UNANTICIPATED MITRAL REGURGITATION DURING CABG SURGERY

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Learning Objectives:

1. Learn to diagnose mitral regurgitation using TEE.
2. Learn quantify the severity of mitral regurgitation using TEE.
3. Learn to characterize pathophysiologic mechanisms of mitral regurgitation using TEE.

Case Presentation:

Patient undergoing CABG and possible mitral valve repair.

a. Evaluate mitral valve function and assess the severity of mitral regurgitation.
b. Determine the mechanism of mitral regurgitation.
c. Determine the likelihood that the patient will develop severe mitral regurgitation.
d. Determine the likelihood that the severity of mitral regurgitation will decrease after CABG.
e. Assess the potential risks and benefits of mitral valve repair.

Discussion:

Transesophageal echocardiography (TEE) with the ultrasound transducer positioned in the esophagus, directly behind the left atrium, provides an excellent acoustic window for imaging the mitral valve. The objectives for the TEE assessment of mitral regurgitation are to detect the presence of regurgitation, quantify the severity of regurgitation, and to diagnose the mechanism causing mitral regurgitation. This can be accomplished using 2-dimensional imaging to assess the structure of the mitral valve apparatus together with Doppler imaging to assess the blood flow characteristics of the mitral regurgitant jet.

Mitral Valve Anatomy

The mitral valve is a complex structure that can be described in terms of a valve apparatus consisting of two valve leaflets, the valve annulus, chordae tendinae, papillary muscles, and the left ventricle. Pathology affecting each of these components of the mitral valve apparatus can contribute to mitral regurgitation. The anterior mitral valve leaflet is attached to the mitral valve annulus between the right and left fibrous trigones that is in direct continuity with most of the left and part of the noncoronary aortic valve cusps. The ventricular side of the anterior mitral valve leaflet forms part of the left
ventricular outflow tract in systole. The posterior mitral valve leaflet is attached to the remaining one-half to two-thirds of the annulus that is primarily muscular with little fibrous tissue. The crescent-shaped posterior leaflet is divided into three scallops separated by clefts. The scallops of the posterior leaflet can be designated as the P1 (anterolateral), P2 (middle), and P3 (posterolateral) scallops. The left atrial surface of the leading edges of the anterior and posterior mitral valve leaflets coapt in systole along the mitral valve commissure. The chordae tendinae span the left ventricular surface of the mitral valve leaflets and the papillary muscles or ventricular endocardium. Chordae from the posteriormedial half of both the anterior and posterior leaflets attach to the posteriomedial papillary muscle. Chordae from the anterolateral half of both the anterior and posterior leaflets attach to the anterolateral papillary muscle. Primary chordae attach to the leading edge of the leaflets and secondary chordae attach to the body of the leaflets.

![Diagram of mitral valve anatomy](image)

**Figure 7** Anatomy of mitral valve. **A1**, lateral third of the anterior leaflet; **A2**, middle third of the anterior leaflet; **A3**, medial third of the anterior leaflet; **P1**, lateral scallop of the posterior leaflet; **P2**, middle scallop of the posterior leaflet; **P3**, medial scallop of the posterior leaflet.

**Quantifying the Severity of Mitral Regurgitation**

Doppler echocardiography is the primary technique for quantifying the severity of mitral regurgitation by detecting retrograde blood flow across the mitral valve into the left
atrium during systole. Using Doppler color flow imaging, mitral regurgitation appears as jets of regurgitant blood flow originating from the mitral valve that extend into the left atrium during systole. Regurgitant jet area, jet length, jet width, and jet duration during systole provide information on the severity of mitral regurgitation. The width of the regurgitant jet at its narrowest point at the site of the regurgitant orifice in the long-axis view is called the vena contracta and provides an estimate of the width of the regurgitant orifice together with an estimate of the severity of mitral regurgitation. In mitral regurgitation, blood flowing into the left atrium accelerates within the left ventricle proximal to the regurgitant orifice during systole. The radius or surface area of these concentric rings of flow convergence or the proximal isovelocity surface area (PISA) can also be used to quantify the severity of mitral regurgitation.

