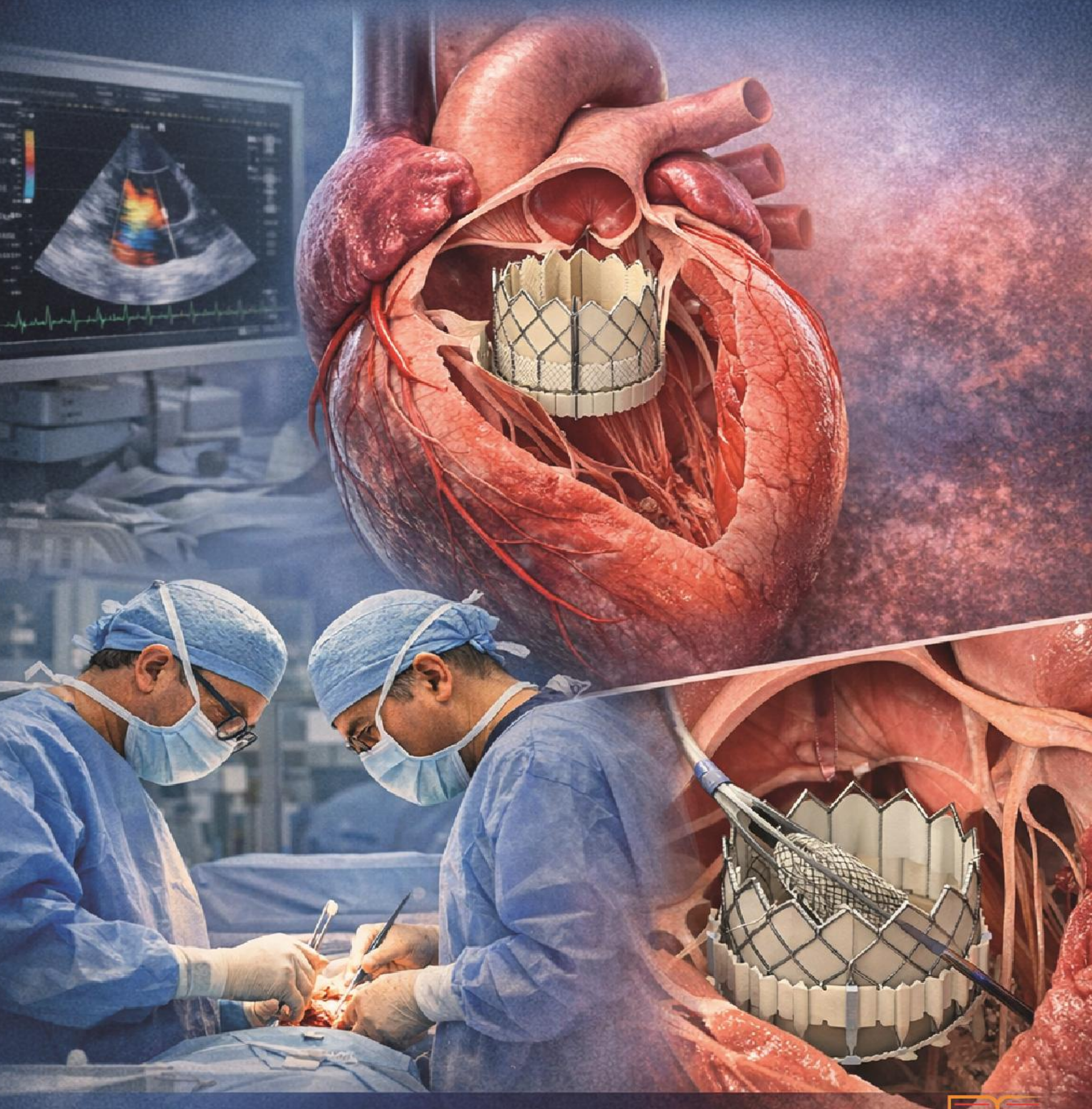
CONTEMPORARY MANAGEMENT OF

HEART VALVE DISEASES

AORTIC, MITRAL, AND TRICUSPID VALVE INTERVENTIONS



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AORTIC VALVE DISEASE: SURGICAL AND TRANSCATHETER TREATMENT STRATEGIES

EMCED KHALIL[1]

INTRODUCTION

Aortic valve disease represents a major global health burden and remains one of the most prevalent forms of valvular heart disease, particularly in aging populations. With increasing life expectancy and improved diagnostic capabilities, the incidence of aortic stenosis (AS) and aortic regurgitation (AR) continues to rise, placing significant demands on healthcare systems worldwide. Degenerative calcific aortic stenosis, in particular, has emerged as the dominant etiology in developed countries, closely linked to age-related processes and sharing pathophysiological features with atherosclerosis (Vahanian et al., 2022; Otto et al., 2021).

The natural history of severe symptomatic aortic stenosis is characterized by a rapid decline once symptoms develop, with markedly reduced survival if left untreated. Similarly, chronic aortic regurgitation may remain asymptomatic for prolonged periods but

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eventually leads to progressive left ventricular dilation and irreversible myocardial dysfunction. Therefore, timely diagnosis and appropriate intervention are critical to improving clinical outcomes (Baumgartner et al., 2009; Pibarot & Dumesnil, 2000). Historically, surgical aortic valve replacement (SAVR) has been the cornerstone of treatment, offering durable and reliable long-term results. However, the past two decades have witnessed a paradigm shift with the advent of transcatheter aortic valve implantation (TAVI), which has dramatically expanded treatment options, particularly for patients previously considered inoperable or at high surgical risk. More recently, TAVI has been validated in intermediate- and low-risk populations, challenging traditional treatment algorithms and redefining the standard of care (Smith et al., 2011; Mack et al., 2019). In parallel, innovations in surgical technology, including sutureless and rapid-deployment valves, have enhanced the efficiency and safety of surgical interventions. These technologies reduce operative times and facilitate minimally invasive approaches, offering an attractive alternative in selected patient populations (Shrestha et al., 2017; Flameng et al., 2010). Despite these advances, the optimal management of aortic valve disease remains complex and requires careful integration of clinical, anatomical, and procedural factors. The emergence of the multidisciplinary "heart team" approach has been pivotal in tailoring individualized treatment strategies and improving patient outcomes (Otto et al., 2021; Nishimura et al., 2017).

This chapter aims to provide a comprehensive and clinically relevant overview of aortic valve disease, focusing on pathophysiological mechanisms, diagnostic evaluation, and contemporary treatment strategies, including both surgical and transcatheter approaches. Particular emphasis is placed on patient selection, procedural considerations, and evolving technologies that continue to shape the future of aortic valve therapy.

PATHOPHYSIOLOGY OF AORTIC VALVE DISEASE

Aortic Stenosis

Aortic stenosis (AS) is a progressive disease characterized by obstruction of left ventricular outflow due to structural and functional abnormalities of the aortic valve. In contemporary clinical practice, the most common etiology is degenerative calcific aortic stenosis, which shares several pathophysiological features with atherosclerosis, including lipid accumulation, chronic inflammation, and active calcification processes. Mechanical stress and endothelial injury initiate a cascade of inflammatory and osteogenic pathways, leading to progressive leaflet thickening, fibrosis, and ultimately calcific immobilization of the valve cusps.

As the aortic valve area decreases, left ventricular outflow becomes increasingly obstructed, resulting in a pressure overload state. In response, the left ventricle undergoes concentric hypertrophy as an adaptive mechanism to normalize wall stress and maintain cardiac output. Although this compensatory remodeling initially preserves systolic function, it is associated with reduced ventricular compliance, impaired diastolic filling, and increased myocardial oxygen demand. With disease progression, these adaptive mechanisms become maladaptive. Persistent pressure overload leads to myocardial fibrosis, subendocardial ischemia, and eventual decline in left ventricular systolic function. Clinically, this transition corresponds to the onset of symptoms such as angina, syncope, and heart failure, which are associated with a marked deterioration in prognosis if left untreated. Importantly, the natural history of severe symptomatic aortic stenosis is characterized by rapid clinical decline, underscoring the critical importance of timely intervention.

