Perspective

# Value of transesophageal echocardiography (TEE) guidance in minimally invasive mitral valve surgery

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The role of intraoperative transesophageal echocardiography (TEE) has increased tremendously since its first use in 1979. Today intraoperative TEE is a class I indication for surgical mitral valve reconstruction for evaluation of mitral valve pathology, graduation of mitral regurgitation and detection of potential risk factors as well as post-repair assessment. Real-time three-dimensional TEE offers anatomical visualization of the mitral valve apparatus, fundamental for virtual surgical planning of proper annuloplasty ring size. As minimally invasive and even off-pump techniques for mitral valve repair become more popular, image guidance by intraoperative TEE will play an essential role.

**Keywords:** Intraoperative transesophageal echocardiography (TEE); image guidance; mitral valve repair; real time three dimensional TEE (RT 3D TEE); minimally invasive

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At the Albert Einstein College of Medicine in New York in 1979, Matsumoto *et al*. described the first use of transesophageal echocardiography (TEE) in a 65-year-old woman undergoing open mitral valvuloplasty (1). This marked the start of rapid growth in this emerging technology in cardiac surgery and anesthesiology. Nowadays, perioperative TEE should be used in all patients undergoing surgical mitral valve repair (2,3). The TEE should be incorporated into a comprehensive examination in both the pre- and post-operative periods (4). The detection of new, unexpected findings due to the comprehensive intraoperative TEE examination varies from 4% to 25% and has a huge impact on surgical decision-making (5-8).

In the pre-operative period, TEE should evaluate: (I) the mitral valve apparatus; (II) the function of the mitral valve leaflets and pathological segments; (III) the severity of mitral regurgitation under general anesthesia; (IV) potential risk factors for the surgical repair; and (V) correct placement of the cannulas used for cardiopulmonary bypass (CPB).

The post-operative TEE examination can be divided into the weaning period from CPB, where the circumflex artery and sufficient de-airing of the left ventricle should be evaluated, and the post CPB period. The post CPB TEE examination should identify: (I) residual mitral regurgitation; (II) possible mitral stenosis; and (III) potential complications of the surgical mitral valve, i.e., systolic anterior motion (SAM), distortion of the circumflex artery, new onset of aortic regurgitation, aortic dissection etc.

## Pre-operative TEE examination

### Evaluation of the mitral valve apparatus

To evaluate the mitral valve apparatus with 2D TEE, the following standard views are necessary:

In the transgastric two-chamber view, the inner dimension of the left ventricle in systole and diastole should be measured (9). This view also allows good visualization of the subvalvular mitral valve apparatus (i.e., papillary muscles and chordae, *Figure 1A*). The transgastric basal short axis view allows planimetry of the mitral valve opening area and visualization of all segments including both commmissures (see *Figure 1B*). In the midesophageal four chamber-, mitral commissural-, two chamber- and long axis views, different

