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Mini Review

Real-Time Three-Dimensional Echocardiography in Evaluation of Mitral Valve Disease

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Abstract

In sub-Saharan Africa, valvular heart disease is the third most common cause of cardiovascular disease after hypertension and cardiomyopathy and generally affects young people. In Angola, of all valve diseases, mitral valve disease is the most frequent.

Transthoracic echocardiography has been the diagnostic technique of choice for the anatomical and functional evaluation of valvular heart disease due to its high anatomical correspondence, ease of execution, availability, low cost and reduced associated risk. Two-dimensional transesophageal echocardiography significantly improved cardiac anatomical details with more information when compared to transthoracic assessment. The real-time three-dimensional echocardiography, adding a new dimension, allowed to improve the visualization of the spatial relationship of the different structures and started to be performed routinely in reference echocardiography laboratories.

In this article, we intend to make a brief review of the importance of three-dimensional echocardiography in the assessment of mitral valve disease, bringing nine years of experience from the author.

Keywords: *Echocardiography; Real-Time Three-Dimensional Echocardiography; Mitral Valve Disease; Mitral Regurgitation; Mitral Stenosis*

Introduction

The echocardiogram has been the diagnostic technique of choice for the anatomical and functional evaluation of cardiac structures due to its high anatomical correspondence, ease of execution, availability, low cost, and reduced associated risk [1]. Since its practical implementation over 60 years ago, much has evolved from a technological point of view, from the one-dimensional and the two-dimensional mode to new ways of quantifying cardiac phenomena and intra-cardiac flows with the introduction of the Doppler technique [1,2].

Two-dimensional transesophageal echocardiography has significantly improved cardiac anatomical detail with increased information when compared to transthoracic assessment. From the point of view of diagnostic information, the two-dimensional technique has limitations in the assessment of cardiac anatomy, with difficulty in demonstrating the spatial relationship of the different structures [1,2].

Three-dimensional echocardiography responded to this limitation. Although the first reports of three-dimensional echocardiography appeared in the seventies, its practical application was limited by the absence of software and hardware capable of processing information and the need for lengthy (deferred) reconstruction processes [1-4]. In the 90s Vom Ramm., *et al.* [5] developed the first 3D probe in

real time and three-dimensional echocardiography has undergone a rapid evolution and its clinical utility has been demonstrated in the assessment of ventricular volumes [6-9] and ejection fraction [6-9], ventricular mass [6,7,9] in valve disease [10-13] particularly with regard to the mitral valve [10,11].

Until 2007, real-time 3D technology was only available for transthoracic echocardiography. Since then, a transesophageal probe has been commercially available, capable of real-time acquisition and online viewing of three-dimensional images [2]. Several studies have demonstrated the additional value of real-time three-dimensional transesophageal echocardiography (RT3D ETE) in the evaluation of the mitral valve and valve prosthesis in the mitral position [14-18] and in non-coronary intervention cardiology [19-22] namely, in the closure of the interauricular communication [19,20], in the closure of prosthetic leak [21] and in invasive percutaneous treatment of aortic stenosis, mitral stenosis and mitral regurgitation [22].

In this article, we intend to make a brief review of the importance of three-dimensional echocardiography in the assessment of mitral valve disease, bringing nine years of experience from the author.

Mitral valve anatomy

Anatomically, mitral valve (MV) apparatus includes the mitral annulus, mitral leaflets, chordae tendinae, and papillary muscles and underlying myocardium. A detailed knowledge of MV anatomy is important in understanding MV function and the mechanism of both primary and secondary mitral regurgitation (MR) [23].

Normal mitral annulus is a D-shaped fibrous structure formed from the fibrous skeleton of the heart that serves to anchor the leaflets. In a normal heart, mitral valve is connected to ventricular myocardium through papillary muscles via chordae tendinae. This is largely responsible for stability of mitral valve apparatus in various loading conditions. The mitral annular area is dynamic throughout the cardiac cycle being largest at mid-diastole and smallest at mid-systole [23].

Mitral valve has two leaflets. Anterior mitral leaflet (AML) and posterior mitral leaflet (PML). The postero-medial and antero-lateral commissures demarcate the posterior from anterior leaflet insertions into the annulus. Total area of these leaflets is twice the area of annulus. AML is longer than PML and is attached to ~1/3rd of annular circumference. The PML commonly is indented twice, resulting in 3 independently mobile scallops identified as P1, P2 and P3, with analogous virtual subdivisions on the nonindented anterior leaflet (A1, A2, and A3) [24,25] (Figure 1).

