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Review Article

Contemporary surgical management of aortic valve disease: From replacement to reconstruction

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Abstract

Aortic valve pathology remains one of the most common causes of cardiovascular morbidity and mortality. Our current understanding of aortic valve disease has changed significantly in recent decades due to advances in imaging techniques, refinements in surgical technologies, and the emergence of reconstructive and transcatheter approaches. Currently, aortic valve treatment encompasses a wide range of interventions, from classic valve replacement to reconstructive surgery, valve-sparing procedures, the Ross procedure, aortic neocuspidization (AVNeo/Ozaki procedure), and transcatheter valve implantation (TAVI). The modern concept of the aortic valve considers it to be part of a functional aortic complex, including the leaflets, annulus fibrosus, commissures, sinuses of Valsalva, sinotubular junction, and ascending aorta. The development of repair-oriented surgery has significantly expanded the possibilities for preserving the native valve, especially in young patients and those with a bicuspid aortic valve. Of particular importance are issues of intervention durability, lifetime management, prevention of prosthesis-patient mismatch, and individualized treatment strategy. This review presents current data on the anatomy, pathophysiology, imaging, and surgical treatment of aortic valve disease, with a particular emphasis on reconstructive surgery, bicuspid aortic valve surgery, AVNeo, valve-sparing procedures, and modern transcatheter technologies.

Keywords: Aortic valve pathology, aortic valve surgery, aortic valve repair, aortic valve reconstruction, aortic valve neocuspidization

INTRODUCTION

Aortic valve pathology is one of the most actual issues in modern cardiology and cardiac surgery. As the population ages and diagnostic technologies improve, the prevalence of degenerative aortic valve disease significantly increases. For decades, mechanical or biological valve replacement remained the standard treatment for severe aortic valve disease. However, despite the excellent durability of mechanical valve replacements, the need for lifelong anticoagulation, the risk of bleeding, thromboembolic complications, and prosthetic endocarditis significantly limit their use in young and active patients. Biological valve replacements avoid anticoagulation, but their durability is limited by structural valve degeneration, especially in young patients (1,2).

In recent years, aortic valve surgery has undergone a fundamental transformation. Modern strategies increasingly focus not only on valve replacement, but also on restoration of physiological valve function, preservation of native structures, and individualized lifetime management (3). The development of reconstructive surgery, valve-sparing procedures on the aortic root, the Ross procedure, and aortic neocuspidization (AVNeo, Ozaki) have significantly expanded treatment options for young patients (4). At the same time, transcatheter aortic valve implantation (TAVI) has become one of the most significant advances in modern structural cardiology (5).

Thus, modern treatment of aortic valve disease requires a comprehensive approach, including a functional assessment of valve anatomy, an analysis of the longevity of various strategies, and individualized lifetime management planning.

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Search Strategy and Selection Criteria

This article is a narrative review of the contemporary surgical management of aortic valve disease. A structured literature search was performed in PubMed/MEDLINE, Embase, and the Cochrane Library for English-language full-text articles, systematic reviews, registry reports, and contemporary practice guidelines published between January 2000 and March 2026. Selection prioritised (i) contemporary randomised trials and large registries reporting long-term outcomes (≥5 years), (ii) guidelines from major cardiovascular societies, (iii) high-volume single-centre series of reconstructive techniques, and (iv) systematic reviews and meta-analyses where available.

Functional Anatomy of the Aortic Valve

To understand the different mechanisms of aortic valve pathologies, modern aortic valve surgery is based on the concept of understanding the aortic valve as a "complex entity" composed of three structures: (1) the functional aortic annulus (FAA), comprising of the ventriculo-aortic junction (VAJ) and the sino-tubular junction (STJ); (2) the leaflets with their attachment; and (3) the three sinuses of Valsalva (6) (Figure 1).

The VAJ is composed in approximately half of its circumference of a fibrous portion and in the other half of a muscular portion. The fibrous portion is posterior and right sided, is located beneath the non-coronary sinus and half of the left coronary sinus. The muscular portion, anterior and left sided, and located under the right coronary sinus and half of the left coronary sinus (6). The superior border of the sinuses is the sinutubular junction, also known as the supra-aortic ridge. The sinutubular junction does not have a perfect circular shape as it takes the contours of the three sinuses (7).

