# Three-Dimensional Transesophageal Echocardiography in Degenerative Mitral Regurgitation

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The morphology of mitral valve (MV) prolapse and flail may be extremely variable, with dominant and secondary dynamic lesions. Any pathologic valve appears unique and different from any other. Three-dimensional (3D) transesophageal echocardiography is a powerful tool to evaluate the geometry, dynamics, and function of the MV apparatus and may be of enormous value in helping surgeons perform valve repair procedures. Indeed, in contrast to the surgical view, 3D transesophageal echocardiography can visualize MV prolapse and flail in motion and from different perspectives. The purpose of this special article is not to provide a comprehensive review of degenerative MV disease but rather to illustrate different types of mitral prolapse and flail as they appear from multiple 3D transesophageal echocardiographic perspectives using a series of clinical scenarios. Because in everyday practice, 3D transesophageal echocardiographic images of MV prolapse and flail are usually observed in motion, each scenario is accompanied by several videos. Finally, the authors provide for each scenario a brief description of the surgical techniques that are usually performed at their institution. (J Am Soc Echocardiogr 2015;■:■-■.)

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Degenerative mitral valve (MV) disease with leaflet prolapse and flail and severe regurgitation is a progressive pathologic condition associated with increased risk for long-term complications, including heart failure and death.[1-3] This condition is actually a spectrum of diseases ranging from prolapse or flail of an isolated segment in an otherwise normal sized valve (the so-called fibroelastic deficiency [FED]) to multisegment prolapse or flail of both leaflets due to an excess of myxomatous tissue and large annulus (Barlow disease). Intermediate stages of the disease are FED+, in which myxomatous changes occur in the prolapsing segment, and forme fruste, in which myxomatous changes affect more than one segment.[4]

It is widely accepted that MV repair represents the "state of the art" of surgical treatment.[5] Compared with valve replacement, MV repair has undeniably lower perioperative mortality, improved survival, better preservation of postoperative left ventricular function, and lower long-term morbidity, regardless of technical complexity.[6,7] Accordingly, MV repair is indicated in symptomatic patients or in those who, though asymptomatic, show initial findings of left ventricular dysfunction (class I), episodes of atrial fibrillation, or pulmonary hypertension (class IIa).[8]

Two-dimensional (2D) transthoracic echocardiography is considered the "first-line" imaging technique before MV repair, providing relevant data for the decision-making processes regarding the severity of regurgitation, the types of lesions, left and right ventricular function, and systolic pulmonary pressure. Two-dimensional transesophageal echocardiography (TEE) may complete the diagnosis, refining the type of lesion and providing useful information on the likelihood of repair. Currently, 2D TEE is considered an indispensable tool for cardiologists and anesthesiologists during MV repair.[9] However, both these techniques have the disadvantage of being tomographic, and only a limited number of cross-sectional planes are useful and standardized. Moreover, the identification of mitral scallops in a given cross-sectional plane may vary according to the individual anatomy (e.g., a large P3 may unexpectedly be intersected by the ultrasound beam in a long-axis view), and misidentification of the lesion may also occur when the echocardiographic plane foreshortens the ventricle.

Real-time three-dimensional (3D) TEE was launched in the diagnostic arena <10 years ago. Since then, it has become clear that this technique provides 3D images of the MV of extraordinary quality and, for the first time, with a visual perspective similar to the surgical view,[10,11] but with a substantial difference: flail or prolapsed leaflets are seen in motion, while in the surgical setting, the heart is still and the leaflets are motionless. In addition, whereas in the operating room, the exposure of the MV allows only a limited view through the left atrium, the 3D transesophageal echocardiographic pyramidal data set can be angulated and rotated in any direction, providing countless perspectives. Recently it has been shown that by using perspectives nearly tangential to the MV plane (angled views),[12] even small prolapses located near the commissures may be easily recognized. Any segment of the mitral leaflets can therefore be independently analyzed from the particular point of view that best displays its morphology (segment-oriented approach), and a precise "topographic map" of the whole MV can be created. It is not surprising, therefore, that the accuracy of 3D images

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| Abbreviations |
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| **FED** = Fibroelastic deficiency |
| **MR** = Mitral regurgitation |
| **MV** = Mitral valve |
| **TEE** = Transesophageal echocardiography |
| **3D** = Three-dimensional |
| **2D** = Two-dimensional |

in the presurgical diagnosis of prolapse and flail is excellent.[13] More recently, La Canna *et al.*[14] emphasized the importance of so-called secondary lesions near the main prolapsing area. In contrast to the large prolapses or flails (dominant lesions), which usually show thick and redundant leaflet tissue, these secondary lesions are mostly limited to late systole and might be not recognized in an arrested heart. Over time, these "dynamic" prolapses may deteriorate and become the cause of repeated surgery.[15] It is also worth mention that Chandra *et al.*,[16] using dedicated quantitative software (which allows measurements of the height, length, surface area, and volume of prolapsing tissue), were able to differentiate myxomatous valves (volume of prolapsed tissue > 1.15 mL) from those affected by fibroelastic degeneration valves (volume of prolapsed tissue < 1.15 mL).