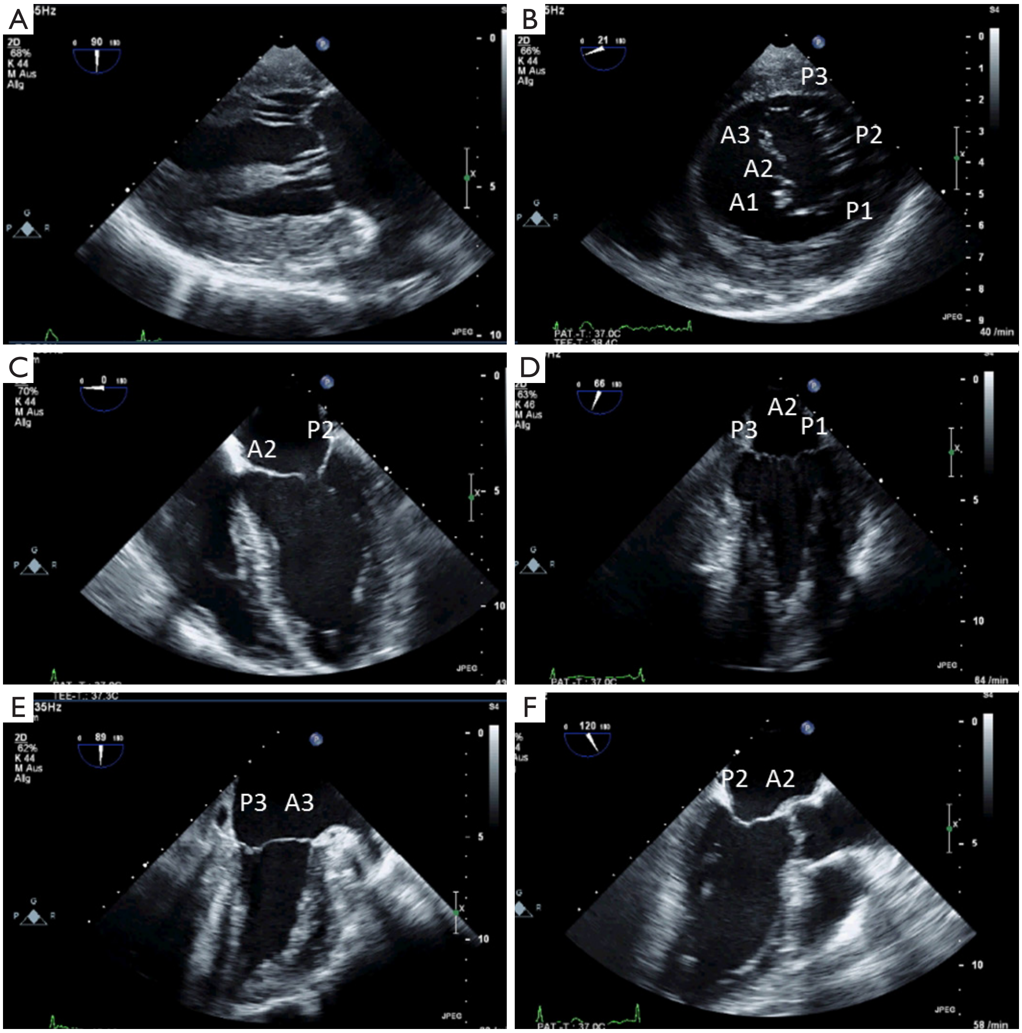


**Figure 1** Visualization of the individual segments of the mitral valve in the standard views: Transgastric two chamber (A), basal short axis view (B), midesophageal-4 chamber (C), mitral commissural (D), 2 chamber (E), and long axis (F) views.

segments of the mitral valve leaflets can be seen (see *Figure 1C-F*). Because the phased-array technology of 2D TEE provides only small cross-sectional images of the heart, mental three-dimensional reconstruction is necessary to get a complete impression of the morphology and pathology of the whole mitral valve apparatus. New matrix transducer technology allows real-time three-dimensional TEE (RT 3D TEE) in the perioperative setting (10) (*Figure 2*).

## Function of the mitral valve leaflets

According to the Carpentier classification, the motion of the mitral valve leaflets can be normal, excessive or restrictive (11). In selecting the type of surgical mitral valve repair, it is essential to identify the pathological segments. The advantage of RT 3D TEE over 2D TEE in localizing diseased segments, according to the Carpentier classification, is still a matter of debate. However, RT 3D TEE is superior in detecting some pathologies of the MV (12-14), especially involving the commissures. The agreement between preoperative echocardiographic findings and direct surgical inspection of the MV ranges between 88-100% (15), assuming that surgical inspection is the "gold standard".

