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GUIDELINES AND STANDARDS

# Recommendations for the Use of Echocardiography in the Evaluation of Rheumatic Heart Disease: A Report from the American Society of Echocardiography

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Acute rheumatic fever and its chronic sequela, rheumatic heart disease (RHD), pose major health problems globally, and remain the most common cardiovascular disease in children and young people worldwide. Echocardiography is the most important diagnostic tool in recognizing this preventable and treatable disease and plays an invaluable role in detecting the presence of subclinical disease needing prompt therapy or follow-up assessment. This document provides recommendations for the comprehensive use of echocardiography in the diagnosis and therapeutic intervention of RHD. Echocardiographic diagnosis of RHD is made when typical findings of valvular and subvalvular abnormalities are seen, including commissural fusion, leaflet thickening, and restricted leaflet mobility, with varying degrees of calcification. The mitral valve is predominantly affected, most often leading to mitral stenosis. Mixed valve disease and associated cardiopulmonary pathology are common. The severity of valvular lesions and hemodynamic effects on the cardiac chambers and pulmonary artery pressures should be rigorously examined. It is essential to take advantage of all available modalities of echocardiography to obtain accurate anatomic and hemodynamic details of the affected valve lesion(s) for diagnostic and strategic pre-treatment planning. Intraprocedural echocardiographic guidance is critical during catheter-based or surgical treatment of RHD, as is echocardiographic surveillance for post-intervention complications or disease progression. The role of echocardiography is indispensable in the entire spectrum of RHD management. (J Am Soc Echocardiogr 2023;36:3-28.)

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*Keywords:* Echocardiography, Rheumatic heart disease, Valvular heart disease, Mitral stenosis, Heart failure, Pulmonary hypertension

## Abbreviations

**2DE** = Two-dimensional echocardiography

**3DE** = Three-dimensional echocardiography

**AF** = Atrial fibrillation

**AR** = Aortic regurgitation

**ARF** = Acute rheumatic fever

**AS** = Aortic stenosis

**ASD** = Atrial septal defect

**AV** = Aortic valve

**AVA** = Aortic valve area

**BSA** = Body surface area

**CMR** = Cardiac magnetic resonance

**CSA** = Cross-sectional area

**CT** = Computed tomography

**CWD** = Continuous-wave Doppler

**EF** = Ejection fraction

**EROA** = Effective regurgitant orifice area

**FAC** = Fractional area change

**GAS** = Group A $\beta$-hemolytic streptococcus

**GLS** = Global longitudinal strain

**LA** = Left atrium

**LAA** = Left atrial appendage

**LV** = Left ventricle

**LVOT** = Left ventricular outflow tract

**MR** = Mitral regurgitation

**MS** = Mitral stenosis

**MV** = Mitral valve

**MVA** = Mitral valve area

**PA** = Pulmonary artery

**PADP** = Pulmonary artery diastolic pressure

**PASP** = Pulmonary artery systolic pressure

**PBMV** = Percutaneous balloon mitral valvuloplasty

**PH** = Pulmonary hypertension

**PHT** = Pressure half-time

**PISA** = Proximal isovelocity surface area

**PR** = Pulmonic regurgitation

**PS** = Pulmonic stenosis

**PV** = Pulmonic valve

**RA** = Right atrium

**RHD** = Rheumatic heart disease

**RV** = Right ventricle

**RVOT** = Right ventricular outflow tract

**STE** = Speckle tracking echocardiography

**TAPSE** = Tricuspid annular plane systolic excursion

**TEE** = Transesophageal echocardiography

**TTE** = Transthoracic echocardiography

**TR** = Tricuspid regurgitation

**TS** = Tricuspid stenosis

**TV** = Tricuspid valve

**TVA** = Tricuspid valve area

**VC** = Vena contracta

**VTI** = Velocity-time integral

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## I. INTRODUCTION

Acute rheumatic fever (ARF) and its chronic sequela, rheumatic heart disease (RHD), are major health problems globally.[1] Worldwide, RHD is one of the most common cardiovascular diseases in children and young people under 25 years of age and remains an important cause of morbidity and mortality throughout developing countries.[1] RHD is the single most important cause of cardiac valve disease in many parts of the world. With ongoing emigration and immigration in recent decades, RHD has crossed borders and become a global burden.

While minimum echocardiographic criteria for the diagnosis of RHD and diagnostic criteria for ARF incorporating Doppler echocardiography have been published previously,[2,3] a guide to comprehensive noninvasive evaluation of rheumatic cardiac lesions is lacking. The purpose of this document is to provide recommendations for the use of echocardiography in the diagnosis, classification, and risk assessment of RHD and to help educate clinicians and sonographers worldwide on the essential role of echocardiography in the comprehensive assessment of the disease, and to provide therapeutic directions.

## II. EPIDEMIOLOGY OF RHEUMATIC HEART DISEASE

A recent report identified more than 33 million cases of RHD globally.[4] However, these statistics may under-represent the disease burden, owing to under-reporting, scarce healthcare resources, and few systematic registry programs in the low-income countries where the disease is endemic.[1] Adding echocardiography to the screening protocols leads to a much higher estimate of RHD prevalence, up to ten times more than identified by clinical screening alone.[5] The highest prevalence is found in Oceania, South Asia, and central sub-Saharan Africa.[4]

While the incidence is low in industrialized nations, ARF and RHD are not uncommon among certain indigenous populations within these countries.[6,7] In addition, new cases of RHD are being seen in industrialized nations with demographic shifts due to immigration from underdeveloped countries.[1,6] In the United States, RHD ranks 8$^{th}$ among the cardiovascular causes in terms of deaths, years of life lost, and the age-standardized mortality rate at the national level.[8]

Given the overall disease burden and the high likelihood of developing RHD from the initial episode of ARF, clinicians must make an accurate diagnosis and promptly institute appropriate antibiotic therapy as well as prophylaxis. With the recent incorporation of echocardiographic findings into the diagnostic criteria for both ARF and RHD, more subclinical cases of rheumatic carditis and RHD are being recognized.[2,3] The application of echocardiography, therefore, has a fundamental implication on modifying the worldwide burden of rheumatic carditis and RHD, its treatment, and prognosis in this globalized era.

## III. BASIC CONCEPTS OF PATHOPHYSIOLOGY, CLINICAL PRESENTATION, AND SCREENING

### A. Pathophysiology and Clinical Presentation

RHD is the long-term consequence of immune-mediated injury to the heart and cardiac valves following infection by group A $\beta$-hemolytic streptococcus (GAS), also known as *Streptococcus pyogenes* (Fig. 1A). ARF is an acute illness following the infection and usually manifests 2-4 weeks after GAS tonsillopharyngitis. Clinical presentations of ARF can be variable and may include fever, arthritis, carditis, chorea, subcutaneous nodules, and erythema marginatum. Of these, carditis is the most common presentation (50%-70%) during the first episode of ARF.[3] While acute rheumatic carditis can present as pancarditis involving the endocardium, myocardium, and pericardium, it almost always involves valvulitis, inflammation of the valvular endocardium. Subclinical carditis is defined by the presence of echocardiographically-detected valvulitis without clinical signs of carditis, and may be present in up to 53% of all cases of ARF.[9] The pathogenesis of acute rheumatic carditis is thought to be immune-mediated following GAS infection. Antibodies developed in response to GAS pharyngitis cross-react with cardiac proteins through a process termed 'molecular mimicry'.[10] The subsequent autoimmune response causes the major manifestations of ARF. The presence of ARF in only a subset of children untreated for streptococcal pharyngitis and the fact that only a minority of the affected children develop RHD also suggest a possible role of host susceptibility.[11] Aschoff bodies (Fig. 1B), the pathognomonic lesions of the rheumatic process that form in the endocardium of the heart valve and in the myocardium, are thought to be sites of granulomatous inflammation as a result of T lymphocyte-mediated delayed hypersensitivity against GAS antigens.[12] Damage to cardiac valves may be progressive, ultimately resulting in RHD, the chronic sequela of carditis, with the development of valvular stenosis and regurgitation, pulmonary hypertension (PH), and heart failure. Thus, the immune-mediated injury responsible for acute rheumatic carditis is dependent mainly on a triad of factors: infection with GAS, a susceptible host, and an aberrant host response.

### B. Echocardiographic Screening in Acute Rheumatic Fever

Echocardiography significantly enhances the diagnostic yield of carditis in suspected cases because mild and moderate pathological valvular regurgitations may be missed with auscultation alone. This is important because a longer duration of secondary prophylaxis is recommended to prevent the recurrence of rheumatic fever in patients with valvulitis.[13] In 2015, the use of echocardiography was formally incorporated into the revised Jones criteria as a tool to diagnose rheumatic carditis, with subclinical carditis (or echocardiographic valvulitis) recognized as a major criterion for diagnosis of ARF.[3] Handheld point of care cardiac ultrasound (cardiac POCUS)

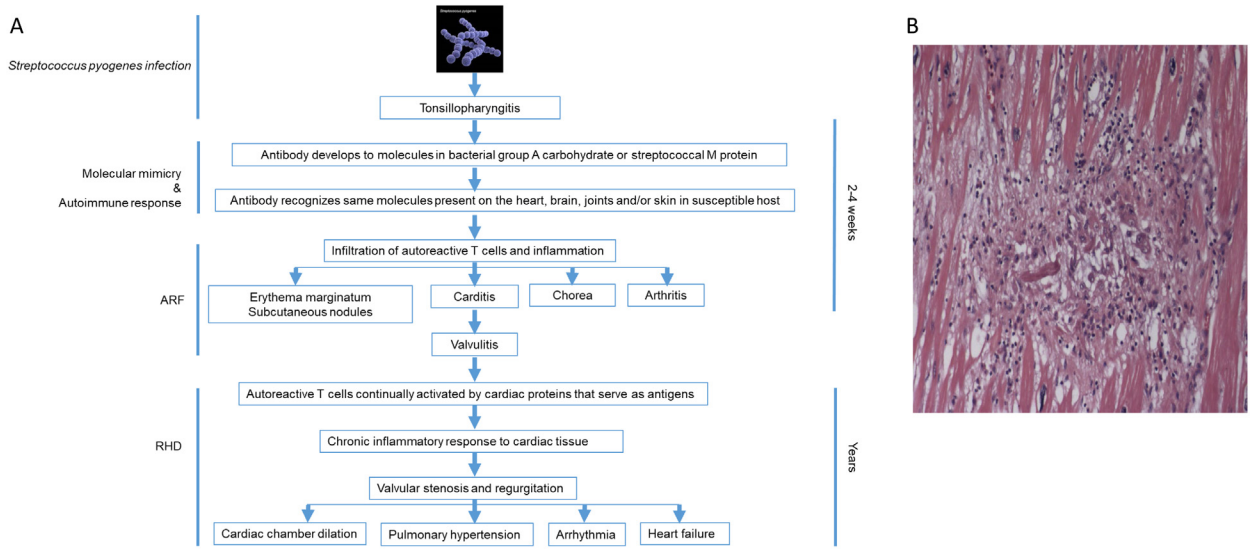


**Figure 1** **(A)** Illustration of pathophysiology and clinical presentation of acute rheumatic fever (ARF) and rheumatic heart disease (RHD). **(B)** Hematoxylin-eosin staining of Aschoff bodies present in myocardium.

instruments are highly portable and less expensive than standardard cardiac ultrasound equipment and pose a promising alternative to enhance diagnosis of RHD.[14] It may be a reasonable alternative to use POCUS for screening in areas of low resources, but POCUS may not provide comprehensive information. Left-sided valve involvement is the most common pathology, as isolated pulmonary or tricuspid regurgitation (TR) is seldom rheumatic in origin. Two types of echocardiographic findings have been proposed to diagnose rheumatic valvulitis: [1] pathological mitral regurgitation (MR) and/or aortic regurgitation (AR) (Fig. 2A) and [2] morphological changes of valvulitis in the mitral valve (MV) and aortic valve (AV) (Fig. 2B-D).[3]

In healthy children, trace physiological regurgitation may be observed in all cardiac valves. More than trace AR or MR in children should be considered pathological and may indicate rheumatic carditis or RHD, provided non-rheumatic causes are excluded. For a regurgitant jet to be considered abnormal, the flow jet should produce a complete continuous-wave Doppler (CWD) spectral waveform. Specifically, pansystolic MR or pandiastolic AR seen in more than 1 view with peak velocity >3 m/s, should be considered significant in at-risk populations. MR occurs in 84-94 % of cases of acute rheumatic carditis, with the jet usually directed posterolaterally due to involvement of the anterior mitral leaflet.[15]

Morphological valvular changes take time to develop and may be absent in the early phase of ARF. When present, valvular thickening with or without restricted leaflet mobility is the most common morphological echocardiographic feature in patients with rheumatic carditis.[15] Such thickening is often seen at the free edge of the leaflet (Figs. 2B and 2C). The MV is most commonly involved in a first as well as recurrent episode of carditis. Nodularity, or beading, along the length of the leaflet can be seen. Measurement of valve thickness should be performed with tissue harmonics turned off as this modality increases apparent tissue thickness.[16] Normal ranges of MV and AV thickness in healthy individuals have been established, and are noted to be increased with aging.[2,17] Normal MV thickness is <3 mm in healthy children and <3.5 mm in adults.[18,19] The AV cusps are thinner, with the mean thickness ranges by age as follows: <20 years of age: 0.67 ± 0.21 mm; 20-59: 0.87 ± 0.27 mm, and >60: 1.42 ± 0.51 mm.[17]

Serial echocardiography should be performed in patients diagnosed with or suspected to have ARF, as the cumulative incidences of ARF recurrence and RHD at 10 years are as high as almost 20 % and 51.9 %, respectively.[20] Currently, there is a lack of systematic prospective scientific studies to make specific recommendations on the frequency and duration of serial echocardiograms after the diagnosis of ARF. Recommended frequency of echocardiograms in patients with established valvular heart disease, including chronic RHD, has been previously published.[21,22]

## Key Points

- RHD is the long-term consequence of ARF.
- Rheumatic carditis from ARF is due to immune-mediated injury to the heart following group A β-hemolytic streptococcus (S. pyogenes) infection, with antibodies developed in response to streptococcal pharyngitis subsequently cross-reacting with cardiac proteins in a susceptible host.
- Valvulitis is the most consistent feature of rheumatic carditis and commonly associated with mitral or aortic valve regurgitation.
- Echocardiographic evidence of valvulitis is a major criterion in the diagnosis of subclinical carditis.

## Recommendations

- More than trace AR or MR in children should be considered pathological and may indicate rheumatic carditis or RHD, provided non-rheumatic causes are excluded.
- Pathological valvular regurgitation suggesting carditis should include pansystolic MR or pandiastolic AR seen in more than 1 view with peak velocity >3 m/s in at-risk populations.
- Measurement of valve thickness should be performed with tissue harmonics turned off as this modality increases apparent tissue thickness.