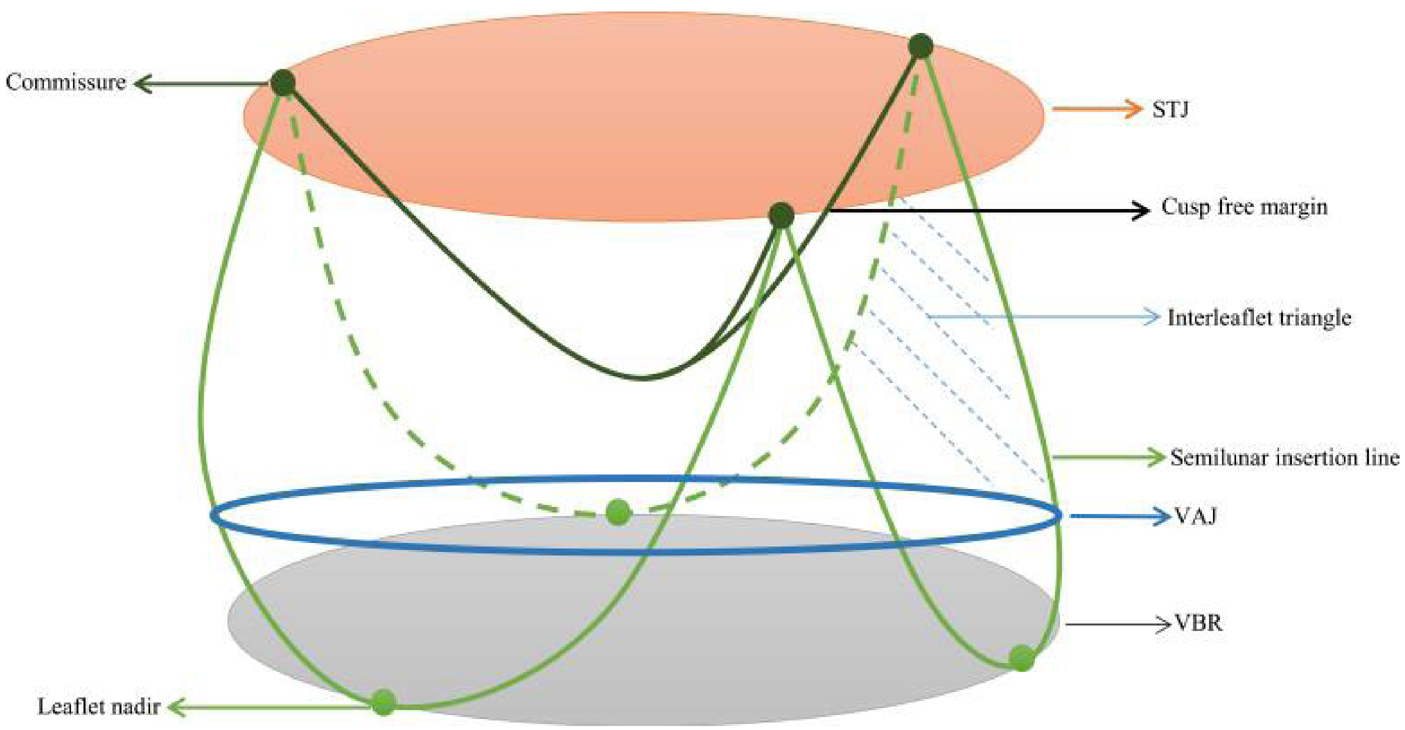

Figure 1. Schematic representation of the aortic valve. Sassis et al. (8)

The normal aortic valve consists of three semilunar leaflets (Figure 2):

- Right coronary;
- Left coronary;
- Noncoronary.

Each leaflet has a complex multilayered structure that provides an optimal balance of strength and elasticity. Valve competence is determined not only by the condition of the leaflets but also by the interaction between the fibrotic annulus, commissures, sinuses of Valsalva, sinotubular junction, and the ascending aorta. The key functional parameters determining the success of reconstructive surgery are:

- Geometric height;
- Effective height;
- Coaptation length;
- Commissural symmetry.

Of particular importance is the concept of the functional aortic annulus. Dilation of the annulus and STJ is one of the key mechanisms in the development of aortic insufficiency.

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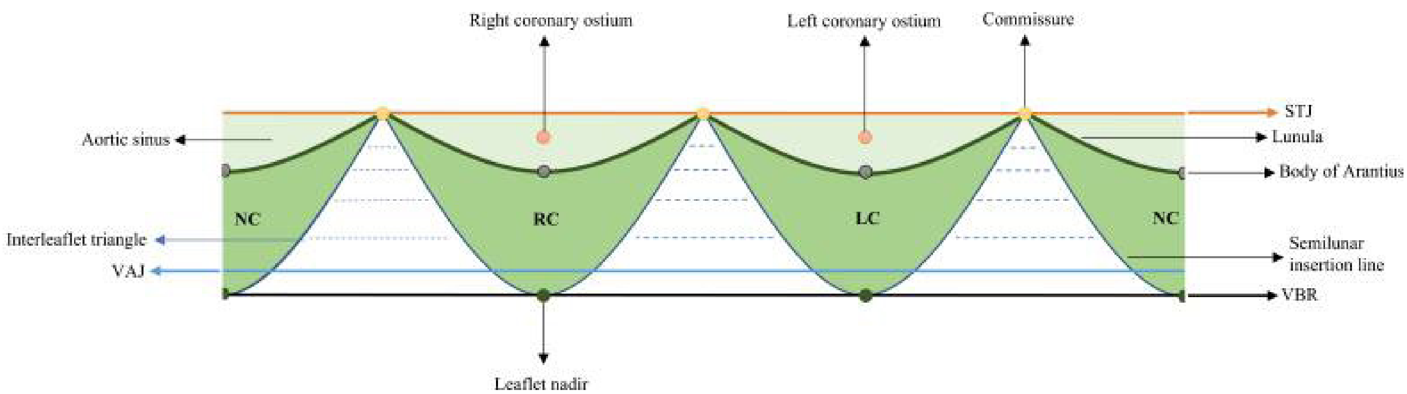