Aortic Regurgitation

Aortic regurgitation (AR) is characterized by the diastolic reflux of blood from the aorta into the left ventricle due to inadequate coaptation of the aortic valve leaflets. The etiology of AR is heterogeneous and may involve primary valvular abnormalities, such as congenital bicuspid valve disease or infective endocarditis, as well as aortic root pathology, including dilation of the ascending aorta or annulus. The principal hemodynamic consequence of chronic AR is volume overload of the left ventricle. During diastole, regurgitant flow increases ventricular end-diastolic volume, leading to progressive ventricular dilation and eccentric hypertrophy. This adaptive remodeling allows the ventricle to accommodate the increased volume while maintaining forward stroke volume and cardiac output for a prolonged period. However, chronic volume overload eventually results in increased wall stress, myocardial remodeling, and gradual impairment of systolic function. As left ventricular contractility declines, patients may develop symptoms of heart failure and reduced exercise tolerance. In addition, increased left ventricular filling pressures may lead to pulmonary congestion in advanced stages of the disease.

Unlike aortic stenosis, which is primarily a pressure overload condition, aortic regurgitation represents a volume overload state with a typically longer asymptomatic phase. Nevertheless, once symptoms or left ventricular dysfunction develop, disease progression may accelerate, and timely surgical intervention becomes essential to prevent irreversible myocardial damage.

CLINICAL EVALUATION AND IMAGING

Clinical Assessment

The clinical evaluation of patients with aortic valve disease requires a comprehensive and systematic approach that integrates symptom assessment, physical examination, and risk stratification. Patients may present with a spectrum of symptoms depending on the severity and type of valvular pathology. In aortic stenosis, the classical triad of angina, syncope, and dyspnea reflects advanced disease and is associated with a significantly worsened prognosis. In contrast, patients with aortic regurgitation often remain asymptomatic for extended periods despite progressive left ventricular dilation, with symptoms typically emerging only in the later stages of the disease. A detailed clinical history should focus on the onset, duration, and progression of symptoms, as well as exercise tolerance and functional capacity, commonly assessed using the New York Heart Association (NYHA) classification. The presence of comorbid conditions, including coronary artery disease, hypertension, and chronic kidney disease, should be carefully evaluated, as these factors influence both prognosis and therapeutic decision-making. In elderly patients, frailty assessment has become increasingly important in determining the most appropriate treatment strategy, particularly when considering transcatheter versus surgical interventions.

Physical examination remains an important component of the diagnostic process. In aortic stenosis, a systolic ejection murmur radiating to the carotid arteries is typically present, often accompanied by a diminished and delayed carotid pulse. In aortic regurgitation, a high-pitched diastolic decrescendo murmur is characteristic, along with peripheral signs of wide pulse pressure in advanced cases. However, clinical findings alone are insufficient for accurate assessment of disease severity, and imaging plays a central role in confirming the diagnosis and guiding management.

Echocardiographic Evaluation

Echocardiography is the cornerstone of diagnostic evaluation in aortic valve disease, providing essential information on valve morphology, hemodynamic severity, and ventricular function. Transthoracic echocardiography (TTE) is the first-line imaging modality and allows comprehensive assessment of both aortic stenosis and aortic regurgitation. In aortic stenosis, severity is determined by a combination of parameters, including aortic valve area, mean transvalvular gradient, and peak aortic jet velocity. These measurements provide a reliable estimation of the degree of obstruction and are critical for determining the timing of intervention. In addition, evaluation of left ventricular function and wall thickness is essential, as these parameters reflect the hemodynamic burden imposed by the disease. In aortic regurgitation, echocardiographic assessment focuses on quantifying regurgitant severity and evaluating its impact on left ventricular size and function. Parameters such as regurgitant volume, regurgitant fraction, and vena contracta width are commonly used to grade severity, while serial measurements of ventricular dimensions are essential for identifying progressive remodeling.

Transesophageal echocardiography (TEE) provides higher spatial resolution and is particularly valuable in cases with suboptimal transthoracic imaging or when detailed anatomical assessment is required. It also plays an important role in intraoperative guidance and in planning both surgical and transcatheter interventions.

Computed Tomography and Advanced Imaging

Advanced imaging modalities have become increasingly important in the comprehensive evaluation of aortic valve disease, particularly in the era of transcatheter interventions. Multidetector computed tomography (CT) is now an essential tool for procedural planning in patients undergoing transcatheter aortic valve implantation (TAVI), as it provides precise anatomical information regarding the aortic annulus, leaflet calcification, coronary ostia, and vascular access routes. CT imaging allows accurate measurement of annular dimensions and assessment of calcification distribution, both of which are critical for appropriate prosthesis sizing and minimizing procedural complications. In addition, evaluation of peripheral vasculature is essential to determine the feasibility of transfemoral access, which remains the preferred approach in most cases.

Cardiac magnetic resonance imaging (MRI) may also be useful in selected patients, particularly for the quantification of regurgitant volumes and assessment of myocardial fibrosis. These advanced imaging techniques complement echocardiography and contribute to a more comprehensive understanding of disease severity and ventricular remodeling.

Heart Team Approach

The management of aortic valve disease requires a multidisciplinary approach that integrates the expertise of cardiac surgeons, interventional cardiologists, imaging specialists, and anesthesiologists. The heart team plays a central role in evaluating each patient and determining the most appropriate treatment strategy based on clinical status, anatomical characteristics, and procedural risk. Decision-making should be individualized, taking into account patient age, comorbidities, frailty, and life expectancy, as well as the relative risks and benefits of surgical versus transcatheter approaches. This collaborative framework ensures that treatment decisions are patient-centered and evidence-based, ultimately leading to improved clinical outcomes.

SURGICAL AORTIC VALVE REPLACEMENT (SAVR)

Indications and Patient Selection

Surgical aortic valve replacement (SAVR) remains the gold standard treatment for patients with severe aortic valve disease, particularly in younger individuals and those with low operative risk.

Current clinical guidelines recommend SAVR in symptomatic patients with severe aortic stenosis, as well as in asymptomatic patients with evidence of left ventricular dysfunction or other high-risk features. In addition, SAVR is generally preferred in patients requiring concomitant cardiac procedures, such as coronary artery bypass grafting or surgery involving the ascending aorta.

Patient selection for SAVR requires a comprehensive assessment that integrates clinical status, anatomical considerations, and surgical risk. Risk stratification tools such as the Society of Thoracic Surgeons (STS) score and EuroSCORE are commonly used to estimate operative risk; however, these tools should be complemented by clinical judgment, particularly in elderly or frail patients. The decision-making process is ideally guided by a multidisciplinary heart team approach to ensure optimal treatment selection.

Surgical Technique

SAVR is traditionally performed via median sternotomy under cardiopulmonary bypass, although minimally invasive approaches have gained increasing acceptance in selected patients. Following aortic cross-clamping and cardioplegic arrest, the diseased native valve is excised, and the annulus is carefully debrided to remove calcific deposits and ensure optimal seating of the prosthetic valve.

Valve implantation can be performed using conventional sutured techniques or sutureless systems. In the standard approach, interrupted or continuous sutures are placed circumferentially around the annulus to secure the prosthetic valve. In contrast, sutureless valve technologies utilize self-expanding or balloon-expandable frames that allow rapid deployment and reduce operative times.

As illustrated in Figure 1 and 2, surgical options include both conventional prosthetic valve implantation and sutureless valve systems, each with specific technical and clinical considerations.

Figure 1. Surgical aortic valve replacement (SAVR).

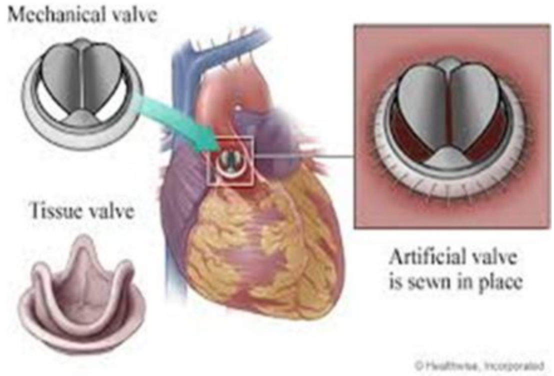


Figure 1: Conventional surgical aortic valve replacement using a sutured prosthetic valve.

Figure 2. Surgical aortic valve replacement (SAVR).