The severity of mitral regurgitation is graded as mild, moderate, or severe. Mild mitral regurgitation does not produce significant circulatory pathology, is not associated with cardiac chamber remodeling, and has a benign clinical course. In contrast, severe mitral regurgitation is associated with significant circulatory pathology, cardiac chamber remodeling, morbidity and mortality. Sometimes a scale of 1 to 4 is used to quantify the severity of mitral regurgitation with 1 being mild and 4 being severe. Trace mitral regurgitation refers to regurgitation at the limits of detection by color Doppler flow imaging and is usually physiologic and not clinically significant. When assessing the severity of mitral regurgitation, it is also important to take into consideration the hemodynamic condition of the patient because the severity of mitral regurgitation can vary depending upon the state of ventricular contractility, preload, or afterload.

Associated echocardiographic findings indicating the physiologic sequelae of mitral regurgitation such as left atrial dilation, eccentric left ventricular hypertrophy, and systolic reversal of pulmonary vein flow velocity are useful also for verifying the clinical significance of mitral regurgitation.
Flow Convergence Method

\[ \text{Reg Flow} = 2\pi r^2 \times V_a \]

\[ \text{EROA} = \frac{\text{Reg Flow}}{P_{kV_{reg}}} \]

Figure 2 Schematic depiction of the flow convergence or proximal isovelocity surface area (PISA) method for quantifying valvular regurgitation. \( V_a \) is the velocity at which aliasing occurs in the flow convergence towards the regurgitant orifice. \( P_{kV_{reg}} \) is peak velocity of the regurgitant jet, determined by continuous wave Doppler. Reg flow, regurgitant flow; EROA, effective regurgitant orifice area; Reg jet, regurgitation jet.

*Figure from J Am Soc Echocardiogr 2003;16:777-802*

| Table 1 Qualitative and quantitative parameters useful in grading mitral regurgitation severity |
|---------------------------------|----------------|----------------|
| Structural parameters          | Mild           | Moderate       | Severe          |
| LA size                        | Normal*        | Normal or dilated | Usually dilated** |
| LV size                        | Normal*        | Normal or dilated | Usually dilated** |
| Mitral leaflets or support apparatus | Normal or abnormal | Normal or abnormal | Abnormal/Flail leaflet/Ruptured papillary muscle |
| Doppler parameters             |                |                |                |
| Color flow jet area\(^a\)      | Small, central jet (usually < 4 cm\(^2\) or < 20% of LA area) | Variable | Large central jet (usually > 16 cm\(^2\) or > 40% of LA area) or variable size wall-impinging jet swirling in LA |
| Jet density -CW                | Incomplete or faint | Dense | Dense |
| Jet contour -CW                | Parabolic       | Usually parabolic | Early peaking-triangular |
| Pathologic valve flow          | Systolic dominance\(^b\) | Systolic blunting\(^b\) | Systolic flow reversal |

| Qualitative parameters\(^c\)      |                |                |                |
| VC width (cm)                   | < 0.3          | 0.3-0.69        | ≥ 0.7          |
| E, Vot (m/s)                    | < 30           | 20-44           | 45-50          |
| R, F (% )                       | < 30           | 30-39           | 40-49          |
| EROA (cm\(^2\))                | < 0.20         | 0.20-0.29       | 0.30-0.39      |

\( CW \), Continuous wave; LA, left atrium; EROA, effective regurgitant orifice area; LV, left ventricle; PW, pulsed wave; RF, regurgitant fraction; R Vol, regurgitant volume; VC, ventricular.

* Unless there are other reasons for LA or LV dilatation. Normal 2D measurements: LV minor axis = 2.8 cm/m\(^2\), LV end-diastolic volume = 82 ml/m\(^2\), maximal LA area-predictor diameter = 3 cm/m\(^2\), maximal LA volume = 26 ml/m\(^2\) (0.23,0.95).
** Exertional acute mitral regurgitation.
\(^a\) As a Nyquist line of 50–60 cm/s.
\(^b\) Pulmonary versus systolic flow reversal is specific but not sensitive for severe MR.
\(^c\) Usually above 60 years of age or in conditions of impaired relaxation, in the absence of mitral stenosis or other causes of elevated LA pressure.
\(^d\) Unless other reasons for systolic blunting (eg, atrial fibrillation, elevated left atrial pressure).

