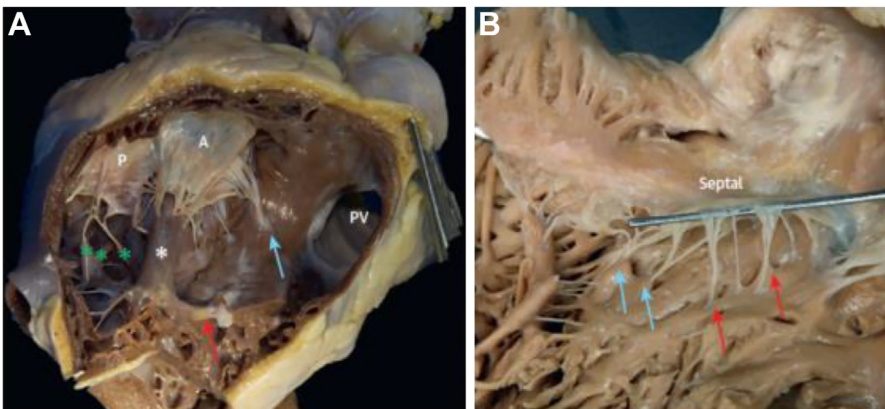


Fig. 17. Tricuspid papillary muscles (PMs). (A) The anterior PM (white asterisk) supporting the anterior tricuspid leaflet and the posterior tricuspid leaflet is the largest one. The moderator band joins this muscle (orange arrow). The posterior PM (green asterisk) supports posterior tricuspid leaflet and the septal tricuspid leaflet. (B) The septal PM attaches to the septal tricuspid leaflet to the septum. A, anterior tricuspid leaflet; P, posterior tricuspid leaflet.

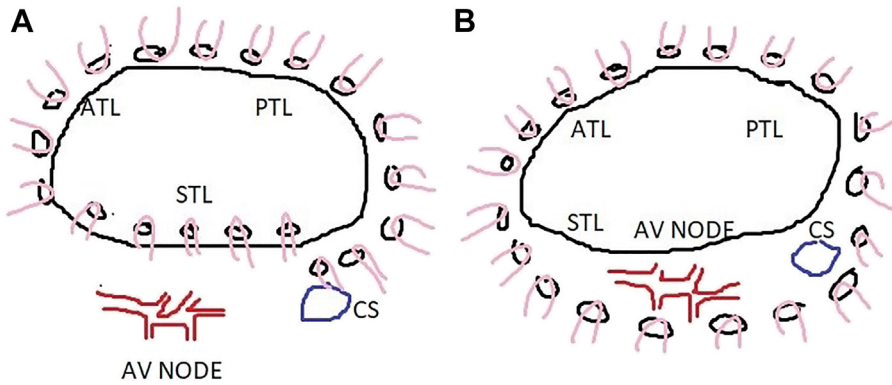


Fig. 18. (A, B) Suturing techniques in tricuspid valve replacement.

Consideration in Transcatheter Tricuspid Valve Interventions

The approach to the tricuspid valve is either via SVC or inferior vena cava. The lack of annular calcification and the large valvular area in case of functional tricuspid valve regurgitations make the device selection very difficult. The valve leaflets are also very thin when compared to mitral valve leaflets. The RVOT is wide and chance of RVOT obstruction is less when compared to TMVR.

SUMMARY

The mitral valve should be considered as a complex and each should be preserved to maintain the LV geometry. Everyone should be familiar with the different suturing techniques of mitral valve replacement and the important surrounding structures, so that the valve can be appropriately placed. Tricuspid valve replacement is mostly done with bioprosthetic valves and care must be taken while placing sutures along the septal annulus to avoid injury to the AV node. From the interventional perspective in case of TMVR, balloon-expandable valves are used and neo-LVOT is important.

CLINICS CARE POINTS

- Mitral valve should be considered as a valvular complex comprising 5 structures, namely annulus, leaflets, chordae, PM, and LV.
- Each structure should be preserved, so that the geometry of the LV is preserved.
- Tricuspid valve replacement is mostly done with bioprosthetic valves and care must be taken while placing sutures along the septal annulus to avoid injury to the AV node.

DISCLOSURE

The authors have nothing to disclose.

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