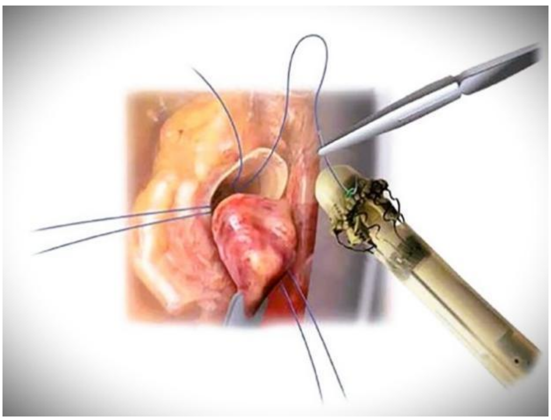


Figure 2: Sutureless aortic valve implantation (e.g., Perceval system) allowing rapid deployment and reduced cross-clamp time.

Prosthetic Valve Options

The choice of prosthetic valve is a critical component of SAVR and should be individualized based on patient age, comorbidities, and preferences. Mechanical valves offer excellent long-term durability and are generally recommended for younger patients; however, they require lifelong anticoagulation and are associated with an increased risk of bleeding and thromboembolic complications. Bioprosthetic valves, on the other hand, do not require long-term anticoagulation and are therefore preferred in older patients or those with contraindications to anticoagulation therapy. Nevertheless, these valves are subject to structural degeneration over time, which may necessitate reintervention.

Sutureless valves represent an important advancement in surgical valve technology. These valves are mounted on a self-expanding frame and can be deployed without the need for multiple sutures, thereby significantly reducing aortic cross-clamp and cardiopulmonary bypass times. This approach is particularly advantageous in elderly patients or those undergoing minimally invasive procedures.

Outcomes and Clinical Considerations

SAVR provides excellent long-term outcomes, with durable valve performance and significant improvement in symptoms and survival. In low-risk patients, operative mortality is low, and long-term survival approaches that of the general population when intervention is performed in a timely manner. However, SAVR remains an invasive procedure and is associated with longer recovery times compared with transcatheter approaches. In elderly or high-risk patients, perioperative morbidity may be substantial, necessitating careful patient selection and perioperative management.

In contemporary practice, the choice between SAVR and transcatheter approaches should be individualized, taking into account patient characteristics, anatomical suitability, and institutional expertise. Despite the rapid expansion of transcatheter therapies, SAVR continues to play a central role in the management of aortic valve disease, particularly in patients with low surgical risk and favorable anatomy.

TRANSCATHETER AORTIC VALVE IMPLANTATION (TAVI)

Historical Evolution and Expanding Indications

Transcatheter aortic valve implantation (TAVI) has emerged as one of the most transformative innovations in cardiovascular medicine over the past two decades. Initially developed for patients deemed inoperable or at prohibitive surgical risk, TAVI has progressively expanded to include high-, intermediate-, and more recently, selected low-risk patient populations. This expansion has been driven by a series of landmark randomized trials demonstrating non-inferiority, and in some cases superiority, of TAVI compared with surgical aortic valve replacement (SAVR), particularly with respect to early morbidity, hospital length of stay, and recovery time. Contemporary clinical guidelines now recognize TAVI as a first-line treatment option in appropriately selected patients, especially in elderly individuals or those with increased surgical risk. Nevertheless, patient selection remains critical, as long-term durability data are still evolving, particularly in younger populations.

Patient Selection and Preprocedural Assessment

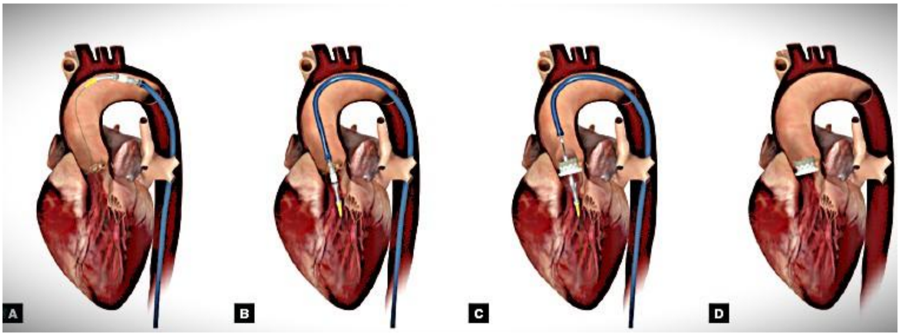
The decision to perform TAVI requires a comprehensive evaluation that integrates clinical, anatomical, and procedural considerations. Key factors include patient age, comorbidities, frailty status, and estimated surgical risk, typically assessed using scoring systems such as STS or EuroSCORE. However, these tools should be interpreted within the broader clinical context, as they may not fully capture all relevant risk factors. Anatomical suitability plays a central role in determining eligibility for TAVI. Detailed imaging assessment is essential to evaluate aortic annulus dimensions, leaflet calcification, coronary ostial height, and the geometry of the aortic root. In addition, careful assessment of vascular access routes is required to ensure procedural feasibility, with the transfemoral approach being preferred in the majority of cases due to its lower complication rates.

Procedural Technique

TAVI is a catheter-based intervention performed under fluoroscopic and echocardiographic guidance, typically via a transfemoral approach. The procedure involves advancement of a delivery system through the arterial vasculature to the level of the aortic valve, followed by crossing of the native stenotic valve with a guidewire. Accurate positioning of the prosthetic valve at the level of the aortic annulus is critical and is achieved using fluoroscopic landmarks and, in selected cases, transesophageal echocardiography. Once optimal positioning is confirmed, the prosthetic valve is deployed using either balloon-expandable or self-expanding systems. Balloon-expandable valves provide precise deployment with high radial force, whereas self-expanding valves allow gradual release and better adaptation to anatomical variations. Following deployment, the prosthetic valve immediately restores forward blood flow and significantly reduces the transvalvular gradient. Careful post-deployment assessment is essential to evaluate valve function and detect potential complications such as paravalvular leak or conduction disturbances.

As illustrated in (Figure 3), the TAVI procedure consists of sequential steps including vascular access, valve crossing, positioning, and deployment, each of which is critical for procedural success and optimal clinical outcomes.

Figure 3. Transcatheter aortic valve implantation (TAVI).



(A) Transfemoral vascular access and advancement of the delivery system.

(B) Crossing of the native stenotic aortic valve with a guidewire.

(C) Positioning of the prosthetic valve at the aortic annulus.

(D) Deployment of the prosthetic valve with restoration of valve function.

Clinical Outcomes and Advantages

TAVI offers several important clinical advantages compared with surgical approaches, particularly in high-risk and elderly patients. These include its minimally invasive nature, avoidance of sternotomy and cardiopulmonary bypass, shorter procedural duration, and more rapid recovery. As a result, TAVI is associated with reduced hospital length of stay and earlier return to normal activities. Large randomized trials have demonstrated that TAVI provides comparable mortality outcomes to SAVR across a range of surgical risk profiles, with additional benefits in terms of early morbidity and quality of life. These findings have contributed to the widespread adoption of TAVI as a standard treatment option in contemporary practice.

Limitations and Complications

Despite its advantages, TAVI is associated with specific complications that must be carefully considered. Paravalvular leak remains more common following TAVI than SAVR and has been associated with adverse outcomes when moderate or severe. Conduction disturbances, including new-onset left bundle branch block and the need for permanent pacemaker implantation, are also more frequently observed, particularly with self-expanding valve systems. Vascular complications, such as access site bleeding or vessel injury, represent additional procedural risks, although these have decreased with advances in device technology and operator experience. Stroke remains a serious but relatively infrequent complication, typically related to embolization during valve manipulation. Furthermore, long-term durability of transcatheter valves remains an area of ongoing investigation, especially in younger patients with longer life expectancy.

Future Perspectives

Ongoing technological advancements continue to refine TAVI procedures and expand their applicability. New-generation valve designs aim to improve sealing properties and reduce the incidence of paravalvular leak, while innovations in delivery systems are enhancing procedural precision and safety. In addition, the development of repositionable and retrievable valve systems offers greater control during deployment. The integration of advanced imaging techniques and computational modeling is expected to further optimize patient selection and procedural planning. As long-term outcome data continue to accumulate, the role of TAVI is likely to expand further, potentially redefining treatment paradigms for aortic valve disease in the future.

DISCUSSION

The management of aortic valve disease has evolved substantially over the past two decades, transitioning from a predominantly surgical discipline to a multidisciplinary field integrating both surgical and transcatheter strategies. Surgical aortic valve replacement (SAVR) remains the reference standard in younger and low-risk patients due to its established long-term durability and predictable outcomes (Brown et al., 2008). Mechanical prostheses provide excellent longevity but require lifelong anticoagulation, whereas bioprosthetic valves offer improved anticoagulation profiles at the expense of structural degeneration over time. Technological refinements in surgical practice, including the development of sutureless and rapid-deployment valves, have enhanced operative efficiency and reduced cross-clamp and cardiopulmonary bypass times, contributing to improved perioperative outcomes (Makkar et al., 2012). These advances have allowed surgery to remain highly competitive even in elderly populations.

