Review Article

My Approach to Three-Dimensional Echocardiography in Mitral Stenosis: How and When?

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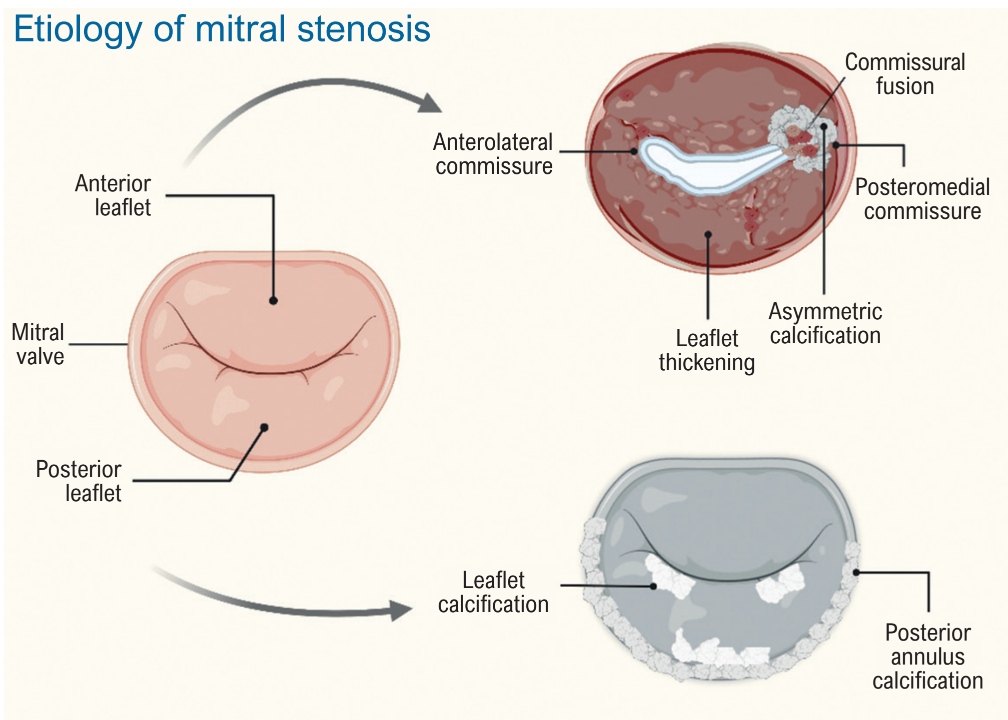
Central Illustration: My Approach to Three-Dimensional Echocardiography in Mitral Stenosis: How and When?



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Schematic illustration of the anatomical manifestations of mitral stenosis according to etiology. On the left, a normal mitral valve. In the upper right quadrant, the rheumatic pattern shows diffuse leaflet thickening with fusion and asymmetric calcification of one commissure. In the lower right quadrant, the degenerative calcific pattern shows extensive calcium deposition in the posterior annulus and the leaflet bases.

Keywords

Three-Dimensional Echocardiography; Mitral Valve Stenosis; Three-Dimensional Imaging

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Abstract

Three-dimensional echocardiography has become an essential tool in the assessment of mitral stenosis, allowing detailed anatomical analyses and reliable measurements, even in complex anatomies or extensive calcification. Based on daily clinical experience in an imaging laboratory, this article offers a practical guide for image acquisition and optimization, multiplanar reconstruction, and three-dimensional planimetry, focusing on technical adjustments, the use of tools such as rotation and cropping, and strategies for integrating the method into the routine workflow of cardiovascular imaging centers.

Introduction

Mitral stenosis remains a clinically relevant condition worldwide. It is associated with significant morbidity, and it impacts patient quality of life and survival. Moreover, in older populations in developed countries, degenerative etiologies have become progressively more frequent, reflecting population aging and increased life expectancy.[1] International guidelines emphasize that mitral stenosis, regardless of etiology, is associated with severe complications, such as pulmonary hypertension, atrial fibrillation, and heart failure, requiring accurate diagnostic and therapeutic strategies to provide details on disease progression and improve prognosis.[1]

Two-dimensional (2D) echocardiography is still the primary method for quantifying valve area in mitral stenosis. However, 2D planimetry is highly dependent on an exact orthogonal slice over the leaflet tips, and slight deviations in the plane or the presence of acoustic shadowing due to calcification can lead to overestimation of the area and even make it impossible to measure.[2]

