

## Three Dimensional Echocardiography in Mitral Valve Disease

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### ABSTRACT

Three-dimensional echocardiography (3DE) has now evolved as a clinical tool widely used in most laboratories. Among many of its clinical applications, it has become particularly valuable in the evaluation and treatment of mitral valve disease. This article will review the contribution of 3DE to the understanding of the functional anatomy of the mitral valve, the evaluation of its pathology and to the guidance of therapeutic procedures.

**Keywords :** Three-dimensional echocardiography, Mitral valve disease, Mitral regurgitation, Mitral stenosis

### Introduction -

Disorders of the mitral valve continue to be debilitating at all ages throughout the world. The treatment of mitral valve (MV) disease has expanded from surgical commissurotomy or mitral valve replacement to surgical mitral valve repair and percutaneous procedures for stenotic and regurgitant valve lesions. Such therapeutic advances necessitate a need for detailed assessment of the MV apparatus. While 2-dimensional echocardiography (2DE) and Doppler modalities remain the mainstay in the diagnostic evaluation of MV diseases, the evolution and availability of 3-dimensional echocardiography (3DE) has provided a robust means of imaging the anatomy and pathology of the mitral apparatus in more comprehensive detail. Advances in the acquisition, storage and analysis of 3DE images have made its use increasingly common in echocardiography laboratories, not only for research purposes but also in daily clinical practice. Three-dimensional echocardiography has enabled us to understand the functional anatomy of the MV and the pathophysiology of MV disease, especially that of mitral regurgitation. Three-dimensional transesophageal echocardiography (3DTEE) has become a critical tool in the guidance of surgical and

catheter-based procedures for MV disease. This review will concentrate on the current utility of 3DE in mitral valve disorders.

### Technical Developments in 3D Echocardiography -

Three-dimensional echocardiography has evolved from a laborious technique of prolonged image acquisition and reconstruction into a push-button tool performed with surface and transesophageal ultrasound transducers. Recent advances in matrix transducers with more than 3000 crystals and new processors allow for the acquisition of real-time images without the need for off-line reconstruction. In addition to the visualization of valvular anatomy, measurements of valvular structures and chamber volumes can also be easily calculated. This technique is superior to 2DE in measuring left ventricular volumes, especially in patients with dilated cavities & distorted ventricular geometry.<sup>1-3</sup> This is largely attributable to the fact that 3DE makes no geometric assumptions in order to calculate volumes. Additionally, color Doppler 3DE displays any flow jet in its true dimensions allowing for more complete understanding of the valvular pathology.

### Mitral Valve Anatomy & 3D Echocardiography -

The functional anatomy and geometry of the MV is complex. The annulus, valve leaflets, chordae, papillary muscles, myocardium and patient hemodynamics are all essential and interrelated and are integral components of a normal functioning mitral valve. The mitral annulus is a roughly elliptical structure whose prominent function is to

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anchor the leaflets by fusion with their intermediate layer, the “lamina fibrosa” (*Figure 1*).<sup>4</sup> In its more elliptical shape (in systole) the ratio of minor to major diameter is approximately 0.75. The longest diameter runs from commissure to commissure, whereas the shortest dimension is from the middle point of the anterior segment to the middle point of the posterior segment. Emerging from the annulus are the leaflets. Two main indentations separate the valve tissue into anterior (or aortic) and posterior (or mural) leaflet. These indentations do not reach the annulus but end about 5 mm short. The anterior leaflet has a roughly triangular free edge and occupies a third of the annular circumference. The posterior leaflet is broad and narrow, attached to the remaining two third of the annular circumference. Small indentations divide each leaflet in three or more scallops. The most frequent approach of identifying the scallops, the Carpentier's classification, designates lateral scallop as A1, middle as A2, and medial as A3 for the anterior leaflet and P1, P2 and P3 for the posterior leaflet. (*Figure 2*). The chordal apparatus inserts to the ventricular side of the leaflets, making it irregular and thick.