Transcatheter aortic valve implantation (TAVI), initially reserved for inoperable or prohibitive-risk patients, has rapidly expanded across all surgical risk categories. Large randomized trials have demonstrated comparable short- and mid-term outcomes compared with SAVR, particularly with respect to recovery time and early morbidity (Webb & Wood, 2012). These findings have reshaped contemporary treatment algorithms and positioned TAVI as a first-line therapy in carefully selected patient groups. Nevertheless, important concerns remain. TAVI is associated with a higher incidence of paravalvular leak and conduction disturbances requiring permanent pacemaker implantation, and durability remains under active investigation (Søndergaard et al., 2017). These considerations are particularly relevant in younger patients with longer life expectancy. Long-term registry data have further highlighted the importance of careful patient selection and procedural planning to optimize outcomes and reduce complications (Tamburino et al., 2015). The multidisciplinary heart team approach therefore remains central to decision-making, integrating clinical characteristics, anatomical suitability, and patient preferences. Ultimately, SAVR and TAVI should not be viewed as competing strategies but as complementary modalities within a patient-centered framework. Ongoing technological innovation and long-term comparative studies will determine the future balance between surgical and transcatheter approaches in the management of aortic valve disease.

CONCLUSION

Aortic valve disease represents a complex and progressive condition that requires a comprehensive and individualized approach to diagnosis and management. Advances in imaging techniques and a deeper understanding of disease mechanisms have significantly improved the timing of intervention and patient selection. Surgical aortic valve replacement (SAVR) remains the gold standard in younger patients and in those with low operative risk, providing excellent long-term durability and clinical outcomes. In parallel, transcatheter aortic valve implantation (TAVI) has transformed the therapeutic landscape, offering a less invasive alternative with favorable early outcomes, particularly in elderly and high-risk populations. The choice between SAVR and TAVI should be guided by a multidisciplinary heart team approach, integrating clinical characteristics, anatomical suitability, procedural risk, and patient preferences. This individualized strategy is essential to optimize outcomes and ensure appropriate treatment selection. Future developments in device technology, imaging, and procedural techniques are expected to further refine treatment strategies and expand therapeutic options. Nevertheless, careful patient selection and long-term follow-up remain essential, particularly in younger populations where durability considerations are of paramount importance.

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MITRAL VALVE DISEASE: CONTEMPORARY SURGICAL STRATEGIES AND EVOLVING TREATMENT CONCEPTS

BURAK YUKSEL[1]

INTRODUCTION

Mitral valve disease constitutes a major component of valvular heart pathology and encompasses a broad spectrum of structural and functional abnormalities affecting the mitral valve apparatus. The most common clinical entities include mitral regurgitation (MR) and mitral stenosis (MS), both of which are associated with substantial morbidity and mortality if left untreated (Otto et al., 2021; Vahanian et al., 2022). Mitral regurgitation is the predominant form of mitral valve disease in developed countries and may be classified as primary (degenerative) or secondary (functional), depending on the underlying etiology. Primary MR is typically caused by intrinsic leaflet abnormalities such as myxomatous degeneration or mitral valve prolapse, whereas secondary MR results from left ventricular remodeling and annular

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dilation in the setting of ischemic or dilated cardiomyopathy (Carpentier, 1983; Dziadzko et al., 2018). In contrast, mitral stenosis is most commonly associated with rheumatic heart disease and remains a significant health problem in developing regions (Vahanian et al., 2022). The pathophysiological consequences of mitral valve disease are primarily driven by chronic volume or pressure overload, leading to progressive left atrial and ventricular remodeling, pulmonary hypertension, and eventual heart failure. Importantly, patients may remain asymptomatic for prolonged periods despite significant hemodynamic impairment, underscoring the critical role of timely diagnosis and imaging-based surveillance (Otto et al., 2021; Carpentier, 1983). Over the past decades, the management of mitral valve disease has undergone substantial evolution. Surgical mitral valve repair has become the preferred treatment strategy for degenerative MR, offering superior long-term outcomes, preservation of left ventricular function, and avoidance of lifelong anticoagulation (Carpentier, 1983; Feldman et al., 2011). When repair is not feasible, mitral valve replacement remains a reliable alternative.

More recently, the development of transcatheter mitral interventions—particularly transcatheter edge-to-edge repair (TEER)—has expanded therapeutic options for patients who are at high or prohibitive surgical risk. These minimally invasive approaches have demonstrated significant improvements in symptoms and quality of life in carefully selected patients (Feldman et al., 2011; Stone et al., 2018). Despite these advances, optimal management of mitral valve disease remains complex and requires careful integration of clinical, anatomical, and procedural factors. The multidisciplinary heart team approach plays a pivotal role in tailoring individualized treatment strategies and optimizing outcomes (Otto et al., 2021; Vahanian et al., 2022; Nishimura et al., 2017).

This chapter aims to provide a comprehensive and clinically relevant overview of mitral valve disease, focusing on pathophysiology, diagnostic evaluation, and contemporary treatment strategies, including both surgical and transcatheter approaches.

PATHOPHYSIOLOGY OF MITRAL VALVE DISEASE

Mitral Regurgitation

Mitral regurgitation (MR) is characterized by the retrograde flow of blood from the left ventricle into the left atrium during systole due to incomplete leaflet coaptation. The underlying mechanisms of MR are diverse and broadly classified into primary (degenerative) and secondary (functional) etiologies. In primary MR, structural abnormalities of the mitral valve apparatus—such as leaflet prolapse, chordal rupture, or myxomatous degeneration—lead directly to valvular incompetence. In contrast, secondary MR arises from geometric and functional alterations of the left ventricle, most commonly in the setting of ischemic or dilated cardiomyopathy, resulting in leaflet tethering and annular dilation without intrinsic leaflet pathology. From a hemodynamic perspective, chronic MR imposes a volume overload on both the left atrium and left ventricle. During systole, a portion of the stroke volume is ejected backward into the left atrium, leading to progressive left atrial enlargement and increased pulmonary venous pressures. In response, the left ventricle undergoes eccentric hypertrophy to accommodate the increased preload while maintaining forward cardiac output. These compensatory mechanisms initially preserve cardiac performance; however, over time, persistent volume overload leads to ventricular remodeling, increased wall stress, and eventual deterioration of systolic function.

As the disease progresses, patients may develop pulmonary hypertension, atrial fibrillation, and symptoms of heart failure. Importantly, a prolonged asymptomatic phase is common, during which left ventricular dysfunction may silently evolve. This underscores the importance of careful longitudinal assessment and timely intervention before irreversible myocardial damage occurs.

Mitral Stenosis

Mitral stenosis (MS) is characterized by obstruction of blood flow from the left atrium to the left ventricle due to narrowing of the mitral valve orifice. The most common cause worldwide remains rheumatic heart disease, which leads to leaflet thickening, commissural fusion, and subvalvular fibrosis. These structural changes result in a progressive reduction in valve area and impaired diastolic filling of the left ventricle. The primary hemodynamic consequence of MS is an increase in left atrial pressure, which is transmitted backward to the pulmonary circulation, leading to pulmonary congestion and, in advanced stages, pulmonary hypertension. Chronic elevation of left atrial pressure also predisposes patients to atrial enlargement and atrial fibrillation, which further exacerbates hemodynamic compromise by reducing diastolic filling time and eliminating atrial contribution to ventricular filling. Over time, sustained pulmonary hypertension may result in right ventricular dysfunction and right-sided heart failure. Unlike MR, where volume overload predominates, MS is primarily a disease of pressure overload affecting the left atrium and pulmonary circulation. Clinical progression is often gradual, but symptoms may worsen abruptly in the presence of tachyarrhythmias or increased hemodynamic demand.

CLINICAL EVALUATION AND IMAGING OF MITRAL VALVE DISEASE

Clinical Assessment

The clinical evaluation of patients with mitral valve disease requires a comprehensive and systematic approach that integrates symptom assessment, physical examination, and risk stratification. Patients with mitral regurgitation or stenosis may present with a wide spectrum of symptoms, ranging from exertional dyspnea and fatigue to palpitations and reduced exercise tolerance. In advanced stages, signs of pulmonary congestion and heart failure may become evident. However, a significant proportion of patients—particularly those with chronic mitral regurgitation—may remain asymptomatic despite progressive structural and functional cardiac changes.