Recognizing these limitations, European guidelines recommend the complementary use of three-dimensional (3D) planimetry, which improves the definition of the smallest functional orifice when 2D imaging is suboptimal.[3] Additionally, area calculation by pressure half-time (PHT) is directly influenced by atrial and ventricular compliance, transient hemodynamic conditions (e.g., aortic regurgitation, diastolic dysfunction), and associated lesions, such as mitral regurgitation, which shorten or lengthen PHT and lead to errors in valve area estimation. These factors explain why, in complex clinical scenarios, the integration of additional parameters such as 3D planimetry may be relevant for accurate classification of mitral stenosis severity.[2,3]

My Approach in Practice

Given these limitations and the need for more accurate measurements, 3D echocardiography has become increasingly integral to mitral stenosis assessment, not only as a supplement but also as a central tool in complex scenarios, especially due to the fact that it allows for orthogonal alignment of the pyramidal beam in relation to the valve plane and due to its high spatial resolution. Below, we describe our approach to this assessment in daily practice.

The first step is always to optimize 2D acquisition. An inadequate 2D image directly compromises the quality of 3D reconstruction. Adjustments such as gain, compression, and alignment should be made before activating 3D mode. A quality 3D assessment cannot be achieved without a stable and well-oriented 2D basis.

Following image optimization, we use 2D multiplane mode to align the orthogonal axes and correctly identify the plane of the leaflet tips. Subsequently, we activate 3D zoom mode to obtain an en face view of the valve orifice, positioning the cutting plane at the smallest diameter during diastole. When necessary, we apply color Doppler, integrated with the reconstruction to assess residual flow or associated regurgitation. Leaflet mobility, symmetry of commissural fusion, and the presence of calcification or subvalvular alterations are assessed by means of multiplanar reconstructions and en face views obtained in 3D mode, allowing detailed analysis of the mitral apparatus in different orthogonal planes.[4]

The Role of 3D Transthoracic Echocardiography

Three-dimensional transthoracic echocardiography (TTE) represents a strategic initial phase in mitral stenosis assessment, especially due to the fact that it provides real-time images with good spatial resolution in patients with a favorable acoustic window.[4] Its main contribution is quick, noninvasive acquisition of the mitral valve. Furthermore, 3D TTE facilitates the morphological characterization of the valve regarding symmetry of commissural fusion, leaflet thickening, and extent of calcifications; this information is relevant to etiological diagnosis and selection of candidates for percutaneous valvotomy. Although it has limitations in complex anatomies or in patients with inadequate windows, this step can anticipate relevant data and more efficiently guide the planning of transesophageal assessment.[4] Figure 1 displays an example of 3D TTE in severe rheumatic mitral stenosis with tunneling, demonstrating the morphological alterations that are typical of this etiology in atrial and ventricular views.

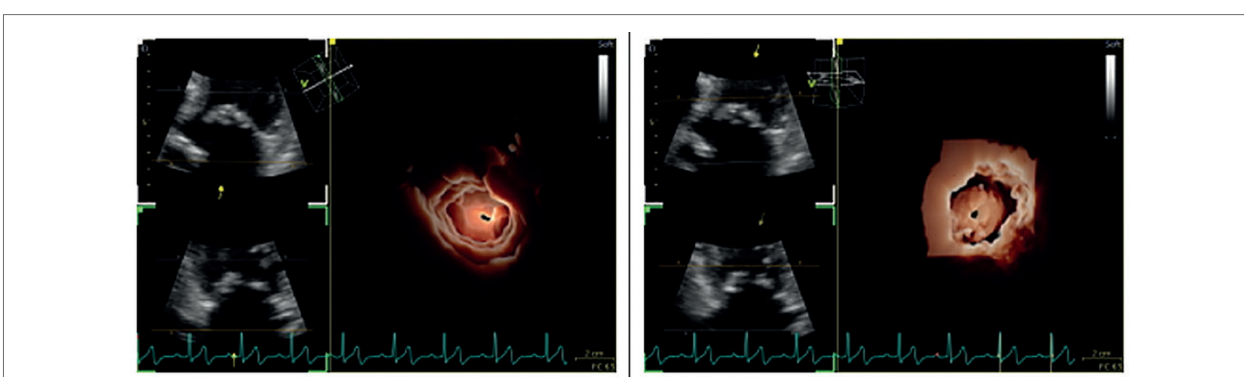

Figure 1 – *Three-dimensional transthoracic echocardiography of the mitral valve in severe rheumatic mitral stenosis with tunneling. On the left, atrial view with the tunneled valve orifice, typical of severe rheumatic anatomies. On the right, ventricular view showing the elongated, narrow trajectory of the functional orifice, with commissural fusion and associated subvalvular restriction.*