## IV. RHEUMATIC VALVE LESIONS

### A. Mitral Stenosis

RHD is the most common global etiology of mitral stenosis (MS), and MS is, in turn, the most common chronic debilitating lesion of RHD.[23] MV thickening and commissural fusion result in a progressive reduction in mitral valve area (MVA). Calcification of the valve and annulus is often noted in chronic severe MS. As MVA (normally 4-6 $cm^2$ in adults) progressively narrows to less than 2.5 $cm^2$, the pressure in

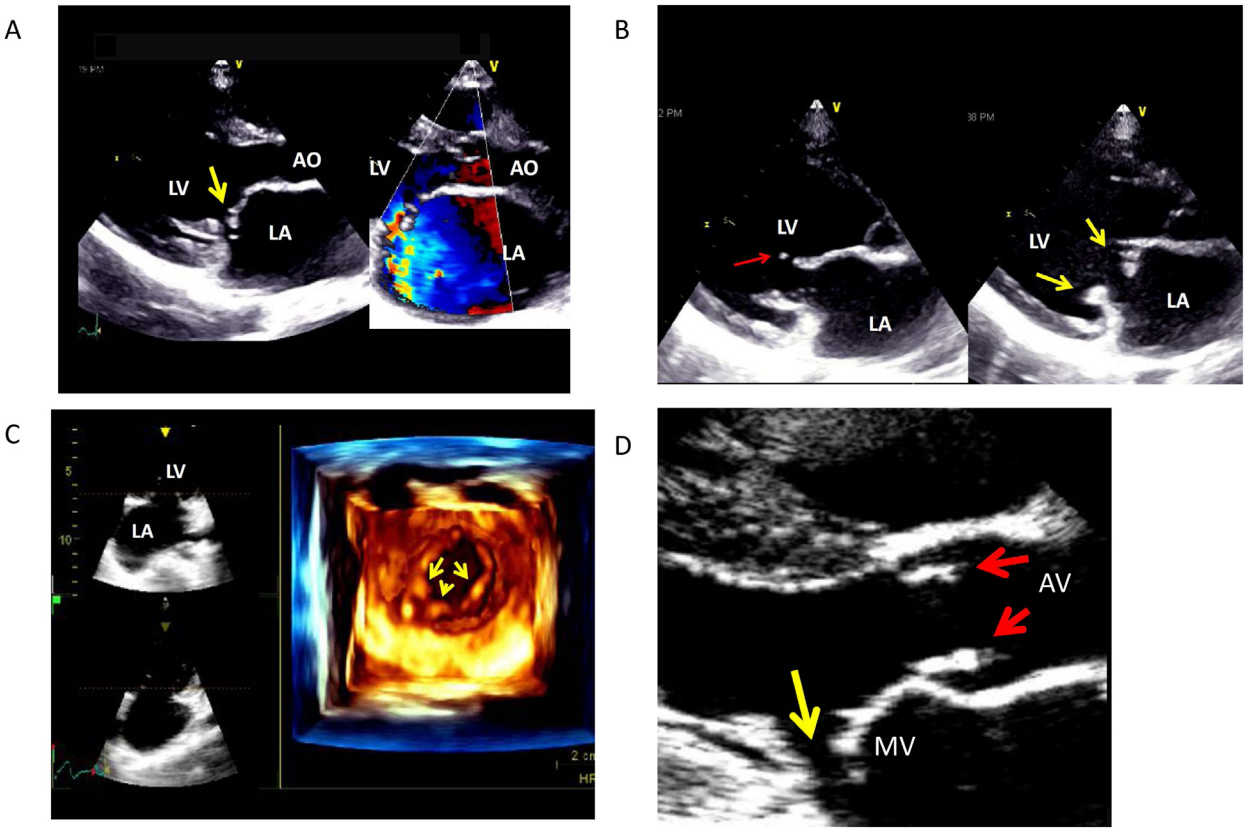


Figure 2 Example of rheumatic mitral valvulitis. **(A)** Transthoracic echocardiographic parasternal long-axis views in a 10-year-old boy with recent onset dyspnea, showing flail anterior mitral leaflet *(arrow in left panel)* and severe mitral regurgitation *(right panel)*. **(B)** Parasternal long-axis view in different phases of diastole in the same patient. Note the chordal tear *(red arrow)* and nodular thickening of both leaflets *(yellow arrows)*. **(C)** 3D en-face view of the mitral orifice at the level of leaflet tips showing nodular thickening of both leaflets *(arrows)* in diastole in the same patient. **(D)** Parasternal long-axis view in systole demonstrating nodular thickening of the aortic leaflets *(red arrows)* in addition to the aforementioned mitral valve findings *(yellow arrow)*.

the left atrium (LA) starts to rise, causing LA remodeling, and leading to increased pulmonary venous pressure (causing symptoms of dyspnea and hemoptysis), and eventually pulmonary artery (PA) pressure elevation. LA pressure rises further, and symptoms are accentuated by factors that increase transmitral flow, such as high cardiac output and shortened diastolic filling time, seen with exercise, fever, pregnancy, hyperthyroidism, anemia, or atrial tachyarrhythmia.

While no single index value should define the severity of MS because of its progressive nature in a disease continuum, given that valve obstruction is the primary cause of hemodynamic and clinical sequelae, MVA is one of the main indicators of severity. In general, patients with MVA greater than 2.5 $cm^2$ are asymptomatic, while those with MVA between 1.5 – 2.5 $cm^2$ may exhibit mild symptoms.[24] MVA less than 1.5 $cm^2$ is considered severe MS.[24,25] When grading MS severity, a multi-parametric approach should be used, including valve area, pressure half-time (PHT), transmitral mean pressure gradient, and pulmonary pressures, taking into account both anatomic and hemodynamic consequences of the pathophysiology of MS (Table 1, Fig. 3). Agreement among these measurements increases the reliability of determining the severity of MS. When these measured variables are inconsistent, stress echocardiography (exercise or dobutamine) aids in assessing the hemodynamic severity of MS. Based on the World Heart Federation criteria, the definition of rheumatic MS requires a transmitral mean pressure gradient $>$ 4 mmHg and at least two morphological changes consistent with a rheumatic MV (Table 2).[2]

***A.1 Anatomic Considerations in the Assessment of Mitral Stenosis.*** Anatomic appraisal of MS requires careful assessment of valvular morphology and associated abnormalities (Table 2). These observations have therapeutic implications when percutaneous balloon mitral valvuloplasty (PBMV) or surgery is considered. The rheumatic involvement of the MV has characteristic morphologic features (Fig. 4A-D, Video 1-4), which include (1) commissural fusion, (2) leaflet thickening with or without calcification, (3) restricted leaflet motion, resulting in a typical "hockey-stick" or "doming" appearance of the anterior mitral leaflet during diastole, and (4) chordal thickening and shortening.

Two-dimensional (2D) and three-dimensional (3D) echocardiography in various views allow for assessment of thickening and calcification of the mitral leaflets. Diastolic doming of the anterior leaflet is best seen in long-axis views, while the restricted motion of the posterior mitral leaflet and commissural fusion (the main mechanism of obstruction), with a small central oval orifice and a "fish-mouth" appearance, are better appreciated in the short-axis orientations. Chordal thickening, shortening, and fusion are visualized in parasternal long-axis and apical views. It is important to pay attention to the extent of leaflet and commissural calcification, as it predicts the

success of PBMV (discussed further in Section V.D.) and may introduce a potential error in measuring MVA by planimetry.

There are important considerations and potential sources of error in direct planimetry of the MVA (Fig. 5A). When measuring MVA by planimetry, the short-axis imaging plane should be positioned at the tip of the valve to avoid overestimation (Fig. 5B-C, Video 5). Imaging the subvalvular region in a short-axis view and slowly tilting the transducer to the level of the valve tip is helpful. 3D echocardiography (3DE) allows for visualization of stenotic valve area both from the LA and left ventricle (LV) (Fig. 6A, Video 6-7). 3DE is particularly useful for measuring MVA in an eccentrically oriented or irregularly shaped MV orifice, as multiplanar imaging can determine the correct short-axis orientation parallel to the MV orifice at the level of the leaflet tips to measure the MVA from the ventricular side (Fig. 6B). 3DE is more accurate and reproducible than 2D echocardiography (2DE) for MVA by planimetry, and provides more precise imaging of the commissural fusion.[26] MVA has been thought to change with flow, a concept based on the invasive Gorlin equation method, influencing "functional" MVA. However, there is echocardiographic evidence that the anatomic MVA is not influenced by changes in flow in moderate and severe MS.[27]

If the diagnosis of rheumatic MS is in question, looking for the presence of commissural fusion in the parasternal short-axis view helps confirm a rheumatic process, as commissural fusion is a characteristic feature of rheumatic MS. Calcification of the mitral annulus is a common finding in elderly patients with atherosclerosis. When caused by annular calcification, stenosis is rarely more than mild unless annular calcification is extensive and involves the basal parts of the leaflets. In contrast, rheumatic MS involves predominantly the tips and margins of the leaflet. Congenital MS is a rare abnormality that occurs in isolation or in association with other congenital heart diseases. Although the thickening and restricted motion of the margin of the mitral leaflet may be seen in congenital MS, multiple segments of the mitral apparatus (tendinous chords, interchordal spaces, and papillary muscles) are usually involved, and commissural fusion is rare. The position, number, and size of papillary muscles, best seen in the parasternal short-axis view, are important to note in differentiating parachute mitral valve from rheumatic MS.

***A.2. Hemodynamic Considerations in the Assessment of Mitral Stenosis.*** Hemodynamic appraisal of MS requires assessment of MV pressure gradient, calculation of MVA by PHT,[28] and estimation of left and right atrial and PA pressures (Fig. 7). Significant PH as a consequence of MS can lead to increased pressure in the right ventricle (RV) and right atrium (RA), enlargement and dysfunction of the RV and RA, functional TR, and signs of systemic venous congestion (dependent edema and hepatic congestion). Systolic and diastolic function of the LV is generally normal but can be compromised by myocardial dysfunction due to chronic rheumatic myocarditis or other causes of LV dysfunction.

The transmitral pressure gradient is measured from the apical window by using CWD aligned coaxially with mitral inflow. The CWD spectral display of mitral inflow yields the [1] velocity-time integral (VTI) of transmitral flow, [2] mean transmitral pressure gradient derived from the VTI, and [3] PHT (Fig. 8A). Transmitral pressure gradients are flow- and heart rate-dependent, and should not be relied upon as the only parameters to assess MS severity. High output states or concurrent MR causes a disproportionate increase in the transmitral flow velocity and pressure gradient. The rhythm and heart rate should be noted and reported.

**Table 1** Classification of Mitral Stenosis Severity

| | Progressive | | |
|---|---|---|---|
| | (Mild) | (Moderate) | Severe |
| Valve area ($cm^2$) | >2.5 | 2.5-1.6 | ≤1.5 |
| Pressure half-time (milliseconds) | <100 | 100-149 | ≥150 |
| Mean gradient (mmHg)* | <5 | 5-9 | ≥10 |
| Systolic pulmonary artery pressure (mmHg) | <30 | 30-49 | ≥50 |

*At a heart rate of 60-80 beats per minute

PHT represents the time required for the instantaneous pressure gradient to decrease by half from its peak value at early mitral inflow. The velocity at which the gradient declines to one-half of its peak is equal to 0.7 x peak velocity. PHT is entered into the equation for calculation of MVA as follows:

$$\text{MVA } (\text{cm})^2 = 220 \,/\, \text{PHT}$$

The rate of decay of the MV pressure gradient is a measure of the severity of MS and is inversely proportional to MVA. The PHT method is easy to perform, provided that the Doppler signal of transmitral flow is of good quality with a well-defined linear deceleration slope of the E wave. When the deceleration slope is bimodal with a rapid decay followed by a more gradual decay, the deceleration slope should be traced in mid-diastole, rather than using the early steep deceleration slope (Fig. 8B).[29] Compared with planimetry, the PHT method yields a smaller MVA when extensive subvalvular disease increases the LA-LV gradient to more than the pressure drop across the leaflet tips. PHT estimates functional valve area from the pressure decay between the LA and LV. Therefore, any factor affecting LA and LV compliance or LV diastolic pressure, such as LV hypertrophy, concurrent AR, or LA fibrosis, may change the result obtained by PHT. In addition, the presence of significant MR reduces the reliability of PHT-derived MVA, with the risk of underestimated valve area. PHT is misleading immediately after PBMV.

The continuity equation assumes that the volume of forward flow across the MV is equal to the volume of flow across a reference valve (typically the AV). MVA by continuity equation is based on the ratio between the stroke volume in the left or right ventricular outflow tract and the VTI of mitral inflow:

$$\text{MVA } (\text{cm}^2) = \text{CSA}_{\text{LVOT}} \times \text{VTI}_{\text{LVOT}} \,/\, \text{VTI}_{\text{Mitral}}$$

where CSA is the cross-sectional area and LVOT stands for left ventricular outflow tract. The reproducibility of this method is limited by potential errors from multiple measurements and assumptions. The continuity equation, although able to calculate MVA theoretically, is not well validated and is infrequently used. The continuity equation should not be used when significant aortic or mitral regurgitation is present. If there is only AR, aortic parameters should be replaced with the flow across the pulmonic valve (PV) and CSA of the right ventricular outflow tract (RVOT):

$$\text{MVA } (\text{cm}^2) = \text{CSA}_{\text{RVOT}} \times \text{VTI}_{\text{RVOT}} \,/\, \text{VTI}_{\text{Mitral}}$$

The proximal isovelocity surface area (PISA) method is based on the concept that, as flow approaches a circular finite orifice,

| | Mild | Moderate | Severe |
|---|---|---|---|
| MVA ($cm^2$) | > 2.5 | 2.5 - 1.6 | ≤1.5 |
| PHT (msec) | < 100 | 100 - 149 | ≥ 150 |
| MG (mmHg) | < 5 | 5 - 9 | ≥ 10 |

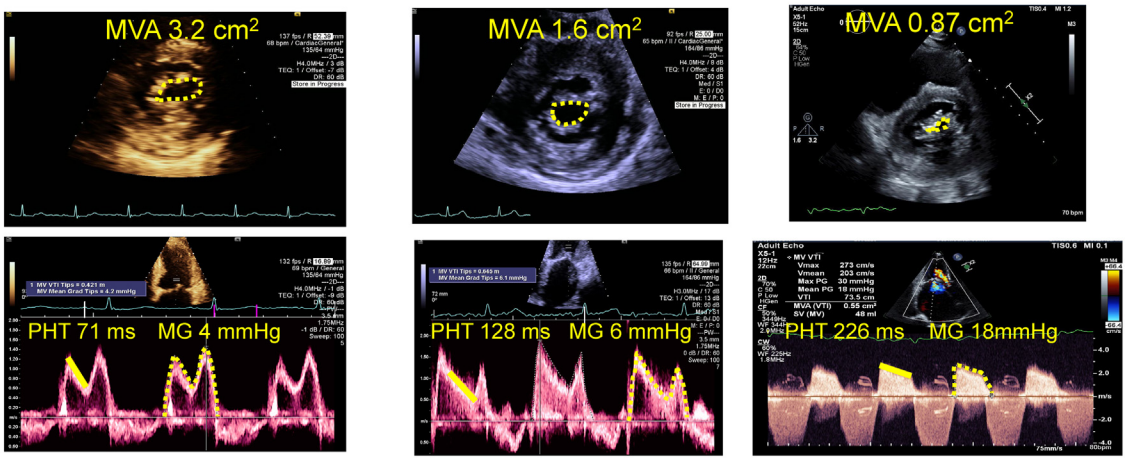


Figure 3 Stages of mitral stenosis by echocardiographic parameters. *MVA*, Mitral valve area; *PHT*, pressure half-time; *MG*, mean gradient.

concentric hemispherical "isovelocity shells" are formed with gradually decreasing surface area and increasing velocity. Although the first validated PISA method was for MR, it can also be used to assess MS.[30] The PISA method assumes that flow across the stenotic orifice equals flow at the level of the convergence zone. As blood flow accelerates when it approaches the stenotic orifice in diastole, the color Doppler Nyquist limit is surpassed, creating aliased isovelocity hemispheres with a bright blue hue (Fig. 8C). The method is technically demanding and requires multiple measurements. The typically funnel-shaped opening of the rheumatic MV, with the angle between the leaflets less than 180°, renders the flow convergence zone non-hemispheric. Therefore, angle correction in the formula is needed for most cases of rheumatic MS, a step that may be impractical in clinical application. Overall, MVA assessment via the PISA and continuity equation methods are not recommended in routine practice due to the complexity of the equations and multiple sources of error. However, they may be considered in patients with inconclusive data from 2D planimetry, PHT, and mean pressure gradient methods.

In patients with atrial fibrillation (AF) and irregular cycle lengths, at least 5 measurements should be averaged to provide an accurate estimation of pressure gradients and valve area, avoiding extremely short and long cycle lengths. If the rhythm is highly irregular with multiple short cycles, measurement of the gradient in the long-cycle beat alone is sufficient.

