**Workshop 1: TEE Intermediate**
Moderator: Mark A. Taylor, MD
Saturday April 28th, 2012

**MITRAL VALVE: Mitral valve case studies – Mark A. Taylor, MD**

At the conclusion of this lecture, the participant will be able to discuss the echocardiographic evaluation of mitral regurgitation and the impact on surgical decision-making.

**Etiology of Mitral Regurgitation**

Mitral regurgitation results from the incomplete closure of the mitral valve during ventricular systole. The mitral valve is an apparatus and consists of the left ventricular walls, the papillary muscles, the chordae tendinae, the valve leaflets, the mitral annulus and the left atrium. Alterations in an individual anatomic structure or the interrelationships between these structures can lead to mitral regurgitation. The regurgitant volume entering the left atrium during systole determines the hemodynamic effects of mitral regurgitation and the effective regurgitant orifice area (EROA) is a main determinant of regurgitant volume. Other factors that affect the regurgitant volume include the duration of systole and the pressure difference between the left ventricle and left atrium.

Carpentier developed a functional classification of mitral regurgitation based upon leaflet motion. Type I lesions have normal leaflet motion but the valve is incompetent secondary to annular dilatation or leaflet perforation. The MR jet in Type I lesions is typically a central jet into the body of the left atrium. Type II lesions are defined by excessive leaflet motion, usually secondary to elongated or ruptured chordae or papillary muscle. This renders the valve incompetent by allowing the valve leaflet to extend beyond the annulus during systole, and the mitral regurgitant jet is usually eccentric and directed away from the diseased leaflet. Type III lesions are characterized by restricted leaflet motion. This category is subdivided into two categories: Type IIIa and IIIb.¹ In IIIa lesions, leaflet motion is restricted in both systole and diastole and typically occurs in rheumatic heart disease. The diastolic restriction leads to mitral stenosis. The mitral regurgitation jet is typically directed towards the restricted leaflet but may be central if both leaflets are equally restricted during systole. In IIIb lesions, leaflet restriction occurs only during systole and is secondary to papillary muscle displacement or an underlying ischemic segment of left ventricular wall. The posterior leaflet is typically involved due to ischemic changes in left ventricular function and the mitral regurgitant jet is directed towards the restricted posterior leaflet. Type IIIb lesions demonstrate restricted leaflets due to an underlying ventricular pathologic state such as a dilated cardiomyopathy with displacement of the papillary muscles and dilation of the annulus.
Figure 1. Carpentier classification of mitral regurgitation based upon leaflet mobility. Adapted from Lambert AS, Chap 8 Mitral Regurgitation in A Practical Approach to Tranesophageal Echocardiography, eds. Perrino and Reeves, 1st ed. Lippincott, Williams & Wilkins, Philadelphia. 2003.

Mitral regurgitation can also be classified upon the basis of mechanism and is divided into organic (intrinsic valve lesion) or functional (ventricular dysfunction with normal mitral valve structure).²

Ischemic MR can lead to type I, II and III leaflet motions. Ischemic MR also is not an isolated valvular process but also includes the ventricle. Ischemic mitral regurgitation is felt to be secondary to LV remodeling and papillary muscle displacement. This leads to leaflet tethering and prevents coaptation during systole. Second order chordae are felt to be restricting the proper coaptation and several small studies have demonstrated a benefit to chordal cutting procedures for this subgroup of patients with restricted leaflet motion.³

**Mitral Regurgitation Severity Grading**

2D and 3D evaluation of the mitral apparatus can define the etiology of mitral regurgitation and can help guide surgical decision-making. 2D and 3D imaging of the ventricular wall, papillary muscles, chordal structures, valve leaflets, annulus and left atrial wall can define the etiology of the mitral regurgitation. Both anatomical structures and function can be assessed with 2D and 3D examination. The addition of color flow Doppler assists in assessing jet direction and
regurgitation severity. Once the valve is found to be incompetent by color flow doppler evaluation, 2D and 3D evaluation of the valve can lead to the underlying etiology for the mitral regurgitation.