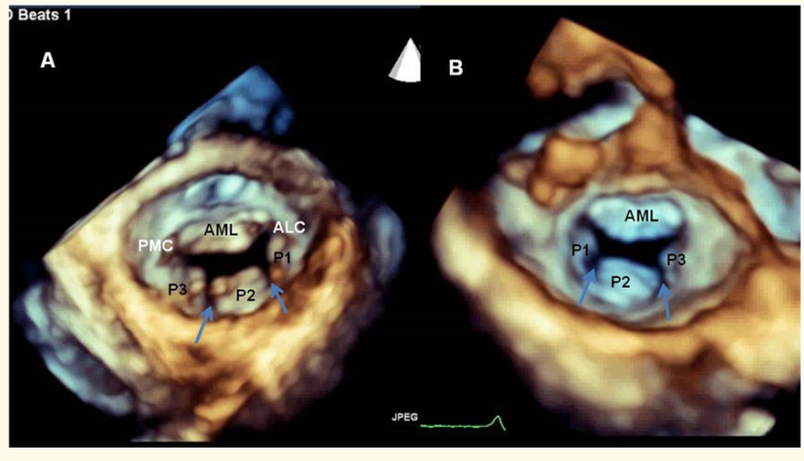

Figure 1: *Real-time 3D transthoracic echocardiography shows a normal mitral valve in mesodiastole A-View from left ventricle; B -view from left atrium, AML Anterior mitral leaflet P1, P2, P3 - segments or scallops of the posterior mitral valve; PMC: Posteromedial Commissure; ALC: Anterolateral Commissure; Cleft-Like Indentation (arrows).*

Chordae tendinae and papillary muscles: there are multiple generations of chordae from tip of papillary muscle to mitral valve leaflets. Chordae from each papillary muscle are attached to both leaflets. They are attached to leaflet margins (primary chordae), body of leaflets (secondary chordae) and base of leaflets (tertiary chordae). The chordae provide the critical functions of anchoring the mitral leaflets during systole, preventing prolapse of the leaflets into the LA, and allowing for symmetric coaptation. There are two papillary muscles in the LV, named by their location of origin, postero-medial and antero-lateral [23,24].

Normal motion of leaflets include complete excursion of both leaflets in diastole with AML moving anteriorly and PML moving posteriorly. In systole, both leaflets join each other at tips with 3 - 5 mm overlap. This 3 - 5 mm part is called zona-coapta [24].

As we can see the mitral valve apparatus is anatomically very complex, which hinders its detailed anatomical study by 2D transthoracic echocardiography (2DTTE). However, 2DTTE remains the primary imaging modality and screening tool for the assessment of MV morphology and geometry, and most importantly it provides accurate quantification of valvular dysfunction. A detailed assessment of mitral valve apparatus by 2DTTE was described by Singh., *et al* [24].

Transesophageal echocardiography (TEE) is ideal to provide a more precise anatomic assessment of MV lesions due to improved spatial resolution. It is more sensitive for the detection of finer anatomic details in patients with severe annular calcification or prosthetic valve materials that might result in acoustic shadowing on TTE [23].

Figure 2 shows four important transesophageal views with the transesophageal probe in the mid-esophageal position for assessment of the mitral valve (MV) abnormalities. All three scallops of both leaflets can be visualized by using different multiplane angles. Four chamber view (at 0 to 10º) show A3, A2 and P2, P1; mitral commissural view (at 50 to70º) usually show (at 50 to70º) P3-A1, A2, A3 and P1. Two chamber view (at 120 to 140º) show P3 and A1, A2, A3 and in long axis view we can see P2 and A2. Additionally, the transgastric basal short axis view is helpful to assess commissural morphology, and the transgastric 2 chamber view provides a clear view of the subvalvular apparatus [23].

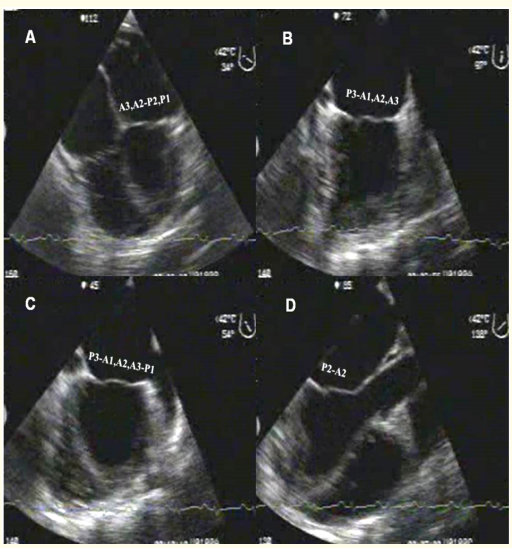

Figure 2: *Basic 2D transesophageal echocardiographic views for the assessment of mitral valve apparatus, in the mid-esophageal position Segments of the anterior leaflet (A1, A2, and A3) and posterior leaflet (P1, P2, and P3) are visualized and labeled in corresponding views. A - parasternal long axis; B - two-chamber; C - mitral commissural; D -three-chamber view.*

