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Review Article

Impact of 3D echocardiography on mitral valve surgery

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ABSTRACT

Clinical echocardiography began as a one-dimensional (1D) technique using initially the A-mode (Amplitude mode) and then the M-mode (time-motion mode) with dedicated investigators exploring the potential applications. The development of two-dimensional (2D) echocardiography expanded the applications and resulted in more widespread applications of the technique. In order to overcome the problem of examining three dimensional (3D) structures, such as the heart with its intricate anatomy, several windows for 2D imaging have been developed. This approach requires a mental reconstruction of the intracardiac anatomy based on multiple 2D imaging planes. A need to define the mitral valve anatomy as related to emerging valve repair techniques resulted in development of systematic transesophageal multiplane images [1,2]. These have permitted accurate assessment of the valve pathology based on mental reconstruction of 3D anatomy with varying success [3]. Even when successful, this approach does not lend itself to easy communication with the surgeon, depending on his/her familiarity with echocardiographic imaging planes. The advent of 3D echocardiography promises to permit more consistent and accurate evaluation of the valvular and other cardiac structures and provide for more effective communication between the echocardiographer and the surgeon.

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3D ECHOCARDIOGRAPHIC APPROACHES

There are two broad approaches to obtaining 3D echocardiographic images:

1. 3D reconstruction based on multiple 2D cross section acquisition. This has been carried out using transthoracic as well as transesophageal cross sections. Each image acquisition is timed to the same portion (R wave) of the electrocardiogram. In addition, respiratory gating permits acquisition during the same portion of the respiratory cycle [4].
2. The volume scanning technique requires the use of ultrasound probes with special matrix array transducers that steer the beam to scan a pyramid shaped volume [5]. Since data acquisition may be accomplished in a single beat or over a few heartbeats, it may involve ECG gating but not respiratory gating. Transthoracic echocardiogram (TTE) as well as transesophageal echocardiogram (TEE) can be used for obtaining 3D data sets. Since TEE provides more discrete and sharper echocardiographic images, 3D TEE using matrix array transducers containing 2,500 independent piezoelectric crystals, is capable of providing diagnostic 3D images of the mitral valve. This is also termed as real-time 3D, in contrast to the off-line reconstruction approach. The quality of the 3D image is determined in no small part by the quality of the 2D image, since any 2D artifact will persist in 3D and may provide poor diagnostic images.

Real-time 3D echocardiographic imaging with a TEE probe is the more commonly used intraoperative approach [6].

3D ECHOCARDIOGRAPHY IN MITRAL VALVE DISEASE

The diagnostic application of real-time 3D echocardiography in mitral valve disease is rapidly evolving, especially in concert with transesophageal echocardiography [6–11]. The mitral valve, more than any other intracardiac valve, lends itself to detailed 3D imaging from the left atrial perspective as viewed by the surgeon (Fig. 1). In addition, cropping from the lateral wall provides a unique perspective with imaging of the left ventricular outflow and leaflet motion in relation to the mitral annulus.

We utilize a classification of mitral valve pathology that has been modified and expanded from the original Carpentier classification (Table 1). We believe that in the current era of echocardiographic imaging, this new classification provides a useful reference for surgical practice.

The role of 3D echo in type I pathology

The detection and localization of leaflet perforation is exceedingly well demonstrated, providing a superior precision to 2D echo imaging (Fig. 2).

The diagnosis of congenital cleft of the mitral valve is facilitated by demonstration of the extent of the cleft with a 3D echocardiographic image (Fig. 3). This provides a superior spatial geometry as compared to 2D images.

Table 1. Classification of mitral valve pathology.

