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TRANSCATHETER VS SURGICAL AORTIC VALVE REPLACEMENT: A COMPREHENSIVE REVIEW OF INDICATIONS AND OUTCOMES

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Abstract
Aortic stenosis is a progressive valvular disorder associated with significant morbidity and mortality if left untreated. Surgical aortic valve replacement (SAVR) has long been the standard therapy; however, the emergence and rapid evolution of transcatheter aortic valve replacement (TAVR) have transformed the management of this condition across a broad spectrum of patient risk profiles. This comprehensive review synthesizes current evidence comparing TAVR and SAVR with respect to clinical indications, procedural approaches, and patient outcomes. Major biomedical databases were reviewed to identify randomized trials, observational studies, registry data, and international guideline recommendations relevant to aortic valve replacement. Outcomes assessed include mortality, major adverse cardiovascular and cerebrovascular events, procedural and valve-related complications, durability, quality of life, and health system implications. Available evidence demonstrates that both TAVR and SAVR offer substantial survival and symptomatic benefit when appropriately applied, with TAVR providing advantages in early recovery and functional improvement, and SAVR maintaining an important role in younger patients and those requiring durable long-term solutions. Persistent uncertainties regarding valve durability, lifetime management strategies, and optimal patient selection particularly in low-risk populations remain key challenges. An individualized, multidisciplinary heart team approach integrating patient characteristics, anatomical considerations, and long-term goals is essential to optimizing outcomes as aortic valve replacement strategies continue to evolve.

Keywords: aortic stenosis, transcatheter aortic valve replacement, surgical aortic valve replacement, clinical outcomes, valve durability

1.Introduction

Aortic stenosis (AS) is the most prevalent valvular heart disease in developed countries and represents a growing global health burden due to population aging and increased life expectancy. The epidemiological study reveals that the prevalence rates of degenerative calcific AS in older adults, particularly individuals over 65 years, are growing serious with an ominous implication on the incidence of morbidity and mortality and consumption of the healthcare resources (Thaden et al., 2014). Recent research also refers to the fact that the untreated severe AS is associated with high mortality and is used to underline the need to diagnose it as quickly as possible and treat (Genereux et al., 2023).

A long period of often asymptomatic nature characterized by natural history of AS is marked by a sudden and swift clinical course as the patient advances to such symptoms as angina, syncope or heart

failure. As it has been observed, in some cases, the moderate to severe disease progression is accompanied by the exacerbation of hemodynamic impairment and negative cardiovascular effects, which precede the onset of any symptoms (Du et al., 2021). Symptomatic severe AS has a poor prognosis, and survival rates are far lower than without definite valve replacement, which strengthens valve intervention as the main tool in the management of this condition (Genereux et al., 2022).

Surgical aortic valve replacement (SAVR) has long been considered the treatment of severe symptomatic AS, which offers permanent hemodynamic and survival advantage. Nevertheless, during the last 20 years transcatheter aortic valve replacement (TAVR) has developed as an offer to change the world, as technological progress has promoted its uptake and a growing clinical experience supports its use. Initially used in patients who are considered either inoperable or at high risk of surgery, TAVR has been increasingly considered and implemented with intermediate- and low-risk patients, facilitated by advances in valve design, delivery tools, and safety during the procedure (Coccia, 2021).

With the constant expansion of indications of TAVR, various randomized trials, observational studies, and meta-analyses have compared both TAVR and SAVR to each other in terms of different risk categories of surgical patients (Arora et al., 2016). There is evidence that TAVR has similar and across some outcomes beneficial short- and mid-term outcomes in low- and intermediate-risk cohorts, as well as less early mortality and accelerated recovery, but raises significant concerns about valve lifespan and outcomes (Virtanen et al., 2019; Latib et al., 2012; Arora et al., 2016). Moreover, the economic analyses have included the disparities in the cost of the process and the usage of the downstream resources in the two techniques (Osnabrugge et al., 2012).

Due to the growing body of therapy, changing guideline recommendations, and still debated best patient selection, a thorough and balanced comparison of the use of transcatheter and surgical aortic valves replacement should be made. The objective of the review is to critically summarize the existing evidence on indications, clinical outcomes, and important considerations related to TAVR and SAVR with the aim of supporting evidence-based decision-making by individual patients with AS.