Figure 2. Schematic representation of the anatomy of the aortic valve. Sassis et al. (8)

The sinuses of Valsalva play an important role in the formation of physiological blood flows, which help reduce leaflet stress and optimize leaflet closure. Modern reconstructive techniques increasingly focus on restoration of normal valve geometry rather than simple correction of regurgitation.

Pathophysiology of Aortic Valve Disease

Aortic Stenosis

Calcific aortic stenosis is an active pathological process involving chronic inflammation, lipid infiltration, endothelial dysfunction, and progressive leaflet calcification (9).

Increased mechanical stress leads to progressive leaflet fibrosis, limited leaflet mobility, and the formation of a fixed obstruction of the left ventricular outflow tract. Pressure overload develops, leading to concentric left ventricular hypertrophy, diastolic dysfunction, and subsequently, decreased myocardial contractility.

Without surgical treatment, severe symptomatic aortic stenosis is associated with an extremely poor prognosis.

According to the 2021 ESC/EACTS guidelines, surgical aortic valve replacement is a Class I recommendation for patients <75 years at low surgical risk, while TAVI is Class I for patients ≥75 years or those at increased surgical risk. The 2020 ACC/AHA guideline additionally recommends TAVI for patients >65 years when predicted post-TAVI survival exceeds 12 months and the patient does not have contraindications to a transfemoral approach.

Aortic Insufficiency

Aortic insufficiency develops due to impaired leaflet coaptation. The current El Khoury classification distinguishes (6):

- Type I — normal leaflet mobility with root/annulus dilation;
- Type II — leaflet prolapse;
- Type III — leaflet restriction.

This classification is important to understand the mechanism of aortic regurgitation and plays an important role in modern reconstructive surgery. Chronic aortic regurgitation leads to volume overload, progressive left ventricular dilatation and eccentric hypertrophy.

Diagnostics and Imaging

Echocardiography

Transthoracic echocardiography remains the primary diagnostic method for aortic valve disease (Table 1). It allows for the assessment of:

- Leaflet morphology;
- Degree of stenosis or regurgitation;
- Aortic root size;
- Left ventricular function.

Table 1. Echocardiographic findings of severe aortic stenosis and regurgitation

Parameters	Severe AS	Severe AR
Vmax	≥ 4.0 m/sec	—
Mean gradient	≥ 40 mm Hg	—
AVA	≤ 1.0 cm²	—
Vena contracta	—	> 6 mm
Regurgitant volume	—	≥ 60 ml
EROA	—	≥ 0.30 cм²

Transesophageal echocardiography is especially important when planning reconstructive surgery. It allows for the assessment of:

- Leaflet prolapse;
- Effective height;
- Commissural orientation;
- Quality of coaptation.

Computed Tomography

While computed tomography is not routinely used in aortic valve pathologies, it is plays a key role in specific situations like TAVI planning, assessment of aortic annulus size and calcification, assessment of coronary ostia and diagnosis of aortopathies.

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Magnetic Resonance Imaging

MRI is increasingly used for assessment of aortopathies, blood flow analysis, flow assessment and assessment of myocardial fibrosis.

Modern Surgical Strategies

Aortic Valve Replacement

Mechanical valves

Mechanical valves provide excellent long-term durability and minimal risk of structural valve degeneration. However, lifelong anticoagulation remains a serious limitation, especially in young patients, women of reproductive age, and physically active individuals. In large long-term follow-up series, the freedom from reoperation after isolated mechanical aortic valve replacement was approximately 94% at 10 years, and the freedom from valve dysfunction was approximately 91% at 10 years (10).

Lifelong warfarin therapy remains the main limitation of mechanical prostheses. Even with adequate INR control, patients remain at risk for both hemorrhagic and thromboembolic complications. In a series of young adult patients after isolated mechanical AVR, freedom from major hemorrhage was 98% at 1 year, 96% at 5 years, and 90% at 10 years, corresponding to a cumulative risk of major bleeding of approximately 10% by 10 years (10).

In more recent population-based data, the risk of bleeding remains significant: in patients after mechanical AVR, the 10-year cumulative incidence of clinically significant bleeding reached 27.9%, and intracranial hemorrhage was 5.8%. Moreover, the quality of anticoagulation is critical: a time in therapeutic range (TITR) of less than 80% was associated with a nearly twofold increase in the risk of bleeding (11).