Type I: Normal leaflet motion
A. Perforation
B. Cleft valve
C. Dilated annulus (without leaflet tethering)
Type II: Excessive leaflet motion
A. Billowing prolapse
B. Flail leaflet (localized to one segment)
C. Bileaflet prolapse with flail segment
Type III: Restricted leaflet motion
A. Systolic and diastolic restriction, e.g. rheumatic
B. Symmetric systolic restriction, e.g. dilated or ischemic cardiomyopathy (dilated annulus with leaflet tethering)
C. Asymmetric systolic restriction, e.g. segmental ischemic dysfunction resulting in focal tethering
Type IV: Systolic anterior motion (SAM) of the leaflet(s)
A. Hypertrophic cardiomyopathy with SAM related mitral regurgitation
B. Post mitral valve repair SAM
C. Hemodynamic induced SAM, e.g. hypovolemia, inotropic stimulation and tachycardia
Type V: Example hybrid conditions
- Prolapse of anterior leaflet with restricted posterior leaflet
- Prolapse of posterior leaflet with SAM of anterior leaflet
- Intrinsic pathology with super added lesion of infective endocarditis

3D echocardiography does not offer any particular advantage over 2D echocardiography in diagnosis of dilated annulus with poor coaptation and a central jet of mitral regurgitation.

The role of 3D echocardiography in type II pathology (valve prolapse)

There are some distinct situations where real-time 3D echocardiography offers distinct a advantage over 2D echocardiography in patients undergoing mitral valve repair (Table 2).

Bileaflet billowing with central regurgitation is appropriately assessed by 2D echocardiography, with little additional information gained from the use of 3D imaging.

Segmental flail leaflet offers a unique application for 3D echocardiography providing spatial geometry of the prolapsing segment (Fig. 4). Aside from confirming location of the prolapsing

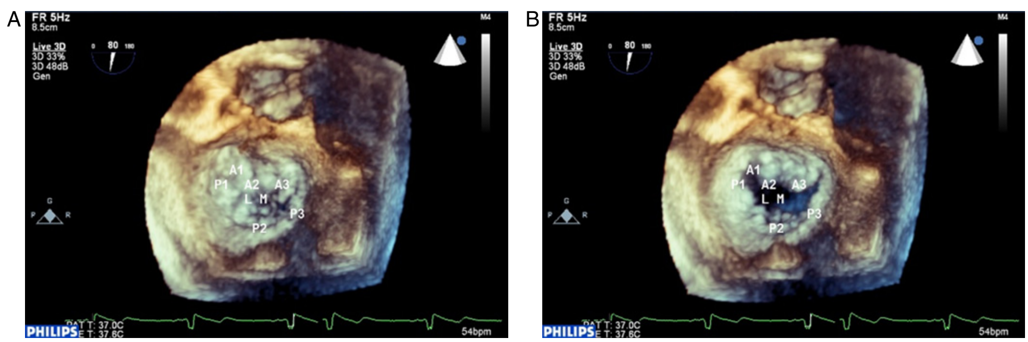

Figure. 1 The mitral valve as visualized from the left atrial perspective in closed position (A) and open position (B). The anterior and posterior leaflets are labeled as A1, A2, A3; and P1 (lateral scallop), P2 (middle scallop) and P3 (medial scallop). Furthermore, A2 and P2 are subdivided into lateral (L) and medial (M) components.

