

A Brief Review of Hemodynamics for Structural Interventions

Part 2: Mitral Stenosis

Morton J. Kern, MD

Last month¹, we reviewed the hemodynamics of mitral regurgitation and the changes seen with the mitral clip percutaneous repair on the left atrial pressure waves. In Part 2 of our brief hemodynamic reviews for structural heart interventions, we will focus on mitral stenosis and mitral balloon valvuloplasty.

The Stenotic Mitral Valve: Anatomy and Function

The stenotic mitral valve is characterized by thickened leaflets with reduced excursion. In the case of rheumatic mitral stenosis (MS), this thickening, calcification, and shortening can extend to involve the subvalvular apparatus (Figure 1). In the elderly, a very calcific, narrowed mitral annulus with extension into the base of the mitral valve leaflets can produce stenosis without as much impairment of the leaflet tip motion. Rare congenital causes of MS also include congenital parachute mitral valve, in which the leaflets attach to a single papillary muscle.

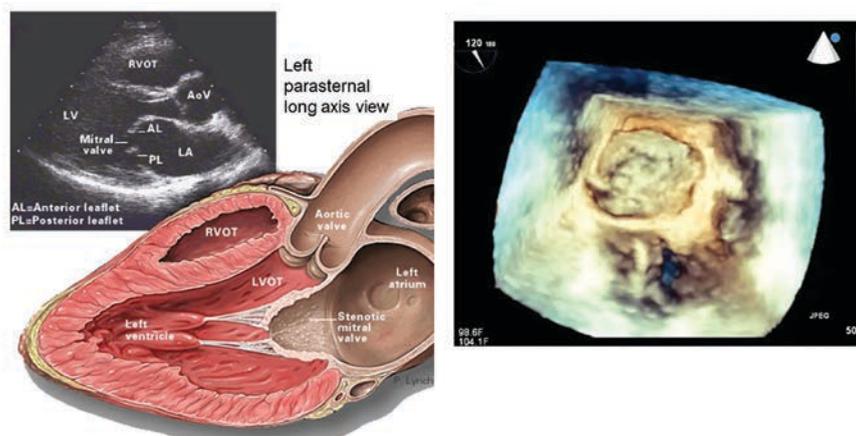


Figure 1. Mitral stenosis (MS), top by transthoracic echocardiography in parasternal long axis and corresponding diagram of heart cut in the parasternal plane of the echocardiogram. The mitral valve is thickened with limited mobility; the chordae are thickened and shortened. There is minimal leaflet calcification in this example. Far right panel shows frame from 3D echo looking at stenotic mitral valve from the left atrial side of the heart. *Left panel reprinted with permission from Mitral Valve Stenosis Topic Review. Learn the Heart. <https://www.healio.com/cardiology/learn-the-heart/cardiology-review/topic-reviews/mitral-stenosis/introduction-and-etiology>. Reprinted with permission from SLACK Incorporated.*

To recap the associated hemodynamic principles, the pressure waves in the left atrium (LA) are determined by 1) the pulmonary vein flow entering the LA from the lungs; 2) the transmitral valve outflow into the LV; and 3) the left ventricular (LV) back pressure or flow, producing resistance to LA outflow. Pressure waves in the LA (and any other chamber) are also the net result of the chamber (LA) stiffness. A low-compliance LA (i.e., stiff chamber) has a steeper P-V curve, which means that a small change in flow can produce a big change in pressure, and vice versa for a compliant or easily expandable LA chamber.² Rheumatic heart disease affects LA stiffness as well as the anatomic valve-related structures.

Transvalvular Mitral Hemodynamics and Clinical Presentations

For MS, increased LA pressure raises the pulmonary venous and capillary pressures, resulting in exertional dyspnea. A transvalvular pressure gradient is a function of the flow and can be calculated by Doppler flow velocity (V) as $\Delta P = 4V^2$. Thus, a doubling the velocity quadruples the pressure gradient. Exacerbating conditions for MS include tachycardia, pregnancy, hyperthyroidism, anemia, infection, and atrial fibrillation, and all of these conditions have one feature in common: an increased heart rate with reduced diastolic filling time. With tachycardia, diastole shortens more than systole, so that at any given stroke volume, the pressure



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Disclosures: Dr. Morton Kern reports he is a consultant for Abiomed, Abbott Vascular, Philips Volcano, ACIST Medical, Opsens Inc., and Heartflow Inc.