3D TTE and specially 3DTEE improves the definition of the anatomy of valves, commissures, mitral annulus and papillary muscles, allowing for a more detailed and accurate study than 2D echocardiography [24,25].

Figure 3 shows an image of real time 3DTEE of the mitral valve seen through the left atrium, also called "en face view" or "surgeon's view". In one acquisition we can see all scallops of the mitral valve leaflets. This specific view facilitates communication between echocardiologists and surgeons and interventionists [25].

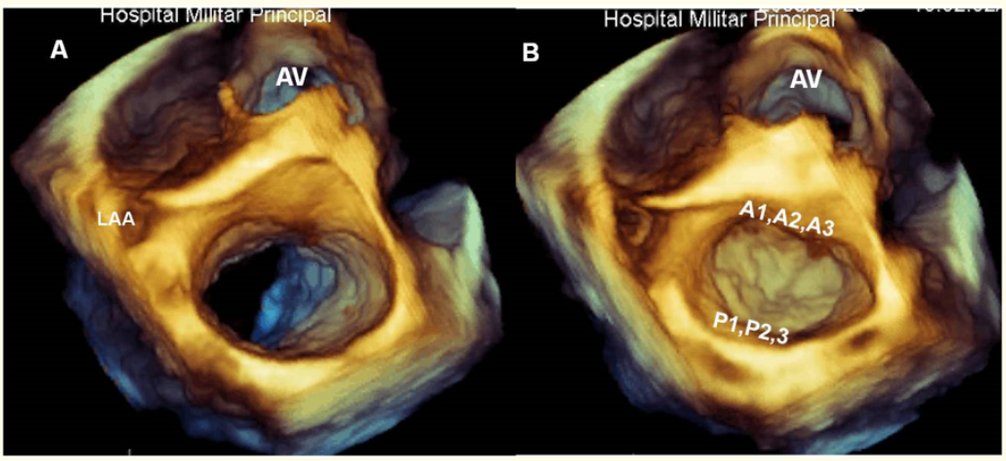

Figure 3: *Real time 3D transesophageal echocardiography (zoom mode) of normal mitral valve, view from the left atrium in diastole (A) and in systole (B). AV: Aortic Valve; LAA: Left Atrial Appendage.*

In sub-Saharan Africa, valvular heart disease is the third most common cause of cardiovascular disease after hypertension and cardiomyopathy and generally affects young people. In our country, of all valve diseases, the mitral valve disease is the most frequent.

Mitral stenosis

Mitral stenosis (MS) is characterized by the fusion of the commeasures, in rheumatic disease (Figure 4A and 4B), or by excessive calcification of the various components of the MV, in degenerative disease, more rarely the etiology of the MS is congenital.

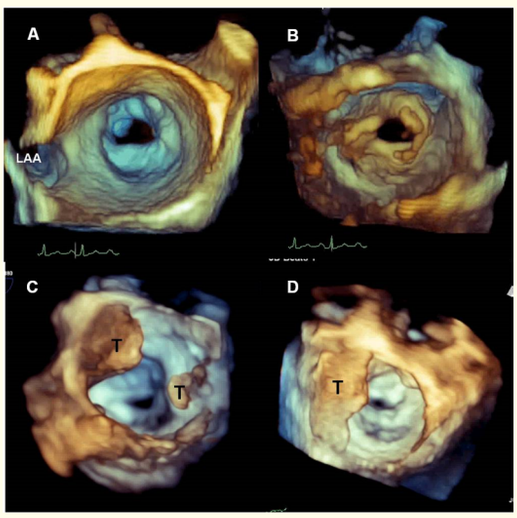

Figure 4: *Real time 3D transesophageal echocardiography (zoom mode) showed mitral stenosis: A-view from let atrium B- view from left ventricle, both commissures are fused; panels C and D shows thrombi in side of the left atrium. LAA: Left Atrial Appendage.*

Quantification of mitral stenosis

Assessment of the severity of MS requires accurate measurements of the mitral valve orifice area (MVA). Ancestrally, the gold standard for the quantification of mitral stenosis is the calculation of the functional area by the Gorlin method, with data obtained in an invasive way. 2DTTE and Doppler echocardiography allows the non-invasive assessment of the MVA using four different methods: mitral valve planimetry; pressure half time (PHT), proximal isovelocity surface areas (PISA) and continuity equation, all of them have its specific well-known limitations [27].