Despite anticoagulation, mechanical valves retain the risk of thromboembolic events, including ischemic stroke, systemic embolism, and prosthetic thrombosis. Recent reviews suggest that the incidence of thromboembolic complications with mechanical aortic valves is typically around 1–2% per year, which is higher than that with bioprosthetic valves in the aortic position (12).

Comparative long-term data are limited by selection bias — younger and lower-risk patients typically receive mechanical prostheses, so reported mechanical durability is not directly comparable to bioprosthetic outcomes in older patients.

Thus, the problem with a mechanical valve is not only the need to prescribe anticoagulation, but also its lifelong management.

Biological valves

Bioprostheses allow for the avoidance of anticoagulation, but their durability is limited by progressive structural valve degeneration. Modern bioprostheses are characterized by:

- Improved leaflet processing;
- Anti-calcification treatment;
- Larger effective orifice area;
- Lower transvalvular gradients.

Of particular interest are new generations of bioprostheses with RESILIA tissue and Linx AC technology, aimed at reducing calcification and slowing structural valve degeneration. Structural valve degeneration remains the major limitation of biological valves and the leading cause of late reoperations.

The durability of modern bioprosthetic valves has improved significantly compared to earlier generations of valves. For the Carpentier-Edwards Perimount, freedom from reoperation for structural valve degeneration was (13):

- Approximately 98% at 10 years,
- 82–85% At 15 years,
- Approximately 60–70% at 20 years.

However, patient age is the most important factor in durability: in patients over 70 years, valve degeneration develops significantly more slowly, while in patients under 50–60 years, the risk of degeneration is significantly higher. In a study by Bourguignon et al., the likelihood of reoperation due to structural valve degeneration in patients under 60 years was almost 5 times higher than in older patients (13).

Most very-long-term durability data came from the Carpentier–Edwards Perimount platform (13); contemporary RESILIA-tissue prostheses show promising early haemodynamics, but there is no long-term data yet exist. The widely cited high 60–70% freedom from reoperation at 20 years (13) refers to selected older patients and cannot be extended to patients under 60. In younger patients, freedom from reoperation after bioprosthetic AVR can decrease to 55–65% at 15 years, and less than 50% at 20 years (14).

Reasons for the more rapid development of structural valve degeneration in younger patients include:

- More active calcium metabolism;
- High hemodynamic stress;
- Increased immune response;
- Longer prosthesis function;
- Chronic mechanical stress.

Additional risk factors include chronic renal failure, hyperparathyroidism, calcium-phosphorus metabolism disorders, diabetes mellitus, patient-prosthesis mismatch (15).

Hemodynamic advantages of bioprostheses

One of the important advantages of biological valves is their more physiological hemodynamics compared to mechanical prostheses.

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Modern pericardial bioprostheses provide:

- Low transvalvular gradients;
- Larger effective orifice area;
- Improved LV mass regression.

This is especially important in patients with a small annulus, severe left ventricular hypertrophy, in elderly patients and with valve-in-valve planning.

The absence of the need for lifelong anticoagulation significantly impacts patients' quality of life. There are several advantages that influence quality of life after the bioprotheses implantation like no need for constant INR monitoring, lower risk of major bleeding, no restrictions during pregnancy, lesser limitations in physical activity and less impact on lifestyle.

These factors have become one of the reasons for the global shift toward bioprosthetics, even in younger patients (16).

Aortic Valve Reconstructive Surgery

Over the past two decades, aortic valve repair or reconstructive surgery has developed into an independent field of modern cardiac surgery.

The main goal in valve repair is not simply the elimination of aortic insufficiency or stenosis, but the restoration of the normal three-dimensional geometry of the entire functional aortic complex: valves, commissures, annulus, sinuses of Valsalva, and the sinotubular junction.

The basic principles of modern repair-oriented surgery include:

- Restoration of valve geometry;
- Prolapse correction;
- Annular stabilization;
- Commissural symmetry;
- Optimization of coaptation.

Functional Classification of Aortic Insufficiency

Modern reconstructive surgery is based on the El Khoury functional classification (17), similar to the Carpentier classification for the mitral valve.

The following are distinguished:

Type I - Normal leaflet mobility, regurgitation due to:

- Adilatation;
- STJ dilatation;
- Root aneurysm.

Type II - Excessive cusp motion:

- Prolapse;
- Free-edge elongation.

Type III - Restricted cusp motion:

- Fibrosis;
- Calcification;
- Retraction.

This classification is fundamental for choosing a reconstructive strategy.

The most commonly used techniques are free-margin plication, free-edge reinforcement, subcomissural annuloplasty, external ring annuloplasty, internal ring annuloplasty, commissural stabilization, patch reconstruction and cusp extension (17-19).

Indications for valve repair: Type I and Type II AI in the El Khoury classification; repairable cusps (effective height ≥9 mm); non-dilated or dilatable root.

Contraindications: heavy cusp calcification; retracted cusps; extensive cusp destruction; active endocarditis.