Table 1. Criteria for Severity Grading of Mitral Stenosis.

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Mitral Valve Area	Mean Gradient*	ASE	ACC/AHA
>1.5cm ²	<5 mmHg	Mild	At Risk (Stage A) Progressive MS (Stage B)
1.0 – 1.5cm ²	5-10 mmHg	Moderate	Severe MS • Asymptomatic (Stage C) • Symptomatic (Stage D)
<1.0cm ²	>10 mmHg	Severe	Very Severe MS • Asymptomatic (Stage C) • Symptomatic (Stage D)

*At a normal heart rate.

ASE: American Society of Echocardiography (ASE) guidelines; ACC/AHA: American College of Cardiology/American Heart Association guidelines; MS: mitral stenosis

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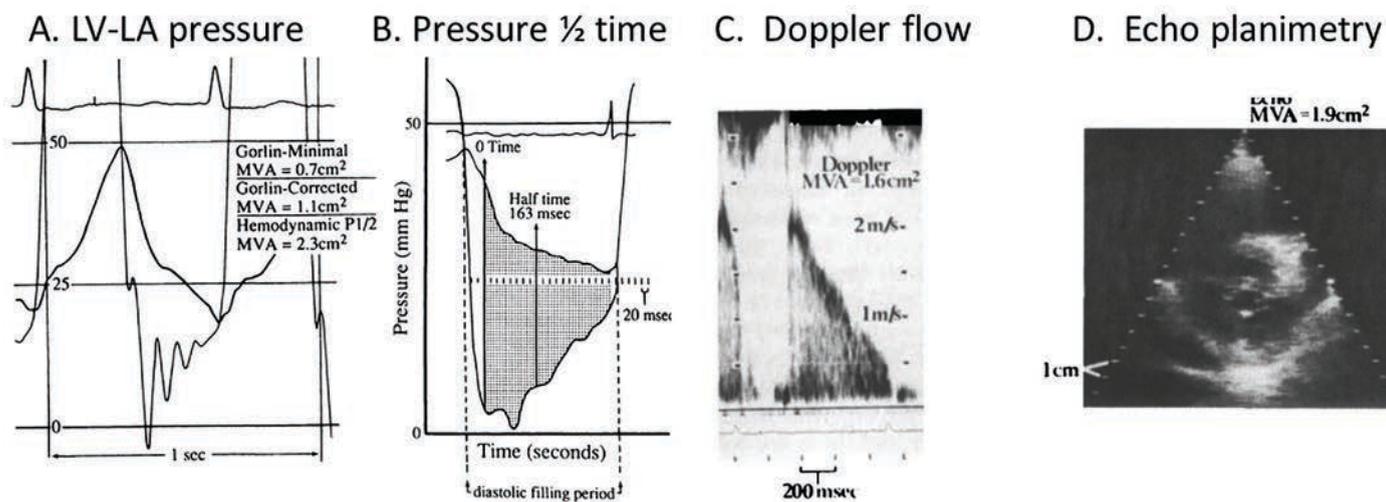


Figure 2. Four methods to calculate mitral valve area (MVA). Using the simultaneous left atrial and left ventricular diastolic pressures in patients with MS, the maximal transmitral valve gradient occurring during the diastolic filling period is measured. (B) Pressure half-time method. Pressure half-time in mild MS is 100-200 msec, moderate 200-300 msec, and severe >300 msec. Normal valves have a pressure half-time of <25 msec. (C) The Doppler method use the pressure half-time from Doppler is computed as $220/T_{1/2}$ where $T_{1/2}$ is the time from peak to one-half of peak (peak 1/2) velocity. Peak 1/2 velocity is the peak mitral velocity divided by 1.4, representing the velocity at which the diastolic transvalvular pressure gradient has fallen by one half. (D) 2D echocardiographic mitral valve area planimetry. Reprinted with permission from *Am Heart J.* 1990 Jan; 119(1): 121-129.⁶

gradient increases faster than the flow velocity. In atrial fibrillation, the irregular rhythm and loss of the atrial contraction further reduces the cardiac output by about 20%, a reduction independent of the increased resistance to transvalvular flow. The combination of reduced flow with high LA pressures ultimately brings about the onset of symptoms.³ The severity of MS is summarized in Table 1.