Objectives of this study

1. To compare the clinical indications for transcatheter and surgical aortic valve replacement in patients with aortic stenosis
2. To evaluate and contrast clinical outcomes associated with TAVR and SAVR, including mortality, complications, and valve-related performance
3. To highlight key considerations influencing treatment selection and future directions in aortic valve replacement

2.Methodology

A structured literature review was conducted using major biomedical databases including PubMed, Embase, Scopus, and the Cochrane Library to identify relevant studies comparing transcatheter and SAVR. Randomized controlled trials, observational studies, large registry analyses, meta-analyses, and international clinical guidelines evaluating indications and outcomes in adult patients with AS were included. Key outcomes assessed included mortality, procedural complications, valve-related outcomes, quality of life, and durability. Data were synthesized qualitatively due to heterogeneity in study design and outcome definitions. Greater interpretive weight was given to high-quality trials and large multicenter studies. Methodological limitations were acknowledged to ensure balanced interpretation of the evidence (Figure 1).

Figure 1: Workflow of Literature Selection, Appraisal, and Thematic Synthesis

Pathophysiology of Aortic Stenosis

AS is a progressive valvular disorder most commonly caused by degenerative calcification of the aortic valve in older adults, with additional etiologies including congenital bicuspid valves and rheumatic heart disease. Active inflammation, lipid deposition, fibrosis, and calcification are the disease processes that result in progressive thickening of the leaflet and decrease the mobility of the valve (Akahori et al., 2018; Joseph et al., 2017). Valvular obstruction increases, and initially the cardiac output is maintained by means of compensatory mechanisms, but with further development of the disease, the compensatory mechanisms eventually lead to the symptomatic deterioration and poor clinical outcomes (Shah et al., 2023).

Chronic overload of left ventricular pressure characterizes the hemodynamic feature of AS and results in concentric hypertrophy to sustain systolic performance. Although it is in the beginning adaptive, chronic pressure overload results in diastolic dysfunction, myocardial fibrosis, poor coronary perfusion, and cardiac reserve. When the size of valve orifice areas is reduced slightly, it can create substantial changes in transvalvular pressure gradients and significantly change the ventricular workload and systemic hemodynamics (May et al., 1963). These alterations add up to cardiac failure symptoms and risk during perioperative.

AS risk stratification is not limited to the severity of the valves but rather the magnitude of myocardial and extracardiac damage. Modern evidence proves that progressive cardiac damage, which encompasses the left ventricle, atrium, pulmonary circulation, and the right ventricle-has a high prognostic effect and affects the outcome after valve replacement (Generex et al., 2022). Improved imaging approaches and new evaluation methods contribute to risk analysis, which enhances previous and more personalized intervention to patients who undergo transcatheter or SAVR (Shah et al., 2023).

3.Evolution of Aortic Valve Replacement

3.1 Surgical Aortic Valve Replacement (SAVR)

Severe symptomatic AS has been treated by SAVR over the last several decades, and it provides long-term elemental recovery and persistence of life. Initial procedures used in surgery were based on open sternotomy and cardiopulmonary bypass, which, despite its high effectiveness, were accompanied by a significant morbidity in the course of the operation in the patients. With time, improvements in performing operative procedures, myocardial protection measures, and perioperative support have become a crucial factor in surgical success, making it possible to perform SAVR in a large variety of patients (Siontis et al., 2016).

Modern SAVR involves the use of various types of valve prostheses, mechanical and bioprosthetic, which are determined depending on the age of the patient, comorbid conditions, and potential expectations of future durability. Mechanical valves are durable over the long term, but require additional life-long anticoagulation, but bioprosthetic valves do not require permanent anticoagulation at the cost of short life. Surgical intervention Surgical intervention Surgical

intervention can be further optimized with the developments of minimally invasive surgical methods and redo-strategies of the valve, but the repeat operation is still linked with a higher risk of the surgical process in comparison with the primary operation (Sá et al., 2021).

3.2 Transcatheter Aortic Valve Replacement (TAVR)

TAVR is an example of a paradigm shift in the treatment of patients with AS, which was, at first, proposed as a less invasive treatment option in patients who are considered inoperable or have prohibitive surgical risks (Schymik et al., 2015). The faster change in technology, increased delivery systems and greater experience of the operators have resulted in increased indications and increased procedural safety. Randomized trials and meta-analytic studies have shown similar and in selected populations better results of TAVR compared to SAVR especially in the initial mortality and recovery (Siontis et al., 2016).

The modern TAVR platforms have enhanced designs of valves that are lower in profile, have better sealing systems, and can be resettled to minimize complication like paravalvular leak and conduction disturbances. These inventions have enabled wider usage of transfemoral entry and enhanced results in intermediate and low risk populations. Moreover, valve-in-valve TAVR has become an effective solution to redo SAVR in patients who had degenerated surgical bioprostheses, and it provides good short-term outcomes and low procedural morbidity (Sá et al., 2021; Avvedimento and Tang, 2021).