Annuloplasty for aortic valve repair

The concept of annular stabilization in aortic valve repair is based on the understanding that the aortic annulus is not a discrete fibrous ring, but rather a dynamic "functional aortic annulus" comprising the ventriculo-aortic junction, the aortic root, and the sinotubular junction (17). Dilation of any of these components - particularly the basal ring at the level of the VAJ - has been identified as a key mechanism of recurrent aortic insufficiency after repair, especially in bicuspid valves.

Without addressing annular dilatation, even a technically perfect cusp repair could fail over time due to progressive annular stretching. This principle, learned from the mitral valve repair experience, has driven the development of dedicated annuloplasty devices for the aortic valve. Main techniques include subcomissural annuloplasty, external ring annuloplasty or internal annuloplasty.

Historically, subcommissural annuloplasty has been widely used, however, its effect is often limited, as it does not provide full circular stabilization of the ventricular-aortic junction. Therefore, in modern repair concepts, external or internal ring systems, which allow to standardize the diameter of the annulus and increase the area of coaptation, are becoming increasingly important.

Concept of internal annuloplasty

Internal annuloplasty refers to stabilization of the aortic annulus from within the aortic root, through placement of a subannular device that reduces and remodels the basal ring. The technique is based on the following surgical principles:

- **Geometric remodeling:** Restoration of a symmetric, circular annular geometry
- **Reduction of annular diameter:** Typically downsizing to a physiological range appropriate for the patient's body surface area

- **Stress distribution:** Evenly redistributing mechanical stress across the repaired cusps
- **Prevention of recurrent dilatation:** Providing a rigid scaffold that prevents future annular expansion

This contrasts with the earlier and simpler subcommissural annuloplasty, which uses pledgeted sutures placed at the subcommissural triangles to provide partial annular stabilization without a circumferential device. In the initial multicenter clinical investigations, internal geometric ring annuloplasty was demonstrated to be a safe and effective adjunct to aortic valve repair. However, longer follow-up data is needed to confirm the long-term efficacy and safety.

Repair versus replacement

Repair of aortic valve have several advantages over replacement like absence of prosthetic material, absence of lifelong anticoagulation, reduced risk of bleeding, reduced risk of thromboembolism, maintained physiological hemodynamics and better adaptation to physical activity. However, reconstruction has some limitations related to high technical complexity, significant dependence on the surgeon's experience, risk of recurrent aortic regurgitation and limited applicability in calcified aortic valve.

Therefore, aortic valve repair should not be considered as a universal alternative to valve replacement. It is a strategy for carefully selected patients, particularly those with types I-II aortic insufficiency, preserved leaflet tissue, and the possibility of reliable annular stabilization.

Aortic valve repair outcomes are dominated by a small number of high-volume centres. Lower-volume centres require a learning curve with approximately 40-50 cases to achieve stable results, and outcomes in lower-volume centres may be significantly inferior. In experienced centres, freedom from reoperation after repair reaches about 85–90% at 10 years (19).

Valve-Sparing Aortic Root Surgery

Valve-sparing root surgery is one of the most significant advances in modern aortic surgery. The main concept is to eliminate the pathology of the aortic root while preserving the aortic valve's own cusps. There are two main concepts (20):

- Remodeling technique (Yacoub)
- Reimplantation technique (David).

Additionally, following valve-sparing procedures used in selected cases: Florida sleeve, partial sinus replacement, partial root remodelling, valve-sparing procedures with external annuloplasty.

The David procedure provides more reliable annular stabilization and excellent long-term durability, especially in patients with connective tissue disorders.

Valve-sparing surgery is especially important:

- In young patients;
- In Marfan syndrome;
- In root aneurysms with repairable cusps.

The 2021 ESC/EACTS guidelines assign a Class I recommendation to valve-sparing root replacement in patients with aortic root aneurysm and repairable cusps. In experienced centers valve-sparing surgery demonstrates excellent outcomes with operative mortality <1–3% and freedom from reoperation >85–90% at 15 years. Results demonstrate low thromboembolic risk and excellent quality of life after valve-sparing operations (21,22). However, long-term outcomes are derived predominantly from the originating David and Yacoub centres.

Ross Procedure

The Ross procedure is experiencing renewed interest in modern aortic valve surgery.

Key advantages:

- Near-physiologic hemodynamics;
- No anticoagulation;
- Excellent exercise capacity;
- Low thromboembolic risk.

The Ross procedure is particularly attractive in young patients, athletes, women planning pregnancy. However, the procedure remains technically demanding and requires significant surgical experience.

The Ross procedure carries a Class IIa recommendation in the 2021 ESC/EACTS guidelines for young adults who require aortic valve replacement and have a contraindication to mechanical prosthesis.

Indications: age <50–60; women of reproductive age; athletes; contraindications to anticoagulation; centres with experienced surgeons.

Contraindications — pre-existing pulmonary valve disease; severe connective tissue disease affecting the autograft; active endocarditis; severe pulmonary hypertension.