Rheumatic MS is a slowly progressive disorder with an insidious natural history. The patient may be compensated and remain relatively asymptomatic at baseline despite the hemodynamic limitations posed by the stenosis. In some cases, this is due to patients limiting their activity. When imaging data and symptoms do not correlate with each other, stress echocardiography is useful to assess the functional significance of MS. Stress-induced increase in heart rate and cardiac output allows evaluation of the hemodynamic behavior of the valvular obstruction and its influence on the pulmonary circulation, helps clarify any discordance between resting echocardiographic data and symptoms, and aids in risk stratification of patients with moderate stenosis. The exercise portion of the test may be performed using simple alternate leg raising, a recumbent bicycle, or a treadmill. If a patient is unable to exercise, dobutamine stress echocardiography can be employed.[31] Echocardiographic data to be obtained during stress testing include transmitral gradient, stroke volume, MVA, pulmonary artery systolic pressure (PASP; based on TR velocity and estimated RA pressure), LV and RV function, and any change in MR if present. Heart rate change should be reported. An increase in transmitral mean gradient >15 mmHg with exercise or ≥18 mmHg with dobutamine infusion may explain exertional dyspnea due to hemodynamic consequences of MS and identify high-risk patients who may benefit from intervention.[32,33] A stress-induced PASP >60 mmHg has been considered another marker of hemodynamically significant MS.[34] However, resting and exercise-induced PASP is age-dependent,[35] and post-exercise PASP has been shown to

Table 2 Anatomic/Morphological Parameters in the Echocardiographic Assessment of Mitral Stenosis

| Valvular Findings | Associated Findings |
|---|---|
| • Extent and pattern of commissural fusion<br>• Degree and extent of valve thickening and calcification<br>• Degree of subvalvular abnormalities<br>• Severity of valve narrowing (valve area and transvalvular gradient) | • Left atrial size<br>• Presence of thrombi and/or spontaneous echo contrast ("smoke") in the left atrium and/or appendage<br>• Right ventricular and atrial size<br>• Other co-existent abnormalities (e.g., multivalvular disease) |

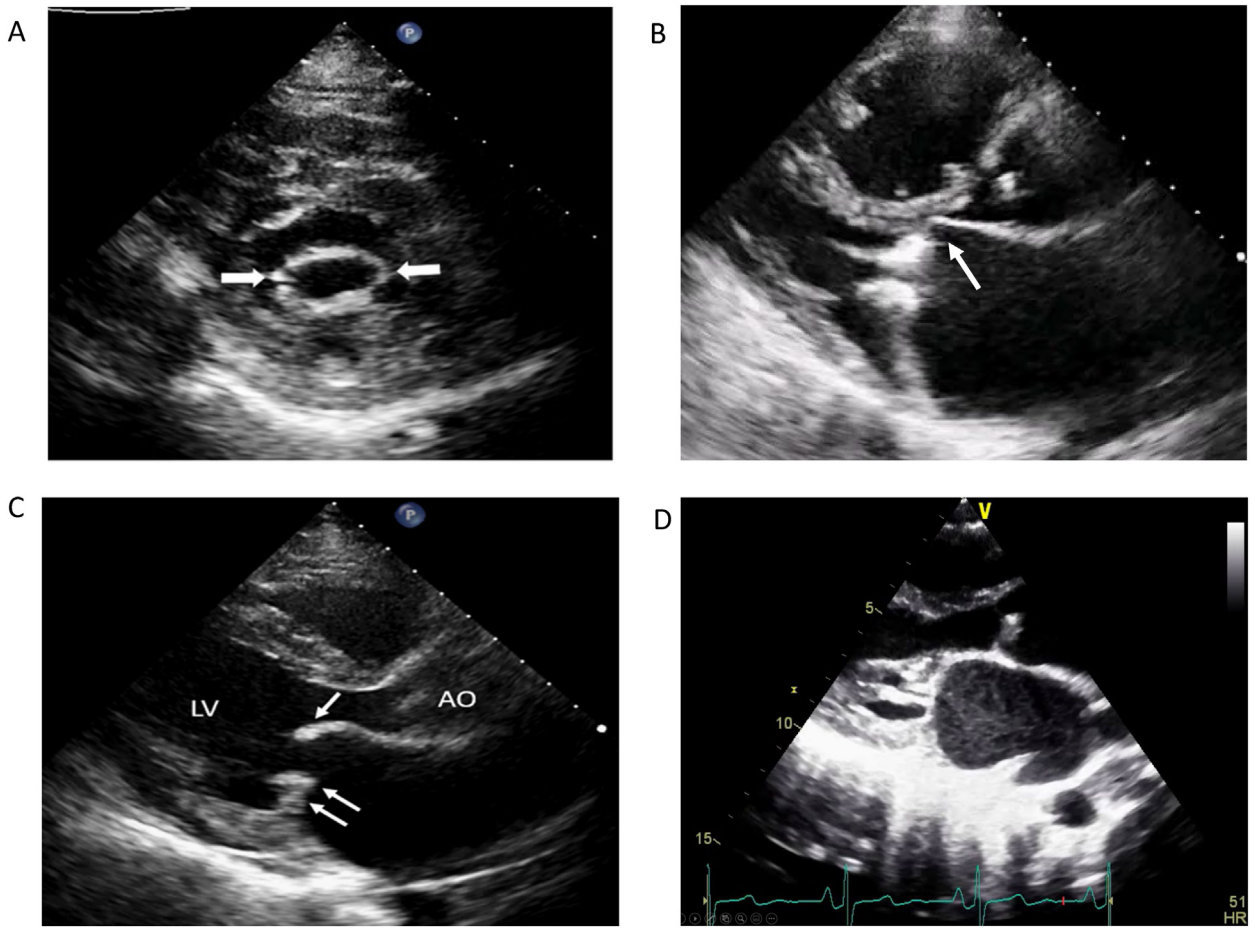


Figure 4 2D echocardiographic findings of MS. **(A)** Bi-commissural fusion *(arrows)* of a rheumatic valve in parasternal short-axis view. **(B)** Thickened and calcified mitral valve leaflets seen in parasternal long-axis view, with diastolic doming of the anterior leaflet *(arrow)*. **(C)** Thickened and doming mitral anterior leaflet *(single white arrow)* and restricted motion of posterior leaflet *(double arrows)* in parasternal long-axis view. **(D)** Chordal thickening and calcification seen in parasternal long-axis view.

correlate poorly with the onset of symptoms.[36] Therefore, PASP at peak exercise should be interpreted in the context of age and other diagnostic indices discussed above. An early increase in PASP to a value >90 % than its resting value may also have prognostic implication.[36]

***A.3. Mitral Stenosis in Pregnancy.*** Severe MS in pregnancy is associated with a significant risk of morbidity and mortality in both mother and fetus. Pregnancy is associated with a significant increase in plasma volume, cardiac output, and heart rate. This results in an increase in transmitral gradient even in moderate MS while the anatomic MVA may not significantly change. Interpretation of the gradient and MVA and their implications should be done in each patient's clinical context.

## Key Points:

- Rheumatic MS is defined by a transmitral mean pressure gradient >4 mmHg and typical morphological changes in the valve consistent with a rheumatic process: thickened mitral leaflets, commissural fusion, restricted MV leaflet motion, diastolic doming of the anterior mitral leaflet, and/or chordal thickening/calcification.
- Severe rheumatic MS is indicated by MVA ≤1.5 $cm^2$, PHT ≥150 msec, and transmitral mean gradient ≥10 mmHg.

## Recommendations:

- MS should be evaluated in a comprehensive approach, including a careful examination of valve morphology with 2DE, accurate determination of MVA by planimetry at the level of the leaflet tips, with 3DE multiplanar guidance if needed, hemodynamic assessment with Doppler echocardiography to determine PHT and mean pressure gradient, and supportive data, such as pulmonary artery pressure estimation and left atrial size.
- Planimetry is the preferred method for determination of anatomic MVA. The imaging plane should be positioned at the leaflet tips, and the smallest orifice area should be traced in zoom mode, with an optimized gain setting to avoid signal "drop-out".
- Excessive gain, which can result in MVA underestimation, should be avoided.
- The cardiac rhythm and heart rate should be noted as part of Doppler assessment of MS.
- When the CWD spectral pattern of mitral inflow is bimodal with an initial rapid deceleration followed by a slower rate of decline, the linear portion of the mid-diastolic slope should be traced for PHT, rather than using the early steep deceleration slope.
- Stress echocardiography should be considered in patients whose symptoms are incongruent with echocardiographic data and for risk stratification of patients with MS. A transmitral mean gradient >15 mmHg during exercise echocardiography (or ≥18 mmHg during dobutamine echocardiography) should be considered hemodynamically significant rheumatic MS and identifies patients who might benefit from intervention.

### B. Rheumatic Mitral Regurgitation

Rheumatic MR is caused by incomplete leaflet coaptation due to thickening and scarring of the leaflets as well as chordal shortening that restricts the motion of the leaflets in systole. MR is the most

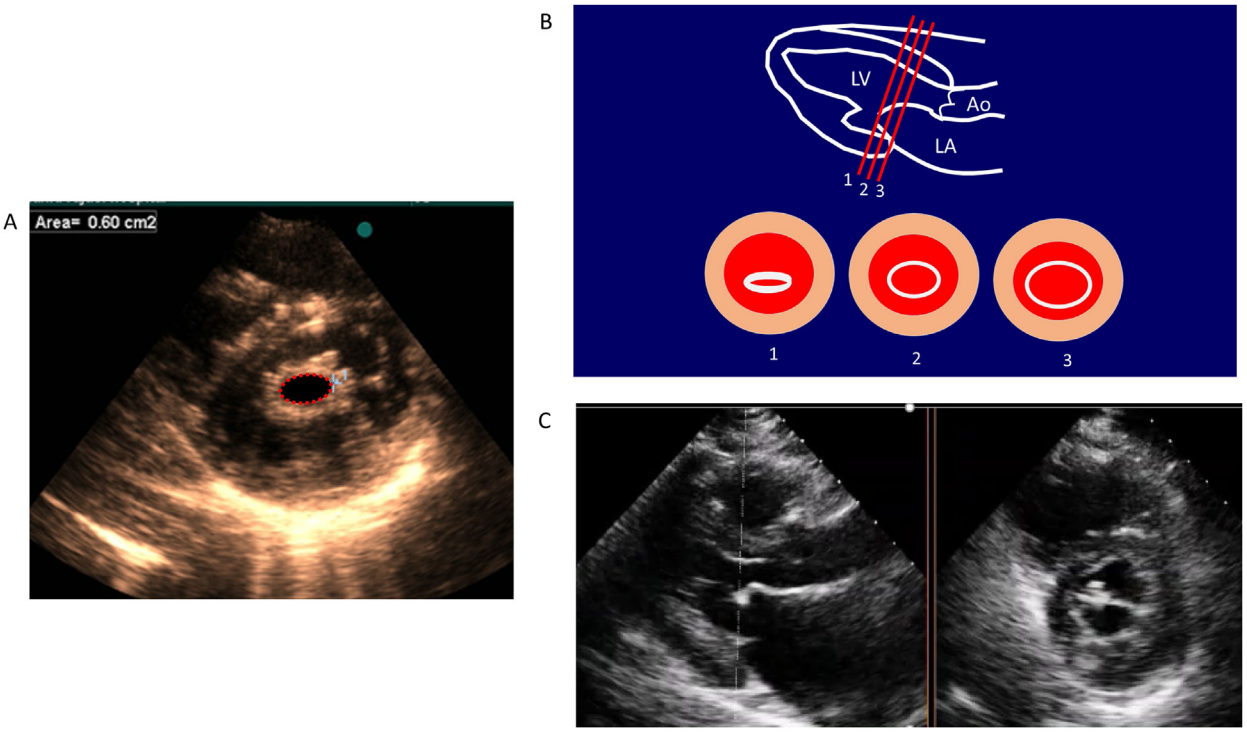


Figure 5 **(A)** Mitral valve area measurement by planimetry at the leaflet tip level in parasternal short axis. **(B)** Illustration of potential overestimation of mitral valve area when the short-axis imaging plane is not at the mitral leaflet tips. **(C)** Orthogonal (bi-plane) views to ensure that the short-axis imaging plane for planimetry of the valve area is at the tip of the valve to avoid overestimation.

frequent valvular abnormality in RHD.[37] The echocardiographic evaluation of rheumatic MR should follow previously published guidelines on native valvular regurgitation.[38] MR is considered severe with a vena contracta (VC) ≥0.7 cm, VC area ≥0.40 $cm^2$, regurgitant volume ≥60 mL, regurgitant fraction ≥50 %, and regurgitant orifice ≥0.40 $cm^2$.[38]

***B.1. Anatomic Considerations in the Assessment of Rheumatic Mitral Regurgitation.*** The first step in the approach to patients with MR is to evaluate the morphology of the valve and to determine whether the etiology of the MR is primary or secondary. 2D transthoracic echocardiography (TTE), and transesophageal echocardiography (TEE) in the case of nondiagnostic TTE, play a key role in the assessment of the MV structure and the hemodynamic effects of MR on the cardiac chambers. In general, MR is classified as primary (or organic) if the regurgitation results from the abnormality of the MV proper, or secondary (or functional) if regurgitation is caused by distortion of the MV apparatus due to LV and/or LA remodeling.[22,38]

In young individuals with a predominantly regurgitant rheumatic MV or those with acute rheumatic carditis, excessive leaflet tip motion can be seen because of elongation or restriction and thickening of the primary chords, with displacement of the leaflet tips toward the LA, leading to incomplete leaflet apposition and resulting MR (Fig. 9). Excessive leaflet tip motion is less common beyond the third decade of life as MS becomes predominant.

Rheumatic MR is pathological regurgitation of the MV with at least two morphological features of a rheumatic MV in the absence of other etiologies (Table 2).[2] The revised Jones criteria note that MR is considered pathological when [1] a holosystolic jet is seen in at least 2 views, [2] jet length is ≥2 cm in at least one view, and [3] peak MR velocity is ≥3 m/s (Fig. 10).[3] However, the jet length or the regurgitant velocity does not necessarily reflect the severity.

3DE with real-time volumetric imaging enhances the echocardiographic characterization of anatomic pathology behind MR. It is particularly useful for investigating the regurgitant orifice or guiding surgical planning or interventional mitral procedures. Combined with color Doppler, 3DE provides an accurate and reliable measurement of MR severity and has been demonstrated to correlate well with cardiac magnetic resonance (CMR) imaging.[39] 3DE better predicts surgical repair feasibility and complexity,[40] and, combined with color Doppler, has the ability to determine the origin, extent, and trajectory of the regurgitant jet. The VC area measured by 3DE provides a semi-quantitative method to estimate significant MR. (Fig. 11)

***B.2 Hemodynamic Considerations in the Assessment of Rheumatic Mitral Regurgitation.*** MR from RHD develops over years and is typically not acute unless there is concurrent infective endocarditis or other trauma to the valve. Rheumatic MR jets may be central or eccentric. Eccentric jets are often due to a pseudo-prolapsing anterior leaflet that appears to slide over the posterior leaflet, which is restricted by valvular and chordal thickening and shortening (Fig. 9). The hemodynamic aspects of rheumatic MR should follow the same principles detailed in the previous American Society of Echocardiography (ASE) recommendations on native valvular regurgitation.[38]

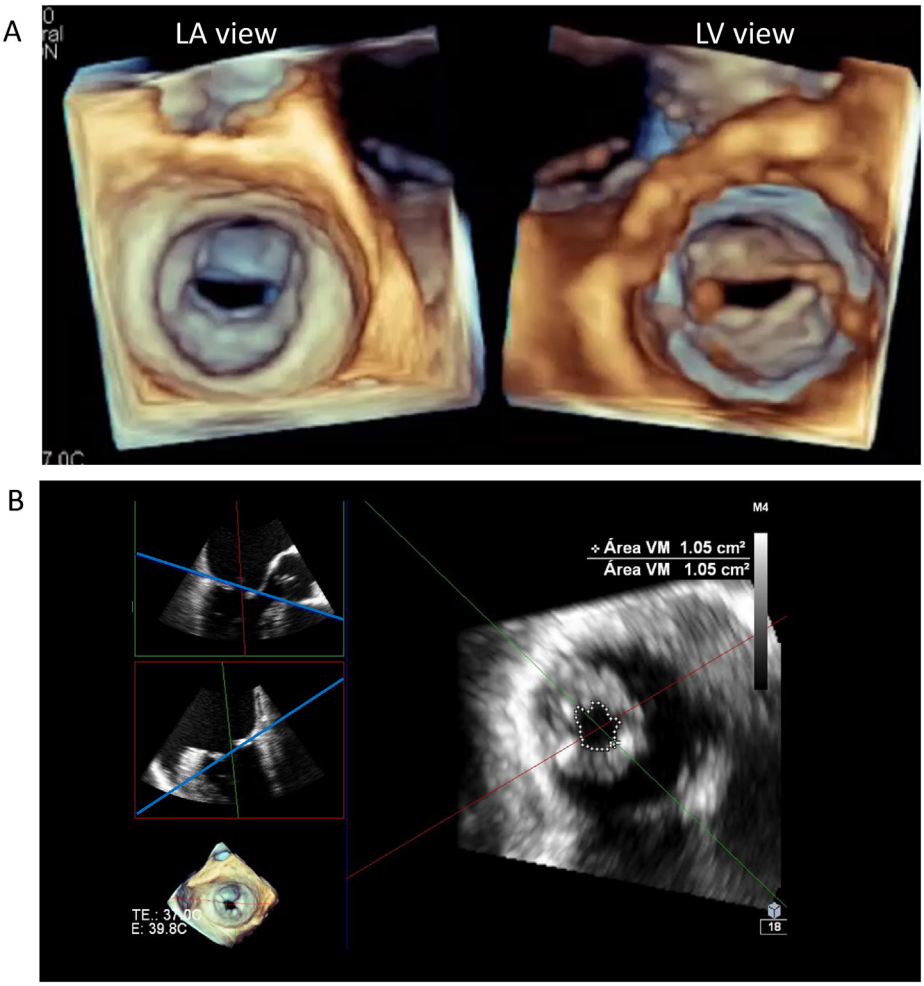


Figure 6 3D echocardiography of rheumatic MV. **(A)** Visualization of stenotic valve area from left atrial (LA) and left ventricular (LV) views. **(B)** Multiplanar imaging to guide the imaging plane *(blue line)* at the mitral valve tip for planimetry of irregularly shaped MV opening.