Table 2. Comparison of Guideline Recommendations for TAVR and SAVR

Parameter	ACC/AHA	ESC/EACTS
Age	TAVR favored in older patients; SAVR in younger patients	TAVR ≥75 years; SAVR <75 years
Surgical Risk	TAVR for high risk; appropriate for selected low risk	TAVR for high risk; SAVR for low risk
Life Expectancy	SAVR preferred with long life expectancy	Strong preference for SAVR with long life expectancy
Anatomy	TAVR for favorable anatomy; SAVR for complex anatomy	Emphasizes anatomy and future coronary access
Heart Team	Mandatory	Mandatory

Abbreviations: TAVR: transcatheter aortic valve replacement, SAVR: surgical aortic valve replacement.

Source: Lee et al., 2023.

4.Current Guidelines and Indications

The existing global recommendations focus on the personalized decision-making process in treating severe AS. According to the American College of Cardiology/ American Heart Association (ACC/AHA) guidelines, TAVR should be used in the patient with high or prohibitive surgical risk and also in intermediate and selected low-risk patients, especially in older patients with good anatomical features (Figure 2). SAVR is still the instrument of choice when a patient is still younger with longer lifespan and when he requires other cardiac surgeries, which demonstrates the concerns of valve longevity and survival (Lee et al., 2023).

The guidelines of the European Society of Cardiology/European Association to the cardio-thoracic Surgery (ESC/EACTS), in contrast, are more age-based with a general preference of TAVR in elderly patients and SAVR in younger patients with low surgical risks. Guideline frameworks include both surgical risk assessment, life expectancy and thorough anatomical assessment including: vascular access, valve morphology, annulus size, and coronary anatomy in treatment choice. Although the aspects vary, both of the guidelines firmly support the idea of a multidisciplinary heart team approach that would be most effective in the event of patient-centered, evidence-based decision-making in aortic valve replacement (Bakris et al., 2019; Lee et al., 2023).

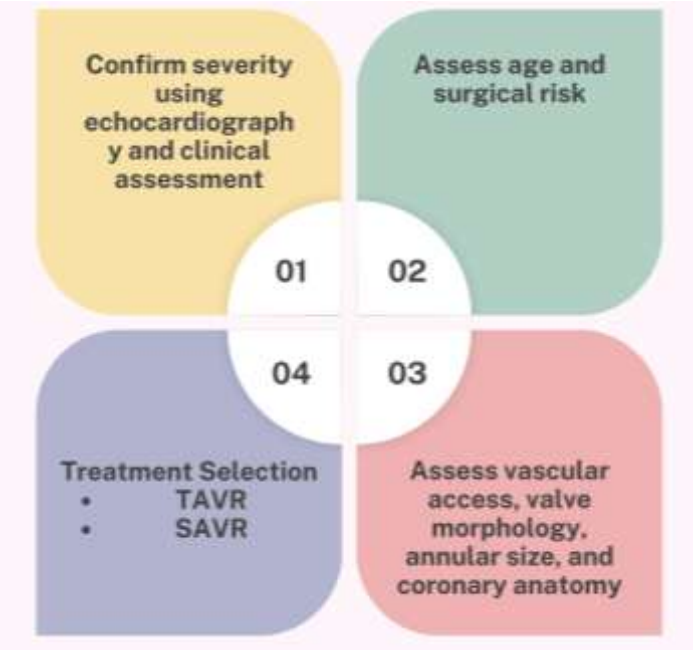

Figure 2: Decision Algorithm for Transcatheter and Surgical Aortic Valve Replacement

5.Patient Selection and Heart Team Approach

Management of AS best depends on a multidisciplinary heart team approach that will combine the skills of interventional cardiology, cardiac surgery, imaging, anesthesiology, and other concerned healthcare experts. This participatory model will enable in-depth assessment of patients, a mix of clinical risk, anatomical appropriateness, and patient preferences, to decide on the best intervention. It has been demonstrated that heart team framework enhances clinical decision-making, procedural planning, and outcomes, especially in complex or high-risk cases being subjected to TAVR (Sintek & Zajarias, 2014; Morton et al., 2018).

Risk stratification is an important element of the patient selective procedure and includes validated surgical risk assessments, including the Society of Thoracic Surgeons (STS) score and the European System of Cardiac Operative Risk Evaluation II (EuroSCORE II). Although these tools give standardized predictions of perioperative mortality, they fail to exhaust factors like frailty, cognitive functioning and functional status that are gaining prominence in determining outcomes. Therefore, frailty evaluation and shared decision-making should be considered to distribute treatment options according to patient objectives and anticipated quality of life (Gao et al., 2021; Sintek and Zajarias, 2014).