In a prospective study involving 105 patients with severe mitral stenosis, despite the lower image resolution of 3D TTE compared to 3D transesophageal echocardiography, both techniques showed excellent agreement (significant correlation; mean bias < 0.01 cm^2), confirming the reliability of 3D TTE for quantifying valve area.[5]

Although the role of 3D TTE is relevant and can provide reliable data, especially in favorable acoustic windows, transesophageal echocardiography is still an indispensable step for detailed assessment. It is during this phase that we systematically apply the following acquisition and optimization parameters.

Image Assessment and Optimization Parameters

3D Planimetry

Three-dimensional planimetry is currently considered the most accurate method for determining mitral valve area in mitral stenosis, as it reduces errors related to oblique views and dependence on acoustic windows that limit 2D planimetry. Using multiplanar reconstructions and en face visualization in 3D transesophageal mode, it is possible to accurately identify the smallest orifice in diastole, even in complex anatomies with calcification or asymmetric commissural fusion.[2,3]

In addition to greater accuracy in measuring valve area, 3D planimetry has demonstrated relevance in prognostic stratification. In a comparative study, the method consistently yielded smaller valve areas than PHT and 2D planimetry, reclassifying mitral stenosis severity in nearly 20% of cases.[6] More importantly, only classifications of severe stenosis obtained by 3D planimetry were significantly associated with clinical outcomes, such as the need for valvotomy, valve surgery, or hospitalization for heart failure; it also showed better correlation with hemodynamic markers, such as right ventricular systolic pressure and left atrial volume.[7,8] These findings reinforce the value of 3D planimetry not only in anatomical assessment but also in identifying patients at higher risk of clinical events.[6]

Figure 2 illustrates an example of 3D planimetry obtained by 3D transesophageal echocardiography, highlighting multiplanar reconstruction and en face visualization for precise plane positioning in the smallest functional orifice during diastole. FlexiSlice® (GE Healthcare) was used for precise plane alignment and visual optimization.

Comparison with PHT and 2D Planimetry

When compared to traditional methods, 3D planimetry shows lower interobserver variability and avoids biases associated with the method of PHT and 2D planimetry.[2,4] Whereas PHT is directly influenced by atrial and ventricular compliance, the presence of associated regurgitation, and transient hemodynamic conditions, compromising the accuracy of valve area estimation, 2D planimetry can overestimate or underestimate stenosis severity when there are non-orthogonal slices or acoustic shadowing.[2,3] Therefore,

