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Beyond the valve: Advances in Mitral Stenosis Diagnosis and Management

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ABSTRACT

Mitral stenosis (MS) remains a significant valvular heart condition, even though its incidence is declining worldwide. In low- and middle-income nations, rheumatic heart disease (RHD) still predominates, but in high-income countries, older adults are increasingly suffering from degenerative mitral stenosis (DMS) caused by mitral annular calcification (MAC). During diastole, MS obstructs left atrial outflow, increasing left atrial pressure and contributing to heart failure, right ventricular strain and pulmonary hypertension. Echocardiography remains crucial for the diagnosis, evaluation of complications, valve structure and disease severity. Management strategies varies by comorbidities, anatomy, etiology and patient-specific variables. Medical therapy aims to prevent thromboembolic events and symptom control, particularly in patients with DMS. Percutaneous balloon mitral valvotomy (PBMV) remains as the preferred treatment for rheumatic MS with favorable anatomy and emerging therapies like lithotripsy-assisted PBMV show promise for highly calcified valves along with better outcomes. Surgical interventions such as commissurotomy, transcatheter mitral valve replacement (TMVR) and mitral valve replacement (MVR) are reserved for cases of complicated valve disease or inappropriate PBMV candidates. Valve choice between mechanical or bioprosthetic prostheses depends on comorbidities, patient age and anticoagulation considerations. Special considerations include pregnancy, where multidisciplinary care and selective interventions help reduce maternal fetal risk and the elderly, where the high surgical risk and comorbidity burden must be taken into account. Improvements in imaging, technology and selection criteria are expanding

therapy possibilities, despite ongoing challenges in optimizing intervention timing and long-term outcomes.

KEYWORDS: "Mitral stenosis"; "Rheumatic heart disease"; "Degenerative mitral stenosis"; "Percutaneous balloon mitral valvotomy"; "Transcatheter mitral valve replacement"; "Rheumatic mitral stenosis".

Introduction

Mitral stenosis (MS), a valvular heart disease is characterized by a constriction of the mitral valve (MV) orifice which restricts diastolic blood flow from the left atrium to the left ventricle. By echocardiography, its identified as having a mitral valve area of below 1.5 cm^2 **[1,2].** Despite becoming less common globally, MS is a significant clinical issue due to its consequences and evolving etiologies **[3].**

Rheumatic heart disease (RHD) caused by rheumatic fever due to GAS pharyngitis is the most common cause of MS worldwide **[3]**. Persistent poverty and restricted access to healthcare are socioeconomic factors that continue to contribute to high incidence rates in emerging nations **[4]**. Improvements in these regions have been associated with a lower incidence of streptococcal infections and consequently, lower rates of rheumatic fever **[4]**. Conversely, among high-income nations, degenerative mitral stenosis (DMS) is becoming more prevalent among the elderly. Primarily caused by progressive mitral annular calcification (MAC), DMS is closely linked with age, particularly in older adults. Although less common, congenital abnormalities and radiation-induced valve damage are additional causes **[4,5,6].** Additionally, the hemodynamic characteristics of the two types differ, with DMS patients often having greater stroke volumes despite having a bigger mitral valve area **[7]**. According to epidemiological data, both rheumatic and degenerative forms of MS are widely prevalent. Mostly in regions with high sociodemographic indices, the Global Burden of Disease (GBD) Study 2021 found 15.5 million instances of nonrheumatic degenerative mitral valve disease **[8]**. During the same year, an estimated 54.8 million persons suffered from RHD, with the majority of those cases likely developing rheumatic MS **[8]**. According to a previous GBD-based estimate, there were approximately 24.2 million instances with degenerative mitral valve disease in 2019 **[9]**, indicating that the incidence of DMS is increasing as the population ages. These studies also reveal contradictory patterns: age-standardized rates of RMS are declining, but DMS is still growing in absolute numbers **[8, 9].**

Echocardiography continues to be the gold standard for diagnosing MS and assessing its severity and consequences **[10]**. Speckle tracking echocardiography is an innovative approach for identifying left atrial dysfunction early on, anticipating when atrial fibrillation would occur, and predicting negative outcomes for MS patients **[11].** The first-line treatment for severe RMS is percutaneous mitral balloon commissurotomy (PMBC), if the patient meets anatomical requirements. Several echocardiographic scoring systems are available to assess valve morphology and determine procedural adequacy. MV surgery is usually considered for patients with degenerative mitral valve disease, severe mitral regurgitation occurring concurrently, or when percutaneous management is contraindicated or has

historically failed. Patients who have a history of rheumatic heart disease are still recommended to have secondary antimicrobial prophylaxis even after surgical valve replacement **[12].** For accurate management techniques that can enhance patient outcomes, individualized approaches that align with symptoms, the severity of MS, and mitral valve structure are crucial **[11].**

This review aims to give an overview of MS, encompassing its pathogenesis, clinical manifestation, diagnostics employing current imaging techniques, treatment modalities, complications and long-term prognosis.