6. Procedural Approaches and Techniques

6.1 Transcatheter Aortic Valve Replacement Approaches

Transfemoral route is the preferred access to TAVR because it is minimum invasive, and, it is linked with better procedural outcomes. Nevertheless, other forms of access such as transaxillary, transcarotid, transapical, and transcaval assumes are used in patients with poor iliofemoral anatomy. New imaging, device descriptions, and approaches to the procedure have increased the possibility and safety of alternative approaches to access, allowing procedural planning and a broader range of patient eligibility (Young et al., 2018; Abdelnour et al., 2024; Lutz et al., 2024).

6.2 Surgical Aortic Valve Replacement Techniques

Traditionally SAV replacement is done through median sternotomy and this gives a great exposure and long-term results. Minimally invasive procedures of surgery like partial sternotomy, right anterior thoracotomy- have been designed in the selected patients to minimize surgical trauma, shorten patient recovery time, and enhance the aesthetic effects without losing the effectiveness of the procedures. Individualized surgical planning is emphasized by the necessity of surgical planning on a patient-by-

patient basis depending on patient anatomy, comorbidities, and the requirement of concomitant cardiac surgery as a part of the heart team plan (Sintek & Zajarias, 2014).

Table 3. Procedural Characteristics of Transcatheter and Surgical Aortic Valve Replacement

Characteristic	TAVR	SAVR
Access Route	Transfemoral (preferred); alternative access routes	Median sternotomy or minimally invasive approach
Anesthesia	Local anesthesia or general anesthesia	General anesthesia
Procedure Duration	Shorter	Longer
Cardiopulmonary Bypass	Not required	Required
Typical Hospital Stay	Shorter	Longer

Source: Adapted from Siontis et al. (2016) and Avvedimento & Tang (2021).

7.Comparative Clinical Outcomes

Transcatheter and SAVR have shown comparatively similar patient outcomes in terms of mortality over the short, intermediate, and long-term follow-up when properly matched patient cohorts are involved. The differences in baseline cardiovascular risk and comorbid burden are thought to affect long-term outcomes because early survival benefits have been found to depend on less invasive approaches due to the reduction in procedural stress and a more rapid recovery. Major adverse cardiovascular and cerebrovascular events (MACCE), such as myocardial infarction and stroke are important prognosis outcomes of valve replacement since perioperative cardiovascular instability and cerebral events are important contributors of survival and functional recovery (Smilowitz et al., 2017).

Complications related to the procedures and valves vary between the transcatheter and surgical methods, and they add to the heterogeneity of outcomes. Blood loss and acute renal failure are more commonly linked to the surgical procedure that indicates the invasivity of the cardiopulmonary bypass than transcatheter procedures because of the location of the valves and closeness to the conduction system. The impact of cerebrovascular vulnerability also increases the outcomes, as patients with neurological injury are more susceptible to the future occurrence of cardiovascular events, underlining the interdependence of the systemic risk and the events of the procedure (Nyam et al., 2019).

8.Valve Durability and Structural Valve Degeneration

Structural valve degeneration (SVD) is described as the inherent degeneration of bioprosthetic valve functioning causing stenosis, regurgitation or both which is a crucial drawback of bioprosthetic valve replacement of the aorta (Figure 3). Mechanically, the calcification is not only the cause of SVD but also the noncalcific mechanisms like the presence of fibrosis in the leaves, collagen destabilization, and immune-induced tissue remodeling that might lead to the deterioration of the valves over time (Marro et al., 2021). These degenerative mechanisms impact surgical and transcatheter bioprosthetic valves and are predetermined by the age of the patient, metabolic processes, hemodynamic stress, and valve design (Rodriguez-Gabella et al., 2017).

The existing long-term durability data indicate that modern surgical bioprostheses show a decent performance after 10 years in older populations, but long-term performance of transcatheter valves remains to be under development. There are no studies with available evidence on similar mid-term durability between TAVR and SAVR in the chosen populations, but there are still worries about the durability of transcatheter valves in younger patients with increased life expectancy (Rodriguez-Gabella et al., 2017). The overall results of valve replacement include functional status and quality-of-life, which are usually positive with both options, and transcatheter strategies tend to have more immediate increase in functional status, whereas long-term functional outcomes are mostly similar (Arnold et al., 2017; Duffy et al., 2023).