## Severity of mitral regurgitation

In common practice, there are three methods to quantify

 

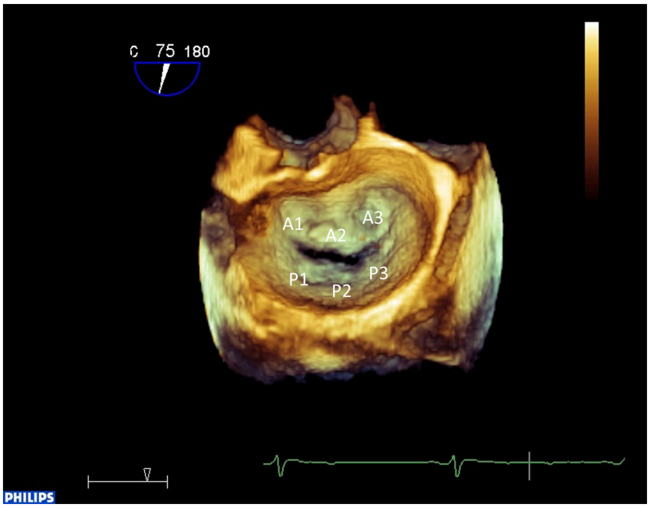


**Figure 2** Visualization of the individual segments of the mitral valve in real-time 3D "surgical view".

the severity of mitral valve regurgitation: the calculation of effective regurgitation orifice area (EROA) by using proximal isovelocity surface area (PISA), the measurement of the vena contracta width and the interrogation of pulmonary vein flow.

The calculated EROA, as the most robust parameter of all three, is recommended whenever feasible. According to the guidelines of the European Association of Echocardiography (EAE), mitral regurgitation is classified as mild (EROA <20 $mm^2$), moderate (EROA 20-39 $mm^2$), and severe (EROA >40 $mm^2$) (2).

Vena contracta is the narrowest width, with the highest velocity of a flow jet measured at the atrial side of the leaflet tips. A vena contracta width <3 mm denotes mild and >7 mm is specific for severe mitral regurgitation. Intermediate values roughly correlate with moderate mitral regurgitation. In this case, another quantitative method should be used for confirmation. Vena contracta works well for central and eccentric jets, but it is difficult to apply in multiple mitral regurgitation jets.

For both EROA and Vena contracta methods, geometric assumptions are required that can limit the clinical application. Most of the regurgitation jets are not circular in shape (16). The limitation of these two commonly used 2D measurements may be overcome with 3D color Doppler echocardiography and the planimetry of the regurgitant orifice area (17).

General anesthesia in patients undergoing mitral valve repair results in an underestimation of the severity of mitral regurgitation due to altered loading conditions (18,19). Adjusting the baseline shift of the Nyquist limit can partially compensate for that effect (19). Therefore an intraoperative graduation of the mitral regurgitation before repair is essential to act as a baseline for the postoperative evaluation of a residual mitral regurgitation.

In normal pulmonary venous flow, the S-wave is larger than the D-wave with both waves in the same direction from baseline. With increasing severity of mitral regurgitation, systolic velocity gradually decreases and even reverses in severe mitral regurgitation (*Figure 3*). Normally, the pulmonary flow is measured in the left upper pulmonary vein by TEE. In the presence of an eccentric regurgitation, jet evaluation in both left and right upper pulmonary veins is recommended.

## Potential risk factors for surgical repair

Secondary SAM is a complication virtually unique to mitral valve repair. The postoperative incidence is reported to range between 1-16%. SAM can be diagnosed as minor chordal protrusion in the LVOT to life-threatening LVOT obstruction with mitral regurgitation. In the preoperative TEE (ME AV SAX view) structural and geometric factors like the anterior to posterior leaflet height ratio (<1.4), the absolute height of the posterior leaflet (>1.5 cm) and the minimum distance from the coaptation point to the septum (C-Sept, <2.5 cm) can be used as predictors of LVOT obstruction and SAM (20).

Distortion of the circumflex artery, due to sutures necessary to fix the annuloplasty ring during mitral valve repair occurs in up to 1.8% of patients (21). With TEE, it is possible to visualize the circumflex artery in most of the patients undergoing mitral valve repair (22). The comparison between pre- and postoperative assessment of the circumflex artery helps to identify patients with compromised circumflex artery as early as possible after mitral valve repair and should therefore be part of the routine examination (23).