From the left atrial perspective, the leaflet apposition forms a cavo-convex zone of 5 to 8 mm deep, which prevents valvular regurgitation when moderate degree of annular dilation occurs (valve reserve).<sup>5</sup> The line or surface of contact between 2 structures is called commissure. By convention, each end of the closure line is considered one commissure and are termed the anterolateral commissure and posteromedial commissure. Such commissures are the first to be involved in the scar process following rheumatic fever and their fusion is responsible for valve area reduction in mitral stenosis. In normal individuals, during mitral valve closure, the leaflets coapt at the level of the mitral annulus and the portion of the anterior leaflet closest to the aortic root protrudes slightly towards the left atrium. Chordae tendinae are string-like structures that connect the leaflets to the papillary muscles. Since chordae usually branch distal to their muscular origins, there are four to five times more chordae attached to the leaflets than to the papillary

muscles. The two papillary muscles, anterolateral and posteromedial units, are the anchors from which chordae tendinae emerge. The integrity and function of the myocardium subjacent to the papillary muscles are important determinants of mitral valve closure.

### **Mitral Regurgitation -**

For normal MV closure, all components of the mitral apparatus must work in synchrony. Major abnormalities anywhere in the MV apparatus - valve leaflets, mitral annulus, chordae tendinae or papillary muscles - can result in mitral regurgitation (MR), referred to as primary mitral regurgitation. Incomplete coaptation of the leaflets caused by regional or global left ventricular dilation or dysfunction can cause secondary mitral regurgitation, also called functional mitral regurgitation.<sup>6</sup>

The most common etiology for mitral regurgitation (MR) is degenerative or myxomatous disease of the valve. 3DE provides incremental and more accurate information over 2DE on MV apparatus in this disorder. Abnormalities such as MV prolapse, flail leaflets, subvalvular lesions, leaflet perforation, clefts and leaflet retraction all are more comprehensively visualized by 3DE than 2DE. With 3DE, the topography and amount of prolapsed or flail tissue, the ratio of prolapsed / non prolapsed tissue, the extension of prolapsed tissue measured at its annular insertion or size of prolapsed area are precisely defined. Examples of prolapsing and flail mitral valve leaflets and ruptured ends of chordae tendinae are shown in *Figure 3*.

In addition, 3DE has helped to better understand of the mechanisms of functional MR in ischemic and nonischemic cardiomyopathy. In both, there is left ventricular remodeling, leading to progressive mitral annular dilatation, flattening of the saddle shape of the annulus, apical papillary muscle displacement, and increased tethering of the leaflets.<sup>7,8</sup> This results in decreased leaflet coaptation and MR. Abnormalities in the geometry of the annulus, leaflet area, tenting volumes, and tethering distances are related to the severity of the regurgitation. 3D imaging has helped demonstrate

that in ischemic cardiomyopathy with regional contractile disorders, it is the localized geometric distortions and wall motion abnormalities that primarily lead to asymmetric tethering and eccentric regurgitation. In nonischemic dilated cardiomyopathy with global LV dilatation, the tethering is more symmetric, producing a more central regurgitant jet. The effects of exercise and dynamic changes caused in patients with heart failure and mitral regurgitation can also be evaluated by stress 3DE. Exercise-induced changes in cardiac synchrony, sphericity, and coaptation distance may offer more insights into the mechanism of MR in patients with functional regurgitation and aid therapeutic advances.<sup>9,10,11</sup>

Color Doppler 3DE portrays MR jets more reliably than 2DE color flow imaging that may display a curvilinear jet as two different flow jets. The site, size and direction of MR jets can be viewed from various vantage points. Besides visualization of the pathoanatomy responsible for MR, 3DE may aid in the quantification of MR. While the proximal isovelocity surface area (PISA) seen by color 2D color Doppler method has been touted as a good method to quantify MR volume and derive regurgitant orifice area, 3DE has underlined the flaws and unreliability of the PISA approach.<sup>12,13,14</sup>

The fundamental assumptions employed in the PISA method that the flow convergence zone is a perfect hemisphere and that the vena contracta is circular have been proven wrong by 3DE flow imaging. **Figure 3** depicts three examples of regurgitant orifice, none of which is circular. A highly irregular proximal flow convergence zone is also illustrated. In eccentric and irregular MR jets, quantitation by 2D color Doppler PISA method could be highly misleading. An improved method of measuring regurgitant orifice area is direct visualization and planimetry of the area of the flow convergence zone and vena contracta by 3DE.<sup>15,16</sup> This could prove to be a much more robust measure of MR severity. Direct visualization of the site and number of actual regurgitant orifices is also possible on 3DE images in many patients. In patients with cleft MV, the location and extent of the cleft are portrayed in a realistic manner by 3DE.<sup>17,18</sup> **Figure 4** shows the

visualization of the cleft in the anterior MV leaflet and also the triangular shape of the vena contracta.