Methodology: A comprehensive literature review was conducted using PubMed, Scopus and Google Scholar. English language articles published between 2018 and 2025 were included. Keywords such as "mitral stenosis"; "rheumatic heart disease";"degenerative mitral stenosis";"mitral annular calcification"; "percutaneous balloon mitral valvotomy"; "transcatheter mitral valve replacement" were used. Studies focusing on epidemiology, pathophysiology, diagnostic imaging and treatment modalities including medical and surgical interventions were included.

Discussion

1.Pathophysiology:

Mitral stenosis arises from hemodynamic blockage across the mitral valve due to structural defects of the valve apparatus, resulting in heightened resistance to transmitral flow **[5].** RMS and DMS are the two primary causes of mitral stenosis. DMS is more common in developed countries and affects older people, whereas RMS is more prevalent in poorer nations and in young people **[13].**

1.1 RMS: RMS typically caused by rheumatic fever which leads to commissural fusion, chordal shortening, decreased mobility and thickening of the tip of posterior mitral valve leaflet **[14].** Rheumatic fever is caused by an autoimmune reaction, mediated by molecular mimicry to a group A streptococcal (GAS) pharyngeal infection in a genetically predisposed individual **[15].** The innate immune system leads to activation of T and B cells because of the initial pharyngeal infection. CD4+ T cells stimulate production of IgG and IgM antibodies. Carditis will result from T cell proliferation and antibody binding from a cardiovascular perspective **[16].**

1.2 DMS: Chronic non-inflammatory degradation and calcification of the fibrous mitral annulus cause DMS, linked to advanced age, female gender and cardiovascular risk factors like diabetes, high blood pressure and coronary artery disease. The condition affects the posterior mitral annulus, causing calcium deposit localization between the left ventricular (LV) wall and mitral valve leaflets **[14].** Echocardiogram frequently reveal MAC, especially in older patients. MAC is usually limited to the basal leaflets and mitral annulus; however, calcification can occasionally spread farther into the leaflet **[17].** Reduced normal annular dilatation during diastole and impaired anterior mitral leaflet mobility, causing the leaflet's hinge to shift towards its free edge, are the two likely ways MAC can cause DMS **[18].** The earliest documented example of MAC was identified in a 60-year-old Egyptian woman over 4,000 years ago and a 1962 pathological study proposed it as the cause of inflow obstruction **[19].** The key differences between DMS and RMS are summarized in Table 1.

1.3 Hemodynamic consequences: As MS progresses, the mitral valve opening narrows from a typical 4-6 cm^2 to less than 2 cm^2, which keeps the LV from filling during ventricular diastole and raises Left atrial (LA) pressure. The resulting remodeling and enlargement of the LA increases the risk of atrial fibrillation, decreases flow velocities and promotes blood stasis in the LA increasing the risk of thromboembolism **[16,20].** In MS patients, the left ventricle is normal with a longer transmitral gradient defined as the pressure difference between the left atrium and left ventricle during diastole and reduced diastolic filling. However, in the presence of atrial fibrillation diastolic filling time reduces, heart rate and the transmitral gradient increases. Loss of LA contraction reduces forward stroke volume. As the disease worsens, pulmonary artery pressure (PAH) might develop. If chronic, it can lead to right ventricular dilatation, hypertrophy, and ultimately advanced stages of heart failure **[20].**

Table 1: Comparision Between Rheumatic and Degenerative Mitral Stenosis

Features	Rheumatic Mitral Stenosis (RMS)	Degenerative Mitral Stenosis (DMS)	References
Etiology	Autoimmune reaction to Group A Streptococcal (GAS) pharyngitis	Chronic non-inflammatory degeneration and calcification	[14,15]
Pathogenesis	Molecular mimicry activates T and B cells leading to Inflammation and valve damage	Mitral annular calcification (MAC) impairs valve flexibility	[15,17,18]
Valve Morphology	Commissural fusion, chordal shortening, leaflet thickening (esp. posterior)	Calcification of posterior annulus and basal leaflet thickening	[14,17]
Mobility of Leaflets	Decreased due to fibrosis and thickening	Decreased due to calcium-induced hinge restriction	[14,18]
Associated Risk Factors	More common in younger patients from low-income regions, History of RHD, genetic predisposition	Older age, female gender, hypertension, diabetes, coronary artery disease (CAD)	[13,14]
Imaging Findings	Thickened and fused leaflets on echocardiography	Echocardiographic evidence of MAC, often limited to annulus and basal leaflet	[17]