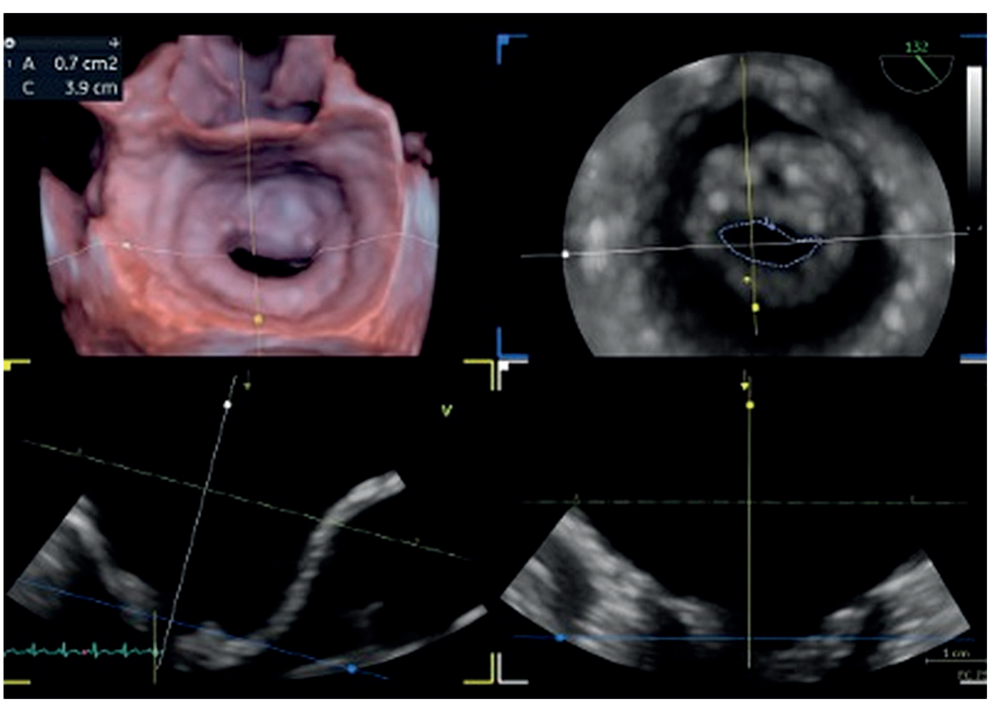

Figure 2 – *Multiplanar reconstruction by three-dimensional transesophageal echocardiography in mitral stenosis, allowing precise positioning of the plane in the narrowest portion of the valve orifice during diastole, facilitating reliable anatomical measurement of the functional area.*

the integration of 3D planimetry into the diagnostic workflow has a significant clinical impact, allowing more accurate stratification of disease severity and assisting in decision-making and planning of interventions, such as percutaneous valvotomy or surgery.[2-4]

Multiplanar Alignment in Volume Acquisition

Before capturing 3D volume, whether in zoom or full-volume mode, it is essential to use 2D multiplanar mode in order to correctly align the orthogonal axes to the mitral valve plane. This alignment during the acquisition phase is especially important in cases of mitral stenosis, where anatomy is often asymmetrical, and the minimum functional area may not coincide with a standard anatomical plane. Adjusting the lateral-medial and anteroposterior planes over the leaflet ends ensures that the plane of maximum diastolic opening is recorded, thus reducing errors and facilitating post-processing.

For rheumatic valves, it is recommended to align the coronal plane between the commissures (anterolateral and posteromedial), respecting any eventual asymmetries. The axial (transverse) plane should be verified to ensure that the functional orifice is centered and avoid tangential cuts. When there is asymmetric calcification or anatomical distortion, small adjustments to probe tilt can reposition the beam in a more favorable manner. The presence of an irregular rhythm, such as in atrial fibrillation, justifies the preference for 3D zoom mode with single-beat acquisition, avoiding stitch artifacts, which are common in full-volume images.

During 3D zoom acquisition, it is important to maintain a reasonable frame rate, ideally above 20 volumes per second (VPS), in order to preserve temporal clarity. Single-beat acquisition modes can reach up to 25 VPS, improving definition in patients with irregular rhythms, whereas multiple beats can increase the frame rate to even higher values (such as 80 VPS), but they require regular rhythm and pose the risk of artifacts. Very low rates can make it difficult to identify the smallest functional diameter, especially in complex anatomies.

The systematic adoption of these strategies during acquisition provides volumes that are more representative of functional anatomy, reduces the need for extensive corrections in post-processing, and increases the accuracy of valve area measurement by 3D planimetry.

Post-processing and Optimization of 3D Images

High-quality 3D images for mitral stenosis assessment directly depend on appropriate gain, brightness, and compression settings during acquisition and post-processing. Gain should be adjusted to enhance the echogenicity of the leaflets and commissures without saturating the image or introducing artifacts. Excessive gain amplifies low-intensity echoes, which can generate artificial shadows, whereas insufficient gain compromises visualization of the valve edges and valve orifice. A proper balance ensures that anatomical boundaries are clear, facilitating multiplanar reconstruction and 3D planimetry.[4]

Brightness and compression (contrast adjustment) also play a fundamental role. In the analysis of mitral stenosis, low- to medium-intensity compression is recommended, preserving the contrast necessary to clearly differentiate the edges of the functional orifice and commissures, without saturating echogenic areas. Excessive compression reduces the grayscale range, which can mask fine calcifications or partial fusions; very low compression excessively increases the dynamic range, resulting in reduced margin definition. Adjustment should be performed progressively during post-processing, verifying sharpness and anatomical continuity in multiplanar reconstructions before planimetry, in order to highlight the valve apparatus without distorting morphology.[4]