The percutaneous balloon valvuloplasty approach to mitral stenosis is the preferred treatment if subvalvular disease, calcification, thickening, and mobility of the valve leaflets is moderate or less (using a Wilkin's score⁴<11), mitral valve regurgitation is no greater than mild, and thrombus is not present in the left atrium. Table 2 provides scores with recommendations from

the American College of Cardiology/American Heart Association (ACC/AHA) for percutaneous balloon mitral valvuloplasty (PBMV). The results of PBMV are equal or superior to surgical commissurotomy. The rate of success and complications correlates strongly with experience; both the success and avoidance of complications are predicated in part on appreciating subtleties of hemodynamics during the screening and intra-procedure phases of management.⁵

Hemodynamics of MS Before and After Balloon Valvuloplasty

In general, the stenotic mitral valve area (MVA) can be measured in several ways (Figure 2).⁶ With confidence in the echocardiographic data, patients may be suitable for balloon valvuloplasty to open

the stenotic valve and permit adequate cardiac output, and keep pulmonary hypertension at bay. At times, with equivocal data, exercise hemodynamics in the cath lab may be necessary. For best pressure and gradient data, use direct LA pressure from a transeptal approach rather than the pulmonary capillary wedge pressure (Figure 3). However, when pulmonary capillary wedge pressure is low and normal, it provides an effective first-line tool to screen for significant mitral valve gradients.

Percutaneous Mitral Balloon Valvuloplasty (PBMV) Hemodynamics

PBMV results in a gradient decrease of 50% or more, and a valve area increase to 1.5 cm², the definition of success in the majority of the literature. In ideal valve anatomy, the mitral valve area will typically increase to 1.8 cm² or more. Examples of the hemodynamic changes occurring in the pressure wave forms for a patient with MS before and after mitral balloon valvuloplasty are shown on Figure 4.

Figure 5 demonstrates the results of PBMV in young patient with low Wilkins

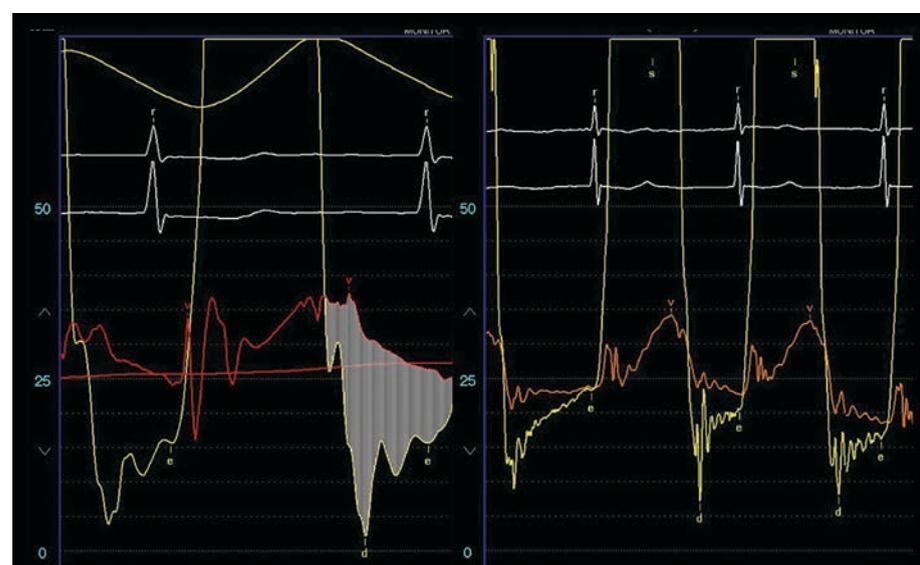


Figure 3. (Left panel) Simultaneous left ventricular (LV) and pulmonary capillary wedge (PCW) pressures and (right panel) left atrial (LA) with LV pressures in the same patient with atrial fibrillation. The pressure gradient (shaded area) formed by the PCW is higher than the LA/LV gradient formed by the LA pressure. PCW pressures may be elevated over the LA pressure due to pressure fidelity, pulmonary vascular resistance, or other artifacts. For best LA/LV gradient measurements, use LA pressure. Reprinted with permission from *J Am Coll Cardiol.* 2014 Jun 10; 63(22): 2438-2488.³