2. Clinical Manifestations and Findings:

MS is a form of valvular heart disease marked by constriction of the mitral valve orifice and narrowing of the mitral valve leading to increased transmitral pressure gradient and elevation in LA pressure **[13,21].** Typical early clinical presentations of MS include dyspnea on exertion, exhaustion, reduced

exercise tolerance, atrial fibrillation (AF), thromboembolism, chest pain and signs of right heart failure, all resulting from the malformed mitral valve. Hemoptysis may also occur due to elevated pressures causing pulmonary arteries to rupture, indicating severe MS [22]. In RMS, MS manifests as orthopnea and paroxysmal nocturnal dyspnea (PND) 20 to 40 years after the Rheumatic fever (RF) episode [1]. Patients with RF present with a combination of carditis, arthralgia, chorea, erythema marginatum and subcutaneous nodules [23]. AF increases thromboembolic events and weakens hemodynamic tolerance in MS patients, contributing to 60% of heart failure deaths and eventually leading to poor prognosis [20]. 0.4% of people worldwide suffer from rheumatic valve disease, mostly in low-income nations. More women are affected by rheumatic mitral stenosis and 40-75% of patients may have AF and rise with age [24]. Stroke is a major cause of death in MS patients and thromboembolism accounts for 50% of cardioembolic and 10% of ischemic strokes, with risk factors including higher mitral annular calcification score, dyslipidemia, male gender and diabetes mellitus [1]. Mild MS patients may experience embolism before symptoms appear, potentially as the initial sign of the disease, with AF being present in 80% of such patients [25]. A distinctive high-pitched early diastolic sound associated with MS is called the opening snap, which is caused by the abrupt tensing of the stenotic valve leaflets during opening. This is often accompanied by mitral facies (plethoric cheeks with bluish discoloration), a tapping apex and an apical diastolic thrill. During MV closure, the first cardiac sound (S1), which is typically loud is caused by an abrupt rise in right ventricular pressure. The strength of the S1 may fluctuate with RR intervals until AF develops [26]. The characteristic low-pitched rumbling apical mid-diastolic murmur with presystolic accentuation is best heard near the apex in the left lateral position. 90% of patients with a diastolic apical murmur show no signs of MS on echocardiography and in elderly patients, a diastolic rumble is most often caused by mitral annular calcification [26].

3. Diagnostic Evaluation:

3.1 Echocardiography: The gold standard for diagnosing mitral stenosis (MS) is echocardiography, due to its non-invasive, easily accessible, and portable nature [27,28]. Echocardiography assesses mitral valve morphology, disease severity and hemodynamics using the mean transmitral gradient and effective valve area [28]. The Wilkins score assesses severity by checking mitral apparatus thickness, leaflet mobility, calcification and eligibility for percutaneous mitral balloon valvuloplasty [27,29]. Trans-thoracic echocardiography (TTE), especially 3D echocardiography provides detailed assessment of mitral valve anatomy and detect pulmonary hypertension [28,29]. MS echocardiography shows thickening at leaflet tips, restricted valve motion, decreased leaflet mobility, calcification of leaflets, and chordal shortening [29].

Transesophageal echocardiography (TEE) rules out the possibility of left atrial thrombus before surgeries, embolic events, for valve morphology clarification, or mitral valve suitability for percutaneous mitral commissurotomy [29]. Due to the proximity to the valve's posterior location, TEE provides a better view of valvular anatomy and the sub valvular apparatus [27].

3.2 Stress Testing: Stress testing assesses MS in asymptomatic patients with severe MS and when exertional symptoms cannot be explained by resting valvular hemodynamics and measured valve area [28,30]. Severe MS is diagnosed if the mean gradient is >15 mmHg on exertion, or >18 mmHg with

dobutamine [28]. It indicates poor exercise tolerance, whereas dyspnea at low workload indicates poor left atrial compliance [30]. Treatment for non-severe MS can be decided based on stress tests and mitral interventions may be considered if the exercise transmitral gradient exceeds 15 mmHg [30]. A study revealed that 46% of patients with moderate to severe rheumatic conditions experience MS symptoms during stress tests [31].