* Qualitative parameters can help sub-classify mitral regurgitation (ie, mild-to-moderate and moderate-to-severe).

*Table from J Am Soc Echocardiogr 2003;16:777-802*

Pathophysiologic Mechanisms of Mitral Regurgitation

The pathophysiologic mechanism of mitral regurgitation can be discerned by combining information from the 2-dimensional together with the Doppler echocardiographic
examination. For example, a prolapsing or flail segment of the mitral valve leaflet detected by 2-dimensional imaging should be accompanied by an eccentric jet of mitral regurgitation directed away from the defect on imaging by Doppler echocardiography. Mitral regurgitation caused by endocarditis may be associated with leaflet destruction, perforation, or vegetations. Rheumatic disease causing mitral regurgitation may be characterized by leaflet thickening, restricted leaflet motion, and mitral stenosis. Myxomatous mitral disease is associated with excessive leaflet tissue, leaflet prolapse, and annular dilation. Ischemic mitral regurgitation is associated with left ventricular dilation, decreased left ventricular ejection fraction, mitral annular enlargement and apical tethering of the mitral valve leaflets. Congenital cleft anterior mitral valve leaflet causing mitral regurgitation is associated with endocardial cushion defects. Echocardiographic clues to the pathology and location of defects causing mitral regurgitation can be provided by the regurgitant jet direction and location of the origin of the jet along the mitral valve commissure.

A classification system based on leaflet motion devised by Carpentier is often used to characterize the mechanism of mitral regurgitation. In this classification, type I lesions have normal leaflet motion with mitral regurgitation caused by annular dilation or leaflet perforation. Type II lesions are characterized by excessive leaflet motion with mitral regurgitation caused by leaflet prolapse or flail (ruptured chordae). In type III lesions, mitral regurgitation is caused by leaflet restriction such as fibrosis in rheumatic heart disease or by leaflet tethering in cardiomyopathy. Type I lesions typically cause a central mitral regurgitant jet, type II lesions cause an eccentric jet directed away from the diseased leaflet segment, and type III lesions cause a regurgitant jet overlying the tethered leaflet.

Figure from: J Thorac Cardiovasc Surg 1983; 86:323-37
Identifying the severity of mitral regurgitation and the specific pathology and location of the defects with TEE is important for determining if mitral valve repair or replacement is clinically indicated. Structural lesions affecting mitral valve function such as a ruptured chord producing a flail leaflet segment typically cause severe mitral regurgitation and is an indication for surgical repair or replacement. Functional or ischemic mitral regurgitation presents a more challenging dilemma. In functional or ischemic mitral regurgitation, structural alternations of the mitral valve apparatus are more subtle and the severity of mitral regurgitation detected by Doppler echocardiography may vary depending on the hemodynamic condition of the patient at the time of the examination.

**Definition of Ischemic and Functional Mitral Regurgitation**

Functional or ischemic mitral regurgitation is defined as mitral regurgitation caused by disease affecting primarily the left ventricle that alters the function of an otherwise anatomically normal mitral valve apparatus. Ischemic mitral regurgitation can be caused by ischemic cardiomyopathy, papillary muscle dysfunction, or papillary muscle rupture. Functional mitral regurgitation is a term that is used to describe both ischemic mitral regurgitation and mitral regurgitation caused by non-ischemic cardiomyopathy.