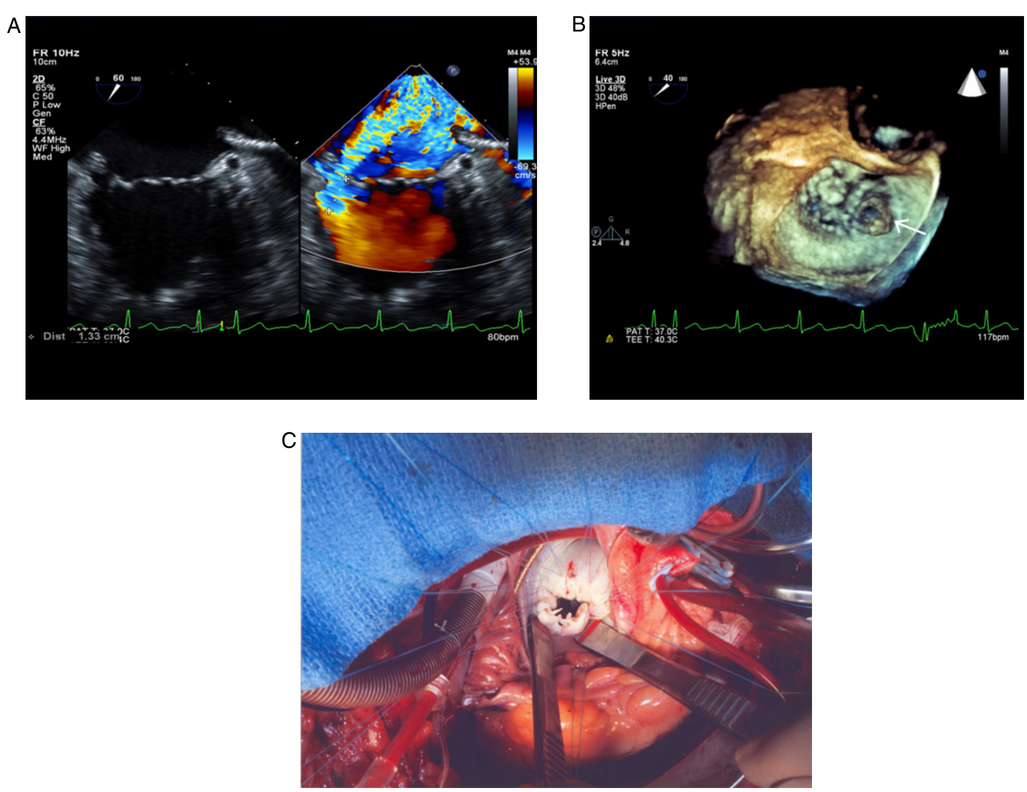

Figure. 2 TEE based 2D echocardiograph image (60° plane) from midesophagus (A) showing flow acceleration with color flow image through P3 (medial scallop). 3D echocardiograph image (B) demonstrates a discrete perforation on P3 (arrow). This corresponds to the surgical anatomy of the perforation secondary to prior infective endocarditis.

segments, real-time 3D echocardiography depicts leaflet asymmetry. It is not uncommon to see the prolapsing segment to be much taller (or longer) as compared to adjacent leaflet segment. For instance, P2L (lateral half of the middle scallop of the posterior leaflet) may be taller than P2M (medial half). The valve repair on this setting would necessitate surgical techniques to correct this asymmetry. Similarly, acquired clefts may be detected between scallops of the posterior leaflet, e.g. between P1 and P2 or P2 and P3 (Fig. 5). These could contribute to residual regurgitation jets following mitral valve repair and may readily be proactively plicated. Similarly, P1 (the lateral scallop) and P3 (the medial scallop) are normally smaller leaflet segments; they may be enlarged in some cases, especially in patients with Barlow's valve pathology. It has been suggested that focal prolapse of one segment represents fibroelastic deficiency whilst generalized involvement of multiple segments results from degenerative myxomatous valve disease. The term Barlow's valve is used when there is excessive leaflet tissue involving several segments of both leaflets and is associated with elongated or ruptured chordae tendinae (Fig. 6). In reality, there is considerable overlap between these conditions. We restrict the use of fibroelastic deficiency to focal chordal rupture without leaflet thickening or elongation, especially in elderly subjects.

The role of 3D echocardiography in type III pathology (leaflet restriction)

Although rheumatic mitral valve disease can be diagnosed using 2D echocardiography, there are some applications in which 3D imaging provides a more accurate assessment. For instance, measurement of the planimetered mitral valve area using 3D echocardiography is more accurate since the true orifice can be visualized. Commissural calcification and subvalve pathology may be better evaluated by viewing cropped sections of the left ventricular cavity.