A detailed medical history should focus on symptom onset, progression, and functional capacity, typically assessed using the New York Heart Association (NYHA) classification. The presence of atrial fibrillation, prior cardiovascular events, and associated comorbidities should be carefully evaluated, as these factors significantly influence prognosis and therapeutic decision-making. In elderly patients, frailty assessment has become increasingly important in determining the suitability of surgical or transcatheter interventions. Physical examination may reveal characteristic findings, including a holosystolic murmur at the apex in mitral regurgitation or a diastolic rumble in mitral stenosis. Additional signs such as pulmonary rales, peripheral edema, or jugular venous distention may indicate advanced disease and right-sided heart involvement. Nevertheless, clinical findings alone are insufficient for accurate severity assessment, and imaging plays a central role in diagnosis and management.

Echocardiographic Evaluation

Echocardiography remains the cornerstone of diagnostic evaluation in mitral valve disease, providing detailed anatomical and functional information. Transthoracic echocardiography (TTE) is typically the first-line imaging modality and allows for assessment of valve morphology, severity of regurgitation or stenosis, and left ventricular size and function.

In mitral regurgitation, quantitative parameters such as effective regurgitant orifice area (EROA), regurgitant volume, and regurgitant fraction are essential for grading severity. In addition, evaluation of left ventricular dimensions and ejection fraction is critical for determining the timing of intervention. In mitral stenosis, key parameters include mitral valve area, transmitral gradient, and pulmonary artery pressure, which collectively reflect the hemodynamic burden of the disease.

Transesophageal echocardiography (TEE) provides superior spatial resolution and is particularly valuable in complex cases, such as the assessment of leaflet pathology, detection of thrombus, and pre-procedural planning for both surgical and transcatheter interventions. Furthermore, intraoperative TEE plays a crucial role in guiding surgical repair and evaluating procedural success.

Advanced Imaging Modalities

In addition to echocardiography, advanced imaging techniques play an increasingly important role in the comprehensive evaluation of mitral valve disease. Cardiac magnetic resonance imaging (MRI) offers highly accurate quantification of regurgitant volume and ventricular remodeling, particularly in cases where echocardiographic assessment is inconclusive. It also provides detailed tissue characterization, which may be useful in identifying underlying myocardial pathology.

Computed tomography (CT) has become particularly relevant in the era of transcatheter interventions. It enables precise anatomical assessment of the mitral annulus, leaflet calcification, and surrounding structures, which are critical for procedural planning in transcatheter mitral repair or replacement. Additionally, CT allows evaluation of vascular access and spatial relationships within the heart, facilitating safe and effective device deployment.

Heart Team Evaluation and Decision-Making

Given the complexity of mitral valve disease and the expanding range of therapeutic options, a multidisciplinary heart team approach is essential for optimal patient management. This collaborative model brings together cardiac surgeons, interventional cardiologists, imaging specialists, and anesthesiologists to ensure comprehensive evaluation and individualized treatment planning.

Decision-making should be based on a combination of clinical status, anatomical suitability, procedural risk, and patient preference. Particular attention should be given to identifying patients who may benefit from early intervention, even in the absence of symptoms, in order to prevent irreversible cardiac damage. Conversely, in high-risk or frail patients, less invasive transcatheter therapies may provide a safer and more appropriate alternative.

SURGICAL MANAGEMENT OF MITRAL VALVE DISEASE

Principles of Surgical Management

Surgical intervention remains the cornerstone of treatment in patients with severe mitral valve disease, particularly in those with symptomatic mitral regurgitation or advanced mitral stenosis. The primary goals of surgery are to restore normal valve function, alleviate symptoms, prevent progressive ventricular remodeling, and improve long-term survival. The choice between mitral valve repair and replacement depends on multiple factors, including the underlying pathology, valve anatomy, surgeon expertise, and patient-specific considerations. Over the past decades, mitral valve repair has emerged as the preferred strategy, particularly in degenerative mitral regurgitation, due to its well-documented advantages in terms of survival, preservation of left ventricular function, and avoidance of prosthesis-related complications. Nevertheless, valve replacement remains an essential option in cases where repair is not technically feasible or unlikely to yield durable results.

Mitral Valve Repair (Annuloplasty-Based Techniques)

Mitral valve repair aims to restore native valve competence by correcting leaflet pathology and re-establishing normal annular geometry. Among the various repair techniques, annuloplasty ring implantation represents a fundamental component, providing structural support to the mitral annulus and enhancing leaflet coaptation. As illustrated in Figure 1, annuloplasty involves the placement of a prosthetic ring along the mitral annulus to reduce annular dilation and stabilize the repair. This approach is frequently combined with additional techniques such as leaflet resection, chordal replacement (neochordae), or commissural repair, depending on the specific lesion.

The advantages of mitral valve repair include preservation of the subvalvular apparatus, maintenance of left ventricular geometry, and elimination of the need for lifelong anticoagulation. Furthermore, repair is associated with lower operative mortality and superior long-term outcomes when performed in experienced centers. Consequently, current guidelines strongly recommend repair as the first-line surgical strategy whenever feasible.

Figure 4.Surgical treatment of mitral valve disease

Figure 1: Mitral valve repair using annuloplasty ring implantation to restore annular geometry and improve leaflet coaptation.

Figure 5.Surgical treatment of mitral valve disease

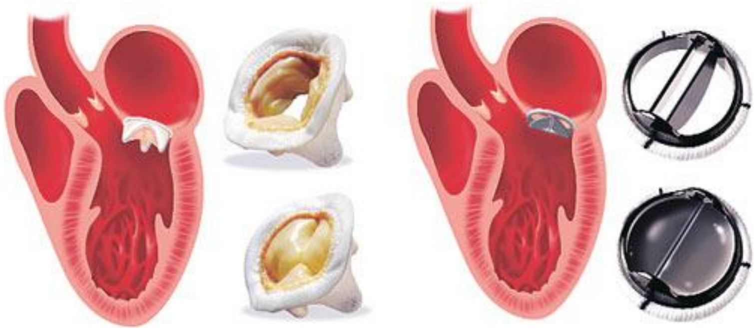

Figure 2: Mitral valve replacement with prosthetic valves, including biological and mechanical valve types.

Mitral Valve Replacement

Mitral valve replacement is indicated when the valve anatomy is not suitable for repair or when repair is unlikely to provide durable results. This includes cases of extensive leaflet calcification, rheumatic disease with severe subvalvular involvement, or failed prior repair. As shown in Figure 2, replacement involves excision of the native valve and implantation of a prosthetic valve, which may be either mechanical or bioprosthetic. Mechanical valves offer excellent durability but require lifelong anticoagulation and carry a risk of thromboembolic and bleeding complications. In contrast, bioprosthetic valves provide a more favorable anticoagulation profile but are subject to structural degeneration over time.

Whenever possible, preservation of the subvalvular apparatus during replacement is recommended, as it plays a critical role in maintaining left ventricular function and improving postoperative outcomes.

Repair versus Replacement: Clinical Decision-Making

The decision between repair and replacement should be individualized and guided by a comprehensive evaluation of valve anatomy, patient characteristics, and institutional expertise. Repair is generally favored in degenerative mitral regurgitation due to its superior outcomes, whereas replacement is more commonly required in rheumatic or complex pathological conditions.

The durability of repair is closely linked to the underlying etiology and surgical technique. In experienced centers, repair rates exceeding 90% can be achieved in degenerative disease, with excellent long-term durability. Conversely, in cases where repair durability is uncertain, replacement may provide a more predictable outcome. Importantly, the choice of surgical strategy should also consider patient age, comorbidities, life expectancy, and the risks associated with anticoagulation. The integration of these factors within a multidisciplinary heart team framework ensures optimal decision-making and patient-centered care.

Outcomes and Contemporary Perspectives

Surgical treatment of mitral valve disease has evolved significantly, with continuous improvements in operative techniques, perioperative care, and patient selection. Mitral valve repair is associated with excellent survival rates, low recurrence of regurgitation, and improved quality of life. On the other hand, mitral valve replacement remains a reliable and effective treatment option in appropriately selected patients. In the current era, the boundary between surgical and transcatheter therapies is increasingly blurred, and hybrid strategies may be considered in selected cases. Nevertheless, surgery continues to play a central role, particularly in patients with favorable anatomy and acceptable operative risk.