**MITRAL VALVE JET AREA:**
Set aliasing velocity at 50-60 cm/s.
Obtain the mid esophageal 4 chamber view with emphasis on mitral valve and left atrium.
Set the color flow Doppler sector scan on mitral valve and activate color.
Capture entire mitral regurgitation jet in Doppler sector scan.
Record several frames and then scroll through cardiac cycle to determine largest jet area.
Planimeter the surface area of the regurgitant jet using the trace function.

<table>
<thead>
<tr>
<th>Mild MR</th>
<th>Moderate</th>
<th>Severe</th>
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</thead>
<tbody>
<tr>
<td>Small central jet</td>
<td>variable</td>
<td>Large central jet</td>
</tr>
<tr>
<td>Jet area &lt; 4 cm²</td>
<td></td>
<td>&gt; 10 cm²</td>
</tr>
<tr>
<td>&lt; 20% LA area</td>
<td></td>
<td>&gt; 40% LA area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>wall hugging jet</td>
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Limitations to using mitral valve jet area is that it is difficult to obtain a an accurate left atrial area as all the walls of the left atrium are difficult to visualize using the ME 4 chamber view due to the close proximity of the left atrium to the ultrasound probe. Utilization of the deep transgastric view may allow visualization of the left atrium wall but is limited by far field depth. Wall hugging jets (Coanda effect) are underestimated by mitral valve jet area secondary to significant jet area may be outside of the sector scan. In patients with markedly elevated left ventricular systolic pressure such as severe systemic hypertension or aortic stenosis, mitral regurgitation may be overestimated by mitral valve jet area. In patients undergoing general anesthesia, mitral valve severity by mitral valve jet area tends to be underestimated secondary to changes in left ventricular afterload. Intraoperative evaluations of mitral regurgitation in patients under general anesthesia should have awake loading conditions simulated by the maintenance of adequate preload or increasing afterload by administrating a vasopressor.
Figure 2. ME 2 chamber TEE view with a demonstrating a mitral valve regurgitant jet area of 6.52 cm² consistent with moderate mitral regurgitation by one quantification method.

VENA CONTRACTA:
Visualize mitral valve with ME LAX view and zoom on mitral valve leaflets. Set aliasing velocity 50-60 cm/s. Focus on regurgitant orifice on the ventricular side of the mitral valve. Color flow Doppler displays area of flow convergence proximal to the regurgitant orifice. Narrowest portion at coaptation site is the vena contracta. Measure width of vena contracta using the Caliper function.

<table>
<thead>
<tr>
<th>Mild MR</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC width &lt;0.3 cm</td>
<td>VC width 0.3-0.69 cm</td>
<td>VC width &gt; 0.7 cm</td>
</tr>
</tbody>
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Limitations to vena contracta width is it is not a load independent measure of mitral regurgitation as previously believed and is affected by changes in afterload.
Figure 3. Midesophageal two chamber TEE view with black arrows indicating the vena contracta and a vena contracta width of 0.66 cm consistent with moderate mitral regurgitation.

REGURGITANT VOLUME:

Flow across a regurgitant valve is always greater than forward stroke volume. In mitral regurgitation, the difference between flow across the incompetent mitral valve and flow across another competent cardiac valve is regurgitant volume.

\[ RV_{\text{mitral}} = SV_{\text{mv}} - SV_{\text{lvot}} \]

\[ RV_{\text{mitral}} = MV \text{ annulus area} \times VT_{\text{mv}} - LVOT \text{ annulus area} \times VT_{\text{lvot}} \]

\[ \text{MV annulus area} = \pi r^2 \text{ (circular)} \quad \text{OR} \quad \text{MV annulus area} = \pi/4 \times AB \text{ (ellipse)} \]

\[ A = \text{annular diameter in one plane} \quad \text{(ME LAX)} \]
\[ B = \text{annular diameter in another plane perpendicular to A} \quad \text{(ME mitral commissural view)} \]

\[ \text{LVOT area} = \pi r^2 \]
\[ \text{LVOT area} = 0.785 D^2 \]
REGURGITANT FRACTION:

Regurgitant fraction is the ratio of regurgitant volume in the mitral valve to the forward stroke volume times 100.

\[ RF_{\text{mitral}} = \frac{\text{MV annulus area} \times \text{VTI}_{\text{mv}} - \text{LVOT annulus area} \times \text{VTI}_{\text{lvot}}}{\text{LVOT annulus area} \times \text{VTI}_{\text{lvot}}} \times 100 \]

EFFECTIVE REGURGITANT ORIFICE AREA (EROA):

Stroke volume is equal to orifice area times the velocity time integral through the orifice. For mitral regurgitation during systole, the stroke volume (regurgitant volume) equals the EROA times the velocity time integral of the mitral regurgitation jet.

\[ R\text{Vol}_{\text{mitral}} = E\text{ROA}_{\text{mitral}} \times \text{VTI}_{\text{mr jet}} \]

\[ E\text{ROA}_{\text{mitral}} = \frac{R\text{Vol}_{\text{mitral}}}{\text{VTI}_{\text{mr jet}}} \]

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<th>Mild MR</th>
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<th>Severe</th>
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</thead>
<tbody>
<tr>
<td>RVol (cc/beat)</td>
<td>&lt;30</td>
<td>30-44</td>
<td>45-59</td>
</tr>
<tr>
<td>RF (%)</td>
<td>&lt;30</td>
<td>30-39</td>
<td>40-49</td>
</tr>
<tr>
<td>EROA (cm²)</td>
<td>&lt;0.20</td>
<td>0.20-0.29</td>
<td>0.30-0.39</td>
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Limitations to these quantitative measures of mitral regurgitation include that significant sources of error may be introduced during the squaring of diameter measures and the processes are time consuming. Calculation of quantitative measures of mitral regurgitation can be helpful for patients who have conflicting qualitative parameters of mitral regurgitation.

PROXIMAL ISOVELOCITY SURFACE AREA (PISA):

In mitral regurgitation, as blood flows and accelerates towards the regurgitant orifice during systole, velocities increase in hemispheric shells. The area of one such hemispheric shell can be determined. Once the area of the hemispheric shell is known, the flow at this hemispheric shell can be determined and based upon the conservation of flow, flow at the shell level will equal flow at the level of the regurgitant orifice.
To calculate PISA for mitral regurgitation:

Obtain the mid esophageal 4 chamber or 2 chamber view with focus on mitral valve. Activate color flow Doppler with aliasing velocities around 40 cm/s. Interrogate the left ventricular side of the valve and look for hemispheric shells of color which transition from red to blue color. If necessary shift the baseline of the aliasing velocity upwards towards the left atrium to have a lower velocity towards the probe and higher velocity scale away from the probe. This may improve resolution of the shell and shift the shell farther away from the EROA and into the left ventricle. Using Calipers measure the radius from the vena contracta to the hemispheric shell in the left ventricle.

Surface area of hemisphere (cm$^2$) = $2\pi r^2$

Flow at hemisphere where aliasing occurred = $2\pi r^2 \times \alpha/180 \times V_{aliasing}$

Where $\alpha/180$ is an angle correction for an angled ventricular-mitral valve orifice interface.

Figure 4. ME 2 chamber TEE view with color flow Doppler evaluation of the mitral regurgitant jet utilizing PISA. In the ventricle, there are hemispheric shells of color shifts from red to blue indicating where the velocity exceeds the aliasing velocity. The velocity at the shell equals the
aliasing velocity and the area of the shell can be calculated by obtaining the radius R from the mitral tips to the hemispheric shell.