### 3D Echocardiography for Mitral Stenosis - (Figure 5)

The most common cause of mitral stenosis (MS) in many countries is rheumatic heart disease. In rheumatic MS, the smallest area is at the leaflet tips while the belly of the valve is often pliable. When the mitral valve becomes calcified, it becomes tubular in shape. Increased pressure gradients across the valve are reliably determined by pulsed and continuous wave Doppler. Pressure half-time method of calculating MV area is reliable in most patients. However it could be flawed in the setting of co-existing disorders. Doppler data may be influenced by numerous hemodynamic factors like heart rate, cardiac rhythm, left ventricular systolic and diastolic dysfunction, left ventricular and atrium compliance, and concomitant valvular disease. Planimetry of the MV area (MVA) on 2DE short-axis images is commonly employed in patients with MS. While such 2DE planimetry is reliable in many patients, highly distorted mitral apparatus may not allow accurate acquisition of short-axis images at the level of the tips. Measurements of the MVA are made in the short axis view with no verification from an orthogonal plane that the imaging plane corresponds to the smallest and most perpendicular view of the mitral valve orifice. The stenotic mitral valve is a funnel-shaped structure, and minor changes in the depth or angle of the ultrasound beam may result in overestimation of the MVA. 3DE provides not only the anatomic structure of mitral valve but also the optimal plane to measure the smallest mitral valve orifice (**Figure 6**). The advantage of 3DE is the ability to confirm that the short axis section of the mitral orifice is in fact at the tip of the mitral leaflets, obviating errors due to malpositioning of a 2DE probe.<sup>19,20,21</sup> Also, planimetry using 3DE can be performed not only from images obtained from parasternal windows but also from apical windows. It is not limited to the parasternal window and allows MVA measurement from an apical window. Fibrocalcific MS encountered in the elderly is different in that the smallest orifice area is near the annulus and that the

orifice shape also tends to be tubular.<sup>22</sup> En face visualization of the narrowest MV area is possible by 3DE in these patients.<sup>23</sup> Color Doppler 3DE-defined planimetry at the smallest annular orifice is another aid in determining the accurate MV area. Furthermore assessing the whole volume of the stenotic mitral valve could offer more insights in understanding the hemodynamic and pathophysiologic sequelae of fibrocalcific MS.<sup>24,25</sup>

### **3D Echocardiography in the Evaluation of Prosthetic Mitral Valves -**

Both bioprosthetic and mechanical valve components, including the leaflets, rings, and struts are well visualized by 3DTEE both from the left atrium and from the left ventricle. In cases of dehiscence and paravalvular holes, en-face views from the left atrium nicely reveal the location and number of paravalvular discontinuities, without hindrance by acoustic shadowing. This allows for improved planning of appropriate corrective surgical or percutaneous repairs. Prosthetic valve stenosis, obstruction due to pannus or thrombus, and vegetations when present are also well delineated by en-face projections.<sup>26</sup> *Figure 7* shows a normally functioning mechanical valve (top panel), a well-placed mitral ring (left, bottom panel) and paravalvular holes around a tissue prosthesis.

### **Role of 3DE in Guiding Surgery and Interventions -**

3DE has become an important tool in defining and guiding MV repair in the operating room and interventional laboratory. Chordal cutting, shaving or repositioning of papillary muscles are examples of surgical procedures increasingly applied for correction of MR. Detailed understanding of the abnormalities causing MR aids in tailoring the repair to individual patients. In the operating room, the efficacy of MV repair and the mechanism of residual MR if present are readily gauged by 3DTEE to ensure correct management. Valve models can be generated to allow surgeons to test a resection strategy before surgery or intraoperatively with the goal to optimize valvular repairs. A future direction of 3DE is in the application of development of new annuloplasty rings that will help restore normal

geometry.