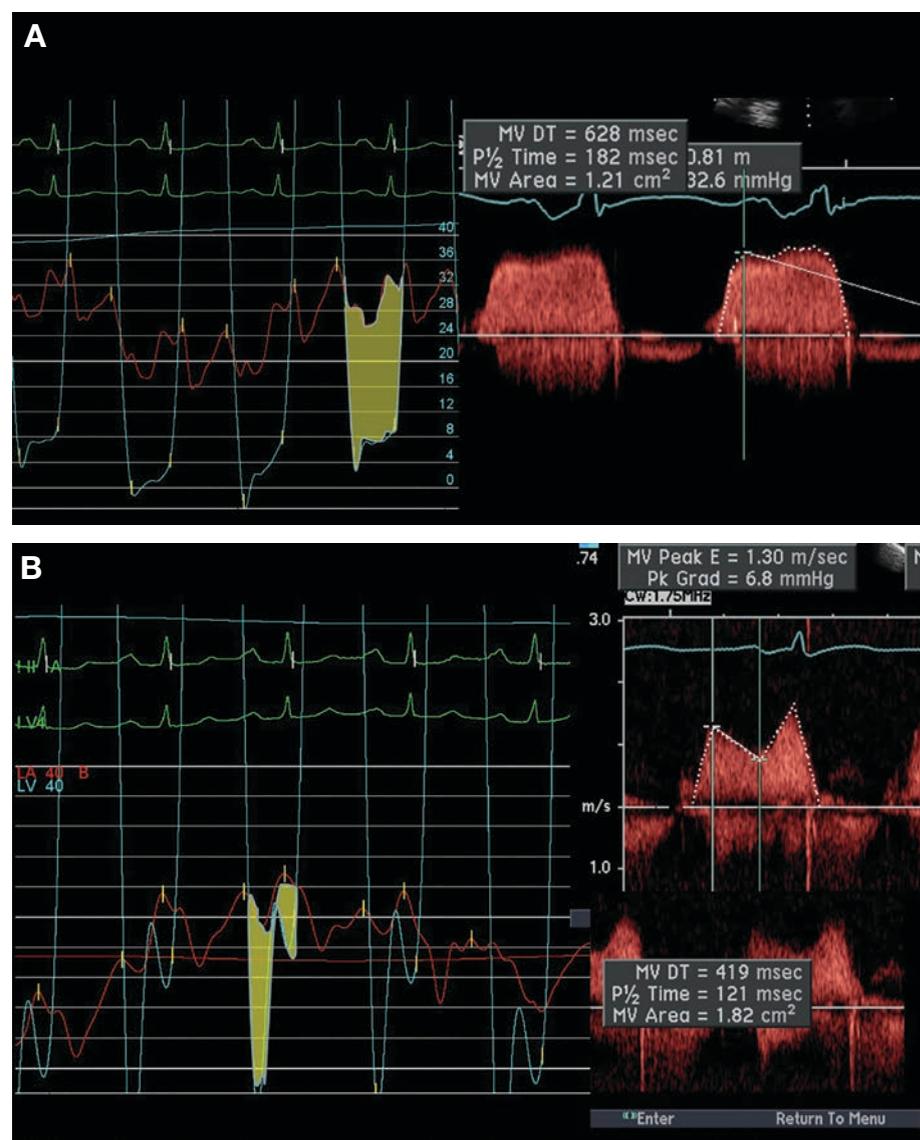


Figure 4A-B. A) Hemodynamics and Doppler echo findings before PBMV. Left, LV (blue) and LA (red) pressures show large mitral valve gradient (shaded area, 25 mmHg) with mitral valve area (MVA) of about 1.0 cm². Right, transmitral flow shows slow pressure 1/2 time (182 msec) with MVA of 1.2 cm². B) Hemodynamics and Doppler echo findings after PBMV. Left, LV (blue) and LA (red) pressures show small mitral valve gradient (shaded area, 5 mmHg) with mitral valve area (MVA) of about 2.0 cm². Right, transmitral flow shows restoration of filling wave with rapid pressure 1/2 time (121 msec) with MVA of 1.8 cm².

scores with reduction of the mitral gradient after a single balloon inflation. Although occasionally seen, caution in achieving complete resolution of a residual gradient should be used to avoid producing severe mitral insufficiency. In fact, the absence of a gradient after PBMV more commonly correlates with severe mitral insufficiency. The hemodynamics of this example suggest a competent valve; in fact, no mitral regurgitation was detected by echocardiography. It is worth noting that there is often a characteristic minimal peri-commissural leak seen with successful PBMV.