3.3 Imaging Studies: Computed tomography (CT) and cardiovascular magnetic resonance (CMR) are recommended when echocardiography is insufficient, technical difficulties exist or additional information is required [32]. CT is a high-resolution imaging used to assess leaflet thickening, mitral annular calcification (MAC), coronary artery disease, and to rule out thrombus formation before surgery [28,32].

CMR assesses MS severity using transvalvular flow and velocity and shows hypointense tissue characteristics on MRI in patients with MAC and atrial fibrillation. Research suggests that mitral velocities calculated from CMR are less than those from TTE due to the inferior temporal resolution [28,32]. Diagnosing obese patients is challenging due to artifacts and overlapping symptoms, underscoring the need for specialized imaging. Similarly, the high death rate from fungal endocarditis as a result of delayed diagnosis emphasizes the significance of advanced imaging for precise assessment of mitral stenosis [33,34].

3.4 Biomarkers: Studies have shown that stress on the myocardium increases NT-pro BNP levels, especially in heart failure and RHD disease patients. However, these biomarkers lack specificity in diagnosing MS since their raised levels can be seen in other cardiac conditions as well. NT-pro BNP level measurement serves two purposes in the management of MS by tracking disease advancement and evaluating the condition's severity, along with treatment effectiveness. Levels significantly reduced after the percutaneous mitral commissurotomy intervention in RHD MS patients [35].

3.5 AI based Studies: Recent research suggests that clinical judgment is necessary since AI-based ECGs can screen for valvular heart disease with high accuracy but low positive predictive value (PPE). Multiple factors can cause low PPV, with the main reason being the natural variability in the ECG recordings, and additional factors like electrode placement, patient position, and minor arrhythmia could influence AI's interpretation of ECG readings [36]. Another research study using a deep learning model for diagnosing MS showed 100% sensitivity, specificity and accuracy in classifying patients needing intervention by using heart sounds [37].

4. Management Strategies:

4.1 Medical management: Medical therapy of symptomatic MS aim to prevent recurrence of RF, relieve symptoms and reduce thromboembolic events [20]. In particular for DMS, which is increasingly prevalent in older adults, it remains the first-line treatment when the time of the intervention is uncertain [12].

For symptomatic MS patients, medical treatment options include diuretics to relieve heart failure symptoms and beta blockers to prolong diastolic filling period. This is especially important for patients with sinus rhythm (SR) who experience symptoms during exercise, as well as those with AF and rapid

ventricular response. Beta blockers (atenolol or propranolol) are effective in pregnant women, improving symptoms and reducing mean gradients and pulmonary pressure **[20].**

For DMS, medical therapy includes heart rate management using beta-blockers, calcium channel blockers, or ivabradine in sinus rhythm prolongs diastole, which improves left ventricular filling **[12].** For patients with RMS and either of AF, a previous embolic event or LA thrombus, anticoagulation with a vitamin K antagonist (VKA) was advised **[12].**

As per the 2021 ESC/EACTS guidelines, patients with moderate to severe MS and AF should be treated with VKA (Vitamin K Antagonists) anticoagulants so as to prevent the risk of thromboembolic events in such patients **[38].** For patients with mitral stenosis in sinus rhythm, oral anticoagulation therapy with VKA is recommended if there has been a history of systemic embolism or presence of a thrombus in the left atrium or if TEE shows a dense spontaneous contrast or LA enlargement (M mode diameter >50mm or LA volume > 60ml/m2) **[38,39].** Although randomized trials have not evaluated direct oral anticoagulants (DOACs) in this setting, recent observational studies suggest its comparable efficacy to VKAs and a twofold reduction in intracranial hemorrhage **[12].**

4.2 Percutaneous Balloon Mitral Valvotomy (PMBV)

Open heart surgery remained the mainstay of MS treatment for many years. In 1984-85, Inoue and Lock created a different minimally invasive technique known as PMBV, which later became the norm **[40].** PMBV uses single, double and Inoue balloons, with the Inoue approach and double-balloon technique being the most common. While the double-balloon technique carries a risk of LV puncture caused by a balloon tip or guidewire, the Inoue approach is used more frequently as it allows progressive dilatation of the stenotic valve with less complications. Both the techniques assess left and right heart pressure, cardiac output and saturation before and after mitral valvulotomy, using the Gorlin formula for mitral valve area and Seller's categorization for MR severity **[41].**

Percutaneous Mitral Valvuloplasty (PMV) is a well-established intervention for patients with moderate-to-severe symptomatic RMS, particularly those with favorable valve morphology defined by a low Wilkins score (≤8), non-calcified, pliable leaflets, and absence of significant mitral regurgitation. Usually, its reserved for NYHA class II-IV patients with appropriate anatomy **[42].** Surgical therapy should be recommended for patients with a score of >9-10, except in those with severe comorbidities **[43].**