## Key Points:

- An integration of multiple parameters is essential to examining rheumatic MR.
- Severe rheumatic MR is indicated by a VC ≥0.7 cm, VC area ≥0.40 $cm^2$, regurgitant orifice area ≥0.4 $cm^2$, regurgitant volume ≥60 mL, and regurgitant fraction ≥50 %.
- Quantitative indices include effective regurgitant orifice area (EROA) by PISA, regurgitant volume (using the PISA-derived method, continuity equation, or by 3DE), and regurgitant fraction (a ratio of regurgitant volume to forward stroke volume).[38]
- Semiquantitative parameters include VC, which is relatively unaffected by loading conditions and may be used with eccentric MR jets (common in RHD), VC area by 3DE color Doppler, and mitral to aortic valve VTI ratio (>1.4 suggests severe MR and <1 indicates mild MR[41] in the absence of moderate or severe aortic valve regurgitation).
- Supportive data include mitral inflow peak E velocity, mitral inflow E/A ratio, pulmonary venous flow pattern, CWD profile of the MR jet, and LA and LV size.

## Recommendations

- A quantitative approach should be used when more than moderate central MR is observed.
- Quantification of MR severity by VC and the PISA method should be included in the assessment of rheumatic MR, whenever feasible.
- 3DE with real-time volumetric imaging should be attempted whenever feasible, as it adds to the echocardiographic characterization of anatomic pathology of MR. Combined with color Doppler, 3DE is superior to traditional 2D PISA measurement of MR severity and provides an accurate VC area.

### C. Rheumatic Aortic Valve

Rheumatic AV involvement almost always occurs in the presence of rheumatic MV disease. Regurgitation is more common (47 %) than stenosis (14 %) in rheumatic AV disease.[37] Basic echocardiographic parameters to assess aortic stenosis (AS) include peak transvalvular jet velocity, mean pressure gradient, and AV area (AVA), as detailed in the previous recommendations.[42] General principles of data recording and measurements for quantitation of AS apply to rheumatic AS. Severe AS is suspected when transaortic flow Vmax ≥4 m/s, mean pressure gradient ≥40 mmHg, AVA <1 $cm^2$, indexed AVA <0.6 $cm^2/m^2$, and the ratio of LVOT velocity and AV velocity <0.25.

***C.1. Anatomic Considerations in the Assessment of Rheumatic Aortic Valve.*** Rheumatic AV disease is characterized by commissural fusion, fibrotic thickening, and retraction of the leaflet edges, giving a triangular or rounded orifice in systole (Fig. 12A-C, Video 8-10). Varying degrees of calcification may be seen with age. Calcification of a rheumatic AV commonly starts from the edges

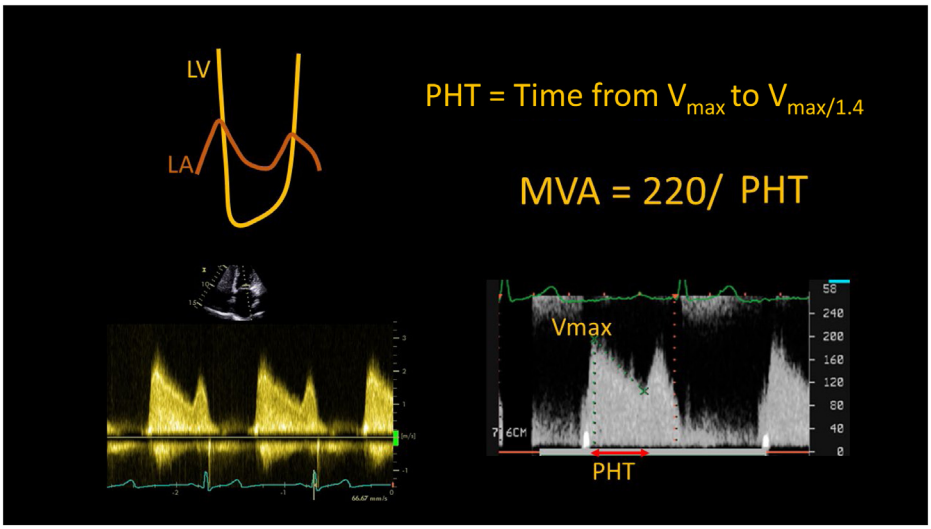


**Figure 7** Overview of hemodynamic assessment of MS. MS results in increased left atrial pressure, shown in simultaneous LA and LV pressure tracings (*upper left)*, resulting in increased transmitral pressure gradient and velocities, seen in the continuous-wave Doppler waveform of mitral inflow *(lower left)*. The mean gradient across the stenotic MV is measured from the transmitral flow VTI. Elevated early inflow peak velocity (Vmax) may be used to calculate PHT, which in turn yields calculation of mitral valve area (*upper and lower right)*. *LV,* Left ventricle; *LA*, Left atrium; *PHT*, pressure half-time; *MVA*, mitral valve area.

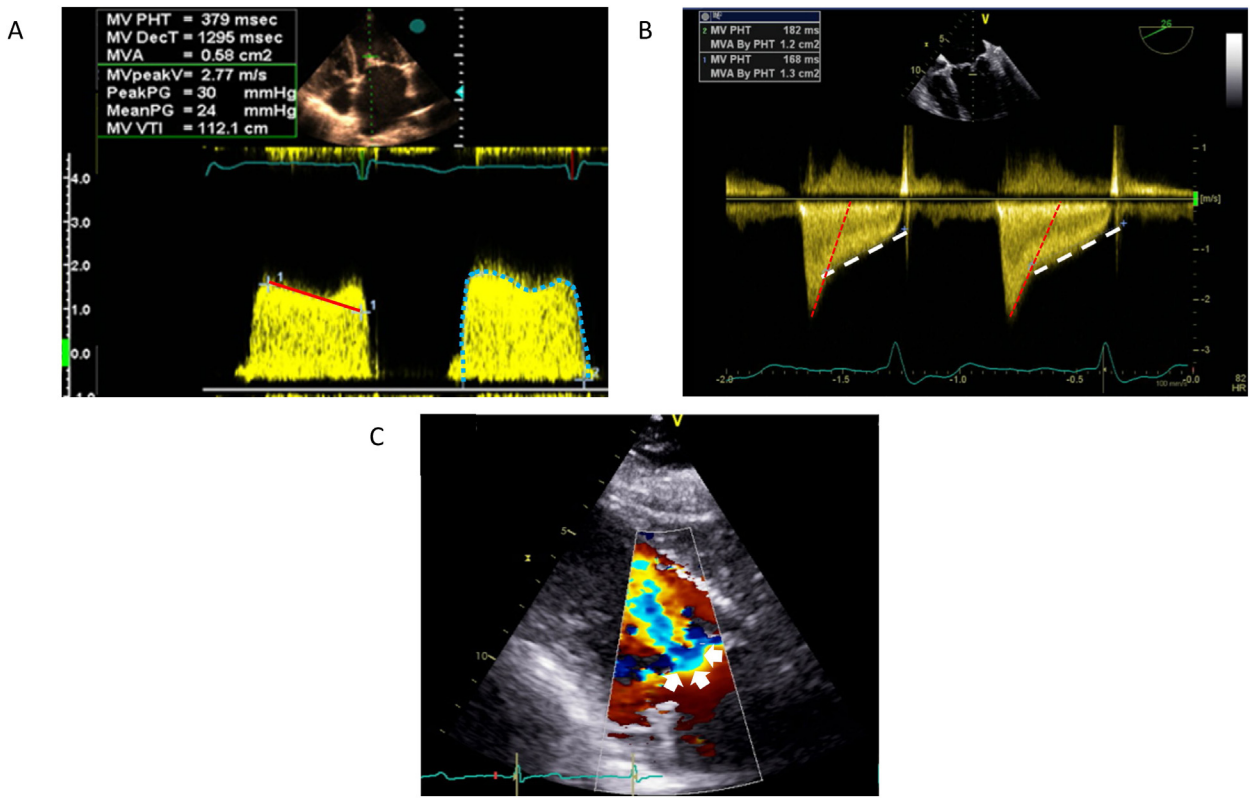


**Figure 8** Examples of Doppler echocardiography in MS. **(A)** Continuous-wave Doppler waveform of mitral inflow in severe MS, demonstrating long PHT *(red line)* leading to reduced MVA calculated from PHT, and elevated mean gradient (24 mmHg) derived from the VTI *(in blue dotted outline)* of mitral inflow. **(B)** When the deceleration slope of the MV inflow is biphasic with a rapid decay *(red line)* followed by a more gradual decay, the deceleration slope should be traced in mid-diastole *(white line)* rather than using the early steep deceleration slope. **(C)** Color Doppler of the MV in diastole indicating the acceleration of flow toward the stenotic orifice and hemispherical isovelocity surface "shells" *(white arrows)* formed at the stenotic MV.

rather than the body and base of the leaflets, in contrast to calcific AS. Congenital AS due to bicuspid or unicuspid AV may be differentiated from rheumatic AV in early stages, based on the morphology, but once the valve is significantly calcified, it may be difficult to delineate the etiology.

Valve anatomy should be assessed in the parasternal long- and short-axis views of 2DE, preferably with the use of zoom mode. TEE may be helpful to better appreciate the doming and commissural fusion of the rheumatic AV and to ensure optimal positioning of the short-axis plane at the leaflet tips (Fig. 12D). A short-axis view of the AV is important to note commissural fusion, thickening, and calcification at the cusp edges characteristic of a rheumatic AV. When obtaining an en-face view of the AV orifice is difficult with 2DE, multiplanar 3D imaging should be utilized to aid the complete characterization of the AV morphology. The AV cusps and their mobility can be obtained reliably by real-time 3D TEE. 3DE is especially useful in assessing an irregularly shaped or angulated orifice in a severely thickened or domed AV. Multiplanar imaging via 3DE improves the accuracy of planimetry of the anatomic AV orifice, as it helps to avoid over-measurement of the valve area within domed leaflets. AVA measured by 3DE has been shown to correlate better with the valve area determined by computed tomography (CT) and by cardiac catheterization than AVA measured by 2DE.[43] Improved accuracy of 3DE can reclassify the severity of AS in up to 25 % of patients.[44]

***C.2. Hemodynamic Considerations in the Assessment of Rheumatic Aortic Valve Stenosis.*** AVA may be obtained from planimetry or derived from the continuity equation. In the latter case, quantification by 3DE may be useful, as the multiplanar imaging of 3DE yields more accurate sizing of the left ventricular outflow tract (LVOT). If 3D visualization of the LVOT CSA is not satisfactory, cardiac CT can be considered as an alternative, keeping in mind the calculated valve area would be larger using the LVOT CSA derived from CT.[42,45] Effective AVA derived from the continuity equation has been well-validated, is an important parameter for decision-making, and is a robust predictor of clinical outcome.

Mean pressure gradient and peak velocity across the AV obtained from the apical views are susceptible to malalignment of the CWD cursor. Therefore, every effort should be made to ensure the Doppler cursor is coaxial to flow through the AV, and a non-imaging transducer should be used with additional echocardiographic windows, such as right parasternal, suprasternal, and right supraclavicular views. Additional parameters, including AVA indexed to body surface area (BSA), acceleration time (time from the valve opening to the peak velocity of AV flow), stroke volume index, and Doppler velocity index (ratio of LVOT VTI to AV VTI), should be examined to ensure consistency in the multi-parametric approach.

In case of discrepant results, a careful review of potential measurement errors, including the angle of Doppler interrogation, location of the LVOT sample volume, and accuracy of the LVOT diameter measurement should be conducted. In addition, attention should be paid to systemic blood pressure, BSA, and high or low flow conditions. Concurrent cardiomyopathy, severe MR, or MS may affect the quantitative echocardiographic findings of AS in RHD.

In asymptomatic patients, careful attention should be given to complementary findings to support the diagnosis of AS, including LV hypertrophy, evidence of subclinical LV dysfunction via global longitudinal strain (GLS), extent of valve calcification, rate of hemodynamic progression, increase in transvalvular pressure gradient during exercise, and pulmonary artery pressures, especially in the case of mixed valve disease.[46-49]

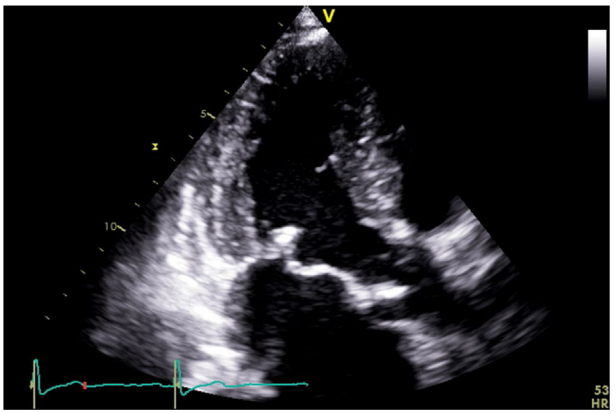


Figure 9 Parasternal long-axis view of rheumatic MV. Excessive leaflet tip deformation can be seen, with pseudoprolapsing anterior leaflet appearing to slide over the posterior leaflet, leading to incomplete leaflet apposition.

***C.3. Hemodynamic Considerations in the Assessment of Rheumatic Aortic Valve Regurgitation.*** Rheumatic AS usually coexists with some degree of AR because of retraction of the cusp edges. Typically, rheumatic AR exceeds rheumatic AS in severity. Severe AR increases flow across the LVOT and AV, thus peak velocity and gradients may be higher than expected for a given valve area, but valve area calculation by the continuity equation remains applicable. It has been shown that mixed AV disease of moderate severity has adverse outcome comparable to severe isolated AS with preserved ejection fraction (EF), and significantly worse outcome than isolated moderate AS or AR.[50] In mixed AV disease, peak velocity and mean gradient remain the major predictors of outcome.[38,51]

Overall, Doppler assessment of rheumatic AR remains in keeping with the same principles detailed in the previous recommendations on native valvular regurgitation.[38] An integration of multiple parameters is essential to grade AR severity, including:

- Qualitative indices: CWD jet density, flow reversal in the descending aorta, flow convergence, regurgitant PHT by CWD
- Semi-quantitative indices: VC width, regurgitant jet width/LVOT width
- Quantitative Doppler measurements: regurgitant volume, regurgitant fraction, and EROA
- Supportive findings: LV size and function

Severe AR is indicated by a dense CWD jet density, PHT $<$200 msec, VC width $>$0.6 cm, regurgitant jet width/LVOT width $\geq$65 %, regurgitant volume $\geq$60 ml, regurgitant fraction $\geq$50 %, and EROA $\geq$0.3 $cm^2$. Flow reversal in the descending aorta and LV enlargement are present.[38]

3DE with color Doppler improves accuracy in determining the severity of AR by making direct measurement of the VC area feasible. The 3DE color Doppler technique may be similarly superior for quantification of flow convergence using the PISA method, without geometric assumptions inherent in the 2D PISA method. Rarely, additional quantification by CMR may be needed when echocardiographic measurements are discordant, inconclusive, or inconsistent with the patient's symptoms, or when images are of suboptimal quality.

## Key Points

- The presence of commissural fusion and thickening of the free edges of the AV leaflets helps identify rheumatic involvement.
- Doppler assessment of rheumatic AR remains in keeping with the same principles detailed in the previous recommendations on native valvular regurgitation.
- Severe AS is suspected when transaortic flow Vmax ≥4 m/s, mean pressure gradient ≥40 mmHg, AVA < 1 $cm^2$, indexed AVA <0.6 $cm^2/m^2$, and the ratio of LVOT velocity and AV velocity <0.25.
- Severe AR is indicated by a dense CWD jet density, PHT <200 msec, VC width >0.6 cm, regurgitant jet width/LVOT width ≥65 %, regurgitant volume ≥60 ml, regurgitant fraction ≥50 %, and EROA ≥0.3 $cm^2$. Flow reversal in the descending aorta and LV enlargement are present.

## Recommendations:

- 2D and Doppler assessment of rheumatic AS should be complemented by a multiparametric approach that includes anatomic AVA determined by planimetry, effective AVA calculated from the continuity equation, AVA indexed to BSA, mean pressure gradient, transvalvular peak flow velocity, Doppler velocity index, and acceleration time.
- Valve anatomy should be assessed in the parasternal long- and short-axis views of 2DE, with the use of zoom mode.
- In the presence of significant leaflet doming, AVA by planimetry should be guided by 3D multiplanar imaging for optimal positioning of the imaging plane at the level of the leaflet edges to avoid overestimation of AVA.
- Assessment of the severity of rheumatic AR should rely on qualitative, semi-quantitative, and quantitative Doppler measurements together with the assessment of LV size and function.
- 3DE with color Doppler should be considered to assess VC area in moderate and severe rheumatic AR.
- In case of discrepant results, a careful review of potential technical errors or supportive findings should be performed. They include the angle of Doppler interrogation, location of the LVOT sample volume, accuracy of the LVOT diameter measurement, systemic blood pressure, BSA, high output states, and low flow conditions.

### D. Rheumatic Tricuspid Stenosis

Isolated rheumatic TS is uncommon, and occurs usually in concert with rheumatic mitral and/or aortic valve disorders. The normal tricuspid valve (TV) orifice area is 7-9 $cm^2$. Narrowing of the TV orifice results in elevation of RA pressure and systemic venous pressure. Similar to the assessment of MS, the severity of TS should not be defined by a single metric, rather by a multiparametric approach including valve area, mean transvalvular gradient, and RA chamber size.