Smoothing is another available feature, which acts to reduce the graininess of a reconstructed surface. Although it is useful for creating a more homogeneous appearance of the valve and facilitating visual analysis, excessive use of this tool can distort irregular surfaces and attenuate the perception of critical structures, such as punctual calcifications or areas of fusion. In mitral stenosis, smoothing should be applied cautiously, only to improve image uniformity without compromising anatomical accuracy. Similarly, a well-optimized 2D image prior to volume capture is indispensable, given that any artifacts that arise during acquisition propagate to the 3D dataset, compromising multiplanar analysis and subsequent measurement of the valve area.[7,8]

Gamma adjustment can also be used to balance the distribution of grayscale in 3D imaging. Lower values increase contrast in darker areas, enhancing edges and fine calcifications, whereas higher values facilitate the visualization of less echogenic structures. Adjustments should be moderate in order to avoid loss of detail or distortion of anatomical perception.

In 3D analysis of mitral stenosis, features such as Clarity can be used to enhance edges and reduce noise, improving valve contour definition and facilitating planimetry, especially in complex anatomies or those with calcification. Adjustments should be moderate in order to avoid artifacts or artificial highlights. As a complementary and optional feature, HD Live can be used for volumetric rendering with lighting simulation, altering depth perception and 3D realism. Although this feature does not directly influence measurement accuracy, it can assist in spatial understanding and visual communication of anatomical findings.

Artifact and Noise Correction

High-quality 3D images for mitral stenosis assessment do not depend only on appropriate gain, brightness, and compression adjustments, as mentioned above, but also on strategies to reduce artifacts and noise that can compromise valve area measurement. A frequent challenge is acoustic shadowing caused by extensive calcification, which leads to loss of definition in the leaflets and subvalvular region. In order to mitigate this, the following are recommended:

- Slightly reduce the gain and adjust the compression to enhance valve edges without saturating calcified areas.
- Experiment with small changes in the probe angle, seeking windows with lower acoustic interference.

- In persistent cases, apply 3D zoom mode with a restricted focus on the valve, minimizing the need for extensive reconstructions and areas affected by shadowing.

Speckle noise is another issue that can make accurate identification of the valve contour difficult. Smoothing or noise suppression filters may be applied, provided that they are used moderately, given that excessive use tends to distort the actual geometry, especially in areas with calcification or commissural fusion.

In full-volume acquisitions, motion artifacts, for example, stitch artifacts, are common in patients with atrial fibrillation or tachycardia. In these cases, the use of smaller volumes or single-beat acquisition is preferable to avoid loss of anatomical continuity, even with lower spatial resolution.

Careful application of these techniques, combined with proper alignment of orthogonal planes and rational use of rotation and cropping tools, is essential to ensure that the final dataset faithfully represents anatomy, enabling reliable and reproducible planimetry.

Finally, it is important to bear in mind that all 3D analyses depend on the quality of the original 2D image. Artifacts acquired in the 2D base propagate to the reconstructed volume, impacting the accuracy of planimetry. A stable, well-centered, and distortion-free acquisition is the first step to effective post-processing.

Rotation and Cropping Functions in Post-processing

During 3D analysis of mitral stenosis, volume manipulation with the rotation and cropping functions is applied to optimize visualization of the valve orifice and mitral apparatus. Rotation of the volumetric block along orthogonal axes allows for precise alignment of the plane of view with the leaflet tips, facilitating an en face view of valve opening during diastole. This step is particularly important in complex anatomies, where asymmetric commissural fusions or calcifications can distort the standard orientation, making it difficult to measure the functional area.[6,8]

The cropping feature makes it possible to remove portions of the 3D volume that do not contribute to analysis, for example, adjacent cavities or redundant portions of the left atrium, allowing for exclusive focus on the mitral valve and its orifice. This cleaning process improves image clarity and structural definition, in addition to facilitating multiplanar reconstruction and planimetry.[4] Careful use of the cropping function also reduces artifacts and avoids overlapping structures, especially in cases with significant atrial dilation or multiple flow planes that could interfere with interpretation.[8]

The combination of these techniques, in conjunction with previously applied gain, brightness, compression, and smoothing adjustments, results in a more stable reconstruction that is faithful to the actual anatomy. Accordingly, systematic use of rotation and cropping tools not only improves visual quality but also increases the accuracy of valve area measurement and anatomical characterization, contributing to more reliable diagnostic analysis in mitral valve stenosis.