A recent meta-analysis supports PMBV for young patients with appropriate anatomy due to reduced procedural morbidity than MV replacement **[44].**

Chichareon.et al, reported successful PMBV was defined as post-procedural MVA ≥1.5 cm2 or ≥50% increase in MVA and MR below grade 3+ without cardiac tamponade, stroke, mortality or mitral surgery. The secondary outcome was the combination of all-cause mortality, MV surgery, or repeat PMBV following discharge **[41].**

4.2.1 Lithotripsy Facilitated PMBV: Although PMBV has been widely used to treat RMS, its usage in the treatment of MAC has been discouraged due to concerns regarding its efficacy due to the absence of commissural fusion and calcified leaflets. Therefore, there is a growing demand for innovative techniques like lithotripsy-facilitated PMBV to overcome the possible drawbacks of traditional PMBV

for MAC **[45].** Intravascular lithotripsy (IVL) delivers sonic pressure waves using a low-pressure balloon to break both superficial and deep calcium deposits while protecting soft tissue. Unlike other debulking methods, IVL leaves calcium components in place, reducing the danger of distal embolization **[14].**

The first instance of IVL-facilitating PMC in calcific rheumatic MS was reported by Sharma et al. in 2020 involving a 86-year-old man with calcific RMS and a TMGP of 14 mmHg. The MV was concurrently inflated with three 7.0 × 6.0 mm lithotripsy balloons. On TEE, the mean transmitral pressure gradient (TMPG) dropped to 6 mmHg. After doing PMC with 24 mm, the final TMPG was 4 mmHg **[46].**

A 2025 systematic review by Bassim et al observed that conventional PMBV performed in MAC was associated with reduction in mitral gradients and 14% required reintervention in short time whereas, lithotripsy-facilitated PMBV was successful in lowering the mean gradient by 5 to 8mm Hg without significant rise in MR **[45].**

4.3 MV Surgery: Commissurotomy & Replacement:

Severe MS patients who are not candidates for PMBV should consider MV surgery. Before cardiopulmonary bypass, the only surgical option for treating RMS was a "closed" commissurotomy, introduced in 1948 **[20].** MV commissurotomy is a procedure that separates fused commissures of the mitral valve, improving blood flow and valve function while relieving MS. Symptomatic, moderate-to-severe MS, severe MS leading to PH and MS with new onset or recurrent AF are key indications.

There are two types of commissurotomy: open and closed. Open valve commissurotomy with cardiopulmonary bypass is considered the gold standard for mitral valve stenosis repair, providing direct vision of the entire valve **[47].** Closed valve commissurotomy involves a left posterolateral or anterolateral thoracotomy at the fifth rib level, providing access to the heart without full valve visualization. This procedure can be carried out via a small thoracotomy incision with port placement and guidance from TEE **[47].**

4.4 Transcatheter Mitral Valve Replacement (TMVR): It's relatively novel but less advanced than transcatheter aortic valve replacement because of the intricate anatomy of mitral valve including asymmetric annulus, complex sub valvular apparatus and its close proximity to the LV, which is subsequently impacted by changes in LV function. A 2019 systematic review David et al, stated that the risk of heart failure can reach 31% and the 1 year-mortality rate ranged from 10% to 60% after TMVR. TEE guiding helps for accurate valve placement **[48].**

4.4.1 Tendyne TMVR prosthesis (Abbott Vascular): It's the first CE-marked tool that can be fully repositioned and retrieved (2020). It features a bioprosthetic valve, tether system and epicardial pad and is delivered via a 34 Fr transapical sheath through a minor left anterior thoracotomy. The apical pad secures the device, and the tether tension can be adjusted to lessen obstruction of the left ventricular outflow tract (LVOT) and paravalvular leakage **[49,50]**

TMVR is a successful alternative to traditional surgery for individuals with MAC leading to MS, resulting in lower morbidity, better recovery and shorter hospital stays. Functional improvement at

follow-up is correlated with improved left atrial pressure during TMVR. However, patients with significant mitral annular calcification may have different hemodynamic responses to TMVR **[51].**

4.5 Prosthetic Valve Choice: Both mechanical and bioprosthetic valves can be used for MVR but optimal choice depends on variables such as patient age or prosthesis position. The American Heart Association (AHA) recommends a mechanical valve prosthesis for patients under 50 and a biologic valve for those over 70. The European Society of Cardiology recommended surgery with mechanical valves for individuals under 65 and bio-prosthesis for patients over 70 **[52].**