**Pathophysiology Ischemic and Functional Mitral Regurgitation**

The mitral valve apparatus consists of the mitral valve annulus, the anterior mitral valve leaflet, the posterior mitral valve leaflet, the chordae tendinae, the anterolateral papillary muscle, and the posteromedial papillary muscle. The normal functioning of the mitral valve apparatus is therefore intimately linked to the size and function of the left ventricle. In diseases affecting the left ventricle, ventricular dilation, systolic dysfunction, and eccentric hypertrophy can lead to mitral valve dysfunction. Anatomic changes in the mitral valve apparatus caused by left ventricular disease include annular dilatation, annular flattening, apical and lateral tethering of the mitral valve leaflets, and papillary muscle displacement. Functional alterations in the mitral valve apparatus caused by left ventricular disease include decreased annular contraction, papillary muscle dysfunction, and decreased mitral leaflet closing forces. These consequences of left ventricular disease impair mitral leaflet coaptation and lead to mitral regurgitation. The onset of mitral regurgitation contributes further to the disease process by increasing left ventricular volume overload, left ventricular end diastolic pressure, and pulmonary hypertension. Long-standing disease may even cause remodeling of the mitral valve apparatus producing anatomic changes in the mitral valve leaflets.

**Echocardiographic Features Ischemic and Functional Mitral Regurgitation**

Doppler echocardiography is the conventional method for detecting and grading the severity of mitral regurgitation based on characteristics of the mitral regurgitant jet such as the regurgitant jet area, vena contracta width, and proximal isovelocity surface area radius. However, Doppler echocardiographic assessment of functional mitral regurgitation can be problematic because the severity of mitral regurgitation in the
condition is dynamic and may vary according to the hemodynamic state of the patient. For example, severe mitral regurgitation in a patient with ischemic mitral regurgitation caused by papillary muscle dysfunction or displacement may only manifest in the presence of myocardial ischemia. In another common scenario, a patient with significant functional mitral regurgitation during a medical evaluation may only manifest mild mitral regurgitation during intraoperative assessment under general anesthesia. For these reasons, Doppler echocardiography alone is often inadequate to fully assess the severity of functional or ischemic mitral regurgitation. The sensitivity of Doppler echocardiography for diagnosis of functional mitral regurgitation can sometimes be improved by provocative testing. Exercise, volume expansion, and vasopressor administration are sometimes necessary to elicit mitral regurgitation that can then be detected and graded by Doppler echocardiography.

Because functional mitral regurgitation is the consequence of left ventricular dysfunction, the first step in the echocardiographic assessment for the disease is characterization of left ventricular size, shape, and function. Left ventricular volume is increased and left ventricular ejection fraction decreased in patients with functional mitral regurgitation compared to controls. In patients with functional mitral regurgitation associated with ischemic or non-ischemic cardiomyopathy, left ventricular end-diastolic volume index (170 ml/m^2 v. 60 ml/m^2) and end-systolic volume index (135 ml/m^2 v. 25 ml/m^2) is more than twice normal and left ventricular ejection fraction is less than half normal (30% v. 65%). In addition, some studies have demonstrated an increase in the spherical shape of the ventricle as measured by the cavity diameter to length ratio in patients with functional mitral regurgitation. In ischemic mitral regurgitation, other echocardiographic features that may be present include ruptured papillary muscle or left ventricular segmental wall motion abnormalities in the segments adjacent to the anterolateral or posteromedial papillary muscles.

Both clinical and experimental models of functional mitral regurgitation have demonstrated mitral annular enlargement and annular flattening in ischemic mitral regurgitation. Because the mitral valve annulus is non-circular and non-planar, annular dimensions cannot be easily characterized based on geometric assumptions. In studies performed using 2-dimensional echocardiography, mitral annular diameter was larger in functional mitral regurgitation, averaging 20% to 30% larger than controls (35 mm v. 28 mm). To provide a more precise description of mitral annular size, 2-D echocardiography can be used to provide the septal-lateral diameter of the mitral annulus (from the mid-esophageal long-axis view) together with the commissure-commissure diameter (from the mid-esophageal mitral valve commissural view). Recent developments in 3-dimensional echocardiography have made it feasible to measure precisely mitral annular dimensions, mitral annular circumference, and mitral annular height. Mitral annular height provides a measure of the degree of alteration or flattening of the normally non-planar saddle-shaped annulus that occurs in association with functional mitral regurgitation.