The typical step-wise Inoue balloon (Toray) technique for PBMV involves assessing a maximal balloon size using the patient's height; inflations usually begin with a balloon size several millimeters smaller (Figure 6). After each inflation, hemodynamics are reviewed for reduction of gradient and induction of any new mitral regurgitation. This is done by a combination of echocardiography (transesophageal or intracardiac echo, and occasionally, by transthoracic echo) and hemodynamics. A decrease in gradient of at least 50% and particularly an increase in mitral insufficiency by one grade should signal the operators to stop. Figure 7 shows this stepwise dilatation technique with an unfortunate result. The initial tracing (Figure 7, left panel) is consistent with severe mitral stenosis in severely symptomatic woman. After initial inflation the gradient is significantly reduced (Figure 7, middle panel), but the operators continued to attempt to achieve a lower residual gradient. The next inflation with a 1 mm-larger balloon resulted in abolition of the gradient, but produced a giant 'v' wave to 70 mmHg (Figure 7, right panel), consistent with severe iatrogenic mitral insufficiency. At surgery to repair the torn valve, a commissure split was the predominant mechanism. The patient did well after emergency mitral valve replacement.

The Bottom Line

Mitral stenosis is relatively uncommon in the United States, but still plagues many developing areas of the globe. Prior to

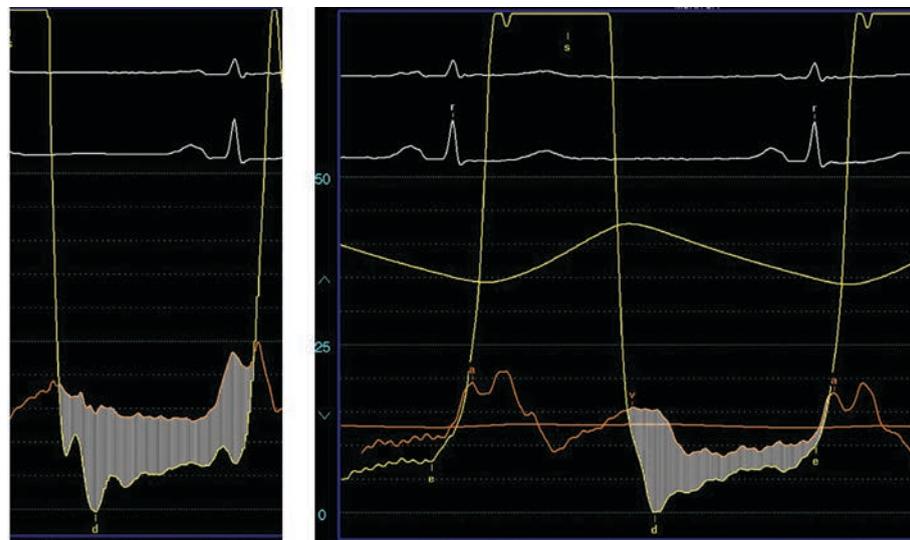


Figure 5. Left panel, left atrial (orange) and left ventricular (yellow) pressures before and after PBMV. Note the gradient pre-dilatation of approximately 12 mmHg reduced to 4 mmHg after PBMV (right panel).