3D echocardiography adds little to the mitral valve assessment in patients with dilated or ischemic cardiomyopathy, or those with segmental ischemic disease. It may be used to delineate ventricular function with greater accuracy (Fig. 7).

The role of 3D echocardiography in type IV pathology (systolic anterior motion of the valve)

The left ventricular outflow tract and SAM (systolic anterior motion) involving one or both mitral leaflets are readily diagnosed using 2D echocardiography. The role of 3D echocardiography is limited to enhanced spatial imaging of the outflow tract and interventricular septum. This can be done through the aortic valve or by cropping into the left ventricle from its lateral wall.

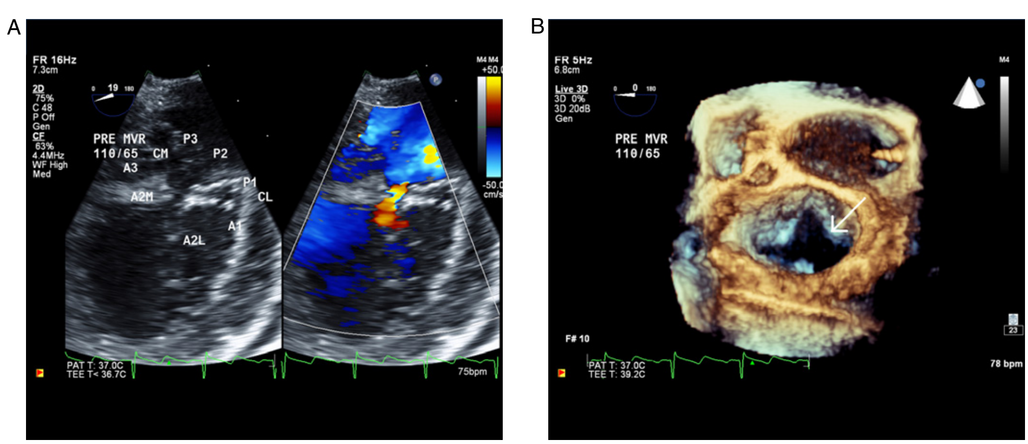

Figure. 3 A transgastric short axis section of the mitral valve indicates a cleft through which systolic flow is observed. The real-time 3D image of the anterior leaflet (B) clearly demonstrates width and height of the cleft in anterior mitral leaflet.

Table 2. Superiority of 3D echocardiography in mitral valve prolapse.

1. Demonstration of spatial geometry and localization of pathology
2. Detection of leaflet asymmetry of different segments of both leaflets
3. Detection of interscallop clefts
4. Visualization of left ventricular outflow tract which may alert one to the possibility of post-repair SAM

The role of 3D echocardiography in type V pathology (hybrid pathologies)

When not readily detected by 2D echocardiography, hybrid pathologies may be uncovered using 3D imaging. Restricted posterior leaflet along with flail anterior leaflet may also be assessed with greater accuracy, for instance, the posterior leaflet restriction may be localized along the P3 segment, and this may impact the surgical approach to valve repair.

The role of 3D echocardiography in visualization of a mitral valve annuloplasty band or ring

Real-time 3D echocardiography is used to image the annuloplasty band or ring following mitral valve repair. The image resolution permits visualization of the ring in a filled beating heart (Fig. 8).

The role of 3D echocardiography in mitral valve prosthesis dysfunction

As with a native mitral valve, 3D echocardiography allows for a more diagnostic evaluation of structural dysfunction of a mitral valve prosthesis [12–16]. Real-time 3D TEE permits enhanced spatial imaging of the leaflet morphology and motion for bioprosthetic as well as mechanical valves. It is possible for the bioprosthetic valve function to be only mildly abnormal using 2D echocardiography, even as two of the three leaflets are thickened and immobile (Fig. 9).