Valve-in-valve surgery has become a significant management technique of failed bioprosthetic valves especially in patients who are at high risk of surgery. Transcatheter valve-in-valve valve implantation is an alternative approach to redo surgery at the expense of less invasive procedures, satisfactory hemodynamic functionality, and symptomatic improvement. However, such challenges as patientprosthesis mismatch, coronary obstruction, and cumulative durability should be thought over, particularly in young patients who may need several interventions during their lives (Rodriguez-Gabella et al., 2017). Therefore, the factor of durability is of primary importance in lifetime valve management and stresses the significance of personalized treatment choice.

Figure 3: Progression and Management Pathway of Structural Valve Degeneration

9.Quality of Life and Functional Outcomes

Functional status and health-related quality of life (HRQoL) is one of the most important therapeutic targets of aortic valve replacement. Both transcatheter and surgical techniques have revealed the generation of significant modifications in both the functional class and functional capacity of the New York Heart Association (NYHA). Registry-based studies and systematic reviews demonstrate that the use of transcatheter-aortic-valve-replacement is associated with a high and instantaneous response to physical activities and HRQoL in elderly and high-risk patients (Straiton et al., 2018). Baseline hemodynamic burden and vascular load are determinants of functional recovery that can be used to enhance exercise tolerance and long quality of life (Nuis et al., 2020). There has also been a significant change in favor of SAVR in the elderly in terms of physical performance, cognitive performance, and HRQoL, which means that it can be sustained to be used in properly selected individuals (De Rui et al., 2022).

10. Economic and Health System Considerations

The economic and health system implications in the treatment decision of AS have higher importance today. Procedural invasiveness, recovery time, and complication profiles also vary impacting the length of stay in hospitals, rehospitalization, and the general resource consumption. Transcatheter approaches that are less invasive have been linked to reduced length of hospital stay and earlier discharge to functional independence that can compensate high initial expenditures on devices in specific groups. Surgical methods, in turn, can be cost-effective in younger patients because of valve longevity, and, therefore, value-based decision-making is required in modern healthcare settings on a patient-specific level.

Table 8. Economic and Health System Considerations of TAVR and SAVR

Parameter	**TAVR**	**SAVR**
Procedure Cost	Higher upfront device cost	Lower initial procedure cost
Length of Hospital Stay	Shorter	Longer
ICU Utilization	Reduced or none	Routine ICU requirement

Cost-Effectiveness Trend	More cost-effective in elderly/high-risk patients	More cost-effective in younger/low-risk patients

Source: Adapted from Osnabrugge et al. (2012) and Duffy et al. (2023

11. Limitations, Future Directions, and Clinical Implications

Although major progress has been made in aortic valve replacement, there are critical constraints and unresolved controversies, especially on the unavailability of long-term comparative data, concerns on durability in younger and low-risk groups, and the variation in outcomes based on the experience of operators and centers. Such uncertainties make the lifetime decisions of valve management difficult and highlight the importance of expansion of the transcatheter therapies beyond the traditional risk groups with caution. The future directions consist of the creation of the next-generation technologies of valves and their durability, hemodynamic performance, with the incorporation of cerebral embolic protection and reduction of the neurological complications, and personalized valve therapy based on the specifics of the patient. The gaps in the evidence are also likely to be closed in the course of the ongoing clinical trials that are expected to optimize the choice of patients. A multidisciplinary heart team is clinically important, based on the evidence-based approach, which focuses on an individual choice of treatment, systematic decision-making algorithms, and a lifetime management approach to achieve the best results in patients with AS.

12. Conclusion

The contemporary management of AS reflects a dynamic and evolving interplay between transcatheter and SAVR, each offering distinct advantages when applied to appropriately selected patients. The effectiveness of TAVR and SAVR to enhance survival, functional status and quality of life has been accumulated with growing evidence that results of the two procedures are more dependent on patient factors, anatomy and skillful practice than the modality of treatment. The transcatheter methods are growing at a very fast rate because they are minimally invasive, have good early results and are applicable in the older and more risky population, whereas surgery replacement continues to be part of the younger ones, those with higher life expectancy, the valve anatomy is complicated and or they require other cardiac surgeries. However, the doubts concerning long-term durability of the valve, their lifetime management, and the most effective order in which the interventions should be performed, especially in low-risk and younger groups, still influence the clinical decision-making. New technology of the valve, techniques of the procedure as well as adjunctive therapy is likely to overcome much of these issues yet the effective adoption of these innovative techniques will be pegged on strong evidence over long term and close selection of the patients. Finally, a personalized, evidence-based practice with a multidisciplinary heart team and in line with the preferences of the patient is the necessary approach to achieving the maximum. Since innovation keeps recreating the discipline, the balanced focus on durability, safety, and long-term value would be essential in providing high-quality, patient-centered care in the field of aortic valve disease.

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