The morphology of degenerative MV disease is extremely variable, with dominant and secondary dynamic lesions, and any pathologic valve appears unique and different from any other. Accordingly, the purpose of this special article is not to provide a comprehensive review of degenerative MV disease but rather to illustrate different types of mitral prolapse and flail as they appear from multiple 3D transesophageal echocardiographic perspectives using a series of clinical "scenarios."

On the other hand, the surgical technique used for a given valve depends not only on the underlying anatomy but also on surgical experience and preference. Indeed, there is not one single type of correction for a given valve prolapse, and different surgeons tackle these valves differently according to their expertise, access modality (minithoracotomy vs sternotomy) and their "surgical school." In this article, we provide for each scenario a brief description of the surgical techniques that that are usually performed at our institution.

Finally, in everyday practice, 3D transesophageal echocardiographic images of prolapse and flail are usually observed in motion; accordingly, each scenario is accompanied by several videos. The multipanel figures are still images derived from the corresponding videos chosen to indicate particular anatomic features or to emphasize specific 3D perspectives.

## THREE-DIMENSIONAL TRANSESOPHAGEAL ECHOCARDIOGRAPHIC MITRAL VALVE IMAGING ACQUISITION

The ideal imaging technique for visualizing the "dynamic" morphology of MV prolapse and flail requires high spatial resolution to identify fine morphologic details of the valve and high temporal resolution, which makes leaflet motion look "fluid" and natural, allowing an accurate frame-by-frame analysis of leaflet motion without large temporal gaps between frames.

The temporal resolution of 3D TEE depends on the number of volumes scanned per second (volume rate). Because there is an inverse relationship between temporal resolution and the width of the pyramidal data set, the operator can change the volume rate by acting both on the volume width and depth: decreasing the volume width automatically increases volume rate.

The spatial resolution in the beam direction (i.e., the axial resolution) depends exclusively on the pulse length; it is typically in the range of 0.8 to 1.0 mm and is unrelated to the volume rate or to the size (width and depth) of the pyramidal data set. The spatial resolution lateral to the beam direction (i.e., the lateral and elevation resolution) depends primarily on beam width and geometry. However, in a narrow sector, the spaces between lines are reduced (i.e., the line density is increased), and consequently, both temporal and spatial resolution is improved. Line density can also be electronically changed independently. In general, it can be stated that the narrower the pyramidal data set, the higher the spatial (both lateral and elevation) and temporal resolution.

There are three main options of acquiring a volumetric data set of the MV: "zoom" mode, wide-angle single-beat, and full volume multiple-beat. Table 1 summarizes limitations and advantages of each modality.

Briefly, the zoom mode is a real-time modality and consequently does not suffer from artifacts due to arrhythmias or patient or probe movement. When zoom mode is activated, two orthogonal 2D preview images show the "truncated" pyramid. The operator can then move this pyramid over the region of interest and adjust its size accordingly. Minimizing the sector width and length is important for increasing temporal resolution. Thus, although this modality is particularly useful for small structures such as the aorta or the left atrial appendage, it may be less suitable for a large degenerative MV. Indeed, to include the entire valve from lateral to medial commissure, the truncated pyramid must be wide enough that a reduction in temporal resolution up to 10 to 12 volumes/sec is inevitable. Moreover, increasing the volume width results in decreases in line density and, consequently, spatial (lateral) resolution.

The full-volume multiple-beat modality uses electrocardiographic gating to capture a large volumetric data set by acquiring narrow subvolumes over two to seven sequential cardiac cycles. Being a summation of these subvolumes, this modality, despite the large sector (90° × 90°), maintains the same high spatial resolution and provides a view of the whole MV with excellent image quality. Moreover, the high temporal resolution (up to 56 Hz) allows frame-by-frame analysis of leaflet motion, making this acquisition a formidable modality for accurately defining even small morphologic (and functional) valve abnormalities. Finally the same modality may display 3D color Doppler with an acceptable volume rate (up to 25–30 volumes/sec), though with a narrower sector. However, this modality is not "real time" (the last sector is acquired four to six beats after the first), and it may suffer from "stitching" artifacts caused by incorrect juxtaposition of subvolumes due to respiration, irregular heart rhythm, or any transducer or patient movement. Thus, to avoid or minimize stitching artifacts, the patient must be in sinus rhythm and must stay very still, suspending breathing for a few seconds, while the operator must avoid moving the probe during the acquisition. These conditions might not always occur in patients with severe mitral regurgitation (MR). However, if correctly acquired, full volume is the ideal modality for imaging the MV. Accordingly, the videos presented in this review have been obtained with full-volume acquisition. Videos 1–3 (available at www.onlinejase.com) show the differences among the three acquisition modalities in the same MV P2 prolapse. In zoom mode (Video 1), spatial resolution is preserved, and small secondary lesions can be seen medially to the main lesion (in the P3 area). However, the width sector used to embrace the entire valve results in a temporal resolution as low as 9 Hz; Video 2 shows the same valve acquired with a wide-angle single beat. Spatial resolution appears slightly worse in comparison with zoom mode (the edges of the secondary lesions

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