Aortic Neocuspidization (AVNeo)

Aortic Valve Neocuspidization (AVNeo), developed by Shigeyuki Ozaki, has become one of the most discussed approaches in modern reconstructive aortic surgery (23). The basic concept of AVNeo is the complete removal of pathological aortic valve leaflets, followed by the creation of new leaflets from treated autologous pericardium. Unlike classic repair, AVNeo does not preserve the native leaflets, but allows avoidance of prosthetic implantation, maintains physiological hemodynamics, minimizes prosthesis-patient mismatch and avoids lifelong anticoagulation.

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This method combines elements of reconstructive surgery and valve replacement, forming an intermediate concept between repair and prosthetic replacement.

Commissural fixation is a critical step in AVNeo, because commissural zones experience maximum leaflet stress. Therefore, modern modifications increasingly focus mainly on commissural reinforcement, stress redistribution and stabilization of neocommissures. This can potentially improve the long-term durability of the reconstruction.

One of the main advantages of the AVNeo is its excellent hemodynamic characteristics. In most series, the Ozaki procedure is accompanied by very low transvalvular gradients and large effective orifice area. These advantages are particularly important in patients with small annulus, narrow LVOT, pediatric patients and young adults.

The largest published single-centre series reports excellent early and mid-term results. However, several important issues exist. First, the originating centre is responsible for most of the published long-term data; independent series have frequently shown less favourable results and variable rates of cusp calcification and reoperation. Second, in the originating series the rate of moderate or severe aortic regurgitation rises to 6.6% at 10 years, and neocusp asymmetry together with younger age (<60 years) has been identified as a predictor of late insufficiency. Third, the very-long-term durability (>10–15 years) of AVNeo remains incompletely defined; recent comparative data in congenital patients report a freedom-from-reoperation of 86% with autologous pericardium versus 75% with bovine PhotoFix pericardium at 3 years, with failure mode differing by material (calcification for autologous; annular suture dehiscence for PhotoFix).

Systematic reviews and meta-analyses confirm excellent early haemodynamics and low operative mortality, but the evidence base for long-term durability remains substantially smaller than that for bioprosthetic replacement, Ross, or established valve-sparing procedures.

Taken together, AVNeo is a feasible option for selected patients, particularly those with small annular dimensions or contraindications to anticoagulation. But the current enthusiasm surrounding the technique should be tempered by the absence of robust long-term comparison with established alternatives.

Indications for AVNeo: small aortic annulus; paediatric/young adult patients; women of reproductive age; anticoagulation contraindication; extensive cusp calcification precluding repair.

Contraindications: very large annulus; active endocarditis; severe AR with marked root dilation.

Clinical outcomes and durability

Largest series by Ozaki et al highlight that aortic regurgitation significantly increases over time, reaching 6.6% moderate or severe at 10 years. These findings could impact the reported freedom from recurrent AR and identify neocusp asymmetry and younger age as predictors of late insufficiency.

However, most available data present results of single-center experiences, come from high-volume specialized centers and have a limited number of truly long-term observations.

Systematic reviews demonstrate excellent early hemodynamics with Low operative mortality and acceptable mid-term durability (24).

Despite promising early and mid-term outcomes, long-term durability of AVNeo remains incompletely defined.

Long-Term Outcomes

Direct comparison of long-term outcomes between mechanical, bioprosthetic, and reconstructive strategies is limited by fundamental selection bias. Mechanical prostheses are typically implanted in younger, lower-risk patients; bioprostheses in older patients with more comorbidities; reconstructive procedures in selected candidates at specialised centres; and TAVI in older or higher-risk patients. Long-term outcome figures cited in this section should therefore be interpreted as performance within each population rather than as head-to-head comparisons.

Bicuspid Aortic Valve

Bicuspid aortic valve (BAV) is the most common congenital heart anomaly, occurring in approximately 1–2% of the population (25).

Current thinking considers BAV not an isolated valve anomaly, but rather a complex aortopathy syndrome.

Classification

The most widely used classification is the Sievers classification (26):

- Type 0 — no raphe;
- Type 1 — one raphe;
- Type 2 — two raphes.

The most common variant is fusion of the right and left coronary cusps. This anatomical configuration often dictates specific surgical management strategies, as repair techniques. In recent years, the de Kerchove and El Khoury classification has emerged as a comprehensive framework that emphasizes the functional anatomy of the valve and the dynamic characteristics of the aortic root to guide repair (27). This system categorizes bicuspid valves based on commissural orientation into type A (symmetric phenotype), type B (asymmetric phenotype), and type C (very asymmetric phenotype), thereby facilitating a more tailored approach to valve reconstruction (Figure 3).

BAV is frequently associated with aneurysm of ascending aorta, aortic root dilatation, abnormal wall shear stress and extracellular matrix abnormalities.