***D.1. Anatomic Considerations in the Assessment of Rheumatic Tricuspid Stenosis.*** The morphological characteristics of rheumatic TS are similar to those found in rheumatic MS, except that significant calcification of the TV occurs to a lesser extent. Anatomic appraisal of TS requires assessment of the degree of valve thickening, calcification, commissural fusion, mobility, and diastolic doming, shortening of subvalvular structures, measurement of tricuspid valve area (TVA), and RA size as well as presence of any thrombi. Because of the TV geometry, it is not possible to visualize all 3 leaflets in most 2DE views, while 3DE allows for visualization of the whole TV apparatus (Fig. 13A-C, Video 11-13).

To better appreciate the TV in the apical 4-chamber view, the transducer should be moved medially over the RV apex. In 2D TTE, it may be feasible to obtain TVA by planimetry by visualizing the valve from the subcostal view in short-axis orientation. 3DE allows for visualization of stenotic valve area from either the right atrial or ventricular perspective, and is particularly useful for deriving TVA in an

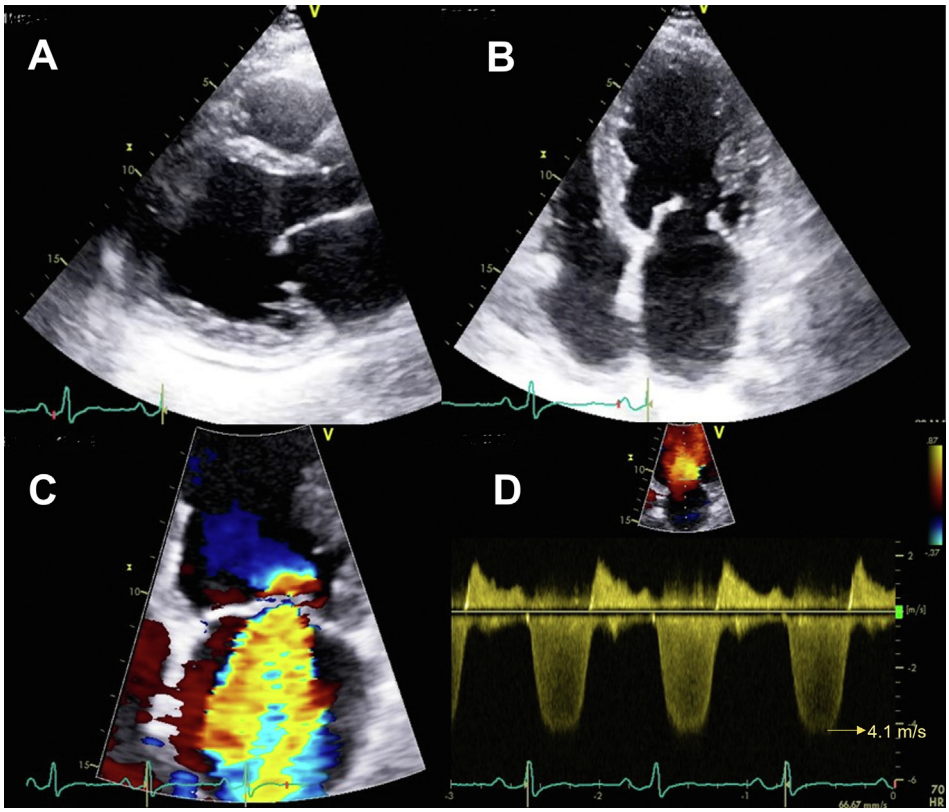


Figure 10 Pathological rheumatic mitral regurgitation. **(A)** Parasternal long-axis and **(B)** apical 4-chamber views showing thickened leaflets with doming typical of rheumatic MV in diastole. **(C)** Zoomed color Doppler image of pathological mitral regurgitant jet in systole, with a jet length ≥2 cm. **(D)** Continuous-wave Doppler waveform of transmitral flow showing pathological regurgitant flow with a peak velocity ≥3 m/s.

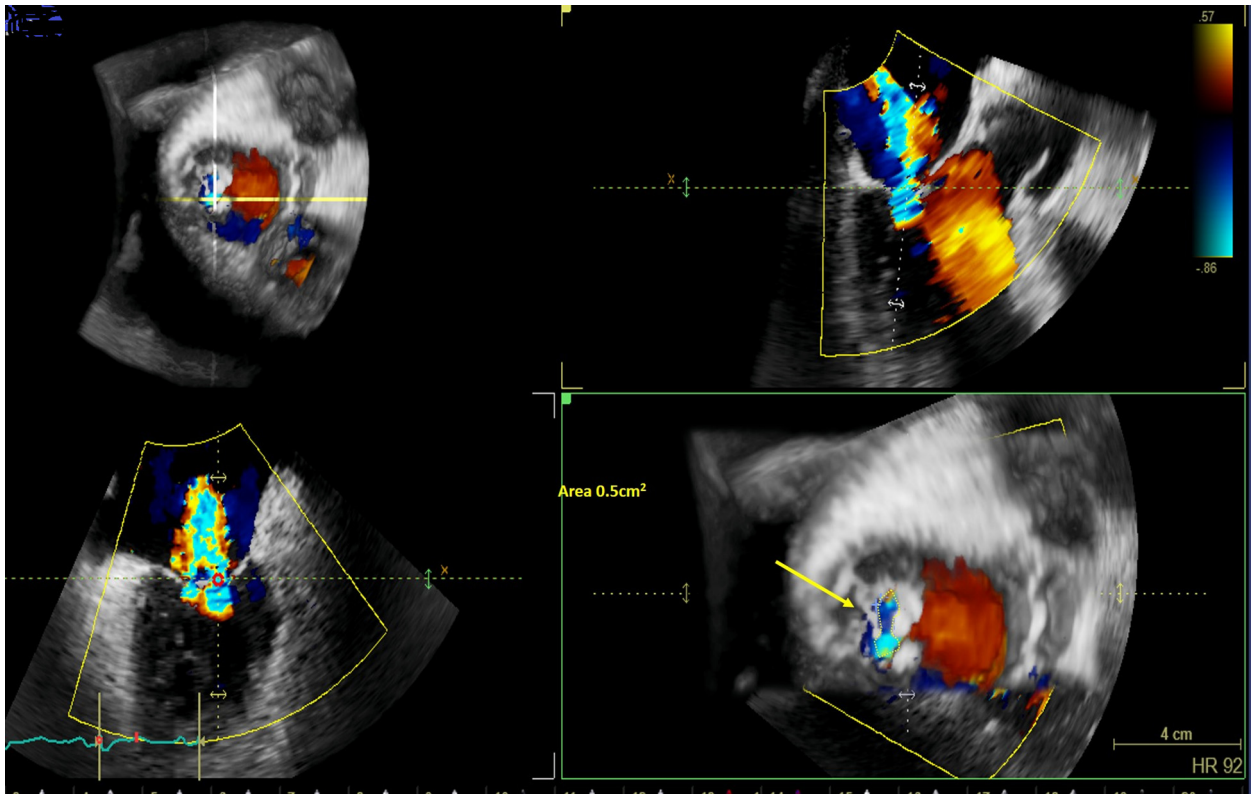


Figure 11 Vena contracta area by 3D TEE multiplanar analysis with color Doppler. Note that optimally oriented cut planes provide an en-face view of the vena contracta region. The regurgitant orifice has an irregular shape *(right lower panel)* that can be directly planimetered *(arrow)* with the use of 3D echocardiography.

eccentrically oriented TV orifice, as multiplanar images of 3D data sets may help identify the correct short-axis orientation to measure TVA.

***D.2. Hemodynamic Considerations in the Assessment of Tricuspid Stenosis.*** Progressive reduction in TVA results in increased RA pressure and diastolic TV pressure gradient and a decrease in forward stroke volume. High RA pressure leads to increasing systemic venous pressure, causing peripheral edema, hepatic congestion, and fatigue. Chronic RA dilation, decreased stroke volume, and AF can result in blood stasis and thrombi in the RA. RV systolic and diastolic function are generally normal but can be compromised by co-existent TR, the impact of left-sided valve involvement, or myocardial dysfunction secondary to chronic rheumatic myocarditis or associated disorders. Hemodynamic appraisal of TS requires measurement of mean TV pressure gradient, estimation of TVA as well as RA and PA pressures, and evaluation of the hemodynamics of associated valve disorders.

The mean tricuspid inflow pressure gradient is calculated from the velocity recording obtained by CWD in any orientation that allows an optimal angle (Fig. 13D). Because tricuspid inflow velocity is easily influenced by respiration and heart rate, the velocity recordings and mean gradient in 5 or more beats should be averaged. TS is considered to be severe if the mean gradient is $\geq$5 mmHg, inflow VTI $\geq$60 cm, PHT $\geq$190 ms, and TVA $\leq$1 $cm^2$. TS is considered to be mild with a TVA >1.5 $cm^2$, and moderate with a TVA 1-1.5 $cm^2$. The PHT-based calculation of TVA is derived by dividing a constant of 220 or 190 by PHT. This method, however, is less reliable than in MS.

Supportive findings of severe TS are those consistent with elevated RA pressure, including a dilated RA, inferior vena cava (IVC) plethora, interatrial septum bowing toward the LA, loss of systolic flow predominance in the superior vena cava, jugular vein, or hepatic veins (ratio of systolic flow velocity to diastolic flow velocity <1), and a tricuspid E/e′ ratio >6.[29] The right atrial sizing in adults should be performed quantitatively, rather than by visual estimation, by following the ASE recommendations for cardiac chamber quantification.[52]

## Key Points

- TS occurs in concert with rheumatic mitral and/or aortic valve disorders.
- Anatomic appraisal of rheumatic TS requires assessment of the degree of valve thickening, calcification, commissural fusion, mobility, diastolic doming, and shortening of subvalvular structures, measurement of TVA, RA size, and notation of presence of any thrombi.
- Hemodynamic appraisal of TS includes mean TV pressure gradient, TVA, and estimation of RA and PA pressures.
- TS is hemodynamically significant with a mean gradient $\geq$5 mmHg, inflow VTI $\geq$60 cm, and TVA $\leq$1 $cm^2$. PHT $\geq$190 or 220 msec may be used, but this method is less reliable than in MS.

## Recommendations

- The severity of TS should be assessed by a multi-parametric approach including valve area, mean transvalvular gradient, RA size, an estimate of PA pressures, and evaluation of the hemodynamics of associated valve disorders.
- 3DE should be considered to measure TVA in multiplanar images for an eccentrically oriented TV orifice.

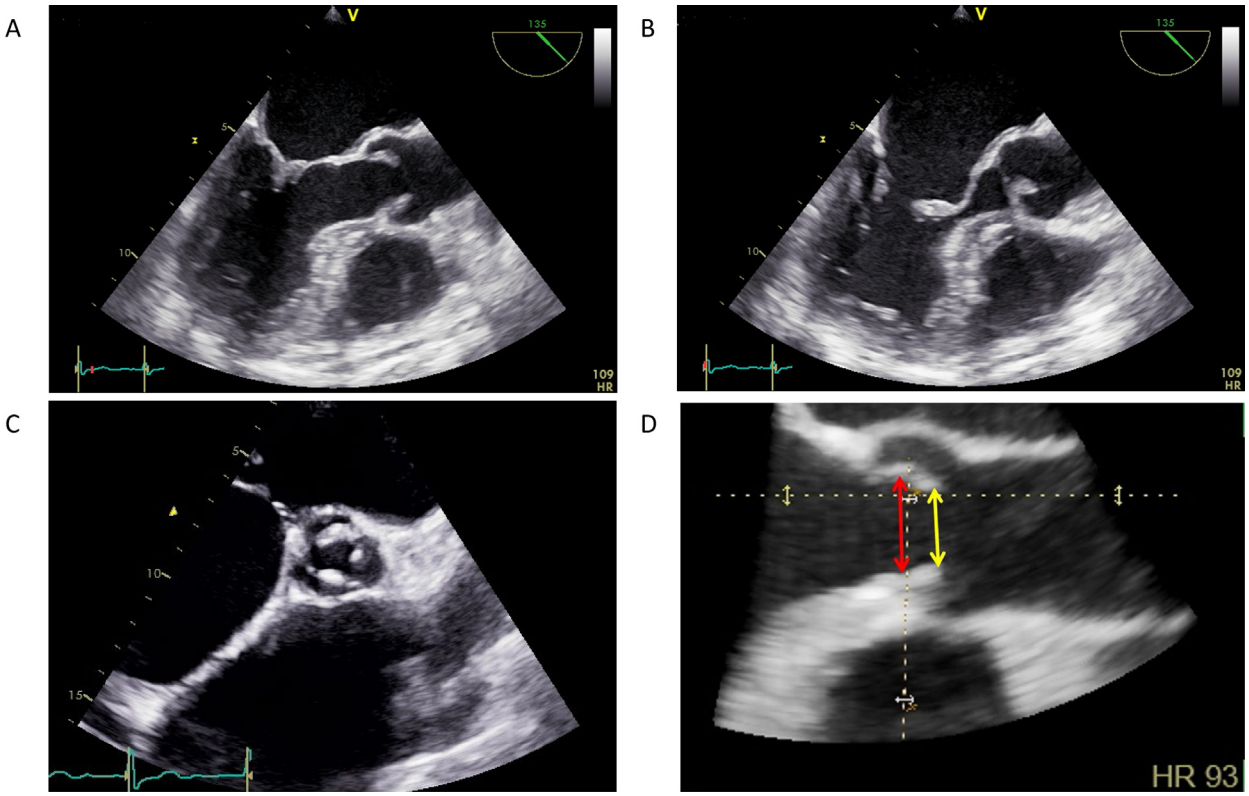


Figure 12 Rheumatic AV anatomy. **(A)** 2D TEE long-axis view in systole, demonstrating AV leaflet doming. **(B)** 2D TEE long-axis view in diastole. **(C)** 2D TEE short-axis view, demonstrating AV commissural fusion and nodular thickening. **(D)** TEE view of AV marking the correct level of cut plane at the leaflet edges *(yellow arrow)* in contrast to a misplaced plane cut at the level of doming *(red arrow)* yielding a larger AVA.

## E. Rheumatic Tricuspid Regurgitation

TR is the third most common valve lesion in RHD after MR and MS, with a reported prevalence up to 70%, and is almost always associated with MS.[37] Rheumatic TR may be classified into primary (organic) or secondary (functional) TR. Primary rheumatic TR results from valvulitis (44% of reported cases) as a complication of ARF,[53] or from chronic sequelae of RHD, leading to scarring of the valve leaflets and/or chordae with thickening, doming, restriction, and calcification of the tricuspid valvular apparatus in variable proportions. Secondary rheumatic TR is due to tricuspid annular dilatation from right heart enlargement and dysfunction associated with left heart valve disease and resultant PH. Mixed TV disease is commonly encountered in RHD, with combined stenotic and regurgitant lesions of varying severity.[53]

Assessment of primary rheumatic TR requires a comprehensive approach with complete visualization and a full description of the TV and subvalvular apparatus. Qualitative and quantitative analysis of the regurgitant severity, as well as anatomic and functional description of the right atrium and ventricle, should follow published recommendations.[38,52] The presence of moderate TR is an independent predictor of new development of severe TR after MV surgery to treat RHD,[54] and severe TR is an independent predictor of heart failure and other major adverse cardiac events.[37] Tricuspid repair for mild or moderate TR associated with tricuspid annular dilation, when performed at the same time as mitral valve surgery, improves both echocardiographic and functional parameters.[55]

***E.1 Anatomic Evaluation of Rheumatic Tricuspid Regurgitation.*** An echocardiographic diagnosis of primary rheumatic TR is made when TR is associated with typical diastolic doming or thickening of the valve with or without limitation of its opening (Fig. 14A, Video 14). In a systematic review of 2,497 patients from 5 reports of RHD, a wide difference in the prevalence of rheumatic TV disease was noted when echocardiograms and autopsy reports were compared (7.7 % vs. 38.5 %, respectively), suggesting TTE may underestimate tricuspid involvement in RHD.[53] The use of 3DE allows for en-face imaging of the TV and accurate measurements of the tricuspid annulus and EROA of the regurgitant jet.[56]

Right heart size and TV annular dilatation may be the cause or result of severe TR. Functional rheumatic TR may result from negative remodeling of the right-sided chambers due to severe rheumatic MS and PH. The tricuspid annulus is considered dilated when its end-diastolic diameter is ≥40 mm (or >21 mm/m$^2$ indexed by BSA) in the apical four-chamber view.[38]

***E.2. Hemodynamic Considerations in the Assessment of Rheumatic Tricuspid Regurgitation.*** Methods for determining the severity of TR are detailed in previously published recommendations.[38] Severe TR (Fig. 14B) is associated with [1] a color Doppler regurgitant jet area >10 cm$^2$ (Nyquist limit set at >50 cm/sec), [2] a VC ≥0.7 cm (acquired from the apical four-chamber or RV inflow parasternal views, with the Nyquist limit >50 cm/sec), [3] a VC area >0.4