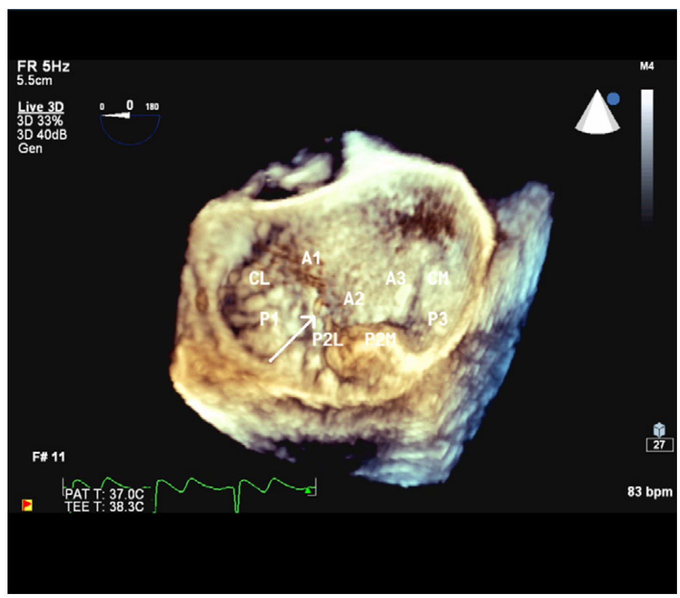

Figure. 4 Real-time 3D echocardiograph of the mitral valve showing ruptured chords at P2L (lateral segment of the middle scallop) pointed by arrow. In addition, P1 is abnormally large requiring height reduction.

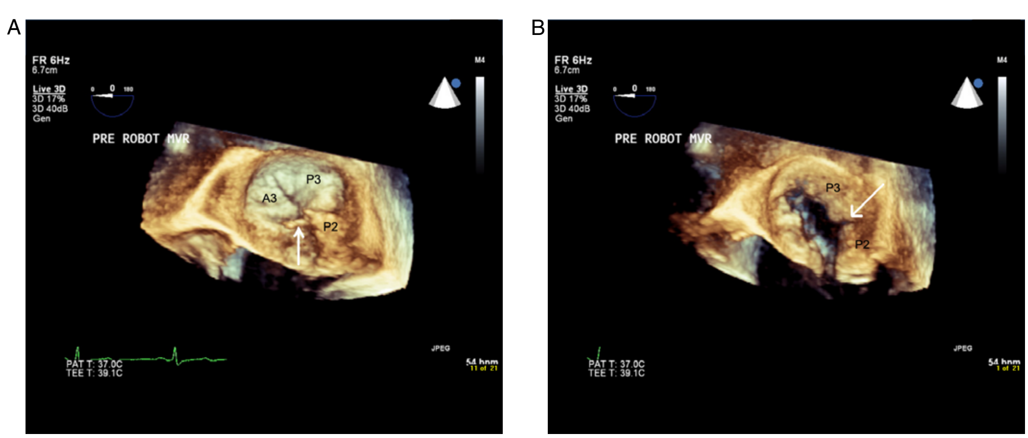

Figure. 5 Real-time 3D echocardiograph image obtained by cropping from the lateral wall (A) shows flail P2 with ruptured chord (arrow) and (B) shows cleft between P2 and P3.

The role of 3D echocardiography in guiding percutaneous cardiac interventions

Several percutaneous catheter based approaches are being developed. These include the use of a mitral e-clip to correct mitral regurgitation, using a principle of Alfieri stitch to approximate the two leaflets. This results in a double orifice mitral valve (Fig. 10).

Similarly, a transcatheter approach to plug paravalvular regurgitation has been developed. Both these procedures are greatly facilitated by the use of real-time 3D echocardiographic imaging, which permits accurate localization of pathology and instrumentation.