DISCUSSION

The management of mitral valve disease has undergone substantial evolution over recent decades, with a clear paradigm shift toward mitral valve repair as the preferred surgical strategy, particularly in patients with degenerative mitral regurgitation. Epidemiological data have highlighted the clinical burden and heterogeneity of severe mitral regurgitation, reinforcing the need for timely and mechanism-based intervention (Mirabel et al., 2007). One of the principal advantages of mitral valve repair lies in its ability to preserve left ventricular geometry and function. Studies evaluating postoperative ventricular remodeling have demonstrated that early surgical correction is associated with significant recovery of left ventricular performance and improved long-term outcomes (Suri et al., 2009). In experienced centers, repair can be performed with high success rates and excellent durability, further supporting its role as the reference standard in suitable patients (David, 2015). Nevertheless, mitral valve replacement remains an essential therapeutic option, particularly in patients with complex or ischemic mitral regurgitation. Randomized data comparing repair and replacement in severe ischemic mitral regurgitation have demonstrated that although repair may be associated with lower early morbidity, recurrence of regurgitation can be higher in certain anatomical settings (Acker et al., 2014). Long-term follow-up studies have further emphasized the importance of patient selection and anatomical considerations when determining the optimal surgical strategy (Goldstein et al., 2016). In parallel with surgical advances, transcatheter mitral interventions have emerged as viable alternatives for selected high-risk patients. The MITRA-FR trial demonstrated that transcatheter edge-to-edge repair did not significantly reduce mortality or hospitalization compared with optimal medical therapy in patients with secondary mitral regurgitation (Obadia et al., 2018). These findings contrasted with other studies and highlighted the complexity of patient selection. Subsequent analyses introduced the concept of proportionate and disproportionate functional mitral regurgitation, suggesting that outcomes of transcatheter therapy are highly dependent on the relationship between regurgitation severity and left ventricular remodeling (Grayburn et al., 2019). This conceptual framework has contributed to a more nuanced understanding of which patients may benefit most from intervention. Overall, contemporary management of mitral valve disease requires a balanced and individualized strategy that integrates surgical expertise, transcatheter innovation, and careful imaging-based assessment. Early diagnosis, mechanism-directed therapy, and appropriate patient selection remain the central determinants of long-term success.

CONCLUSION

Mitral valve disease represents a complex and heterogeneous group of conditions that require a comprehensive and individualized approach to diagnosis and management. Advances in imaging techniques and a deeper understanding of disease mechanisms have significantly improved the timing and selection of therapeutic interventions. Surgical mitral valve repair remains the gold standard for the treatment of degenerative mitral regurgitation, offering superior long-term outcomes, preservation of left ventricular function, and avoidance of prosthesis-related complications. When repair is not feasible, mitral valve replacement provides a reliable and effective alternative, particularly in patients with complex valve pathology. Optimal management depends on careful integration of clinical status, anatomical considerations, and procedural risk. The multidisciplinary heart team approach plays a central role in guiding treatment decisions and ensuring the best possible outcomes. Continued advancements in surgical techniques and perioperative care are expected to further improve durability and patient outcomes. Ultimately, early diagnosis, appropriate patient selection, and timely intervention remain the key determinants of long-term success in the management of mitral valve disease.

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TRICUSPID VALVE DISEASE: CURRENT CONCEPTS AND EMERGING THERAPIES

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INTRODUCTION

Tricuspid valve disease has historically been considered the "forgotten valve" in cardiovascular medicine. For decades, it received considerably less attention compared with left-sided valvular pathologies. However, contemporary guideline updates have emphasized the clinical relevance of moderate-to-severe tricuspid regurgitation (TR) and its impact on long-term outcomes (Vahanian et al., 2022; Otto et al., 2021).

Accumulating observational data have demonstrated that significant TR is independently associated with increased mortality and heart failure hospitalization, even after adjustment for left-sided heart disease and pulmonary hypertension (Nath et al., 2004; Topilsky et al., 2014). The majority of TR cases are functional in

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origin and arise from right ventricular remodeling and annular dilation rather than intrinsic leaflet pathology (Dreyfus et al., 2005).

Progressive annular enlargement, leaflet tethering, and right ventricular dysfunction create a self-perpetuating cycle of regurgitation. Increasing evidence has also supported earlier surgical correction, particularly during concomitant left-sided valve procedures, to prevent irreversible right ventricular remodeling and adverse outcomes (Kim et al., 2009). Advances in multimodality imaging, including comprehensive echocardiographic assessment and three-dimensional visualization of the tricuspid apparatus, have improved diagnostic precision and procedural planning (Hahn et al., 2019). These developments have enhanced risk stratification and facilitated more timely referral for intervention. In parallel, transcatheter tricuspid therapies have emerged as promising alternatives for patients deemed high surgical risk, signaling a paradigm shift in structural heart disease management.

This chapter provides a comprehensive overview of tricuspid valve disease, focusing on pathophysiology, clinical assessment, surgical repair strategies—particularly annuloplasty-based techniques—and emerging transcatheter therapies.

PATHOPHYSIOLOGY OF TRICUSPID VALVE DISEASE

Functional Tricuspid Regurgitation

Tricuspid regurgitation (TR) is predominantly functional in origin and most commonly results from right ventricular (RV) remodeling rather than primary leaflet pathology. Functional TR develops as a consequence of annular dilation and leaflet tethering, typically in the setting of left-sided heart disease, pulmonary hypertension, or chronic atrial fibrillation. Increased pulmonary pressures and left-sided valvular dysfunction lead to progressive right ventricular pressure and volume overload, which in turn promotes right ventricular dilation and geometric distortion. The tricuspid annulus, unlike the fibrous mitral annulus, is more compliant and prone to dilation under chronic hemodynamic stress. Annular enlargement predominantly occurs along the free wall portion of the annulus, resulting in impaired leaflet coaptation. As right ventricular dilation progresses, papillary muscle displacement and leaflet tethering further exacerbate regurgitation. This creates a self-perpetuating cycle in which worsening regurgitation increases right ventricular volume overload, leading to further annular dilation and progressive TR. Importantly, functional TR is not merely a passive bystander condition. Progressive regurgitation leads to chronic right atrial and right ventricular volume overload, eventually resulting in right ventricular systolic dysfunction. As right-sided heart failure develops, systemic venous congestion ensues, manifesting clinically as peripheral edema, ascites, hepatomegaly, and impaired exercise tolerance. In advanced stages, hepatic congestion and cardiorenal interactions may significantly worsen patient prognosis.

Primary Tricuspid Valve Disease

Primary tricuspid valve disease accounts for a smaller proportion of cases and involves intrinsic structural abnormalities of the valve apparatus. Etiologies include infective endocarditis, rheumatic disease, congenital anomalies such as Ebstein anomaly, and traumatic or device-related leaflet injury. In these conditions, regurgitation arises directly from leaflet destruction, perforation, prolapse, or restricted motion. Unlike functional TR, primary disease often presents with localized valvular pathology rather than global right ventricular remodeling. However, chronic severe primary TR ultimately leads to similar hemodynamic consequences, including right atrial dilation, right ventricular enlargement, and progressive right-sided heart failure.

Atrial Functional Tricuspid Regurgitation

An emerging and increasingly recognized entity is atrial functional tricuspid regurgitation. In this scenario, chronic atrial fibrillation and right atrial dilation lead to annular enlargement without significant right ventricular dysfunction or pulmonary hypertension. The pathophysiology is driven primarily by atrial remodeling rather than ventricular distortion. As the tricuspid annulus dilates, leaflet coaptation becomes insufficient, resulting in regurgitation. This distinction is clinically relevant because atrial functional TR may demonstrate different remodeling patterns and potentially more favorable outcomes following annuloplasty-based repair compared with ventricular functional TR.

Hemodynamic and Structural Consequences

The hemodynamic hallmark of chronic TR is right-sided volume overload. During systole, a portion of the right ventricular stroke volume regurgitates into the right atrium, reducing forward pulmonary blood flow. Over time, compensatory mechanisms initially maintain cardiac output; however, chronic volume overload ultimately leads to progressive right ventricular dilation, myocardial fibrosis, and reduced contractile reserve. Right ventricular dysfunction is a critical prognostic determinant in tricuspid valve disease. Once significant RV failure develops, surgical outcomes may be compromised, and postoperative recovery may be incomplete. Therefore, early recognition and timely intervention before irreversible right ventricular remodeling occur are essential components of contemporary management strategies.