Mechanical valves are preferred in younger individuals due to their longevity, reducing future reoperations. However, lifelong anticoagulation is a disadvantage, increasing bleeding and stroke risks. Bioprosthetic valves are preferred for patients unlikely to comply with long-term anticoagulation therapy but these valves are susceptible to structural damage especially in young patient groups and may require reintervention. Therefore, elderly individuals are typically better suited for bioprosthetic valves as they are less likely to outlive the valves' functional lifespan **[52].**

A meta-analysis by Yu et al., reported that patients who had their mitral valves replaced with mechanical prostheses had lower rates of long-term mortality and reoperation than those who received bioprosthetic valves. Nonetheless, there was a noticeably greater risk of severe bleeding, stroke, or systemic embolism in the group with mechanical valves. These results were true for people up to 70 years of age **[52].** A comparative summary of key interventions detailing their indications, advantages, limitations and outcomes, is shown in Table 2.

4.6 Special Considerations: MS is the most common valvular heart condition that complicates pregnancy, resulting in high incidence of maternal deaths in women with severe impairment, particularly in low to middle income nations **[53].** MS increases risk of heart failure and atrial arrhythmias during pregnancy especially in women with moderate to severe MS (MVA <1.5 cm^2), NYHA class III/IV or prior cardiac complications **[54].**

4.6.1 Pregnancy Management: For optimal outcomes by optimizing heart function and minimizing placental hypoperfusion, it requires a multidisciplinary cardio-obstetric team approach that includes expert management both before and after conception, utilizing beta-blockers and diuretics **[12].** Asymptomatic women with severe RMS (MVA≤1.5 cm2), who are planning conception, percutaneous balloon mitral commissurotomy (PBMC) prior to pregnancy with good valve morphology is recommended. PBMC is safe during pregnancy, but contraindicated in significant MR. When replacing mitral valves, consider bioprosthetic or mechanical valves due to increased risk of valve thrombosis. Complications include low birth weight, developmental delay and fetal death **[55].** MV surgery may be considered when the mother's life is at risk as it poses a significant threat to both the mother and fetus **[12].**

4.6.2 Elderly Population: In the elderly population with severe DMS, primary therapy involves regulation of heart rate and diuretic therapy; but this only offers temporary relief. Percutaneous mitral commissurotomy (PMC) is currently performed in the majority of patients with favorable valve anatomy; nevertheless, skilled surgeons may prefer open commissurotomy for younger patients with

concurrent mild to moderate mitral regurgitation **[56].** The latest ESC valvular recommendations state that PMC may even be considered in symptomatic patients with MVA >1.5 cm^2 if symptoms cannot be related to any other reason and the valve design is sound. Open surgery is risky for DMS patients with a calcified valve, especially in the elderly. Symptomatic DMS patients often require surgical mitral valve replacement (SMVR) treatment, but comorbidities could increase operative risk. Delayed intervention can worsen surgical outcomes, although long-term results may improve with SMVR before advanced symptoms appear **[56].**

Table 2: Comparison of Interventions for Mitral Stenosis Management

Intervention	Indications	Advantages	Limitations	Outcomes	References
Medical Therapy (Beta blockers and diuretics)	Symptom control in pregnancy and elderly DMS patients. Patients unsuitable for immediate intervention.	Non-invasive. Can stabilize patients before intervention.	Does not address mechanical obstruction. Only short- to medium-term symptom relief.	Temporary improvement; symptoms often recur.	[12,20,56]
PBMV	Severe rheumatic MS (MVA ≤ 1.5 cm^2) with suitable valve morphology; NYHA class II-IV patients with appropriate anatomy	Minimally invasive. Effective for symptom relief and improving maternal/fetal outcomes.	Contraindicated with significant MR. Requires suitable valve morphology.	Improved cardiac function, reduced maternal/fetal complications.	[41,42,43]
PBMC	Severe rheumatic MS (MVA ≤ 1.5 cm^2); asymptomatic women planning conception with good valve morphology; during pregnancy if indicated	Safe during pregnancy; improves valve area without open surgery	Contraindicated in significant MR	Reduces maternal and fetal risks if performed before conception	[21]
Bioprosthetic or mechanical valve replacement	When replacing mitral valves in women (general consideration)	Durable valve options	Increased risk of valve thrombosis;	Restores valve function	[12]

			need for anticoagulation		
PMC	Elderly with severe degenerative MS and favorable valve anatomy; symptomatic patients with MVA > 1.5 cm^2 if no other cause for symptoms	Less invasive than open surgery	Less suitable for calcified valves	Symptom relief in short to medium term	[56]
Open commissurotomy	Younger patients with mild–moderate MR and favorable anatomy	Allows direct repair	More invasive; higher perioperative risk	Good long-term results in selected patients	[56]
SMVR	Symptomatic DMS patients with calcified valves; when PMC not suitable	Definitive treatment	High surgical risk in elderly; mortality and morbidity risk rise with delay	Potentially improved long-term outcomes if done before advanced symptoms	[56]