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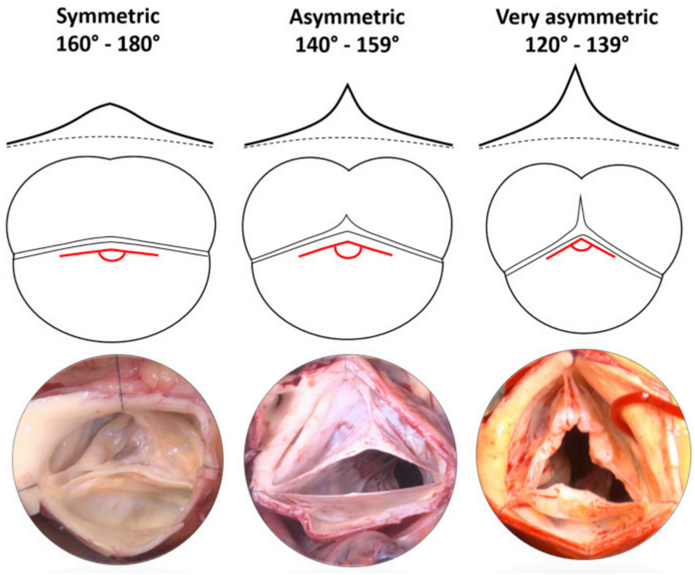

Figure 3. Repair-oriented de Kerchove and El Khoury classification of BAV. Jahanyar J et al. (27)

BAV Surgery

Modern BAV surgery increasingly favors repair-oriented strategies.

Main repair techniques include prolapse correction, raphe modification, commissural reorientation, annuloplasty (25). Nevertheless, the heterogeneous morphology of bicuspid valves—specifically regarding leaflet geometry, raphe presence, and calcification severity—necessitates caution, as these factors significantly influence the surgical strategy and long-term durability (28). Long-term results of BAV repair are good, but leaflet calcification and the need for patch reconstruction are the strongest risk factors for failure; in such cases, prosthetic repair may be preferable (25). Furthermore, aortic valve neocuspidization has emerged as an alternative approach for managing bicuspid anatomy, allowing for complete cusp replacement even in complex cases where traditional repair is anatomically unfeasible (29).

Transcatheter Aortic Valve Implantation (TAVI)

TAVI has fundamentally transformed the management of aortic stenosis.

Initially, the method was used in inoperable and high-risk patients, but subsequent trials have expanded its indications.

According to current ESC/EACTS and ACC/AHA Guidelines, the choice between SAVR and TAVI should be based on Heart Team decision-making (2,12). Key factors include age, frailty, expected survival, anatomy, surgical risk, coronary anatomy, concomitant aortopathy and future intervention strategy.

Major limitations of TAVI are high paravalvular leak, with 17.7% of patients undergoing TAVI compared with 2.0% of patients undergoing surgery at 7 years follow-up regarding latest PARTNER 3 trial (30). 2021 ESC/EACTS guidelines recommend TAVI as a Class IIa recommendation in younger patients with bicuspid anatomy in selected centres.

Indications: severe AS at increased or prohibitive surgical risk; expanded to patients >65–75 years with suitable anatomy; selected low-risk and younger patients in experienced centres.

Contraindications: unsuitable annulus or calcification pattern; prohibitive coronary access; severe concomitant mitral or tricuspid disease requiring surgery.

The issue of long-term management remains especially important for younger patients.

Valve-inValve Strategy

Progression of TAVI radically changed the concept of bioprosthetic durability.

Valve-in-valve (ViV) TAVI could use bioprothesis as a «platform» for future interventions. It could potentially increase the indications towards the younger patients. However, ViV strategy have important limitations as

- Progressive reduction of effective orifice area;
- Higher residual gradients;
- Coronary access difficulties;
- Risk of coronary obstruction;
- Cumulative prosthetic burden.

Valve Surgery Selecting Strategy in Special Situations

Valve Surgery in Young Patients

Choosing the optimal aortic valve treatment strategy in young patients remains one of the most complex and controversial issues in modern cardiac surgery. Unlike in older patients, where the primary focus is often on perioperative risk reduction, in young patients, there are several aspects that influences the choice as durability of the procedure, quality of life, need for anticoagulation, risk of reoperation, physical activity, pregnancy and lifetime management strategy (31).

The traditional concept of "young patient = mechanical valve" has been increasingly reconsidered in recent years. Developments in reconstructive surgery, Ross procedure, AVNeo, modern bioprostheses and valve-in-valve technologies have significantly expanded therapeutic options.

The current trend increasingly favors a repair-first approach whenever feasible.

Pregnancy and Valve Choice

The choice of valve strategy in women of reproductive age requires a separate approach.

Mechanical protheses are associated with:

- Maternal thrombosis risk;
- Fetal warfarin syndrome;
- Pregnancy loss;
- Anticoagulation management complexity.

Even with modern anticoagulation management maternal and fetal risks remain substantial (32).