CONCLUSION

Real-time 3D echocardiographic imaging based on transesophageal echocardiography has proven to be of incremental use over traditional multiplane 2D imaging. The major advantages include

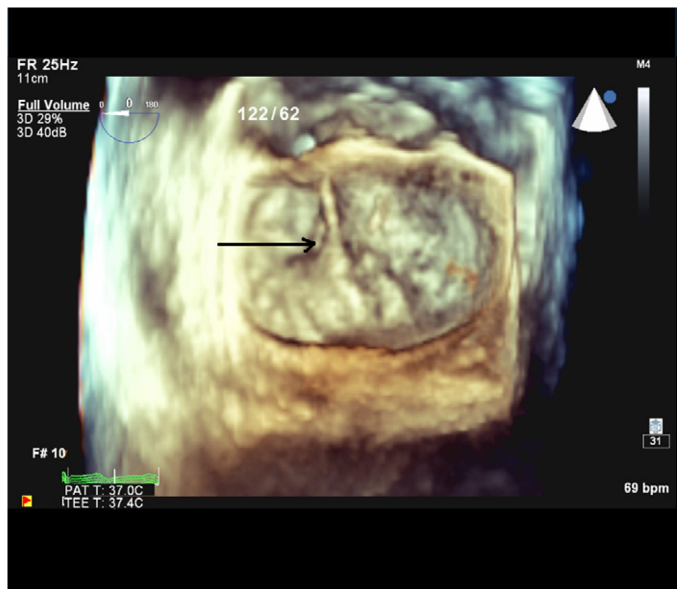

Figure. 6 An example of a 3D echocardiograph image of Barlow's valve with chordae rupture involving medial segment of P2 (arrow) with thickened leaflets without a leaflet closure line.

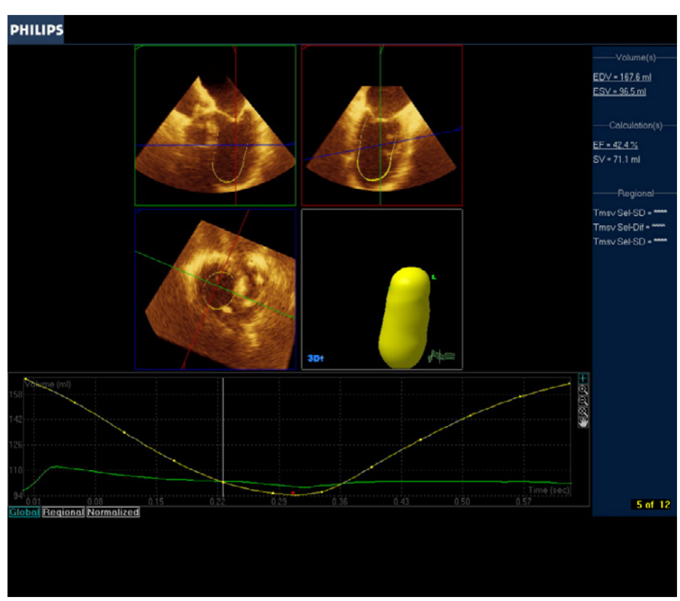

Figure. 7 A 3D full volume data set permits accurate depiction of segmental wall motion abnormality and spatial geometry of apical aneurysm. The left ventricular reduction over time is shown in the lower graph.

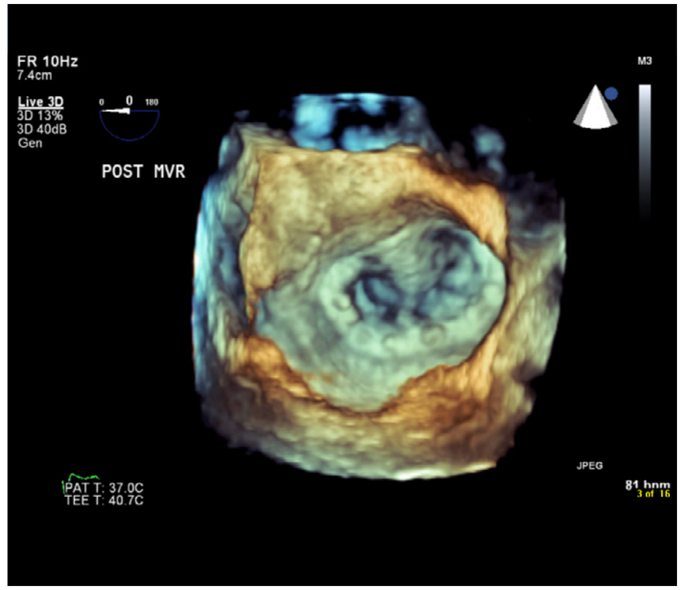

Figure. 8 3D echocardiograph image of annuloplasty band with closed leaflets in systole.