Systematic application of appropriate acquisition strategies, in association with image optimization techniques in post-processing and careful volume manipulation with tools such as rotation and cropping, improves the quality of 3D reconstruction and diagnostic reliability in mitral stenosis. Table 1 summarizes the main recommendations for reducing artifacts and obtaining accurate measurements. When the technical stage is optimized, it is possible to advance to individualized assessment of mitral stenosis according to etiology.

Individual Assessment According to Etiology

Mitral Stenosis of Rheumatic Etiology

Mitral stenosis of rheumatic etiology is characterized by commissural fusion, leaflet thickening that begins at the ends and extends toward the base, and fusion of the subvalvular apparatus, resulting in an orifice with a “fish mouth” appearance and diastolic doming motion of the anterior leaflet[2,8] (Figure 3). Echocardiographic assessment should document not only the extent of commissural fusion but also the presence and distribution of calcium in the commissures, which are fundamental parameters for determining the feasibility and safety of percutaneous balloon valvotomy.[8,9] Asymmetric commissural involvement or the presence of extensive calcification in the commissures are associated with lower hemodynamic success of percutaneous balloon valvotomy and greater risk of significant post-procedural mitral regurgitation[6,8] (Figure 4).

Recent studies show that 3D scores, such as the Anwar score, better capture the severity of commissural calcification and subvalvular involvement. These elements are directly related to the occurrence of suboptimal outcomes, such as final valve area < 1.5 cm^2 or significant post-procedural mitral regurgitation.[10] In a study by Farrag et al., the 3D-Anwar score was superior to the traditional Wilkins 2D score in predicting adverse outcomes, with a more robust negative correlation between the score and the valve area obtained.[9] Therefore,

Table 1 – Practical strategies to minimize artifacts in acquisition and post-processing of 3D volumes in mitral stenosis assessment

Reduce gain and adjust contrast in regions with calcification to avoid saturation and acoustic shadowing.
If there is loss of definition due to acoustic shadowing, adjust the probe angle slightly.
Give preference to 3D zoom mode when full-volume mode generates artifacts, especially in irregular rhythms.
Use smoothing moderately, only to homogenize the image, without losing anatomical definition.
In patients with atrial fibrillation, avoid multi-beat acquisition; single-beat mode is preferable for reduced volumes.
Ensure a good 2D image before capturing volume, as initial artifacts compromise the entire reconstruction.

2D: two-dimensional; 3D: three-dimensional.

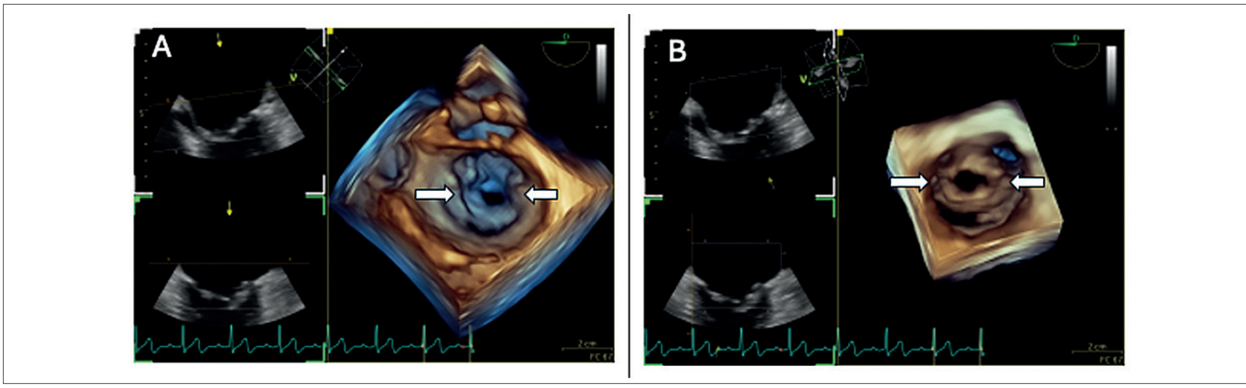

Figure 3 – *Three-dimensional images obtained by transesophageal echocardiography demonstrating commissural fusion, a characteristic of rheumatic mitral stenosis. (A) Atrial view. (B) Ventricular view.*