## Correct placement of the cannula

Correct positioning of the guide-wire (*Figure 4A*) and subsequently of the venous cannula inserted from the groin is usually performed in the midesophageal bicaval view. If no additional cannula for the superior vena cava is used, optimal position is with the tip at least 2-3 cm in the superior vena cava (*Figure 4B*). With a second cannula

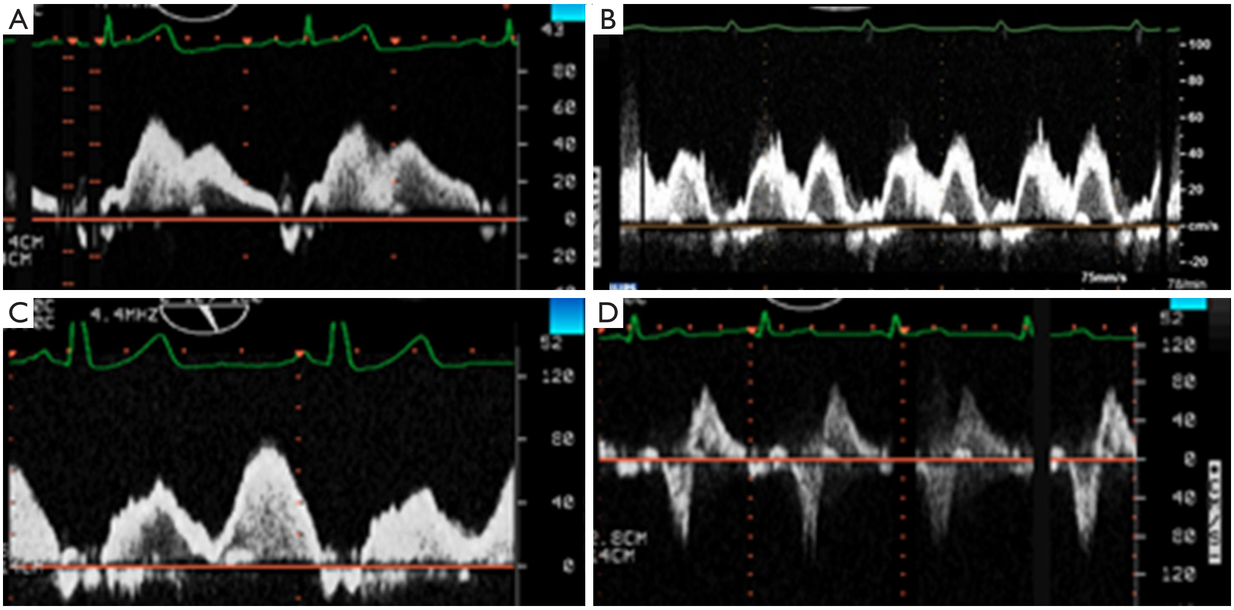


**Figure 3** Pulmonary vein doppler flow: normal (A), mild (B), moderate (C), and severe (D) mitral regurgitation.

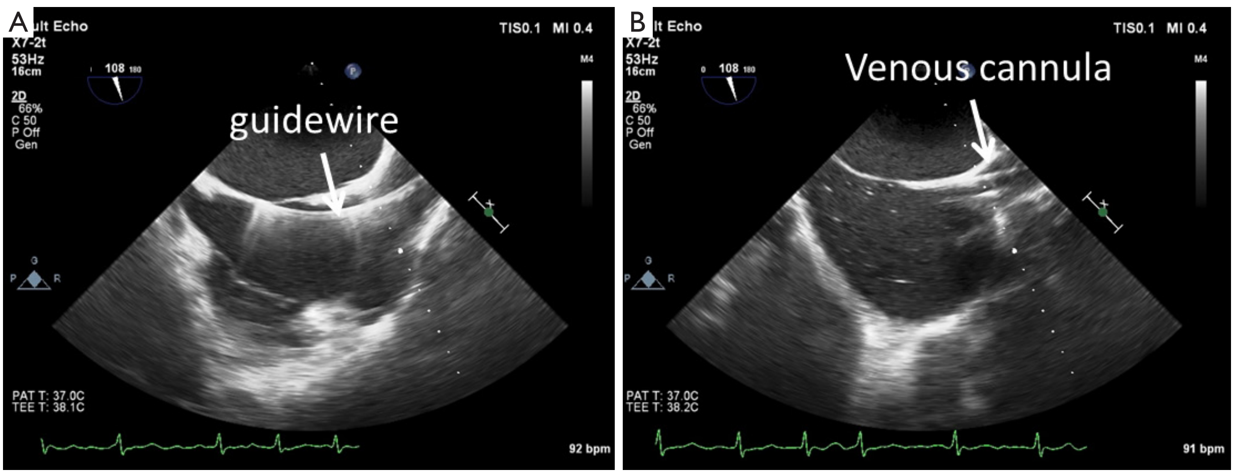


**Figure 4** (A) Guide-wire for the femoral venous cannula coming from the inferior vena cava and going into the superior vena cava; (B) Position of the venous cannula in the superior vena cava.

in the superior vena cava inserted from the right internal jugular vein, the femoral cannula should be positioned in the inferior vena cava. Before insertion of the jugular venous cannula, the