The planimetry of the valve orifice will, theoretically, be the most accurate method for quantifying mitral stenosis; however, for this measurement to be reliable, it is necessary to obtain an image plane that selects the mitral valve leaflets at the level of its smallest orifice; this is the main limitation of 2DTTE, particularly in cases of asymmetric opening of the leaflets, since measurement in potentially skewed planes leads to significant overestimation of the valve area [27,28].

3D echocardiography allows, through multiplanar reconstruction of the acquired pyramidal volume, to obtain in a simple and reliable way the correct plan for its measurement (Figure 5). The mitral area determined by 3DTTE planimetry has already proved to be more accurate than 2DTTE planimetry [28]. Compared with other currently used modalities, 3DTTE echocardiography has the best agreement with the invasively determined Gorlin formula, regarding mitral valve area [12].

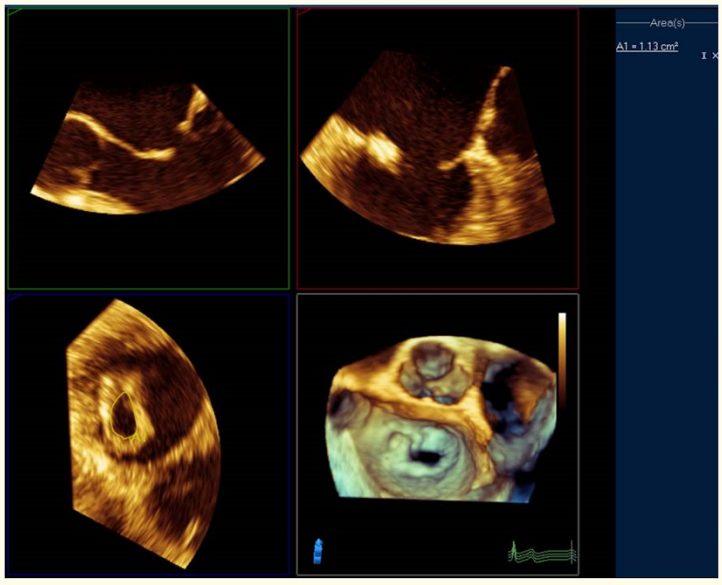

Figure 5: *Multiplanar reconstruction of mitral valve (MV) orifice showing orthogonal imaging planes at the tips of the MV leaflets and 3D planimetry of the MV area traced at the MV leaflet tips using the short-axis view.*

As reported by Schlosshan., *et al*. 3DTEE allows excellent visualization of the MV orifice and leaflets in rheumatic MS and provides important complementary information to 2DTEE. 3DTEE estimation of MVA offers excellent reproducibility and compares favorably with established 2DE methods. 3DTEE provided also detailed assessment of the degree of commissural fusion in all patients [29].

RT3DETE is also an exceptional tool to assess the presence of thrombi in the left atrium (Figure 4C and 4D) that should be excluded before percutaneous mitral valvuloplasty.

Mitral regurgitation

The mechanism of mitral regurgitation (MR) can be categorized as primary (valvular abnormality) or secondary (LV abnormality). An alternate classification of MR proposed by Alain Carpentier based on mitral leaflet motion, widely used to aid in surgical strategy, features 4 categories: normal leaflet motion (type I), excessive leaflet motion (type II), restricted leaflet motion in both diastole and systole (type IIIa) and restricted systolic leaflet motion due to functional leaflet tethering (type IIIb).

Classification, etiologies and echocardiographic features of MR are summarized in table 1.