By conservation of mass, flow at EROA should equal flow at hemisphere calculated above. Flow at the EROA will equal the EROA x peak velocity of the mitral regurgitation jet.

\[ PISA \times V_a = EROA \times V_{mitral\ regurgitation} \]

\[ EROA = \frac{PISA \times V_a}{V_{max\ mr\ jet}} \]

Figure 5. Calculation of the peak MR velocity in m/s. The flow at the hemispheric shell will equal the product of the EROA times the peak MR velocity. One can rearrange the formula and solve for EROA.

Once EROA has been determined, one can calculate Regurgitant volume by the formula:

\[ RV_{mitral} = EROA \times VTI_{mr\ jet} \]
Figure 6. Calculation of the velocity time integral of the mitral regurgitant jet which can be multiplied by the EROA to calculate the regurgitant volume (RV).

Limitations to PISA include assumptions regarding the regurgitant orifice being circular, there only being one regurgitant orifice and the flow acceleration to be a complete hemispherical shell. Recent 3D evaluations have demonstrated that the proximal isovelocity surface area is not hemispherical but hemi ellipsoid and this questions the validity of some of the PISA assumptions.8,9

SIMPLIFIED PISA:

Set aliasing velocity at 40 cm/sec.
Assume MR velocity equals 500 cm/s (LV to LA gradient approximately 100 mm Hg (4v^2))
PISA equation then simplifies to:

\[ \text{EROA} = \frac{2\pi r^2 \times V_{\text{aliasing}}}{500} \]

\[ \text{EROA} = \frac{r^2}{2} \]
To calculate Regurgitant Volume:

$$RV_{\text{mitral}} = \text{MV annulus area} \times \text{VTI}_{\text{mv}} - \text{LVOT annulus area} \times \text{VTI}_{\text{lvot}}$$

$$RV_{\text{mitral}} = \text{EROA} \times \text{VTI}_{\text{mr jet}}$$

To calculate Effective Regurgitant Orifice Area (EROA):

$$\text{EROA}_{\text{mitral}} = \frac{R_{\text{volmitral}}}{\text{VTI}_{\text{mr jet}}}$$

$$\text{EROA} = \text{PISA} \times \frac{V_3}{V_{\text{max mr jet}}}$$

$$\text{EROA} = r^2/2$$

**PULMONARY VENOUS FLOW PATTERNS:**

Obtain the mid esophageal 4-chamber view with focus on left atrial appendage. Left upper pulmonary vein is superior and posterior to the left atrial appendage. Rotate probe forward to 20 to 60 degrees to obtain parallel alignment. Obtain the bicaval view, rotate probe to right and rotate forward to 120 degrees to visualize right upper pulmonary vein. Utilize color flow Doppler to demonstrate flow. Place pulse wave Doppler sample volume 1 cm into pulmonary vein.

Normal pulmonary vein flow pattern should demonstrate a large S wave consistent with large forward systolic component, a slightly smaller D wave consistent with a slightly smaller forward diastolic component, and a small reversed component A wave caused by atrial contraction.

Reversal of the S component is consistent with severe MR (specificity 100%, sensitivity 90%).

Systolic blunting is only consistent with elevated left atrial pressure and is seen in additional clinical states such as atrial fibrillation, or diastolic dysfunction.
Pulmonary Vein Flow Patterns

Severe MR
—Reversal flow in pulmonary veins secondary to volume of regurgitant jet into left atrium during systolic inflow

Figure 7. Schematic representation and TEE correlates of normal pulmonary vein flow Doppler patterns (top panel) and S wave reversal consistent with severe mitral regurgitation (lower panel).

Unanticipated Ischemic Moderate MR—Now what?

Ischemic mitral regurgitation has a negative impact on survival in patients with coronary artery disease, and patients with even mild to moderate mitral regurgitation have a worse prognosis.12
As is reflected in figure 8 from Grigioni et al, patients with greater than mild (EROA < 20) have a worse survival than patients with either no mitral regurgitation or mild mitral regurgitation and is independent of ejection fraction. This data underscores the importance of ischemic mitral regurgitation in regards to severity and outcome in the post MI patient after 16 days. Given this poor outcome, functional ischemic mitral regurgitation may differ from organic mitral regurgitation where severe mitral regurgitation is not defined until EROA exceeds 0.40 cm² and warrants surgical treatment.