position of the guide wire in the right atrium should be verified to avoid vascular complications (*Figure 5A*). After insertion of the cannula, a "bubble test" should be performed to ensure endovascular positioning of the cannula (*Figure 5B*). Before insertion of the arterial cannula into the femoral artery, the guide-wire in the descending aorta should also be visualized, to avoid vascular complications. For port-access minimally invasive mitral valve surgery, the position of the endoaortic balloon in the ascending aorta has to be verified in the midesophageal ascending aortic long axis view (24,25).

## Post-operative TEE examination

Immediately after release of the cross clamp, visualization

 

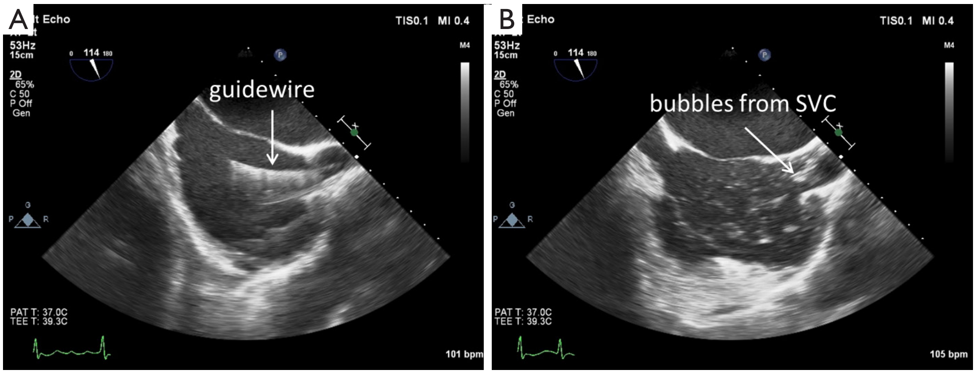


**Figure 5** (A) Guide-wire for the jugular venous cannula coming from the superior vena cava and going into the right atrium; (B) Positive bubble test in the right atrium with bubbles coming from the superior vena cava.