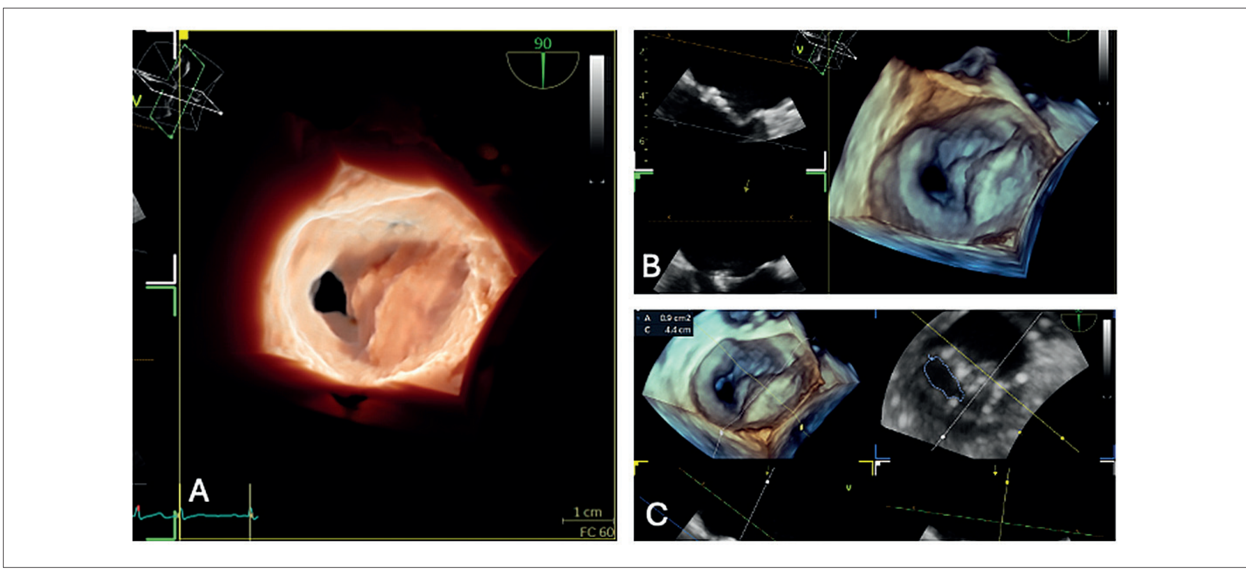

Figure 4 – *Images obtained by three-dimensional transesophageal echocardiography demonstrating partial commissural fusions and asymmetric calcification in rheumatic mitral stenosis. (A) Transillumination image, highlighting extensive calcification and asymmetric fusion of the posteromedial commissure. (B) Three-dimensional en face view of the mitral valve, highlighting the fusion and asymmetric distribution of calcium between the commissures. (C) Three-dimensional transesophageal planimetry showing severe stenosis.*

3D assessment of commissures not only enhances the accuracy of planimetry and anatomical characterization but also also provides fundamental prognostic parameters for candidate selection and planning of percutaneous interventions, reducing the risk of complications such as residual mitral regurgitation (Figure 5).

Mitral stenosis of degenerative etiology

Mitral stenosis of degenerative etiology predominantly occurs in elderly patients, and it results from progressive calcification of the mitral annulus, with frequent extension to the base of the leaflets. This configuration leads to the formation of a tubular or tunnel-shaped orifice, generally without significant commissural fusion, and it usually generates lower transmitral gradients for the same valve area when compared to the rheumatic form.[11,12] These anatomical peculiarities make conventional 2D echocardiography assessment challenging, given that the presence of extensive calcium often produces acoustic shadowing, making accurate 2D planimetry difficult or impossible.[11]

In this scenario, 3D echocardiography also plays an important role in calcific degenerative etiology, as it allows multiplanar reconstructions and en face visualization of the valve orifice, overcoming limitations imposed by acoustic shadowing and providing more reproducible and accurate measurements of mitral valve area.[1,2]