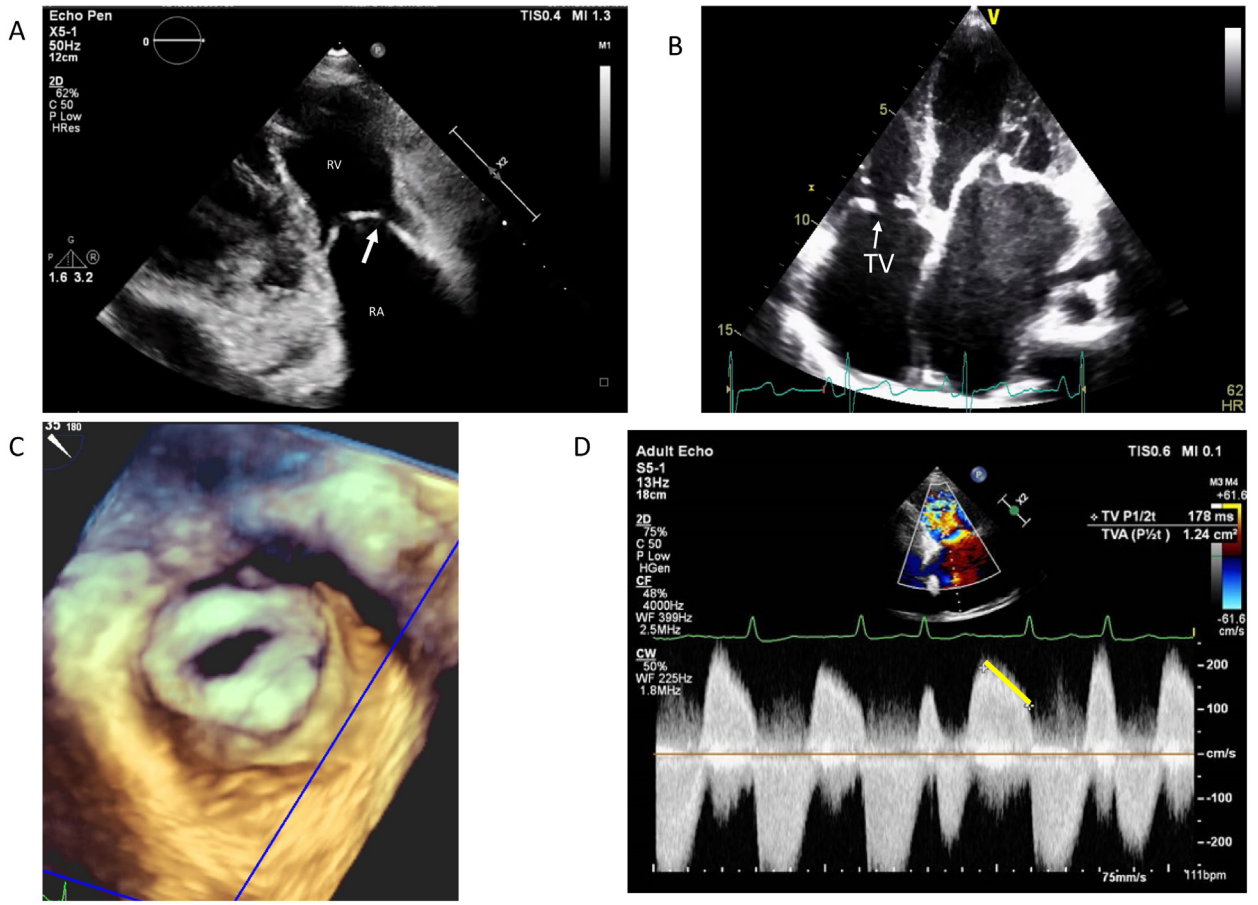


**Figure 13** Rheumatic tricuspid valve. **(A)** A 2D echocardiographic image of a stenotic TV in the right ventricular inflow view. Note the doming leaflets *(arrow)*, with reduced separation of the leaflet tips and enlarged RA. *Figure courtesy of Dr. Satish Govind, Bengaluru, India.* **(B)** A 2D echocardiographic image of a stenotic TV *(arrow)* in the apical 4-chamber view. *Figure courtesy of Dr. Manish Bansal, New Delhi, India.* **(C)** En-face view of thickened, stenotic TV with commissural fusion seen from the right atrial view using 3D echocardiography. **(D)** A continuous-wave Doppler recording through the rheumatic TV shows the PHT of 178 ms, and TVA estimated to be 1.24 $cm^2$ per the PHT method *(yellow line)*.

$cm^2$ via 3DE, [4] a PISA radius ≥0.9 cm (baseline Nyquist limit shifted to ~28 cm/s), [5] an EROA ≥0.40 $cm^2$, and [6] a regurgitant volume ≥45 ml by 2D PISA. In addition, supportive data include prominent hepatic venous systolic flow reversal, a peak tricuspid E-wave velocity >1.0 m/s, and a dense CWD regurgitant waveform. An early peaking and triangular shape of the velocity waveform may be seen with severe acute or subacute TR secondary to rapidly rising right atrial pressure.. Several caveats to consider when examining these indices are as follows:

- In wide-open, torrential TR with little valve coaptation, the regurgitant flow is of low velocity, does not alias, and may lose its appearance as a distinct jet, leading to underestimation of the regurgitant jet area by color Doppler.
- The TR PISA method is similar to that of MR. However, since the peak TR velocity is generally less than in MR, flattening of the contour of the aliased hemisphere closer to the regurgitant orifice may be exaggerated with TR, leading to underestimation of the regurgitant flow.
- The PISA approach may be inaccurate when the orifice is noncircular.
- EROA derived from the TTE 2D PISA method underestimates regurgitant orifice area by the 3D PISA method.
- TR jet velocity is not related to the regurgitant volume.
- AF with significant variation of cardiac cycle lengths or rapid ventricular response may render many of these indices less reliable.

## Key Points

- An echocardiographic diagnosis of primary rheumatic TR is made when there is TR associated with typical diastolic doming or thickening of the valve.
- TR is considered severe if the color Doppler regurgitant jet area is >10 $cm^2$ at a Nyquist limit >50 cm/sec, VC is ≥0.7 cm in the apical four-chamber or RV inflow view, VC area is >0.4 $cm^2$ via 3DE, PISA radius is ≥0.9 cm, EROA is ≥0.40 $cm^2$, and regurgitant volume is ≥45 ml by 2D PISA. Not all of these findings may be present in all patients with severe TR.
- Supportive findings of severe TR include systolic flow reversal in a hepatic vein, tricuspid inflow E-wave velocity >1.0 m/s, and dense CWD waveform of the regurgitant jet.

## Recommendations

- The severity of TR should be determined by assessment of color Doppler regurgitant jet area, VC width and area, PISA radius, EROA, and regurgitant volume.
- Multiplanar images of 3D datasets should be used whenever possible to help identify the correct short-axis orientation to measure the TVA and VC area.
- In patients with concomitant rheumatic MR and AR, increased LV filling pressures can increase pulmonary venous pressure. The regurgitant volume of TR may accordingly increase despite unchanged regurgitant orifice area, thus exaggerating TR severity by Doppler assessment. Also, functional TR may reverse with normalization of LV function/filling pressure. Thus, integrated hemodynamic and anatomic assessment of rheumatic TR should always be taken into consideration for clinical decision-making.

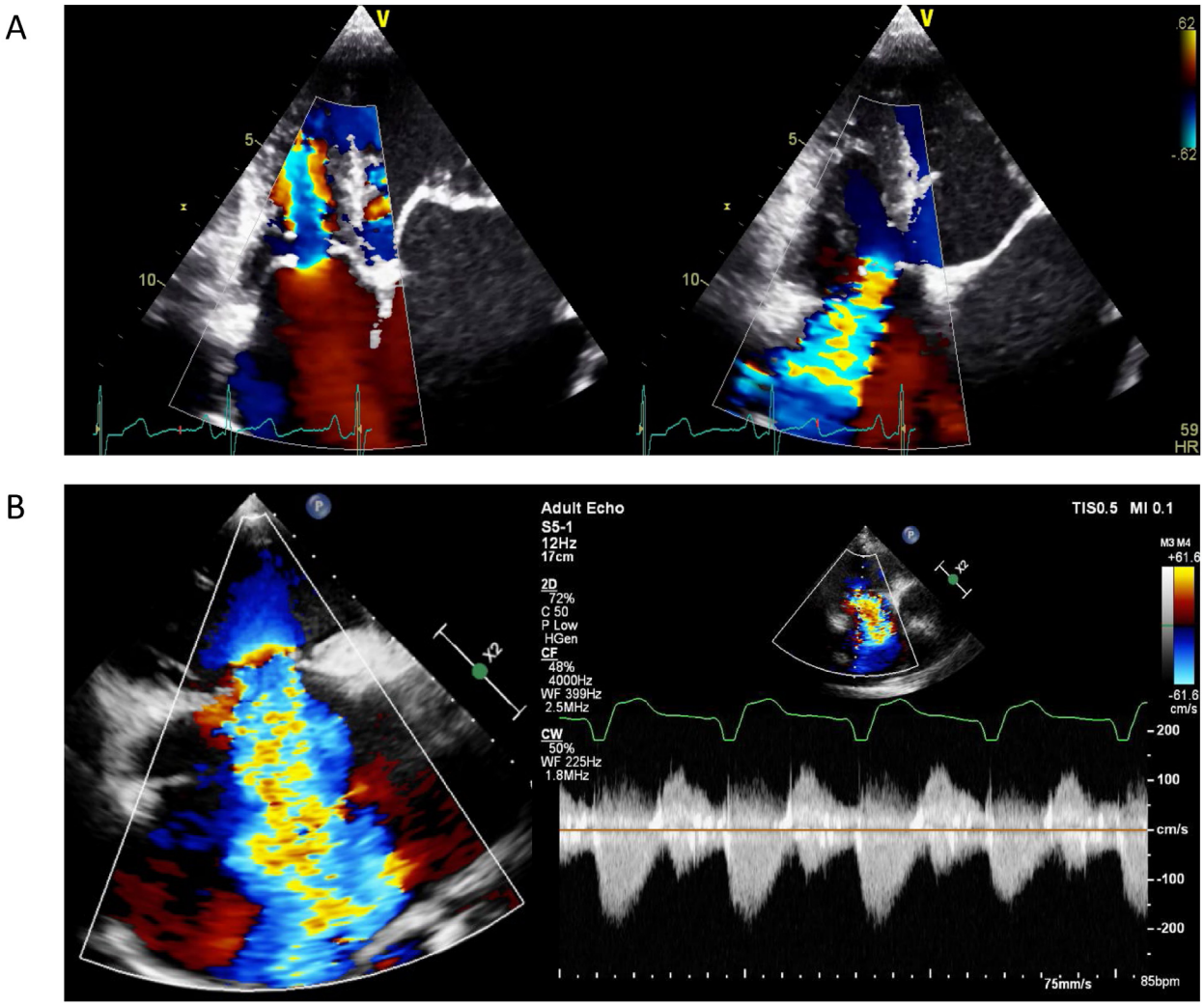


Figure 14 Rheumatic TR. **(A)** ***Left,*** Apical 4-chamber view of TV with color Doppler in diastole; ***Right,*** Apical 4-chamber view of TV with color Doppler in systole. *Figure courtesy of Dr. Manish Bansal, New Delhi, India.* **(B)** Severe TR with a large color Doppler regurgitant jet area, a wide VC ≥0.7 cm, and a dense triangulated continuous-wave Doppler flow profile with low velocity (<2 m/sec), indicating rapidly rising right atrial pressure due to severe TR.

### F. Rheumatic Pulmonic Valve

***F.1. Rheumatic Pulmonic Valve Stenosis.*** The PV is rarely involved in RHD. Rheumatic PV disease, when it does occur, is always associated with MS, and portends advanced stages of RHD, as in cases of quadrivalvular stenosis. However, involvement of the PV may be clinically silent, underscoring the utility of imaging in making the accurate diagnosis and forming appropriate treatments, as late recognition of rheumatic PV disease may result in unintended complications or a delay in treatment. When assessing the stenotic and/or regurgitant PV in RHD, the published guidelines on valvular stenosis and regurgitation should be followed.[29,38]

Rheumatic involvement of the PV typically results in stenosis. 2DE may reveal pulmonic stenosis (PS), depicting limited leaflet mobility with a domed appearance in systole, or calcification and thickening of the leaflets, best seen in the parasternal views where the anterior and right cusps are typically visualized. No imaging plane with 2D TTE captures all three (left, right, and anterior) cusps of the valve. However, with 3DE, the en-face view of the PV can be obtained.

Surgical and postmortem data report a larger mean PV area (PVA) in normal subjects (4.88 ± 1.25 $cm^2$ in males, 4.32 ± 1.03 $cm^2$ in females) than that calculated by Doppler echocardiography using the continuity equation (3.01 ± 0.36 $cm^2$).[57,58] Specific partition values of PVA for the degrees of PS severity have not been identified. However, considering that the range of a normal PV size is similar to that of a normal AV, it would be reasonable to extrapolate from the AV data, and define a PVA less than 1.0 $cm^2$ as severe PS in adults, since a valve area reduced to ¼ of the normal size may be considered severe stenosis.

The severity of PS is commonly assessed with measurement of peak transpulmonic flow velocity by CWD and deriving the peak pressure gradient across the valve by applying the simplified Bernoulli equation. The measurement of a peak PV velocity is typically performed in a parasternal short- or long-axis view, which yield the best alignment of the Doppler signal with the transpulmonic flow. These views also provide opportunities to evaluate the pulmonary artery, which may be dilated in advanced stages of RHD with associated PH. A peak transpulmonic flow velocity of >4 m/s suggests severe PS,

assuming there is no sub- or supra-valvular obstruction.[22,29] Extrapolating from the current guidelines on non-rheumatic PS, a mean gradient greater than 35 mmHg should be considered severe PS, although data to support this threshold are limited.[22] Since rheumatic PS almost always occurs with the involvement of the other valves in advanced stages of RHD, it is important to conduct a comprehensive assessment of right heart size and function, evidence of PH, and staging of the co-existing valve lesions.

***F.2. Rheumatic Pulmonic Regurgitation.*** While trace or mild pulmonic regurgitation (PR) with normal PV morphology is common and clinically inconsequential, isolated rheumatic PR has not been reported in large modern surveys of RHD.[59,60] While there are no data specific to rheumatic PV disease to assign cutoff partition Doppler values, the previously published recommendations should be followed when evaluating rheumatic PR.[38] Quantitative parameters for severe PR include a PR jet width/annulus diameter ratio ≥70%, PHT of a PR jet <100 msec, and deceleration time of the PR CWD waveform <260 milliseconds.

Supportive findings of severe PR include abnormal valve morphology with thickening of the leaflets, a dense PR CWD waveform, early termination of PR flow, and diastolic flow reversal by PW Doppler in the main or branch pulmonary artery. Chronic severe PR may lead to RV dilation and dysfunction, and the ASE guideline on chamber quantification should be followed to quantitatively assess RV size and function.[52] Intervention is considered when PR is severe in the setting of symptoms and/or RV dysfunction.

### Key Point

- Rheumatic PV disease is rare, always associated with MS, and typically manifests as stenosis.
- Severe rheumatic PS has a peak velocity >4 m/s and a mean gradient >35 mmHg.
- Severe PR is defined as a jet width/annulus diameter ≥70%, a PR jet PHT <100 msec, and a deceleration time of the PR spectral Doppler waveform <260 milliseconds.

### Recommendations

- Severity of PR in the setting of RHD should be assessed in a manner similar to that of nonrheumatic PR.
- Quantitative RV size and function assessment should be included in patients with rheumatic PV.

## G. Assessment of Mixed Valve Disease

Mixed valvular disease is common in RHD.[59] Co-existing MV and AV disease is more commonly seen in all age groups of RHD, with an exception of children under 10 years old, in whom pure MR is more prevalent.

As velocities and pressure gradients are flow-dependent, concomitant moderate to severe MR or MS may result in lower transvalvular aortic velocity and pressure gradients. As such, severe AS may present with Doppler hemodynamics that are more consistent with paradoxical low-flow AS (defined by an effective AVA <1.0 $cm^2$, a mean aortic transvalvular pressure gradient <40 mmHg, or a peak velocity <4 m/s, with LVEF ≥50 %). In this case, concomitant rheumatic MV disease limits the use of dobutamine challenge to assess contractile reserve because changes in stroke volume do not necessarily reflect contractile reserve as the LV fails to fill properly in co-existing MS or unloads into the LA in the presence of concurrent MR. Thus, in patients with mixed aortic and mitral valve disease with suspected low-flow low-gradient AS, adjunctive indices such as Doppler velocity index, LVOT flow determined by means other than TTE (3D TEE, CT, CMR, cardiac catheterization), and calcium score (Agatston) of the AV by CT should be sought.[42] However, given the commissural fusion contributing to rheumatic stenosis, the calcium score alone may not accurately reflect the severity of stenosis, whereas CT-derived AVA is a robust measure of severity.