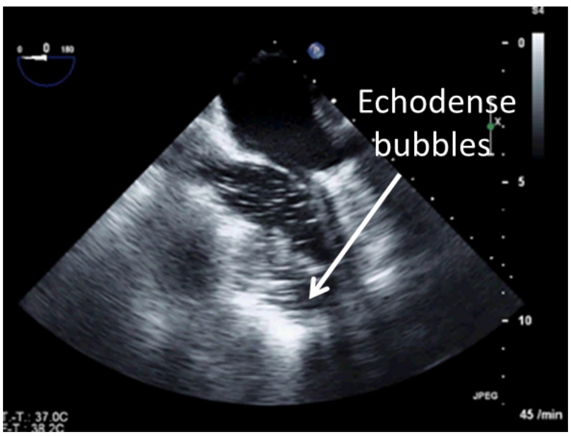


**Figure 6** Arrow indicates echo-dense bubbles in the left ventricle.

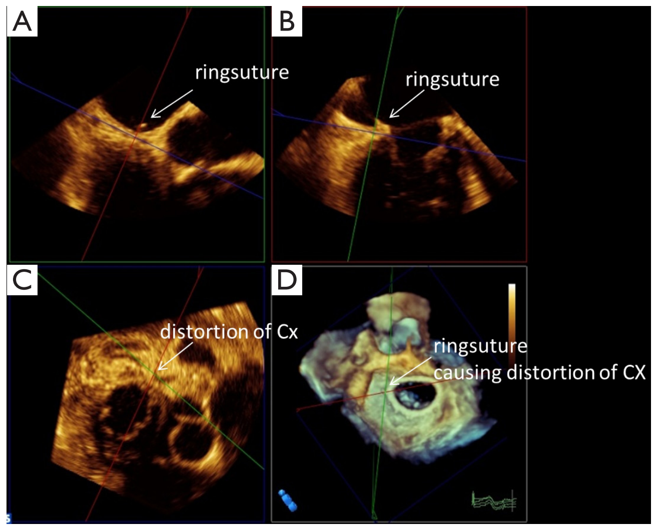


**Figure 7** 3D multiple plane reconstruction of a patient with distortion of the circumflex artery (Cx). With arrows indicating the ringsuture responsible for the distortion in sagittal (A), coronal (B), and transverse plane (C). The crossing of the different planes allows identification of this specific ringsuture in 3D (D).

of the circumflex artery allows early detection of a compromised circumflex artery when compared with the pre-operative TEE examination (26). With RT 3D TEE, the suture causing distortion of the circumflex artery can be identified (*Figure 6*).

Before removal of the surgical vents, one has to check for complete de-airing of the left ventricle to avoid air embolism in the coronary arteries. Intracavitary air is clearly visualized as echodense bubbles in the midesophageal views (*Figure 7*).

Residual mitral regurgitation after repair should be evaluated only after complete weaning from bypass. The same methods for graduation can be used as in the pre-operative evaluation.

## Post-operative mitral stenosis

Mitral stenosis after repair occurs in less than 2% of patients. A pressure gradient of <7 mmHg measured with continuous wave Doppler is associated with significant mitral stenosis. Planimetry of the mitral valve opening area should be performed in the transgastric basal short axis view when using 2D TEE or even better with RT 3D TEE.

Dynamic left ventricular outflow obstruction with accompanying SAM is best visualized in the ME LAX and five-chamber views. Continuous wave Doppler signal of the left ventricular outflow tract shows a characteristic dagger-shaped form because the peak pressure gradient occurs in late systole.

Finally, excluding new onset of aortic regurgitation due to a captured non-coronary cusp of the aortic valve by annuloplasty sutures, aortic dissection (27) and ventricular rupture (28) should be part of the post-operative TEE examination.

## Future perspective

Real-time three-dimensional TEE offers anatomical visualization of the mitral valve apparatus, fundamental for echocardiographic guidance and virtual surgical planning. New surgical interventional (i.e., MitralClip®) and surgical off-pump techniques (i.e., Neochord®) completely rely on echocardiographic guidance (29,30). The results of studies predicting proper annuloplasty ring size using RT 3D TEE and special software are encouraging (31,32).

## Conclusions

There is no doubt that the diagnostic value of perioperative TEE has improved the safety of MV surgery. 2D and RT 3D TEE are complementary in diagnosing complex pathology of the MV and assessing MV repair. As we embrace new technologies, a collaborative approach among the "heart team" assumes even greater importance in ensuring good postoperative outcomes. Finally, while many issues must be overcome in the management of patients with MV pathology, as Karl Popper famously stated, "When we do research, we never apprehend the truth, we merely reduce the level of our error."

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