A B

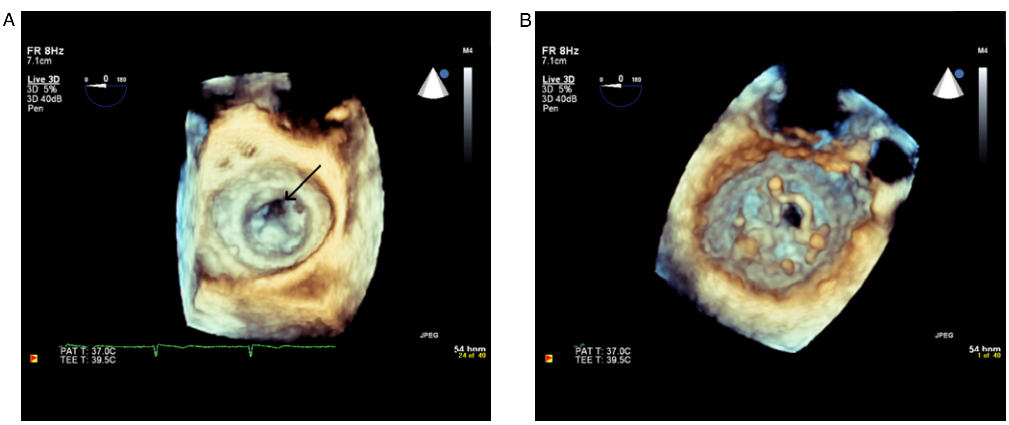

Figure. 9 Dysfunctional bioprosthetic valve showing opening of only one leaflet (arrow) from left atrial view (A) and from the left ventricular view (B).

identifying the spatial geometry of the pathologic lesions, demonstrating asymmetry in leaflet tissue and the detection of interscallop clefts. The images facilitate demonstration and communication in regards to pathologic lesions between surgeons and echocardiographers.

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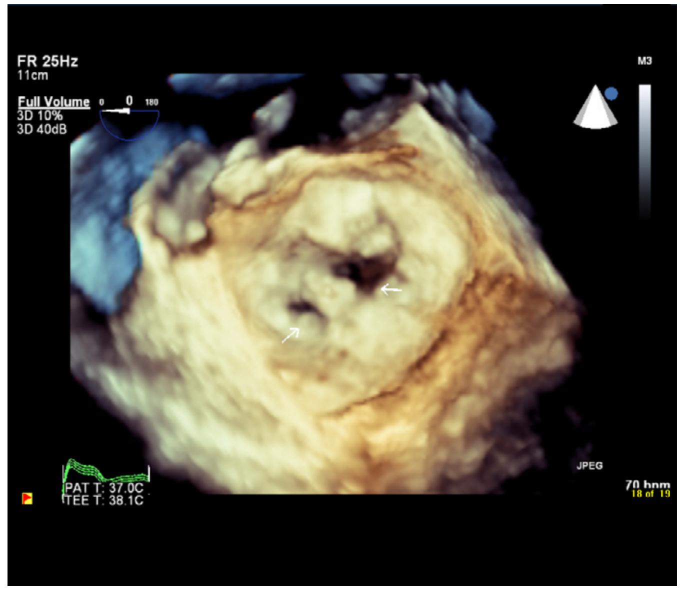

Figure. 10 3D echocardiograph image of two orifices created by E-clip in a patient who developed late failure and required valve replacement.

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