Regarding surgical timing, recent consensus statements have outlined class I and class II indications for surgical intervention for mitral regurgitation. Recent literature continues to define the appropriate timing for surgical intervention for mitral regurgitation and experts disagree on the optimal timing for surgery in patients with functional ischemic mechanisms of mitral regurgitation.

Management of ischemic mitral regurgitation is problematic and suboptimal. Surgical management has a better survival advantage than medical management but still a portends a poor outcome with a 5 survival rate of 55%. In addition the debate of repair vs. replacement continues in the literature. Many studies have identified mitral valve repair as preferable to replacement based upon early lower morbidity and mortality but recurrent mitral insufficiency may limit it long term success. Recent guideline statements regarding patients with valvular disease state that repair is preferable to replacement but this may not be applicable to all patients.

Mechanism for ischemic MR includes LV remodeling with apical and posterior displacement of papillary muscles. This leads to further remodeling with subvalvular dysfunction and leaflet tethering and mitral annular dilation and loss of annular contraction.

Procedures attempting to correct ischemic mitral regurgitation have included CABG alone or CABG in combination with mitral repair (band, suture, ring annuloplasty) or replacement. In addition, concomitant LV remodeling procedures have also been attempted including surgical excision or external restraint devices.

Given the poor long-term results of ischemic MR, some have advocated surgical correction of mitral regurgitation, even if mild to moderated during the CABG procedure. Indications remain unclear yet outcome data may demonstrate some benefit for combined CABG-MV repair for mild to moderate MR.

Changes in surgical technique, ring technology, underlying LV function and decisions regarding repair versus replacement strategies makes interpretation of the literature difficult to state that one surgical technique is superior to another. Regardless of management, overall survival at 5 and 10 years is consistently poor when comparing studies regarding ischemic mitral regurgitation.
Another concern regarding repair techniques involves under sizing the annuloplasty ring by two sizes smaller than the measured intertrigonal length to address mitral annular dilatation. This creates a potential for postoperative systolic anterior motion of the mitral valve (SAM) and left ventricular tract outflow obstruction (LVOTO). In addition, it can create a functional mitral stenosis hemodynamic profile. Magne, et al evaluated mitral valve performance after restrictive mitral valve annuloplasty in patients being treated for IMR. Their results demonstrated a higher peak and mean transmirtal gradient with increased systolic pulmonary artery pressure at 13±3 months in 24 patients undergoing CABG-MV repair. In addition, in 54% of the patients, the postoperative mitral valve effective orifice area was ≤ 1.5 cm². Longer-term follow-up studies of patients who underwent restrictive mitral annuloplasty demonstrated some resolution in the functional mitral stenosis observed in the Magne et al. early postoperative study.

Despite considerable research into ischemic mitral regurgitation, debate still exists on how to best treat this complex disease. Debate still centers around issues regarding repair vs. replacement but questions regarding the impact of both annular and left ventricular size and function remain unresolved. Future studies will be performed to help guide therapies and interventions in this complex cardiac disease process and diverse patient population.

The “definitive” indication for combining mitral valve repair/replacement in patients with mild to moderate mitral regurgitation during a concomitant CABG procedure is unclear presently. There is literature to indicate that mitral valve repair in this patient population is beneficial. In some patients CABG alone with myocardial revascularization can eliminate the mitral regurgitation if it is secondary to ischemia. However, CABG alone is usually insufficient and these patients “would benefit” from concomitant MV repair at the time of CABG procedure. Given the fact mitral regurgitation severity lessens under general anesthesia, and indications for mitral valve repair in conjunction with CABG is supported for mild to moderate mitral regurgitation, the finding of moderate mitral regurgitation during CABG procedures is a indication that the mitral valve needs to be addressed surgically. Specific surgical approach with different ring types, sizes, and associated LV procedures still remain a controversial and highly debated area of cardiovascular medicine.

References: