特　集 (special edition)

# Intraoperative Mitral Valve Evaluation

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## Introduction

Mitral regurgitation is a relatively common finding in patients having cardiac surgery. In addition to those patients with rheumatic and myxomatous mitral valve disease, 10-40% of patients with a prior myocardial infarction have mitral regurgitation. Because it is potentially harmful to needlessly replace a mitral valve or to leave a significantly diseased valve, the clinical decision regarding the surgical intervention is extremely important. Furthermore, incomplete preoperative evaluation and the changing nature of mitral regurgitation[1)], often necessitate intraoperative determination of mitral regurgitation. This assessment of the mitral valve is one of the most important applications of intraoperative echocardiogaphy. The importance lies in the fact that this assessment frequently dictates the ultimate surgical decisions regarding whether or not to intervene, how to intervene, and was the intervention successful.

## Mitral Valve Anatomy

One of the most important questions answered by intraoperative echocardiogaphy is to define the anatomy of the mitral valve, and to elucidate the mechanism of mitral regurgitation. Thus an understanding of the normal structure is extremely important. The mitral valve is a complex structure consisting of the two leaflets (Figure 1), the fibrous annulus, chordae tendineae, two papillary muscles and their attachment sites to the ventricular wall. The annulus is composed of fibroelastic tissue and it completely encircles the orifice in a cone-like shape. The anteromedial leaflet is

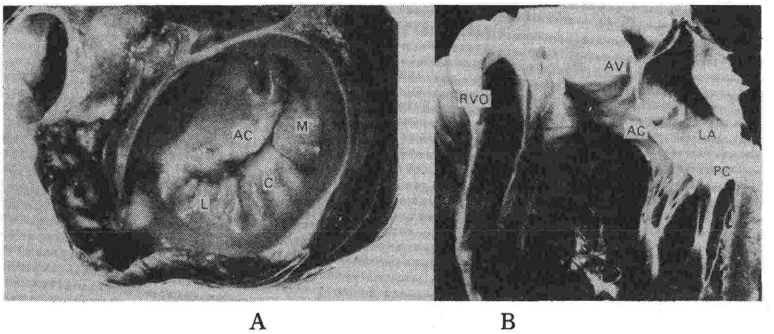


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**Fig. 1** Anatomic Picture of the Mitral Valve. A. short axis view, B. long axis view. AC=anterior commissure, L=lateral scallop, C=center scallop, M=medial scallop.

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triangular in shape, and is continuous with the aortic valve. This leaflet is the more mobile than the posterolateral leaflet, but it only encircles only one-third of the annulus. The posterolateral leaflet is quadrangular in shape, consists of a medial, a center, and a lateral scallop, and covers the remaining two-thirds of the annulus.

Proper mitral valve function is dependent on the normal function of each of the above components. There are numerous etiologies of mitral regurgitation and the distinction is frequently made intraoperatively. The defects of mitral valve function can be divided into four categories: excessive leaflet motion, restricted leaflet motion, perforated leaflet, and annular dilitation. Examples of excessive leaflet motion are mitral valve prolapse, ruptured chordae, and ruptured papillary muscle(s). Restricted motion examples are chordal sclerosis/calcification, papillary muscle or ventricular wall ischemia, and vegetation or mass obstructed coaptation of the leaflets.

## 2-D Echocardiographic Interrogation

2-D echocardiography is used to define the anatomic structure of the mitral valve. Intraoperatively, complete interrogation of the mitral valve can be performed with a biplane or multiplane transesophageal echocardiographic probe. Alternatively, if only a single plane transverse probe is available, supplemental views obtained by epicardial echocardiography are necessary to visualize the entire posterior mitral valve leaflet. It is critical to remember that the heart is a three-dimensional structure and the imaging planes are two-dimensional tomographic cuts. To overcome this limitation the echocardiographer must manipulate the probe to obtain multiple variations of each "classic" view and then the echocardiographer must integrate the images into a coherent picture. The following discussion will focus on the use of biplane transesophageal echocardiography (TEE).

The intimate anatomic relationship of the esophagus and the mitral valve, and the absence of echo impenetrable structures enables the use of high frequency (5 or 7 MHz) probes that provide excellent high resolution images. In the transverse scanning plane, the mitral valve can be imged in both and short axis. The long axis views are obtained at depths of 25-35 cm in the esophagus, and the imaging plane is adjusted mainly by depth and flexion/retroflexion of the probe. In these views, the morphology and excursion of the anterior leaflet is clearly visualized (Figure 2). Only a

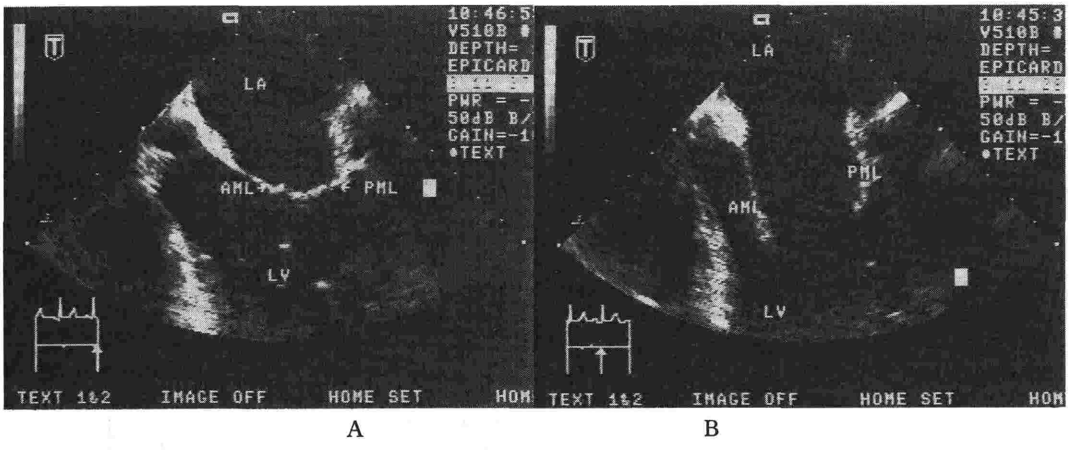


**Fig. 2** Transverse long axis view of the mitral valve in systole (A) and diastole (B). LA=left atrium, LV=left ventricle, AML=anterior mitral leaflet, PML=posterior mitral leaflet.

small, relatively immobile portion of the posterior leaflet is seen in this view. By advancing the probe into the stomach (depth of 35-45 cm) and sharply flexing it, the short axis view of the left ventricle at the level of the mitral valve is obtained (Figure 3). In this view, the leaflets are seen on end in a "fish mouth" appearance. Identification of the anterior and posterior commissures, and localization of a leaflet defect, i. e. which commissure is involved, is also possible. This piece of information is critical for mitral valve repairs.

Longitudinal views of the mitral valve can be obtained both from the transgastric and esophageal positions. In each of these two positions, the image is adjusted primarily by rotation of the probe. Another key difference between longitudinal and transverse scanning planes is that in longitudinal scanning differentiation of the anterior and posterior leaflets is more difficult (Figure 4). The anterior leaflet is only seen during systole in longitudinal scanning and it is only seen in the central portion of the valve on the left ventricular side of the mitral annulus (Figure 5). The posterior leaflet is seen throughout the cardiac cycle, but more completely in systole.

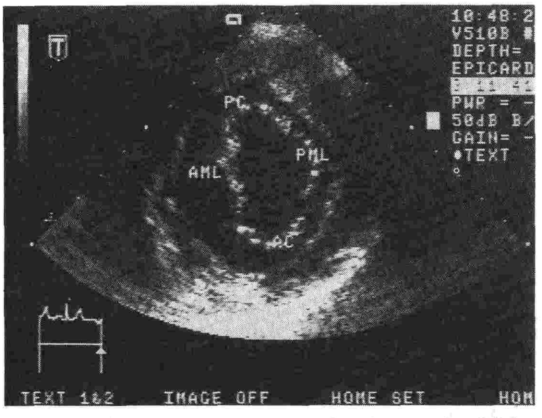


**Fig. 3** Transverse transgastric short axis "fish mouth" view of the mitral valve. AML=anterior mitral leaflet, PML=posterior mitral leaflet, AC=anterior commissure, PC=posterior commissure.

In addition to these views of the mitral valve, several other views must also be obtained. To define the acuity of the regurgtation left atrial size must be determined. This is done in both the transverse short axis basal views of the heart and in the forementioned long axis views. These views are also used to image the entire left atrium, particularly the left atrial appendage, to rule out the presence of clot (Figure 6). Clot will have a different echogenicity than the myocardium, and may be either laminar or pedunculated. Because of the risk of embolization during manipulation, the surgeon must be informed of the presence of clot. These same views of the left atrium are also used to locate the pulmonary veins for Doppler interrogation. (see below) Depending on

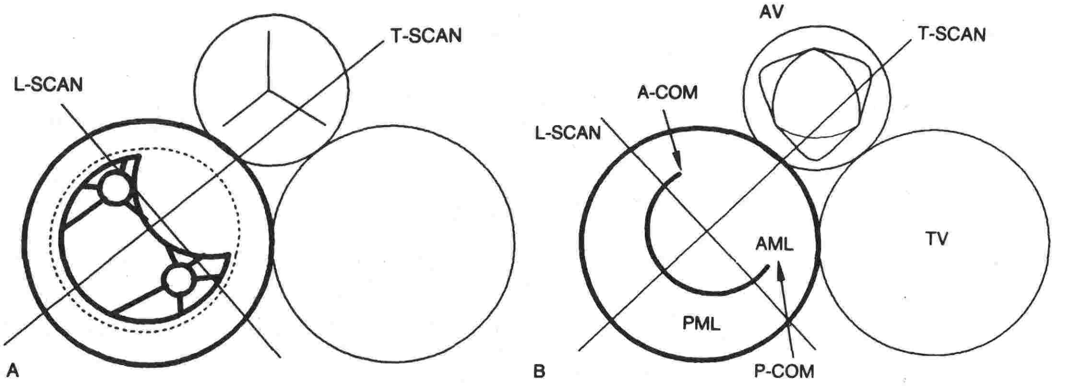


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**Fig. 4** Diagram of longitudinal and transverse scan planes during diastole (A) and systole (B).

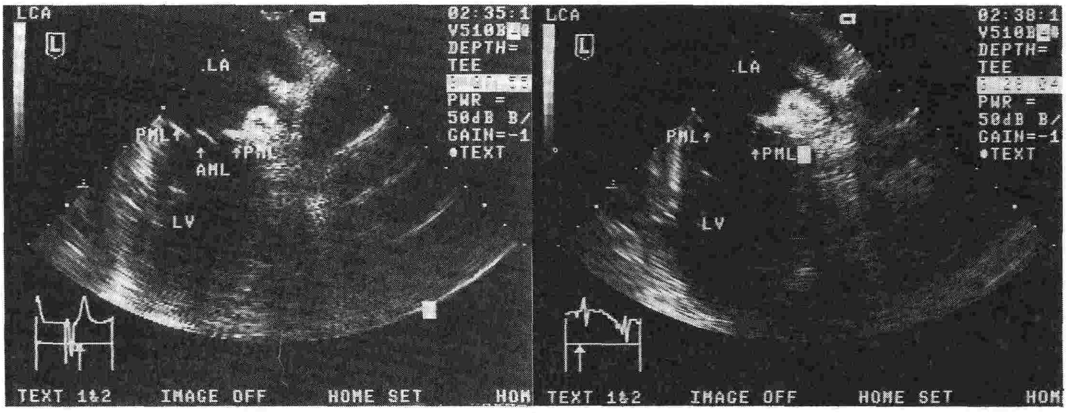


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**Fig. 5** Longitudinal long axis view of the LA LV in systole (A) and diastole (B). LA=left atrium, LV=left ventricle, AML=anterior mitral leaflet, PML=posterior mitral leaflet.

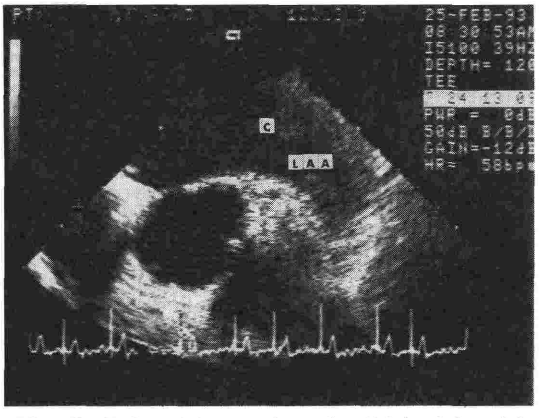


**Fig. 6** Left atrial appendage clot. LAA=left atrial appendage, C=clot.

the orientation of the heart, the pulmonary veins may be more visible and better aligned for Doppler interrogation in either the longitudinal or transverse scanning planes. The role of left ventricular dysfunction must also be defined in both long and short axis views.

## Doppler Principles

Originally applied to the science of astronomy, the Doppler principle basically states that the observed frequency of a wave will vary depending on the relative velocity of the observer and the moving body. In ultrasound, three forms of Doppler echocardiography are used: pulsed-wave, continuous, and color-flow. All three forms yield a measure of blood velocity over time and are best performed with the direction of blood flow parallel to the Doppler beam. Baecause the equation to determine velocity includes the cosine $\theta$, the angle of incidence should be less than 30 degrees. Each Doppler form has its own unique properties. Pulsed-wave Doppler echocardioagraphy provides a measure of velocity in a specific point in space, but has a limited velocity range-the Nyquist limit. Thus pulsed-wave Doppler is ideally suited to the assessment of pulmonary venous flow. Continuous Doppler has a greater velocity range, but has spatial ambiguity. It is best used to evaluate high velocity blood flow such as flow across a severely stenotic mitral valve. Color-flow Doppler is a computer integrated representation of thousands of pulsed-wave Doppler gates, and therefore is also subject to a limited velocity range. Color-flow mapping is used to complement two-dimensional scanning and to provide information on the patterns of blood flow. Most commonly, this involves the assessment of the cardiac valves for competence. There are numerous other applications. Color-flow imaging can also be used to direct pulsed-wave or continuous wave Doppler interrogation; for example in the analysis of pulmonary venous flow. In the assessment of obstructive cardiomyopathies, color-flow mapping is used to detect sub-aortic turbulence, and in the diagnosis of thoracic aortic dissection, color-flow mapping can define the sites of communication and the true and false lumens. Lastly, color-flow mapping is used to detect and localize intracardiac shunts such as ASD's and VSD's.

In spectral Doppler (pulsed-wave and continuous wave), velocity is depicted on a graph varying with time. Blood flow towards the transducer is depicted above the baseline and flow away from the transducer is below the baseline. In color-flow Doppler, all of the gates are displayed simultaneously over the two-dimensional image. By convention, flow towards the transducer is coded as red, and flow away from the transducer is coded as blue. Higher velocities are given brighter hues. If the velocity of blood exceeds the Nyquist limit, there is aliasing of the signal. In color-flow mapping, this may be represented by the inclusion of the opposite color, or in some systems, a new color yellow or green may be added to the image. It must be remembered that these colors represent blood velocity, and not blood volume. Thus a jet area may not be equal to regurgitant volume measured by a volumetric technique.

## Color Flow Mapping in Mitral Regurgitation

Initially, it was believed that color flow mapping would provide a simple rapid means to grade the severity of mitral regurgitation. This grading would be based on either the total turbulent jet area, or as is done with transthoracic echocardiography, the ratio of the jet area to the left atrial area. One grading system that utilizes the two possibilities is as follows: grade I, jet<1 cm long and <1 cm wide, grade II, <1 cm wide and may go to the back of the atrium, grade III, the jet covers one-half of the left atrium, grade IV, the jet covers more than one-half of the atrium. However, it has since been learned that this determination is highly dependent on technical factors, and physiologic factors. Some of the technical factors include the color gain, frame rate, sector width, transducer frequency, pulse repetition frequency, and scanning direction and angle. Thus multiple tomographic cuts are necessary and serial measurments should always be performed with individualized, but consistent instrument setting.

Physiologic variables that may effect the color flow map include jet direction, heart rate, ischemia, ventricular function, and probably the most important—ventricular afterload. Jet direction is important in that for a given regurgitant volume, jets that are directly centrally, i. e. "concentric", will have a larger color flow map representation than a jet that is directed against a lateral wall of the left atrium, i. e. "eccentric". Jet direction also yields valuable mechanistic information. Concentric jets are often due to a dilated annulus, and eccentric jets frequently are directed to the contralateral side of the prolapsed or flail leaflet. The severity of regurgitation may be underestimated in patients with rapid heart rates or poor ventricular function.

Intraoperative assessment of mitral regurgitation is almost always performed after the induction of general anesthesia when the systemic blood pressure is generally below the patient's usual value[2]. The echocardiographic assessment of mitral regurgitation may be significantly altered by the lower blood pressure[3]. Though phenylephrine has been used to minimize this effect[4], some investigations have generally not accounted for this factor[2,5,6]. To define the blood pressure dependence of Doppler indices of mitral regurgitation and the effects of phenylephrine administration in typical clinical doses needed to restore normotension, the assessment of the severity of mitral regurgitation was performed at two different blood pressures: 1) a blood pressure below the patients normal value following the induction of anesthesia, and 2) following normalization of the patient's blood pressure with phenylephrine[7]. Following phenylephrine, the color flow grade increased in 20/24 patients; 2 grades in 5 patients (Figure 7), and 1 grade in 15 patients. Three of the four patients who did not change after phenylephrine had IV+mitral regurgitation prior to phenylephrine. The jet area increased in each patient ($482 \pm 405$ vs $750 \pm 440$ $mm^2$; $p<0.001$). The results of this study clearly demonstrate that color flow of mitral regurgitation vary dramatically within the limits of otherwise clinically unimportant regurgitation vary dramatically within the limits of otherwise clinically unimportant blood pressure variation. Most importantly, the observed changes in the Doppler parameters were so profound that in approximately 25% of the patients mild to moderate mitral regurgitation became moderate to severe mitral regurgitation. Changes of this magnitude could alter surgical therapy.

Because of the above difficulties in using color flow mapping, other approaches have been sought. One idea is to look at the width of the jet at the mitral valve orifice, where the severity of the mitral regurgitation is proportional to the width of the jet. Though the work of Hoit et al[3] found this parameter to be of minimal value, Tribouilloy et al[8] concluded that a jet width of 5.5 mm may be a useful cutoff to differenciate mild and severe mitral regurgitation.

Another approach has been to calculate the regurgitant volume by use of the continuity equation[9]. This approach is called FCR for flow convergence region or PISA for aproximal isovelocity surface area. In this application, the regurgitant volume is equal to the flow across the regurgitant orifice. Color flow mapping is used to define the velocity of blood on the proximal (left ventricular) side of the mitral valve, and the area of this velocity can also be measured. The equation used is as follows:

$$Q_1 = 2\pi r^2 \quad V_r = Q_2$$

where $Q_1$=flow rate of the FCR, $Q_2$=the flow rate through the orifice, r=the radius of the FCR, $V_r$=the velocity of the FCR. Despite some encouraging early work, it is still unclear

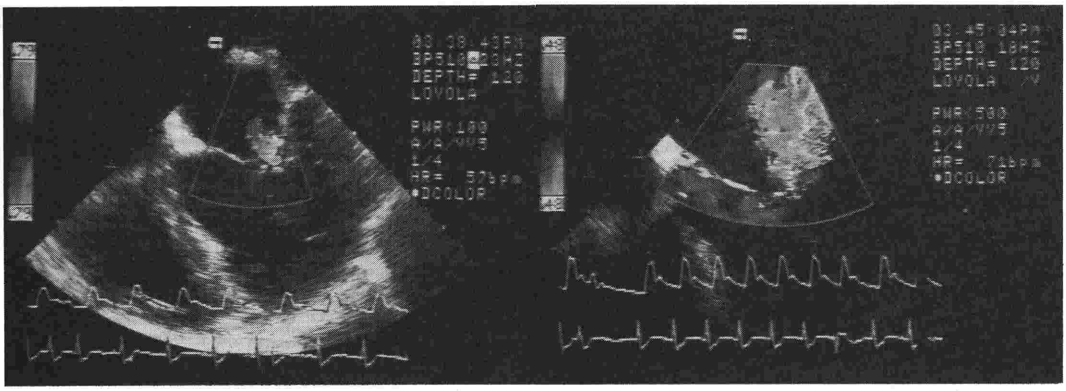


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**Fig. 7** Color flow mapping of the left atrium before (A) and after (B) phenylephrine. Note the dramatic increase in area of the turbulent mosaic area in (B).

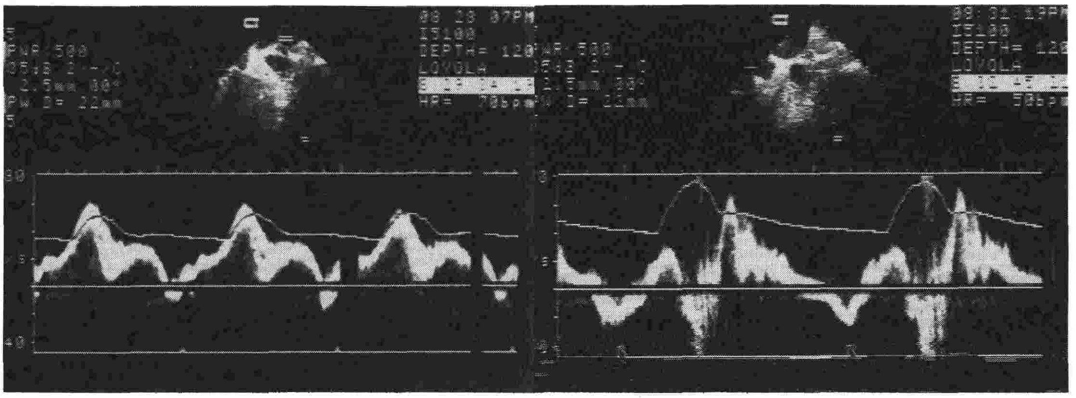

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**Fig. 8** Pulmonary venous flow patterns before (A) and after (B) phenylephrine. Note that the positive systolic flow in (A) had become negative flow, i. e. reversed, in (B).

whether this technique will be of clinical value.

## Pulmonary Venous Patterns

The symptomatic consequence of severe regurgitation is pulmonary edema, due to high left atrial pressure and high pulmonary venous pressure. One way to assess the physiologic impact of mitral regurgitation is to interrogate the pulmonary venous flow pattern by pulsed-wave Doppler. The nomal flow pattern in sinus rhythm is triphasic. Following atrial contraction there a small negative deflection called atrial reversal. Then, with the onset of ventricular systole there is a large positive wave that relates to the preponderance of left atrial filling. During diastole, there is additional flow into the left atrium. But in patients with severe mitral regurgitation the systolic flow is significantly decreased, eliminated, or even reversed[10].

Just as color flow mapping is subject to physiologic variables, there are several important variables for pulmonary venous flow that must be considered. In a given patient, depending on the direction of the regurgitant jet, there may be significant disparity between the right and left pulmonary venous flow patterns. In fact unilateral systolic pulmonary venous flow reversal is one of the likely diagnoses in unilateral pulmonary edema. Ventricular afterload is also a key determinant of pulmonary venous flow patterns. In the same study that looked at color flow mapping changes with phenylephrine, pulmonary venous flow patterns were also examined. Prior to phenylephrine, only one patient had systolic flow reversal, but after phenylephrine, there were 7 patients with systolic flow reversal ($p<0.002$) (Figure 8). Following phenylephrine administration there were significant reductions in the peak systolic velocity and systolic velocity time integral of the pulmonary venous flow. There was also a significant increase in the peak diastolic velocity and diastolic velocity time integral after phenylephrine. Thus afterload must be considered at the time of evaluation, and every attempt to recreate the patient's usual hemodynamic conditions must be made prior to surgical decision making.

## Conclusions

Mitral regurgitation is a relatively frequent finding in the cardiac surgical patient. Intraoperative echocardiography has provided a means to improve surgical decision making by providing on the anatomy and physiology of the valve, and assessing the physiologic impact of the regurgitant jet.

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