Note - MVA: mitral valve area; MR: mitral regurgitation; MS: mitral stenosis; DMS: degenerative mitral stenosis, SMVR: Surgical mitral valve replacement; PMC: Percutaneous mitral commissurotomy; PBMC: Percutaneous balloon mitral commissurotomy.

5. Complications and Prognosis:

The most common complication seen in 80% of patients with MS is AF **[57].** In MS, elevated LA pressure leads to atrial cardiomyopathy and structural remodeling - a precursor to AF development. The stiffened atrial wall in MS impairs contractility, reduces atrial emptying during systole and worsens AF symptoms **[58].** Patients with MS who have AF are at high risk for the development of thrombus within the LA, occurring due to blood stasis, and these patients are at increased risk for systemic thromboembolism **[57,59].** Anticoagulants, particularly vitamin K antagonists are used to prevent thromboembolism **[59].**

A study revealed that pulmonary hypertension is another complication of MS, with a prevalence of 48.1% **[60].** Patients with MS develop pulmonary hypertension due to elevated pressure in the pulmonary circulation and reduced blood flow **[61].** Higher values of LA diameter and pulmonary artery pressures are linked to MS severity and the presence of pulmonary hypertension **[60].** MS remains asymptomatic for years. Once symptoms manifest, the prognosis rapidly worsens with a ten-

year survival rate of less than 20% in 80% of untreated individuals. PH is a complication of MS with a three-year survival rate and is accompanied by heart failure in advanced cases **[27].**

In a recent study, a 61% probability of survival without intervention at 5 years. Patients with moderate MS who underwent transcatheter aortic valve implantation (TAVI) have shown improved outcomes **[62].**

Research shows functional MS after TAVI gives a lower three-year event-free survival when compared to mild or pseudo-MS. Detection of functional MS, in which mitral valve narrowing occurs after mitral valve repair, where the mean diastolic pressure gradient across the valve is 5 mmHg or greater, which can be found using echocardiography and CT in the preoperative TAVI setting, to detect calcification and other relevant features to assess risks and plan better outcome management strategies **[63,64].**

6. Future Directions:

The diagnosis and treatment of mitral stenosis (MS) could be profoundly reshaped by new advances. Transcatheter mitral valve replacement (TMVR) is a viable alternative for high-risk surgical patients, particularly those with extensive mitral annular calcification. Early trial results employing specialized devices like Tendyne bioprosthetic valve and Intrepid valves indicate encouraging technical achievement. In individuals with MAC, surgical valve replacement carries risks such as annular rupture, trouble securing the prosthesis and potential atrioventricular disruption **[14,49,65].** Additionally, imaging is evolving; improvements in left atrial function and valve morphology can be made with 3D echocardiography and speckle tracking. These methods enhance disease severity categorization and support treatment planning in both DMS and RMS **[66,67,68].** Given the operator-dependent variability in echocardiography, future AI models should incorporate normalization techniques and operator-specific features to ensure consistent performance. Machine learning (ML) surpasses traditional methods by detecting complex, nonlinear associations and generating individualized predictions, such as risk patterns and patient-specific survival estimates. Deep Learning (DL) can be used in risk prediction and diagnosis of arrhythmias, detection of valvular disease, and estimation of ventricular function. Patterns in complex data can be detected using deep learning **[69].** AI is rapidly transforming cardiovascular imaging across modalities by automating interpretation and introducing reactive diagnostics that pave the way for proactive, personalized treatment **[70].** Surgical planning that incorporates machine learning (ML) may increase the durability of repairs and enable customized, data-driven treatment regimens. For AI tools to increase clinician confidence and become more widely accepted in the therapeutic setting, they must yield outcomes that are easy to understand. Collaboration between regulators, AI developers, and doctors is essential to establishing stringent validation protocols and ensuring safe deployment. Ultimately, combining human expertise with AI capabilities can lead to the optimization of risk categorization and the guidance of tailored treatments **[71,72].**

Conclusion: The etiology of mitral stenosis varies from rheumatic to degenerative forms in different populations, making it a major global health concern. Procedural and diagnostic imaging breakthroughs have increased therapeutic options, particularly for individuals with complicated or

high-risk anatomy. While PBMV remains the gold standard for suitable rheumatic cases, new approaches such as lithotripsy-assisted PBMV and TMVR provide promise for challenging degenerative presentations. Optimal care requires individualized assessment to balance procedure risks, comorbidities, and patient preferences. Research on long-term outcomes, the timing of interventions, and novel devices is required to improve the quality of life and survival of MS patients.