In addition to accurately measuring the valve area, 3D echocardiography allows for characterization of the distribution and extent of calcification, detailing annular involvement and calcium penetration in the leaflet bases.[11,12] This analysis is particularly relevant because the tubular geometry that is typical in this etiology tends to generate smaller gradients for the same

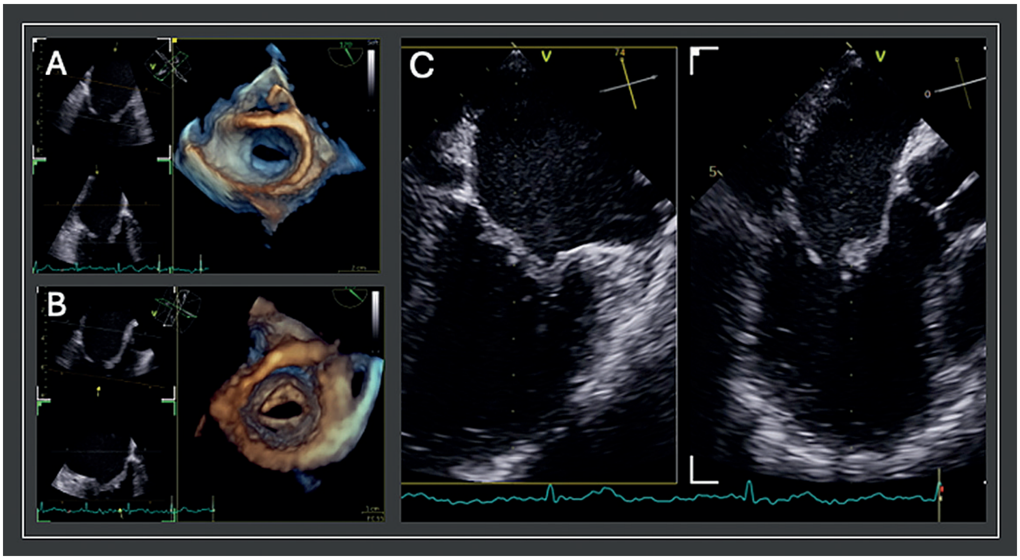

Figure 5 – *Images obtained by three-dimensional transesophageal echocardiography, representing a mitral valve with rheumatic anatomy that is favorable for percutaneous balloon valvotomy. (A) Three-dimensional atrial en face view demonstrating symmetrical commissural fusion with reduced valve area. (B) Three-dimensional ventricular en face view, with typical restricted posterior mobility and absence of significant subvalvular calcification. (C) Multiplanar (Multi-D) reconstruction integrating orthogonal slices for complementary mitral valve assessment.*

valve area, which can mask the severity of the obstruction when only hemodynamic parameters are considered.[11] The use of 3D assessment helps differentiate between low gradients due to reduced flow and those related to valve anatomy, avoiding underdiagnosis of significant stenosis.[10] In cases with extensive calcification or complex anatomical deformity, the integration of 3D assessment with computed tomography has been recommended to complement anatomical definition and guide therapeutic planning.[12]

The Central Illustration displays a comparative summary of the main anatomical characteristics with therapeutic implications for rheumatic and degenerative forms of mitral stenosis.

Conclusion

Three-dimensional planimetry is currently the most reliable method for estimating mitral valve area, especially in scenarios with complex anatomy, asymmetric commissural fusion, or extensive calcification. Even though 2D echocardiography continues to play a central role in the initial assessment, the systematic use of 3D echocardiography should be recommended in both the pre-procedure phase and the follow-up of patients with significant mitral stenosis, contributing to greater diagnostic accuracy and improved therapeutic guidance.

Author Contributions

Conception and design of the research: Costa A; Acquisition of data: Costa A, Sales MAM. Analysis and interpretation of the data: Carvalho MVSF; Writing of the manuscript: Costa A, Sales MAM, Carvalho MVSF; Critical revision of the manuscript for intellectual content: Costa A.

Potential conflict of interest

No potential conflict of interest relevant to this article was reported.

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Study association

This study is not associated with any thesis or dissertation work.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

Use of Artificial Intelligence

The authors did not use any artificial intelligence tools in the development of this work.

Data Availability

The underlying content of the research text is contained within the manuscript.

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