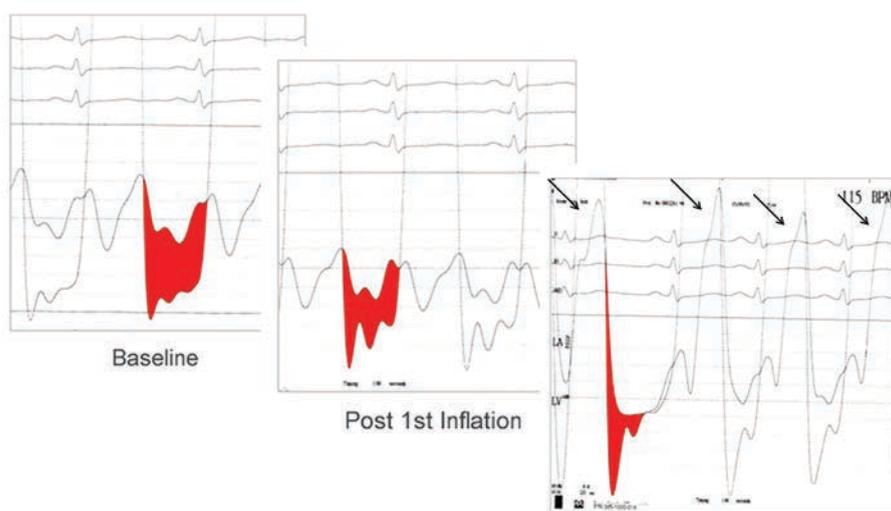


Figure 7. Hemodynamics at baseline (left) with a mitral gradient of 24 mmHg (shaded area). After the first Inoue balloon inflation (middle panel), there is about a 50% reduction of the gradient (about 10-12 mmHg). After another inflation, the gradient is now <4 mmHg, but the LA tracing shows a giant 'v' wave (arrows) of severe iatrogenic mitral regurgitation. At surgery to repair the torn valve, a commissure split was the prominent mechanism. *Courtesy Dr. Zoltan Turi.*

PBMV, the patient should have a thorough physical examination and graphics of the chest x-ray, electrocardiogram (ECG), and detailed 2D and 3D echocardiography. Should conflicting data between clinical

presentation and graphic data of stenosis severity appear, exercise hemodynamic studies may be needed before proceeding to PBMV. Attention to the pressure gradient reduction during PBMV should guide the operators to achieve a satisfactory result with a reduced gradient, but a competent valve. Remember, sometimes the enemy of good is better.

As with our other presentations, I hope the hemodynamic review and waveform interpretation becomes a routine part of your structural heart disease interventional program. ■

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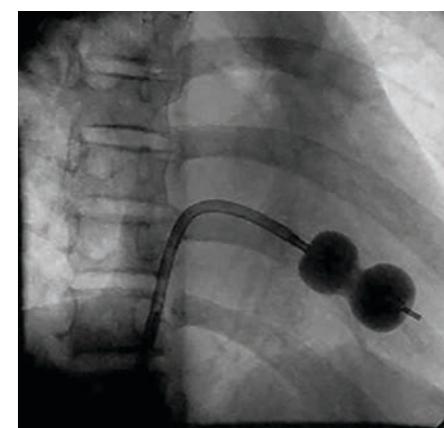
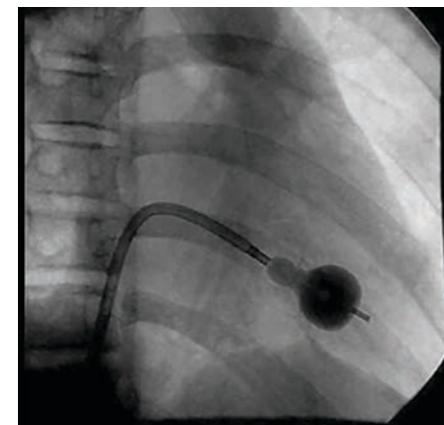


Figure 6. The Inoue mitral valvuloplasty balloon (Toray) showing serial inflations.

Table 2. American College of Cardiology/American Heart Association (ACC/AHA) Criteria for Percutaneous Balloon Mitral Valvuloplasty (PBMV). Reprinted with permission from *J Am Coll Cardiol*. 2006 Aug 1;48(3):e1-e148.7.

ACC/AHA Criteria for PBMV

Symptoms	MVA	Score	Other	Class
+	≤ 1.5 cm ²	≤ 8		I
-	≤ 1.5 cm ²	≤ 8	PA > 50 mm Hg or 60 ex	IIa
III – IV	≤ 1.5 cm ²	> 8	High risk for surgery	IIa
-	≤ 1.5 cm ²	≤ 8	New onset AF	IIb
III – IV	≤ 1.5 cm ²	> 8	Low risk for surgery	IIb

Presumes absence of LA thrombus or moderate to severe MR

MVA: mitral valve area; Score is Wilkins score; PA: pulmonary artery pressure; AF: atrial fibrillation

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