With concurrent AR and MS, transmitral inflow should be carefully distinguished from AR flow, particularly in patients with AF. A stenotic MV with a funnel-shaped orifice can direct mitral inflow toward the interventricular septum, thus mimicking AR (Fig. 15). Additionally, an eccentric AR jet can contaminate mitral inflow. Care should be given to orient the image properly to differentiate these flows. The timing of AR and MS is helpful in identifying the cause(s) of high velocity flow in the LV noted during diastole, with the anterograde flow across a stenotic MV confined to diastole while the AR jet starts earlier at aortic valve closure. PHT may not be a reliable measure of MS in the presence of co-existing moderate or severe AR.

Anatomic valve area should be measured in both valves in patients with combined MS and AS. Multivalvular regurgitation will hamper the use of volumetric methods for quantifying regurgitation because there may be no reference systemic stroke volume to use. In this setting, direct measurement of the forward and reversed flow through a given valve may be the best option.

### Recommendations

- In suspected AS and concurrent rheumatic mitral disease, evidence for a possible low-flow state should be sought by examining LVOT flow determined by 3D TEE, CT, CMR or cardiac catheterization. The severity of low-flow AS should be supported by Doppler velocity index and AVA by CT, if necessary.
- Dobutamine challenge is not recommended to differentiate pseudo-severe from true severe AS in the setting of concomitant significant rheumatic MV disease, as forward stroke volume across the AV may not augment reliably with severe rheumatic MS and/or MR, regardless of contractile reserve of the LV.
- Measurement of anatomic valve area by planimetry should be performed in cases of combined MS and AS.
- In concurrent AR and MS, care should be taken to align the Doppler cursor with mitral inflow, distinguished from the AR jet. The timing of the jet may help distinguish one from the other, with the MS flow confined to diastole while AR starts at AV closure.
- When AR and AS of more than moderate severity coexist, the AVA calculated by the continuity equation remains applicable. Mean gradient and peak velocity are predictors of worse outcomes and should be considered in decision-making.
- The use of volumetric quantification of regurgitation is rendered inaccurate in the presence of multivalvular rheumatic involvement.

# V. OTHER CONSIDERATIONS

## A. Technical Considerations in Echocardiographic Imaging of Rheumatic Heart Disease

2D TTE is recommended as first-line imaging, both for the initial and longitudinal assessment of subjects with valvular heart disease. While harmonic imaging is generally recommended to improve endocardial delineation in a standard adult examination, it may need to be turned off and fundamental frequencies used for determining valve thickness to avoid overestimation of the degree of valvular and chordal thickening, as the extent of the valve and subvalvular thickness has bearing in diagnostic accuracy and subsequent choice of intervention in RHD. With machines that have the capability to manually alter focus, the focus should be positioned at the level of the valve being inspected to optimize lateral resolution.

Gain settings should be adjusted to image the contours of valve leaflets sufficiently while maintaining echo-free visualization of the

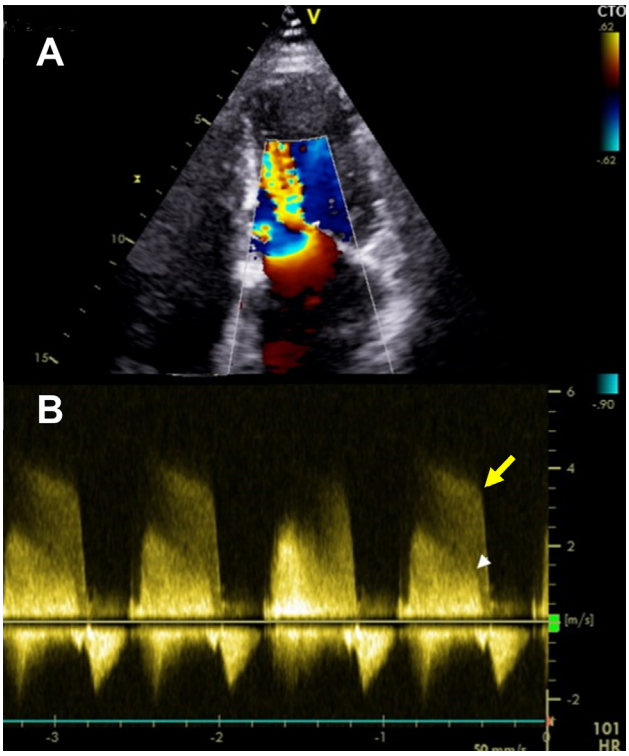


Figure 15 Mixed valve disease with rheumatic AR and MS. **(A)** Color Doppler and **(B)** CW Doppler spectral envelope of the mitral inflow *(arrowhead)* in apical 4-chamber view, demonstrating that the inflow jet through the funnel-shaped, stenotic MV orifice can be directed toward the interventricular septum, mimicking AR *(long arrow)* which lasts longer in diastole.

blood pool. In addition, optimal adjustment of dynamic range is needed to enhance leaflet border recognition. Dynamic range, also called compression, is an important grayscale parameter that adjusts the appearance of the shades of gray on the image and should be optimized for defining morphological details of the valve tissue. An excessively high dynamic range, and thus a very low-contrast image, may lead to poor delineation of endocardial borders.

Heart rate and BP should be recorded before each study, given the strong influence of each on transvalvular gradients. In AF, an average of at least 5 beats or the most representative cycle should be utilized when measuring velocities and pressure gradients.[52] Multiple windows are to be used to assess the jet direction, eccentricity, and multiplicity.[38]

During the acquisition of 3DE images, spatial and temporal resolution should be optimized by using a narrow image sector and reduced maximum imaging depth. Gain should be set in the mid-range, around 50 dB, and optimized with slightly higher time gain compensation to avoid potential signal dropout and subsequent loss of diagnostic information. Excessive gains, however, result in a loss of depth perception and a decrease in resolution. Therefore, gain and compression settings should be balanced for optimal structure visualization.

Stress echocardiography plays an important role in the hemodynamic evaluation of valvular heart disease when symptoms and valve lesion severity measures are discordant.[22] Stress echocardiography should also be used to assess asymptomatic MS before major surgery or planned pregnancy to predict hemodynamic reserve.[34] Images should be acquired at baseline and immediately post exercise within 2 minutes into recovery when using a treadmill. A sweep speed of 100 cm/sec and optimized velocity scale is necessary. Supine bicycle exercise is the preferred modality when assessing hemodynamic consequences of rheumatic valve lesions as it better allows acquisition of Doppler recordings during exercise. Dobutamine stress echocardiography has been shown to have prognostic value but is less physiological than exercise.[32] Low dose dobutamine (up to 20 micrograms/kg/min) may be administered in patients with moderate or severe symptoms when exercise is impossible. Dobutamine stress echocardiography can be used to assess transmitral gradients during stress, but is not recommended for determination of PASP.[34]

## Recommendations

- The use of harmonic imaging is not recommended for assessing valve thickness in RHD.
- Temporal and spatial resolution should be optimized by decreasing scan depth and sector width, positioning the focus at the level of the valve being inspected, and employing the zoom function to magnify the structure of interest before making measurements.
- Gain settings should be adjusted to sufficiently image the contours of the mitral leaflets. Optimal adjustment of dynamic range (compression) may be needed to enhance leaflet border recognition.
- Multiple windows are employed for Doppler interrogation to best align the beam with blood flow during assessment of a valvular lesion.
- When imaging with 3DE, time gain compensation should be increased to avoid potential signal dropout and subsequent loss of diagnostic information. Excessive gains, however, may result in a loss of depth perception and a decrease in resolution.
- Post-exercise imaging during treadmill stress echocardiography should be acquired immediately after stopping exercise, preferrably in the first 2 minutes of recovery.
- Supine bicycle exercise is the preferred modality when assessing hemodynamic consequences of rheumatic valve lesions.

### B. Secondary Hemodynamic Consequences (Pulmonary Hypertension)

An important sequela in the course of RHD is the development of PH, defined as a mean pulmonary arterial pressure (mPAP) ≥25 mmHg at rest.[61] Right heart catheterization is the gold standard for measuring pulmonary artery pressures, but its invasive nature limits routine use for serial hemodynamic assessment. Doppler echocardiography is a cornerstone of estimating PASP noninvasively, and can also provide an estimate of pulmonary artery diastolic pressure (PADP) and mPAP by multiple methods.[62] PASP and mPAP by TTE correlate well with right heart catheterization-derived measurements in patients with rheumatic MS.[63] In the absence of flow obstruction across the PV or in the RVOT, PASP equals RVSP. Therefore, PASP can be estimated by the following equation:

$$\text{PASP} = \text{RVSP} \cong 4V^2_{\text{peak TR}} + \text{RA pressure}$$

where RA pressure is estimated by respiratory variation of the IVC diameter.[52] In the presence of RVOT or pulmonic obstruction, PASP may be estimated by subtracting the systolic pressure gradient across the site of obstruction from the estimated RVSP. Because the presence of TR is a prerequisite to this echocardiographic calculation of PASP, thorough attempts must be made to detect the TR, which may be accentuated with the use of an ultrasound enhancing agent or agitated saline. Only the well-defined, dense spectral envelope (modal velocity) should be measured, and the less-dense "hairs" excluded, to avoid overestimating the peak velocity. Measuring peak TR velocity following an extrasystolic beat should be avoided because the velocity will be higher owing to the larger stroke volume from the compensatory pause following the ectopy and does not represent that of the underlying rhythm.

If PR is present with a good-quality spectral display, PADP can be estimated using the following equation[64]:

$$\text{PADP} = 4 \times (\text{end diastolic velocity of PR})^2 + \text{RA pressure}$$

In the absence of PR, PADP can be estimated from TR.[65-68] TR velocity at the time of PV opening is applied to the simplified Bernoulli equation to approximate PADP at this time, as RV pressure and PADP are equal at the time of PV opening.[69] mPAP, calculated as $^1/_3$ (PASP) + $^2/_3$ (PADP), can be determined by echocardiography in several ways, although none demonstrated superiority to the others in common clinical utility.[70,71]

Qualitative echocardiographic findings indicative of PH include mid-systolic notching in the RVOT PW Doppler display, short acceleration time of pulmonary artery flow, systolic flattening of the interventricular septum with a "D"-shaped LV seen in short-axis, and a dilated RV and RA.

## Recommendations

- Because the development of PH is an important clinical sequela in the course of RHD and correlates with more advanced disease, a thorough echocardiographic evaluation should include estimation of PASP and quantitative analysis of right heart size and function.
- In estimating PASP, measurement of peak TR velocity after an extrasystolic beat should be avoided.
- If the Doppler spectral envelope of the peak TR velocity is not well visualized, the measurement should be repeated with an ultrasound enhancing agent or agitated saline for better delineation of the peak velocity. Only the peak of a well-defined, dense spectral envelope (modal velocity) should be measured, excluding artifact or noise, to avoid overestimating the peak velocity.

### C. Chamber Dysfunction

The LA is the cardiac chamber that is most directly affected by the hemodynamic sequelae of RHD. LA size is a strong predictor of cardiovascular outcome and procedural success of PBMV or MV replacement.[72,73] The left atrial appendage (LAA) should be examined for thrombus, common in those with severe MS and AF. Imaging of the LAA is best performed by 2D and 3D TEE in multiple planes, given the complex and variable anatomy of the appendage. When assessing left atrial size in patients with RHD, the latest recommendations for quantification by echocardiography should be followed in general.[52,74] LA function may be assessed in terms of 2D area, volumetric emptying fractions, myocardial deformation, and spectral Doppler interrogation of transmitral, pulmonary venous, and LA appendage flows.[75-78]

Left ventricular dysfunction is not uncommon in RHD.[59] Changes in LV mass and volume are important prognostic factors of morbidity and mortality in patients with RHD. Thus, it is important to assess the chamber dimensions and volume accurately.[52] The effect of MS on LV function is complex, and the etiology for reduced LV function is unclear. Even with normal LVEF, the LV myocardium demonstrates pathologic changes at the ultrastructural level in rheumatic MS.[79] Subclinical LV dysfunction is believed to develop at an early stage of rheumatic MS, as evidenced by abnormal myocardial strain in mild MS and normal LVEF.[80] PBMV leads to improvement of both diastolic and systolic LV function, demonstrated by changes in regional wall motion abnormalities and LVEF,[81] LV compliance, diastolic filling,[82] LV GLS (Fig. 16),[83,84] and MV annular velocities.[85]

The use of GLS by speckle tracking echocardiography (STE) is not only instrumental in detecting subclinical LV dysfunction in RHD, it is also shown to be a strong predictor of mortality, adding incremental prognostic value over clinical, traditional echocardiographic, and invasive hemodynamic parameters.[83] LV strain imaging via 2D STE should be performed according to the previously described common standards.[86] Reference ranges of 2D STE-derived LV strain in children have also been published.[87] Although 3D STE holds promise, there is currently limited data on its use in the evaluation of RHD.[88]

There are significant ultrastructural changes in the rheumatic right atrial myocardium, including interstitial fibrosis, cellular degeneration, and marked myocyte hypertrophy. These histopathological abnormalities seen in RHD occur independently of the underlying rhythm and are not seen in the RA of non-rheumatic valvular heart disease, coronary artery disease, or congenital heart disease patients.[89,90] Accurate measurement of RA size is a crucial part of assessing atrial function. 2DE-derived RA volume is typically smaller than RA volume obtained with 3DE or CMR.[91] Right atrial myocardial strain determined by STE has been shown to be a robust tool to assess RA function.[92] Normal RA strain values for healthy children and adults have been published.[93,94]

The RV is significantly impacted by the hemodynamic sequelae of RHD. RV injury, subclinical or overt, occurs early in the course of RHD, regardless of the extent of MS.[95] Right ventricular function may be assessed by several echocardiographic indices, including tricuspid annular plane systolic excursion (TAPSE), TV annulus s′ from tissue Doppler imaging, myocardial performance index, fractional area change (FAC), EF by 3DE, and strain by STE.[52] When analyzing the relevant echocardiographic parameters from apical views, it is important to obtain the RV-focused apical 4-chamber view to optimize the visualization of this anatomically complex chamber. Subtle or subclinical RV dysfunction is better detected by strain imaging. Lower RV longitudinal strain values can be seen in RHD independent of the severity of MS, LVEF, TAPSE, or RV FAC, and is prognostic.[96]

## Recommendations

- Analysis of each cardiac chamber size and function should be performed comprehensively, using multimodality echocardiography.
- Imaging of the LAA should involve both TEE and 3DE.
- Strain imaging should be applied whenever possible to assess chamber function in subclinical RHD.

### D. Echocardiographic Guidance for Percutaneous and Surgical Therapy

***D.1. Echocardiographic Guidance for Selection and Intraprocedural Guidance.*** The transcatheter treatment options for RHD other than MS are limited at present. After the introduction of the Inoue balloon catheter in 1984, PBMV became the treatment of choice for symptomatic rheumatic MS.[97] The procedure enlarges the narrowed MVA by splitting the fused commissures. Successful PBMV is defined when a MVA $\geq$1.5 cm$^2$ is achieved with no more than +2 MR.[98] Surgical repair or valve replacement may be chosen for MS not suitable for PBMV and with coexistent valvular lesions. Echocardiographic evaluation that incorporates all modalities is crucial for making these determinations.