Enthusiastic efforts are currently being afoot to develop percutaneous catheter-based procedures for correction of transvalvular and paravalvular MR. They include clips placed on the MV, devices placed in the coronary sinus and occluders placed adjacent to a prosthetic valve. The top panel in *Figure 8* illustrates the advancement of the catheter with the mitral clip in a longitudinal cut, catching the midportions of MV leaflets in an en face view, and the final result; the bottom panel shows a paravalvular hole, passing of the occluder catheter through that hole under 3DE guidance, and the well-placed occluder. For such percutaneous interventions, real-time 3D visualization of the valve and adjacent structures has become a necessity to plan and guide the procedure. Three-dimensional echocardiography has proven to be useful to assess the results of percutaneous mitral valvuloplasty (PMV).<sup>27</sup> Large differences in the immediate post-PMV period may occur between MVA measurements obtained by pressure half-time method and those obtained invasively in the catheterization laboratory. The reasons for this inaccuracy include the development of an atrial septal defect in many patients after PMV and the wrong assumption that the left atrial and left ventricular compliances remain stable after the procedure. 2D planimetry of MVA is less dependent on hemodynamic variables, but it is not exempt from limitations. Following PMV, the mitral orifice becomes irregular and is technically difficult to trace, particularly if calcium is present. 3DE appears to provide better accuracy than 2DE in quantifying the results of PMV. Images before and after PMV in a patient are shown in *Figure 7* demonstrating inadequate splitting of the fused commissures.

### **Conclusions and Future Directions -**

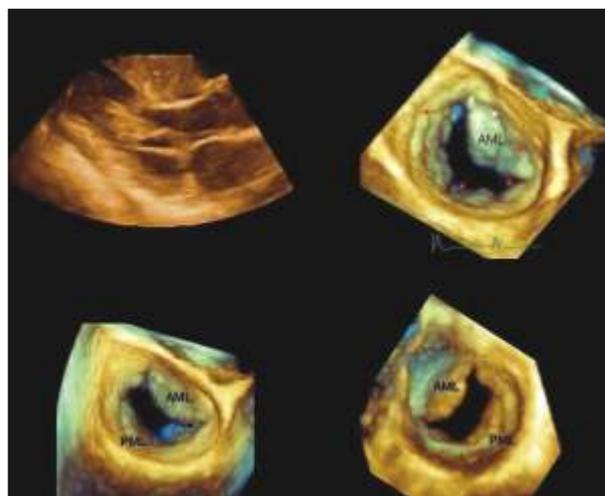
Three-dimensional echocardiography plays a particularly important role in evaluating the pathology and severity of MV disease. In addition, 3DE allows for accurate assessment of volumes and ejection fraction of both ventricles. The major limitation encountered in the use 3DE at the present time is the suboptimal resolution of images obtained

by the transthoracic approach in patients with difficult acoustic windows and the need to acquire data from multiple beats. Ongoing advances in instrumentation are likely to make all 3D approaches truly in real-time yielding better quality images. 3D speckle tracking is another promising approach to evaluate both regional and global LV function. Besides the transthoracic and TEE instrumentation, evolution 3D intracardiac echocardiography is likely to be of value in the interventional laboratory in future.

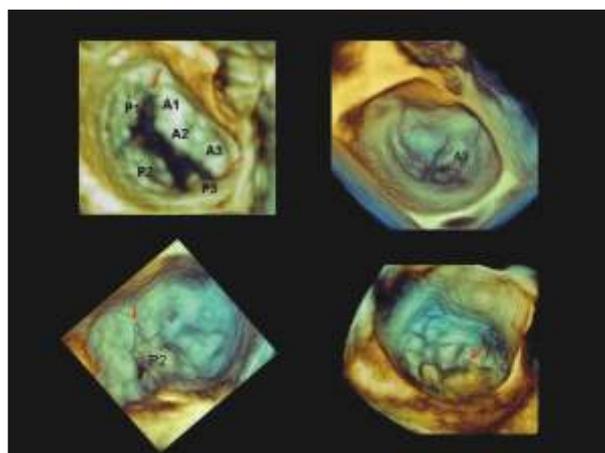
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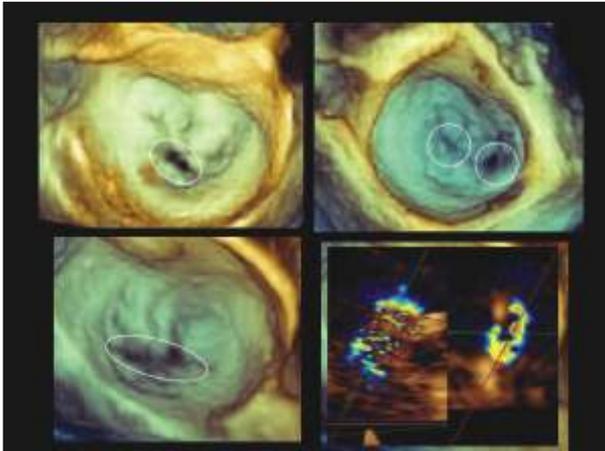
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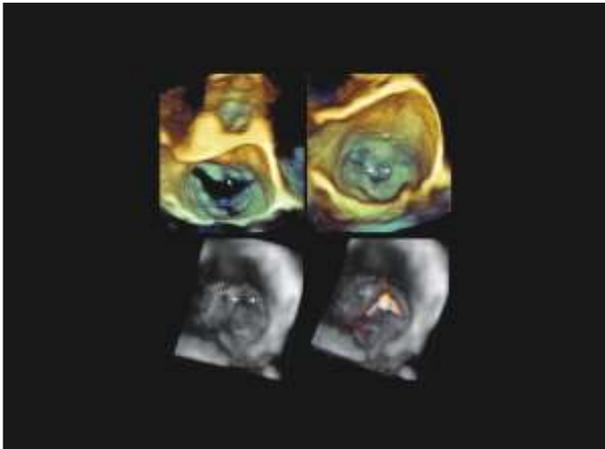
(3DE) images of the normal mitral valve. Top left : A parasternal images in a longitudinal plane reveals the mitral leaflets, Chordae tendinae and the papillary muscles. Top right: The mitral valve as viewed from the left atrium; the arrows point to the annular line. Bottom : The mitral valve leaflets as viewed from the left atrium (left) and from the left ventricle (right). AML, anterior mitral leaflet; PML, posterior mitral leaflet.



from the left atrium. A1, A2, A3 refer to the lateral, middle and medial scallops of the anterior leaflet; P1, P2, P3 refer to the anterior, middle and medial scallops of the posterior leaflet. Top right : Flail A3 scallop is viewed from the left atrium. The arrow points to a torn chord. Bottom left: Flail P2 scallop. Bottom right : Flail P3 scallop; prolapse of multiple scallops is also noted.

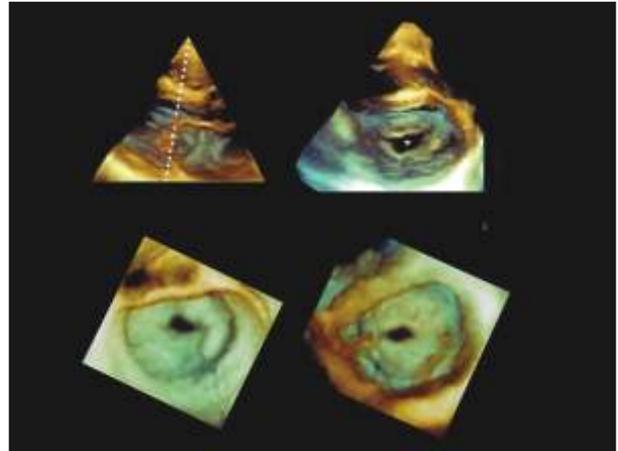


**Figure 3** - The mitral valve as viewed from the left atrium mitral regurgitant orifices of various size and shape. Bottom right : Color Doppler three-dimensional images illustrate the proximal flow convergence of an irregular shape.

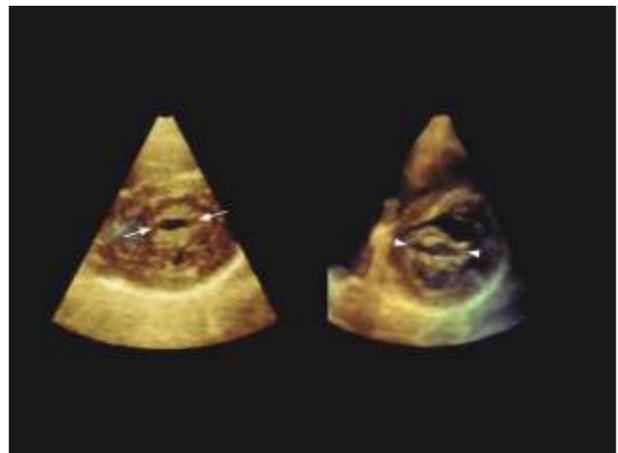


**Figure 4** - Three-dimensional echocardiographic images of a cleft mitral valve.

The arrows point to the cleft in the anterior mitral leaflet (AML). Bottom left: The mitral regurgitant jet with a triangular geometry.

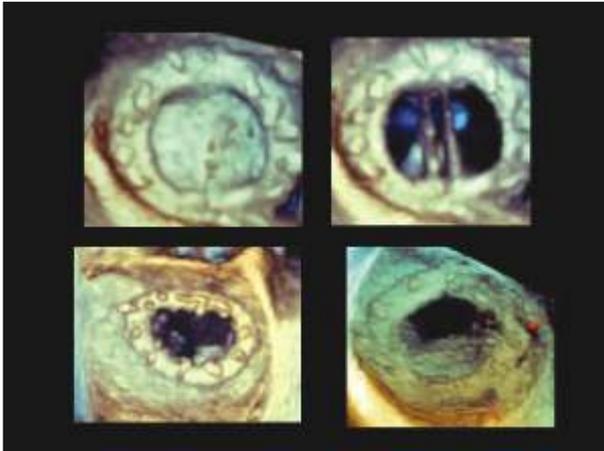


**Figure 5** - Top right : A longitudinal three-dimensional image of the mitral valve. The red dotted line shows the plane of the orifice at the tips. The white dotted line projects the plane of short-axis from a parasternal window. Top right : A mildly stenotic mitral valve with the whole orifice seen from the left ventricular perspective. Bottom left: A severely stenotic mitral valve as viewed from the left atrium. Bottom right: The same valve as seen from the left ventricle.

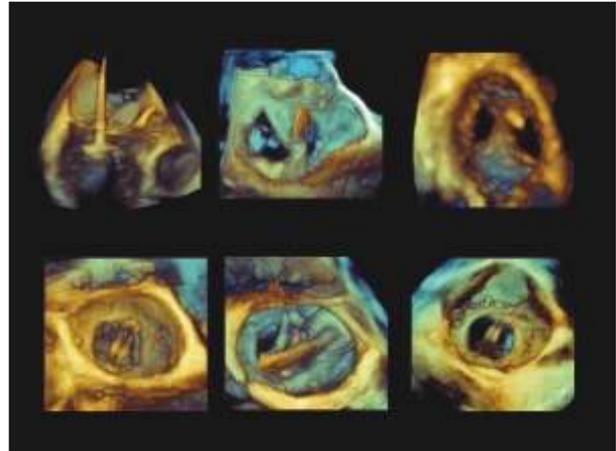


**Figure 6** - A stenotic mitral valve before (left) and after (right) balloon valvuloplasty.

Arrows shows the lateral and medial commissures.



**Figure 7** - Top left : A normally functioning double disc mechanical mitral valve prosthesis as seen from the left atrium during systole. Top right : The same valve during diastole. Bottom left : A well-placed mitral valve ring as viewed from the left atrium. Bottom right : Two paravalvular holes (arrows) seen around a prosthetic mitral valve.



**Figure 8** - Top panel : Images obtained during percutaneous mitral valve clip placement showing the catheter across the mitral valve (left), the clip engaging the middle portions of the leaflets (middle) and final result (right). Bottom panel : Images obtained during percutaneous closure a paravalvular holes showing the paravalvular leak site (left),