The left atrial surface of the leading edges of the anterior and posterior leaflets of the mitral valve coap below the plane of the mitral valve annulus on the left ventricular side. Normally, the contact distance between the anterior and posterior mitral valve leaflets at
their leading edges during systole is 1-2 mm in length. Normally, the maximum distance between the point of coaptation and the plane of the mitral valve annulus is less than 1.0 cm. In functional mitral regurgitation, echocardiographic features of leaflet tethering include decreased contact distance between the anterior and posterior mitral valve leaflets along their coaptation (≤ 1 mm), increased depth of coaptation below the plane of the mitral valve annulus (≤ 0.9 cm), and a steeper angle formed between the anterior (≥ 25°) and posterior leaflets (≥ 45°) with the plane of the mitral valve annulus in mid-systole. Tethering of the anterior leaflet at the site of a secondary chord produces an acute bend at the site of attachment between the chord and the body of the anterior leaflet in systole. Other parameters of leaflet tethering include tenting area and tenting volume (measured using 3-dimensional echocardiography).

When mitral regurgitation is detected using Doppler color flow imaging, characterizing the location and direction of the regurgitant jet is useful for verifying the clinical significance of the anatomic alterations associated with ischemic mitral regurgitation. Bileaflet tethering will produce a central regurgitant jet along the line of coaptation. Asymmetric tethering of the posterior mitral valve leaflet will produce an eccentric mitral regurgitant jet directed away from the anterior mitral valve leaflet and overriding the tethered posterior leaflet.

**Should the Mitral Valve be Repaired if Ischemic or Functional Mitral Regurgitation is Suspected?**

Consensus guidelines recommend mitral valve repair for patients with severe ischemic or functional mitral regurgitation. Although it is widely recognized that the efficacy of mitral valve repair is controversial, the basis for this recommendation is that severe ischemic or functional mitral regurgitation is associated with symptomatic heart failure and poor outcomes with an average 50% survival in 5 years. Further arguments to support the decision for mitral valve repair include mitral regurgitation contributes to the progression of heart failure, mitral regurgitation contributes to the symptoms of heart failure, mitral valve repair is the best treatment option available for this condition, and that mitral valve repair produces excellent echocardiographic results in the short-term. For these reasons, mitral valve repair is typically performed in patients with severe mitral regurgitation detected preoperatively combined with pathological features such as left ventricular dilation, reduced left ventricular ejection fraction, and mitral leaflet tethering detected by intraoperative TEE.

Arguments against mitral valve repair include the lack of randomized controlled trials that demonstrate improved survival or functional status in patients undergoing mitral valve repair for ischemic mitral regurgitation, performing mitral valve repair in combination with surgical revascularization adds risk (approximately 5%) to the operation, the effectiveness of mitral valve repair is not durable and has a high rate of recurrence, and that surgical revascularization alone may correct ischemic mitral regurgitation. Based on this reasoning, an argument can be made to defer mitral valve repair in patients with moderate ischemic mitral regurgitation and viable myocardial
segments in whom it is anticipated that surgical revascularization will restore left ventricular geometry and function.

Summary

Functional or ischemic mitral regurgitation is caused by diseases affecting the left ventricle that causes dysfunction of mitral valve apparatus. The most common pathology is tethering of the mitral valve leaflets as a consequence of dilated cardiomyopathy. While Doppler echocardiography is a standard technique for diagnosis of mitral regurgitation, it may not always accurately grade the severity of functional mitral regurgitation because of the dynamic nature of the condition. Echocardiographic evaluation of structural changes such as left ventricular dilation, mitral annular dilation, and mitral leaflet tethering are important for diagnosis and grading the severity of functional mitral regurgitation. The efficacy of mitral valve repair in the setting of ischemic or functional mitral regurgitation remains controversial.

REFERENCES


Canadian Society of Echocardiography, endorsed by the American College of Cardiology Foundation, American Heart Association, European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography, and Canadian Society of Echocardiography. Journal of the American Society of Echocardiography 2009; 22:975-1014