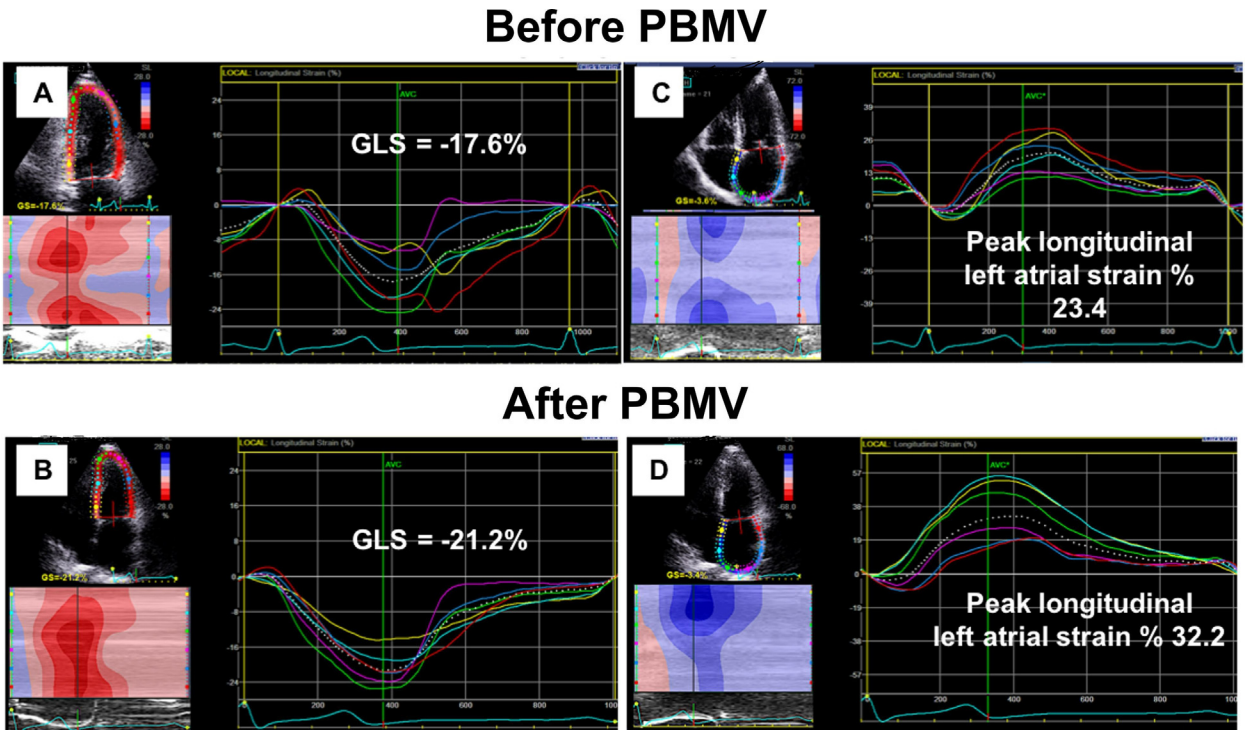


Figure 16 Pre- and post-PBMV global longitudinal strain of LV (**A and B**, respectively) and LA (**C and D**, respectively), showing improvement in the myocardial deformation measurement. GLS, global longitudinal strain. *PBMV,* Percutaneous balloon mitral valvuloplasty.

Pre-procedure echocardiographic assessment for PBMV includes confirmation of the severity of MS as described earlier, the extent of valvular abnormalities, the presence or absence of significant MR, and the presence or absence of clots in the LA body and appendage. Moderate to severe MR is a contraindication for PBMV. PBMV should be postponed until the resolution of LA or LAA clots followed by a period of anticoagulant therapy. Several scoring systems have been proposed to assess the suitability of PBMV.[99-101] They are mostly similar and of almost equal value in predicting the outcome. The key components of the available scoring systems include the degree of leaflet thickening, pliability (doming) of the leaflets (particularly the anterior leaflet), the extent of calcification, extent and symmetry of commissural fusion, and the severity of any subvalvular disease. Highly calcified valve leaflets, severe or asymmetric commissural calcification and fusion, and extensive subvalvular disease do not yield good results and, in fact, can cause complications, such as leaflet tear and significant MR.

Intraprocedural echocardiography offers significant advantages, compared with fluoroscopic guidance, in monitoring procedural efficacy and development of complications. TEE is superior to TTE to guide PBMV. 2D and 3D TEE guide transseptal puncture, pointing out the suitable location, usually in the fossa ovalis zone and posteriorly away from the aorta (Fig. 17A, Video 15). This can be easily visualized in the biplane views of 3DE. 2D and 3D TEE also guide the transport of the balloon catheter across the interatrial septum, then through the stenotic valve and during balloon inflation (Fig. 17B-D, Video 16). The use of echocardiography to guide transseptal catheterization and PBMV is further detailed in the previously published recommendations for echocardiography-guided interventions.[102]

MV surgery is an option for symptomatic patients with severe MS who are not suitable for PBMV and for patients with another co-existent disease that requires cardiac surgery. Surgical commissurotomy can be performed in such patients unless extensive calcification of the valve apparatus precludes it. Surgical MV repair is preferable whenever possible. Careful selection of patients based on the MV anatomy, along with a dedicated and experienced surgical team, are prerequisites for successful repair of a rheumatic mitral valve. The durability of rheumatic MV repair in the modern era has been improving, and the results of the recently published series are promising.[103,104] Success of MV repair is dependent on careful systematic valve analysis with preoperative and intraoperative echocardiography. Intraoperative TEE is useful in outlining the extent of the disease as well as evaluating the efficacy of surgical repair.[105] The imaging methods and data to be acquired are similar to those described for PBMV.

***D.2. Assessment of Post-Procedure Outcomes and Possible Complications.*** Immediate post-procedure imaging by 2DE and color Doppler is indispensable to assess the efficacy of PBMV and to monitor potential complications and hemodynamic changes. 3D TEE is useful in demonstrating the pattern of commissural splitting (Video 17-20). MVA can be measured by planimetry from transgastric short-axis 2D images or the 3D dataset (Fig. 17E). MVA, as assessed by 2DE, is a strong predictor of the immediate results of PBMV.[98] In most successful cases, MVA approximately doubles. Mean pressure gradient should be assessed to evaluate the procedural success and for prognostic value. Immediately after PBMV, PHT is unreliable for calculation of MVA due to an acute change in chamber compliance, and is generally not recommended within 24 hours of PBMV.[106]

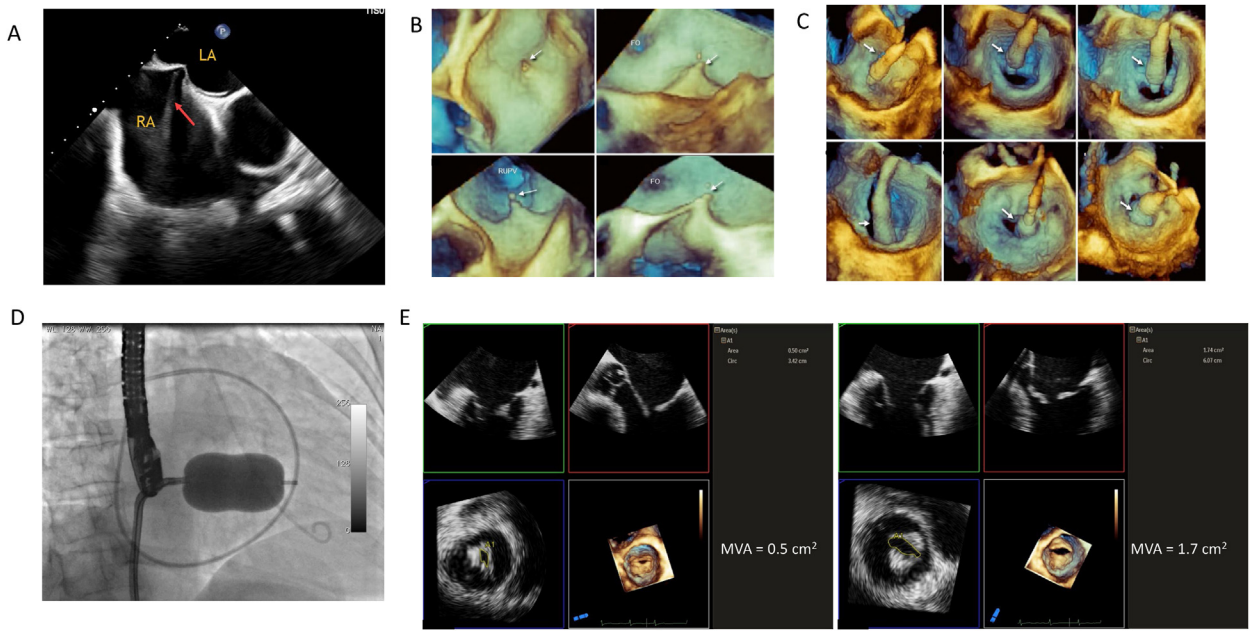


**Figure 17** TEE guidance of PBMV. **(A)** TEE showing the short-axis view marking the transseptal puncture needle (red arrow) in position and the atrial septum bowed into the left atrium. **(B)** Left atrial view during 3D TEE guidance showing the transseptal needle crossing the interatrial septum. **(C)** 3D TEE guidance from the left atrial view during transport of the balloon catheter (arrow) through the stenotic valve and during balloon inflation. **(D)** Fluoroscopic visualization of the inflated valvuloplasty balloon. **(E)** Pre- and immediate post-PBMV imaging (left and right, respectively) by 3D TEE to assess the MVA by planimetry from the 3D dataset. (Panels B and C: Reprinted/adapted by permission from Springer Nature, Real-Time 3D Interventional Echocardiography by Francesco Fulvio Faletra, Gila Perk, Natesa G. Pandian, Hans-Joachim Nesser, Itzhak Kronzon, © 2014, https://doi.org/10.1007/978-1-4471-4745-9)

MVA by planimetry can be used reliably early after PBMV. However, when visualization of the valve is suboptimal, a PHT less than 130 milliseconds is associated with good valve opening post valvuloplasty and may be useful.[107]

Procedural complications include cardiac tamponade, worsening or new acute MR, or occurrence of a major interatrial septal shunt. Echocardiographic signs for cardiac tamponade include [1] early diastolic collapse of the right ventricular free wall, best seen on M-mode echocardiography over the RV wall but with decreased sensitivity in the presence of right ventricular hypertrophy and PH; [2] evidence of increased ventricular interdependence by respiratory discordance of the MV and TV inflow velocities, changes in ventricular internal dimensions with respiration, and interventricular septal bounce; and [3] a dilated IVC with a decreased respiratory response. RA collapse is sensitive but not specific for cardiac tamponade.

Acute severe MR is a serious complication following balloon inflation during PBMV. In case of acute severe MR or worsening MR, the mechanism of regurgitation must be investigated further, such as leaflet tearing, leaflet perforation, or papillary muscle rupture (Fig. 18A). Acute severe MR causes hypotension and high LA pressure, which leads to a low driving pressure. As a consequence, lower MR jet velocity and less turbulent flow by color Doppler will be seen and may underestimate the severity of MR. Depending on the mechanism of MR, the color Doppler jet can be markedly eccentric, which further underestimates the MR severity. Nevertheless, a constellation of findings, such as flail leaflet or ruptured papillary muscle, hyperdynamic LV with paradoxically low systemic output per Doppler values, along with clinical findings should suffice to establish the diagnosis of acute severe MR, even when color Doppler does not show a large MR jet. Pulmonary vein systolic flow reversal is usually present and is helpful. In acute MR, quantification methods to assess chronic MR severity cannot be applied.[38]

Although the iatrogenic left-to-right shunt at the interatrial septum from catheter manipulation occurs commonly (Fig. 18B), most defects are small, restrictive, and may close spontaneously after several months. Close examination of the interatrial septum, including a zoomed subcostal view with color Doppler to assess the extent of the residual shunt, should be performed in post-procedure TTE and may require serial examinations if significant atrial septal defect is present. The use of TEE guidance reduces the incidence of septal puncture at a suboptimal location and decreases complications.

Systemic thromboembolism is caused by dislodgement of thrombus from the LAA, or thrombus formation on the catheter. Pre-procedural TEE or cardiac CT should be performed to rule out the presence of intraatrial thrombus before intervention.

## Recommendations

- Echocardiographic Information needed for patient selection for PBMV should include [1] degree of thickening and calcification of leaflets and commissures, [2] extent and symmetry of commissural fusion, [3] severity of subvalvular thickening, shortening, and fusion, [4] severity of MR, if present, and [5] presence of LA or appendage clots.
- Intraprocedural 2D and 3D TEE is recommended to guide transseptal puncture as well as passage and inflation of the balloon catheter.
- Immediately post-procedure, transmitral pressure gradient and MVA by planimetry should be measured.
- PHT should not be used to calculate MVA immediately after PBMV.
- Post PBMV, the echocardiographic examination should include screening for potential complications, including cardiac tamponade, the severity of MR, and the extent of iatrogenic ASD.

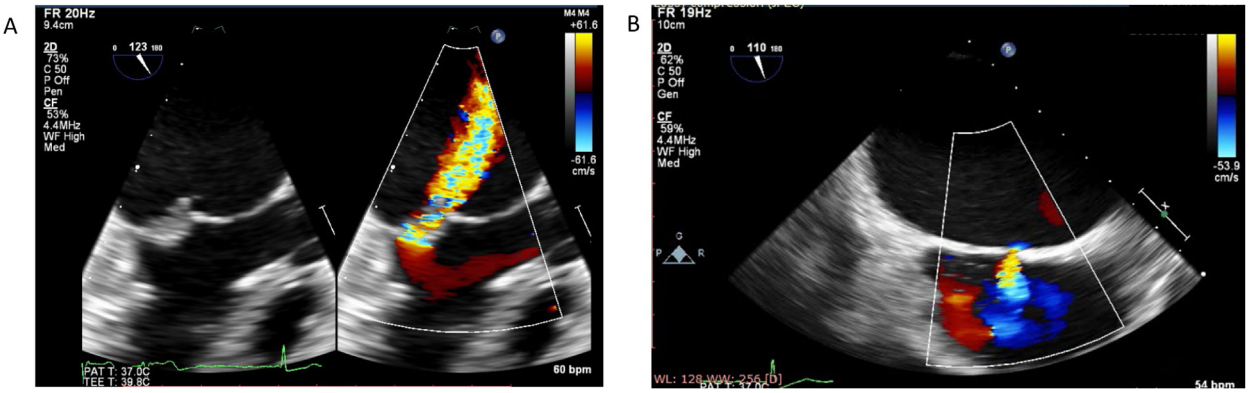


**Figure 18** Examples of complications and common findings from PBMV. **(A)** TEE long-axis view of the MV in 2D and color Doppler post PBMV, demonstrating a complication of leaflet tearing *(left)* leading to acute mitral regurgitation *(right)*. Note smaller than expected MR jet area related to hypotension and high LA pressure caused by acute severe MR, which may underestimate the severity of MR. **(B)** Color Doppler of TEE in bicaval view showing left-to-right shunt across the interatrial septum expected from transseptal puncture post PBMV.

## VI. CONCLUSIONS

RHD is a major health problem globally and one of the most common cardiovascular diseases in young people worldwide. Thus, health care providers everywhere should be cognizant of this disease and have a solid understanding of how to diagnose and treat it. Echocardiography is the most important diagnostic tool in recognizing this preventable and treatable disease, and plays an invaluable role in detecting the presence of subclinical disease needing prompt therapy or follow-up assessment. This document provides broad recommendations for the use of echocardiography in the diagnosis and risk assessment of RHD. Echocardiographic diagnosis of RHD is made when typical findings of valvular and subvalvular abnormalities are seen, including leaflet thickening, particularly nodular fibrosis of leaflet edges, commissural fusion, restricted leaflet mobility, with varying degrees of calcification. The MV is predominantly affected, most often leading to MS. However, mixed valve disease and associated cardiopulmonary pathology are common. Therefore, the severity of valvular lesions and hemodynamic effects on the cardiac chambers should be examined, in addition to screening for PH. It is essential to take advantage of all available modalities of echocardiography to provide accurate anatomic and hemodynamic details of the affected valve lesion(s) for diagnostic and strategic pre-treatment planning. Echocardiographic guidance is critical during and immediately after catheter-based or surgical treatment of RHD, and for ongoing assessment of disease progression. Given the indispensable role of echocardiography in the entire spectrum of RHD management, an integrative, comprehensive approach is recommended, taking into account strengths and pitfalls of the principles and utility of each echocardiographic modality.

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## SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https: //doi.org/10.1016/j.echo.2022.10.009.

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# Update

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# CORRECTION

Check for updates

Correction to the paper entitled "Recommendations for the Use of Echocardiography in the Evaluation of Rheumatic Heart Disease: A Report from the American Society of Echocardiography" by Pandian et al., published in the January 2023 issue of JASE (J Am Soc Echocardiogr 2022;36:3-28).

On page 8, in the section entitled "A.2 Hemodynamic Considerations in the Assessment of Mitral Stenosis," the first sentence of the fourth paragraph was incorreclty stated as, "The rate of decay of the MV pressure gradient is a measure of the severity of MS and is inversely proportional to MVA." The correct sentence is, "The pressure half-time (which increases with a slower rate of decay of the MV pressure gradient) is a measure of the severity of MS and is inversely proportional to the MVA."

The authors would like to apologize for any inconvenience caused by this error.

# CORRECTION

Check for updates

Correction to the paper entitled "Echocardiographic Assessment of Valve Stenosis: EAE/ASE Recommendations for Clinical Practice" by Baumgartner et al., published in the January 2009 issue of JASE (J Am Soc Echocardiogr 2009;22:1-23).

On page 12, the section entitled, "B.1.3 Pressure half-time," the last sentence of the first paragraph was incorrectly stated as, "The decline of the velocity of diastolic transmitral blood flow is inversely proportional to valve area ($cm^2$), and MVA is derived using the empirical formula:[53]." The correct sentence is, "The pressure half-time (which increases with a slower rate of decay of the MV pressure gradient) is a measure of the severity of MS and is inversely proportional to the MVA:[53]."

In Table 8, row 2 for -pressure half-time, under the Concept column, "rate of decrease of transmitral flow is inversely proportional to MVA" should be replaced with "rate of decrease of transmitral flow is directly proportional to MVA."

The authors would like to apologize for any inconvenience caused by these errors.