CLINICAL EVALUATION AND IMAGING OF TRICUSPID VALVE DISEASE

Clinical Assessment

The clinical evaluation of tricuspid valve disease requires careful and often nuanced assessment, as symptoms typically develop late in the disease course. Patients with significant tricuspid regurgitation may initially remain asymptomatic despite progressive right ventricular remodeling. When symptoms occur, they are usually related to systemic venous congestion rather than pulmonary congestion, distinguishing right-sided from left-sided valvular pathology. Common clinical manifestations include fatigue, reduced exercise tolerance, peripheral edema, abdominal distension due to ascites, and hepatic discomfort resulting from venous congestion. In advanced stages, patients may develop cachexia and features of cardiorenal syndrome. A detailed history should focus on prior left-sided valve disease, pulmonary hypertension, atrial fibrillation, or cardiac device implantation, as these conditions are strongly associated with secondary TR. Physical examination findings may include a holosystolic murmur best heard at the lower left sternal border, which typically increases with inspiration (Carvallo's sign). Jugular venous distention, hepatomegaly, ascites, and peripheral edema are common signs of advanced right-sided heart failure. However, auscultatory findings may be subtle, particularly in cases of low-pressure regurgitation, emphasizing the importance of imaging for accurate diagnosis.

Echocardiographic Evaluation

Echocardiography remains the cornerstone of diagnostic evaluation in tricuspid valve disease. Transthoracic echocardiography (TTE) provides comprehensive information regarding valve morphology, regurgitation severity, right ventricular size and function, and pulmonary pressures.

In the assessment of TR severity, a multiparametric approach is recommended. Key echocardiographic parameters include vena contracta width, effective regurgitant orifice area (EROA), regurgitant volume, hepatic vein flow reversal, and jet area relative to right atrial size. Severe TR is typically characterized by a large vena contracta, significant systolic flow reversal in the hepatic veins, and marked right atrial enlargement. Three-dimensional echocardiography has become increasingly valuable in the evaluation of tricuspid valve anatomy, allowing more accurate assessment of annular dimensions, leaflet morphology, and coaptation gaps. This modality is particularly useful for procedural planning in both surgical and transcatheter interventions.

Right Ventricular Assessment

Assessment of right ventricular function is of paramount importance in tricuspid valve disease, as RV dysfunction is a major determinant of prognosis and surgical outcomes. However, accurate evaluation of the right ventricle remains challenging due to its complex geometry. Standard echocardiographic indices include tricuspid annular plane systolic excursion (TAPSE), tissue Doppler-derived systolic velocity (S′), fractional area change (FAC), and right ventricular longitudinal strain. Reduced TAPSE and impaired RV strain are associated with adverse outcomes and may indicate advanced myocardial remodeling. In selected cases, cardiac magnetic resonance imaging (MRI) provides a more precise quantification of right ventricular volumes and function, particularly when echocardiographic windows are suboptimal. MRI is also useful in evaluating myocardial fibrosis and structural remodeling. Early identification of RV dysfunction is critical, as surgical or transcatheter intervention performed after severe RV failure has developed may yield suboptimal recovery.

Grading and Staging of Tricuspid Regurgitation

The grading of tricuspid regurgitation has evolved beyond the traditional three-tier classification of mild, moderate, and severe. Contemporary approaches recognize the existence of “massive” and “torrential” TR, reflecting the wide spectrum of regurgitant severity observed in advanced disease. These expanded categories better capture the hemodynamic burden and may have implications for therapeutic decision-making. In addition to grading regurgitation severity, staging of disease based on right ventricular remodeling and clinical status has gained increasing attention. The integration of RV size, RV function, pulmonary pressures, and symptom burden allows for a more comprehensive understanding of disease progression. This multidimensional evaluation is essential for determining the optimal timing of intervention. Increasing evidence suggests that delaying treatment until advanced RV dysfunction develops may negatively impact long-term outcomes. Therefore, early recognition of progressive annular dilation and right ventricular remodeling is central to modern management strategies.

SURGICAL MANAGEMENT OF TRICUSPID VALVE DISEASE

Indications for Surgical Intervention

Surgical intervention in tricuspid valve disease is most commonly indicated in patients with severe tricuspid regurgitation, particularly when symptoms of right-sided heart failure are present or when concomitant left-sided valve surgery is planned. Current evidence supports a proactive approach, especially in patients undergoing mitral or aortic valve procedures, as untreated moderate or greater TR may progress and adversely affect long-term outcomes. Importantly, surgical timing is critical. Delayed intervention in the presence of advanced right ventricular dysfunction, severe hepatic congestion, or end-organ damage is associated with increased perioperative risk and reduced postoperative recovery. Therefore, earlier referral for surgical correction—before irreversible RV remodeling occurs—has become an increasingly emphasized principle in contemporary practice.

Tricuspid Valve Repair: Annuloplasty as the Cornerstone

Tricuspid valve repair is the preferred surgical strategy in the majority of cases, particularly in functional TR. The fundamental mechanism underlying functional TR is annular dilation; therefore, annuloplasty-based repair directly addresses the primary pathophysiological driver of regurgitation.

As illustrated in (Figure 1), annuloplasty involves implantation of a prosthetic ring along the tricuspid annulus to reduce annular circumference and restore leaflet coaptation. The ring stabilizes the annulus, corrects its dilated geometry, and prevents further enlargement. By re-establishing appropriate leaflet alignment, regurgitant flow is significantly reduced while preserving the native valve apparatus. Compared with valve replacement, annuloplasty offers several important advantages, including preservation of right ventricular geometry, avoidance of prosthetic-related complications, and improved long-term durability in functional TR. In experienced centers, ring annuloplasty has demonstrated favorable outcomes with low recurrence rates when performed before advanced RV dysfunction develops.

Figure 6. Surgical tricuspid valve repair using annuloplasty ring.

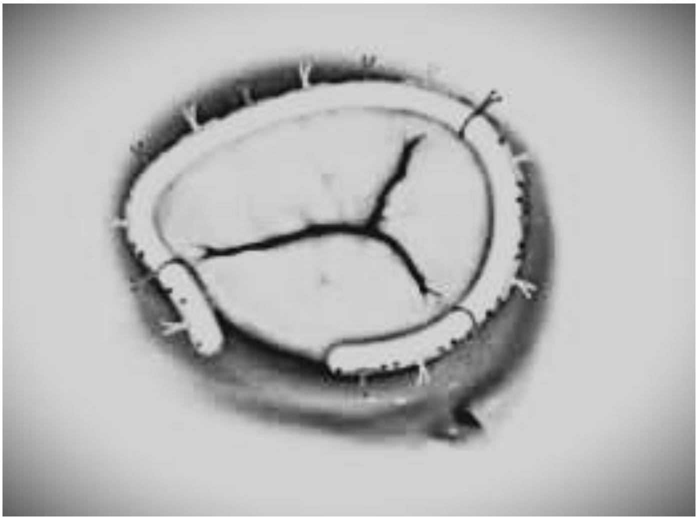

Figure 1: The figure demonstrates ring-based annuloplasty performed to reduce annular dilation and restore leaflet coaptation in functional tricuspid regurgitation.

Types of Annuloplasty Techniques

Annuloplasty techniques may be broadly categorized into suture-based (De Vega) and prosthetic ring annuloplasty. Although suture techniques were historically common, prosthetic ring annuloplasty is now preferred due to superior durability and reduced recurrence of regurgitation. Rigid and semi-rigid rings are designed to restore the physiological three-dimensional geometry of the tricuspid annulus. These devices provide structural support while accommodating dynamic annular motion during the cardiac cycle. In contrast, suture annuloplasty may be associated with progressive annular redilation and higher rates of recurrent TR over time. The choice of ring size and configuration should be guided by intraoperative assessment of annular dimensions and leaflet coaptation. Transesophageal echocardiography plays an important role in evaluating repair adequacy before chest closure.