Classification	Carpentier Classification	Leaflet Motion	Etiologies	Echocardiographic Features
Primary (organic)	Type I	Normal	• Degenerative • Infectious endocarditis • Inflammatory • Congenital	• Annular calcification • Vegetation, mass, leaflet perforation • Cleft anterior leaflet/defect
	Type II	Excessive motion	• Degenerative • Congenital • Infectious	• Leaflet prolapse and/or flail, chordal elongation/rupture • Barlow's disease: bileaflet involvement, • Fibroelastic deficiency: unisegmental involvement
	Type IIIa	Restricted motion in both diastole and systole	• Rheumatic • Inflammatory • Radiation • Drugs	Leaflet thickening/restricted posterior leaflet • Mixed mitral disease: stenosis/regurgitation • Rheumatic: leaflet doming, commissures and leaflet tips fusion
Secondary (functional)	Type IIIb	Restricted motion in systole	• Ischemic • Non-ischemic	• Papillary muscles displacement • Leaflets tethering • Annular dilation

Table 1: *Classification, etiologies and echocardiographic features of mitral regurgitation.*

In sub-Saharan Africa the top three common etiologies of MR are rheumatic disease, degenerative disease, functional MR due to dilated cardiomyopathy. Other less common causes include infective endocarditis, ischemic MR, and congenital diseases.

During the assessment of MR, 3DTEE echocardiography can be used in several clinical contexts due to the better assessment of valve anatomy and geometry, which allows the distinction between the different etiologies and MR mechanisms [25].

The ideal visualization of the mitral valve, especially in 3DTEE, allows to accurately outline specific anatomical lesions, such as: rheumatic retraction of the leaflets, perforation of the leaflets or congenital anomalies (Figure 6).

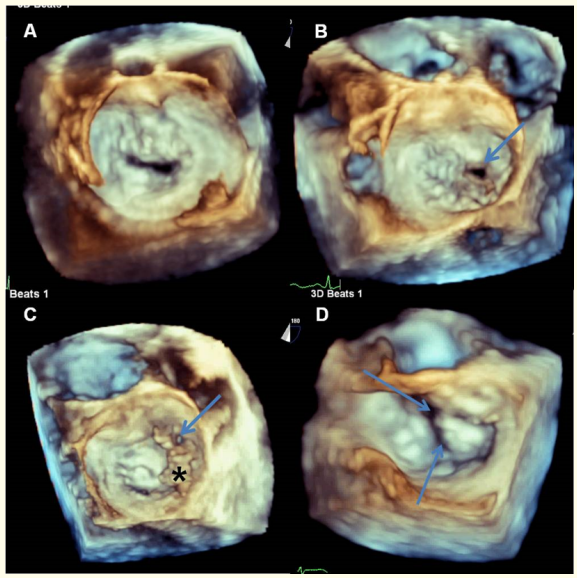

Figure 6: *Real time 3D transesophageal echocardiography (zoom mode) view from the left atrium show mitral regurgitation of several etiologies: A - rheumatic disease; B - perforation of A2 (arrow); C- Infective endocarditis with vegetation (asterisk) and perforation (arrow) in A3; and D - mitral cleft of anterior mitral leaflet (arrows).*

3DTEE also provides a better identification of the location of the prolapsing mitral valve segments and ruptured chordae (Figure 7); this capability is especially useful in patients with complex bileaflet or commissural MV lesions.

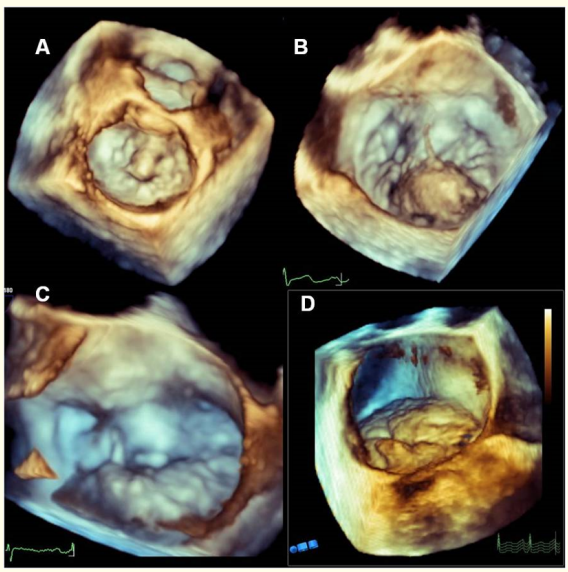

Figure 7: *Real time 3D transesophageal echocardiography (zoom mode) view from the left atrium shows several degrees of mitral valve prolapse; A -prolapse of A2; B Predominant prolapse of P2 (asterisk) with ruptured chordae (arrow) C prolapse of entire posterior mitral leaflet. D Barlow disease with prolapse of the both anterior and posterior mitral valve leaflet.*

In patients with functional mitral regurgitation (ischemic or dilated cardiomyopathy), the mechanism of mitral regurgitation is restriction of leaflets closure as a result of dilation of the mitral annulus, enhanced tethering of the MV leaflets, papillary muscles displacement, and reduced closing force of the leaflets without primary valve leaflet pathology (24) (Figure 9).