Authors' contributions:

DMP was involved in the conceptualization, design, editing and reviewing of the manuscript. AS, NMS, APK and ZF was involved with the data collection, drafting and writing of the manuscript. All authors have read, edited and approved the final manuscript.

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აბსტრაქტი

მიტრალური სტენოზი კვლავ მნიშვნელოვან სარქვლოვან გულის დაავადებად რჩება, მიუხედავად იმისა, რომ მისი შემთხვევები მსოფლიო მასშტაბით იკლებს. დაბალი და საშუალო შემოსავლის მქონე ქვეყნებში რევმატული გულის დაავადება კვლავ დომინირებს, ხოლო მაღალი შემოსავლის ქვეყნებში ასაკოვანი ადამიანები სულ უფრო ხშირად ავადდებიან მიტრალური რგოლის კალციფიკაციით გამოწვეული დეგენერაციული მიტრალური სტენოზით. დიასტოლის დროს მიტრალური სტენოზი აფერხებს მარცხენა წინაგულის გამოსავალს, რაც ზრდის მარცხენა წინაგულის წნევას და ხელს უწყობს გულის უკმარისობის, მარჯვენა პარკუჭის დატვირთვისა და ფილტვის ჰიპერტენზიის განვითარებას. ექოკარდიოგრაფია კვლავ გადამწყვეტი მნიშვნელობისაა დიაგნოზის დასმა, გართულებების შეფასება, სარქვლის სტრუქტურისა და დაავადების სიმძიმის განსაზღვრისთვის. მართვის სტრატეგიები მერყეობს თანმხლები დაავადებების, ანატომიის, ეტიოლოგიისა და პაციენტის სპეციფიკური მახასიათებლების მიხედვით. მედიკამენტური თერაპია მიზნად ისახავს თრომბოემბოლიური მოვლენების პრევენციას და სიმპტომების კონტროლს, განსაკუთრებით DMS-ის მქონე პაციენტებში. პერკუტანული ბალონური მიტრალური ვალვოტომია კვლავ რჩება რევმატული მიტრალური სტენოზის სასურველ მკურნალობად, ხელსაყრელი ანატომიით, ხოლო ახალი თერაპიები, როგორიცაა ლითოტრიფსიით მხარდაჭერილი PBMV, ეფექტურია მაღალი კალციფიკაციის მქონე სარქვლების შემთხვევაში და უზრუნველყოფს

უკეთეს შედეგებს. ქირურგიული ჩარევები, როგორიცაა კომისუროტომია, ტრანსკათეტერული მიტრალური სარქვლის ჩანაცვლება და მიტრალური სარქვლის ჩანაცვლება, გამოიყენება გართულებული სარქვლის დაავადებისა ან PBMV-სთვის შეუსაბამო კანდიდატების შემთხვევაში. სარქვლის არჩევანი მექანიკურ და ბიოპროთეზულ პროთეზებს შორის დამოკიდებულია თანმხლებ დაავადებებზე, პაციენტის ასაკსა და ანტიკოაგულაციურ თერაპიაზე. განსაკუთრებული ყურადღება ეთმობა ორსულობას, სადაც მულტიდისციპლინური მზრუნველობა და შერჩევითი ჩარევები ხელს უწყობს დედისა და ნაყოფის რისკების შემცირებას, ასევე ხანდაზმულ პაციენტებს, სადაც გათვალისწინებულია მაღალი ქირურგიული რისკი და თანმხლები დაავადებების ტვირთი. ვიზუალიზაციის, ტექნოლოგიების და პაციენტთა შერჩევის კრიტერიუმების გაუმჯობესება აფართოებს თერაპიული შესაძლებლობებს, მიუხედავად ჩარევის ოპტიმალური დროისა და გრძელვადიანი შედეგების გაუმჯობესების გამოწვევებისა.

საკვანძო სიტყვები “მიტრალური სტენოზი”; “რევმატული გულის დაავადება”; “დეგენერაციული მიტრალური სტენოზი”; “პერკუტანული ბალონური მიტრალური ვალვოტომია”; “ტრანსკათეტერული მიტრალური ვალვის ჩანაცვლება”; “რევმატული მიტრალური სტენოზი”.