Tricuspid Valve Replacement

Although repair is generally preferred, tricuspid valve replacement may be necessary in cases of severe primary valve destruction, extensive leaflet tethering, or failed prior repair. Replacement involves excision of the native valve and implantation of a prosthetic valve, typically bioprosthetic due to the lower thrombogenic risk in the low-pressure right-sided circulation. However, tricuspid valve replacement is associated with higher operative risk and potential complications, including prosthetic valve thrombosis and conduction disturbances. Furthermore, preservation of the subvalvular apparatus is particularly important in maintaining right ventricular function, emphasizing the importance of repair whenever feasible.

Surgical Outcomes and Contemporary Considerations

Outcomes following tricuspid valve surgery are strongly influenced by the timing of intervention and preoperative RV function. Early surgical correction during left-sided valve procedures is associated with improved long-term survival and reduced progression of right-sided heart failure. Conversely, isolated late-stage tricuspid surgery in patients with severe RV dysfunction carries higher perioperative mortality and less favorable recovery. In contemporary practice, annuloplasty-based repair has become the cornerstone of surgical management in functional TR. Increasing recognition of the prognostic impact of untreated TR has led to a paradigm shift toward earlier intervention and more aggressive correction during concomitant cardiac surgery. Surgical treatment of tricuspid valve disease should therefore be considered within the broader framework of right ventricular preservation and multidisciplinary heart team evaluation.

EMERGING THERAPIES IN TRICUSPID VALVE DISEASE

Transcatheter Edge-to-Edge Repair (TEER)

Transcatheter edge-to-edge repair (TEER) has emerged as the most established transcatheter therapy for tricuspid regurgitation, largely adapted from experience gained in mitral valve interventions. The procedure involves approximation of the tricuspid leaflets using a clip-based system, thereby enhancing leaflet coaptation and reducing regurgitant flow. TEER is particularly attractive in patients with symptomatic severe TR who are considered high or prohibitive surgical risk due to advanced age, comorbidities, or right ventricular dysfunction. Early clinical studies have demonstrated significant reductions in TR severity, improvements in functional status, and enhanced quality of life following transcatheter repair. Importantly, the procedure can be performed via transfemoral venous access under echocardiographic and fluoroscopic guidance, avoiding the need for sternotomy or cardiopulmonary bypass. However, procedural success is highly dependent on anatomical suitability. Adequate leaflet tissue, limited coaptation gap, and favorable annular geometry are critical determinants of effective clip implantation. Severe tethering or extensive annular dilation may limit the feasibility of TEER, underscoring the importance of meticulous preprocedural imaging assessment.

Transcatheter Annuloplasty Systems

In addition to leaflet-based repair, transcatheter annuloplasty devices have been developed to address annular dilation, the primary mechanism of functional TR. These systems aim to replicate the surgical principle of ring annuloplasty by reducing annular circumference and restoring leaflet coaptation. Various device platforms utilize direct annular remodeling or indirect coronary sinus–based approaches. Early clinical experiences suggest that transcatheter annuloplasty can achieve meaningful reductions in annular dimensions and TR severity, particularly in patients with preserved leaflet mobility. As with surgical annuloplasty, timing appears critical, with better outcomes observed before advanced right ventricular dysfunction develops. Although long-term durability data remain limited, transcatheter annuloplasty represents a promising strategy that directly targets the underlying pathophysiology of functional TR.

Caval Valve Implantation (CAVI)

Caval valve implantation (CAVI) represents a distinct therapeutic concept that does not directly repair the tricuspid valve itself. Instead, bioprosthetic valves are implanted within the inferior and/or superior vena cava to prevent retrograde venous flow and alleviate symptoms of systemic congestion.

CAVI is generally considered a palliative option for patients with advanced, inoperable TR and severe right-sided heart failure. By reducing venous backflow, the procedure may improve symptoms such as ascites and peripheral edema, even though the regurgitant lesion at the tricuspid valve level remains unchanged. While early feasibility studies have demonstrated symptomatic improvement, the long-term hemodynamic consequences and durability of CAVI require further investigation. Patient selection is therefore crucial, and this strategy is typically reserved for individuals with limited surgical or transcatheter repair options.

Transcatheter Tricuspid Valve Replacement

Transcatheter tricuspid valve replacement (TTVR) is an evolving field that aims to provide complete elimination of regurgitation through implantation of a prosthetic valve within the native tricuspid annulus. Several dedicated device systems are currently under clinical investigation. The complex anatomy of the tricuspid valve—including its large annular size, non-circular geometry, proximity to the conduction system, and interaction with the right ventricle—poses significant technical challenges. Nevertheless, early experiences have demonstrated promising reductions in TR severity and symptomatic improvement. As device technology advances and procedural techniques are refined, TTVR may become a viable alternative for patients unsuitable for repair-based strategies. However, long-term outcome data remain limited, and further clinical trials are necessary to define its role in routine practice.

Future Perspectives and Integration into Clinical Practice

The emergence of transcatheter therapies has fundamentally reshaped the therapeutic landscape of tricuspid valve disease. What was once considered a surgically neglected pathology is now an active field of innovation within structural heart interventions. A key challenge moving forward will be the identification of optimal timing for intervention. Increasing evidence suggests that earlier treatment—before the development of severe right ventricular dysfunction—may improve outcomes. Integration of advanced imaging, multimodality assessment, and multidisciplinary heart team evaluation will be essential in selecting appropriate candidates for these evolving therapies.

As clinical experience expands and long-term data become available, transcatheter tricuspid therapies are expected to complement surgical strategies rather than replace them. The future of tricuspid valve management will likely involve a tailored, patient-centered approach that integrates surgical repair, transcatheter repair, and replacement options according to individual anatomical and clinical profiles.

DISCUSSION

The management of tricuspid valve disease has evolved substantially over the past decade. Improved imaging techniques and contemporary grading schemes have refined the assessment of tricuspid regurgitation severity and facilitated more accurate timing of intervention (Zoghbi et al., 2017). Registry data have further strengthened the recognition that significant TR is not a benign condition but carries important prognostic implications (Taramasso et al., 2019). Surgical annuloplasty remains the cornerstone of treatment in functional TR. Ring-based repair directly addresses annular dilation and has demonstrated favorable long-term durability when performed before advanced right ventricular dysfunction develops (Lurz et al., 2021). Delayed surgical referral in patients with severe right ventricular failure has been associated with increased perioperative mortality and reduced postoperative recovery (Nickenig et al., 2019).

The emergence of transcatheter therapies has significantly expanded therapeutic options. Early experiences with transcatheter edge-to-edge repair (TEER) have shown reductions in TR severity and improvements in functional status and quality of life in carefully selected high-risk populations (Lauten et al., 2018). In addition, expanded grading systems, including the recognition of massive and torrential TR, have improved patient stratification and procedural planning (Hahn & Zamorano, 2017).

Caval valve implantation (CAVI) has been explored as a palliative strategy in patients with advanced, inoperable TR, aiming to alleviate systemic venous congestion rather than directly correcting the valvular lesion (Kodali et al., 2022). Meanwhile, transcatheter tricuspid valve replacement (TTVR) is emerging as a promising alternative for patients unsuitable for repair-based approaches, although long-term durability data remain limited (Prihadi et al., 2019).

Overall, the management of tricuspid valve disease is shifting from late-stage intervention to earlier and more individualized strategies. Multimodality imaging and heart team collaboration are essential in determining optimal timing and selecting the most appropriate surgical or transcatheter approach. Continued technological advancements and prospective clinical trials will be critical in refining therapeutic algorithms and improving long-term outcomes.

CONCLUSION

Tricuspid valve disease, once regarded as a secondary and often neglected condition, is now recognized as a clinically significant pathology with substantial prognostic implications. Progressive tricuspid regurgitation contributes to right ventricular remodeling, systemic venous congestion, and impaired functional capacity, underscoring the importance of timely diagnosis and intervention.

Annuloplasty-based surgical repair remains the cornerstone of treatment for functional tricuspid regurgitation, particularly when performed before advanced right ventricular dysfunction develops. Early correction during left-sided valve surgery has demonstrated favorable long-term outcomes and reduced progression of right-sided heart failure. The emergence of transcatheter therapies—including edge-to-edge repair, annuloplasty systems, and evolving replacement strategies—has expanded treatment options for patients previously considered inoperable or at high surgical risk. These innovations represent a significant advancement in structural heart disease management and are reshaping therapeutic algorithms. Optimal management of tricuspid valve disease requires a patient-centered, multidisciplinary heart team approach integrating clinical assessment, multimodality imaging, and individualized risk stratification. Future research and technological developments are expected to further refine intervention timing, improve procedural durability, and enhance long-term outcomes.

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