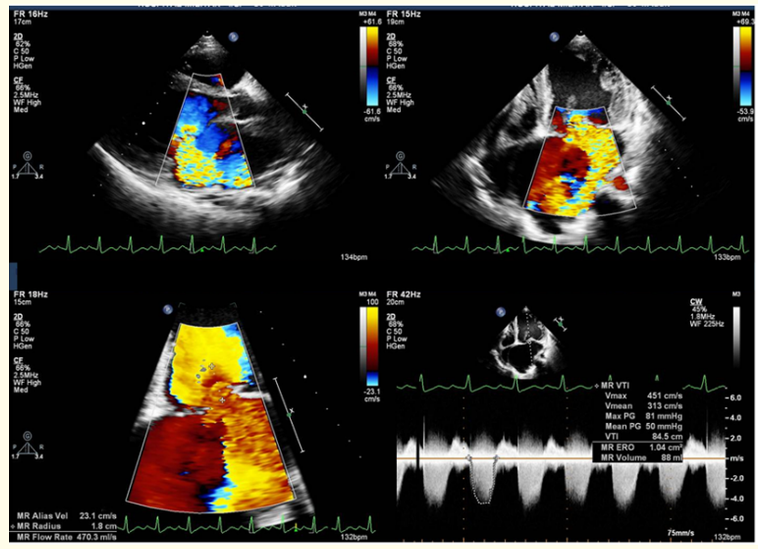

Figure 8: *Transthoracic echocardiography showing quantification of severity of mitral regurgitation by two-dimensional Doppler echocardiography.*

Quantification of mitral regurgitation

2D Color Doppler quantification of mitral regurgitation can be performed by the following methods: quantification of the regurgitant jet area, using the vena contracta, or using PISA method (Figure 8) [30]. Compared with 2D echocardiography, 3D echocardiography has demonstrated improved accuracy in measuring 3D PISA-derived effective regurgitant orifice area and regurgitant volumes [28].

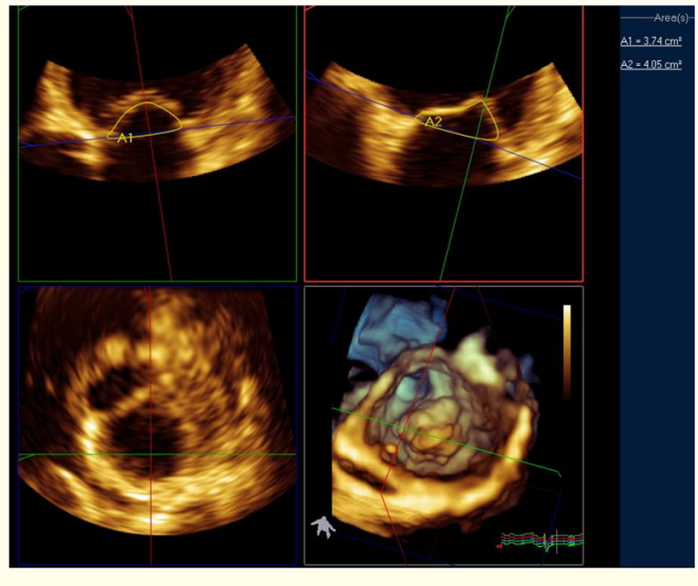

Figure 9: *Multiplanar reconstruction of mitral valve showing mitral valve tenting area.*

However, color Doppler should not be recommended as the sole method for assessment of MR severity and requires corroboration with other echocardiographic and Doppler methods. Pulsed Doppler indices give corroborative information regarding severity of MR by evaluating flow in the pulmonary veins, mitral inflow volume and systemic flows-important in quantization of the MR. Continuous wave Doppler recording of the jet provides the hemodynamic impact of MR, with a depiction of instantaneous pressure difference between the LV and LA [30].

Conclusion

Real-time three-dimensional echocardiography with 30 years of investigation and use in clinical practice is a method, which under specific conditions - as is the case with the assessment of mitral valve disease, is clearly superior to 2D echocardiography and should be used routinely. The use of real-time three-dimensional echocardiography today is not limited to the assessment of heart diseases. It is increasingly used in non-coronary intervention cardiology.

Conflict of Interests

None to declare.

Financial Support

None to declare.

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