Lifelong Management Strategy

Modern aortic valve treatment is increasingly conceptualized around the paradigm of lifetime management - a strategic framework that anticipates the entire treatment trajectory of the patient rather than focusing solely on the intervention. This concept is most relevant in younger patients, in whom every procedure must be evaluated for its immediate result and its compatibility with future interventions. Lifelong management requires the Heart Team to balance immediate procedural risk, durability of the index intervention, impact on quality of life, feasibility of future reinterventions, and patient-specific factors (age, lifestyle, pregnancy plans, occupation) at every decision point (Table 2).

Table 2. Comparative overview of contemporary aortic valve treatment strategies.

Strategy	Ideal patient indication	Key advantages	Key disadvantages	Anticoagulation	Durability (typical)	Reintervention (approx.)
Mechanical prosthesis	Age <60; reliable INR monitoring; no mechanical contraindications	Excellent durability; no SVD	Lifelong warfarin; bleeding; thromboembolism; audible click	Required (lifelong)	>95% at 20 yr in selected series (Bouhout et al., 2013)	5–10% at 20 yr
Bioprosthetic valve	Age >65; anticoagulation contraindication; pregnancy desired	No anticoagulation; quiet	SVD; lower durability in <60 yr	None	60–70% free-reoperation at 20 yr (Bourguignon et al., 2015)	30–40% at 20 yr (<60); 10–15% at 20 yr (>65) (Forcillo et al., 2014)
Valve repair (BAV / AI)	Type I–II AI; repairable cusps; non-dilated/dilatable root	No prosthetic material; no anticoagulation; physiologic flow	Learning-curve dependent; not for calcified/retracted cusps	None	85–90% free-reop at 10 yr (Kerchove et al., 2009)	10–15% at 10 yr
Valve-sparing root (David/Yacoub)	Root aneurysm + repairable cusps; Marfan/connective tissue	No prosthesis; native valve preserved	Technically demanding; root reintervention possible	None	>85–90% free-reop at 15 yr (David, 2013; David et al., 2006; Ouzounian et al., 2016)	10–15% at 15 yr
Ross procedure	Age <50–60; women; athletes; warfarin contraindication	No anticoagulation; growth potential (children); excellent haemodynamics	Two-valve operation; autograft dilation; RVOT degeneration	None	80–85% free-autograft reoperation at 15 yr (El-Hamamsy et al., 2010)	15–20% at 15 yr (any valve)
AVNeo	Small annulus; young adult; anticoagulation contraindication	No prosthesis; autologous material; physiologic haemodynamics	Limited long-term data; possible late AR; calcification	None	~93% free from ≥moderate AR at 10 yr (originating series) (Ozaki et al., 2012)	Limited; 5–15% at 10 yr (early series) (Benedetto et al., 2020; Chávez et al., 2025; Enrique et al., 2026)
TAVI	Age >65–75; high/ intermediate surgical risk; selected low-risk	Minimally invasive; rapid recovery; no sternotomy	Paravalvular leak; pacemaker; long-term durability uncertain; coronary access	Brief antithrombotic periprocedural only	5–7-yr data reassuring; >10-yr data limited (Kalogeropoulos et al., 2022)	~5–10% at 5–7 yr

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Future Directions

Modern aortic valve surgery is rapidly evolving toward:

- Personalized treatment;
- AI-assisted imaging;
- Computational modeling;
- Tissue engineering;
- Patient-specific repair planning.

In the coming decades, the primary goal of modern aortic surgery will be not only prolonging survival but also creating the most physiological and durable individualized valve strategy.

CONCLUSION

The contemporary management of aortic valve disease has evolved from a binary choice between mechanical and biological replacement into a portfolio of reconstructive, transcatheter, and hybrid strategies. Each modality offers distinct advantages, and some principles should guide current practice.

First, durable mechanical replacement remains an excellent option for selected younger patients. But we should not forget that lifelong anticoagulation has its own morbidity: particularly bleeding, thromboembolic events, and foetal risk in pregnancy.

Second, bioprosthetic valve durability has improved, but structural valve degeneration is an inevitable sequela in young recipients. New tissue bioprotheses show promising early and mid-term results, however long-term outcomes yet not exist.

Third, reconstructive techniques — aortic valve repair, valve-sparing root replacement, the Ross procedure, and AVNeo — provide physiological alternatives to prosthetic replacement in appropriate candidates. However, these are technically more challenging, published evidence is heavily dependent on originating referral centres, and generalisability is uncertain.

Fourth, TAVI has become a default strategy in elderly and high-risk patients, but its extension to younger and lower-risk populations raises unresolved issues of transcatheter heart valve durability, coronary access, redo-TAVI feasibility, and lifetime management.

Knowledge gaps and research priorities not adequately addressed by current literature include very-long-term durability of contemporary bio- and transcatheter prostheses; the optimal reconstructive strategy in young adults, patient-specific lifetime modelling integrating cumulative reintervention risk; the role of AI-assisted imaging and computational flow modelling in personalised procedure selection. Progress in these areas will likely determine the next decade of aortic valve surgery.

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