Lesson 290: PreAnesthetic Assessment of the Pregnant Patient With Mitral Stenosis

Authored by: Michael Mazzeffi, MD, MPH, Chief resident in anesthesiology, Mount Sinai Medical Center, New York, New York

Reviewed by: Ronald Kahn, MD, Professor of anesthesiology and surgery, Mount Sinai School of Medicine, New York, New York

DATE REVIEWED: January, 2011

Read this article, reflect on the information presented, then go online and complete the lesson post-test and course evaluation before the termination date below. (CME credit is not valid past this date.) You must achieve a score of 80% or better to earn CME credit.

TIME TO COMPLETE ACTIVITY: 2 hours
RELEASE DATE: February 1, 2011
TERMINATION DATE: February 28, 2012

COPYRIGHT: This material is subject to copyright ©2011 Mount Sinai School of Medicine. All rights reserved.

Needs statement

Mitral stenosis often is first diagnosed during pregnancy when normal physiologic changes exacerbate symptoms of the disease. To manage the obstetric patient with mitral stenosis, a multidisciplinary approach is crucial for ensuring an optimal outcome. A cardiologist, high-risk obstetrician, cardiothoracic surgeon, and anesthesiologist should be involved as early as possible in the patient’s care and delivery plan. Anesthesiologists also should be aware of the hemodynamic goals for mitral stenosis and how to manage the decompensating patient. This topic has been identified by committee as important information for anesthesiologists.

Learning objectives

At the end of this activity, the participant should be able to:

1. Explain why mitral stenosis is commonly diagnosed for the first time during pregnancy.
2. Recognize the echocardiographic findings used to classify the severity of mitral stenosis.
3. Describe the normal physiologic changes in the cardiovascular system during pregnancy.
4. Assess the indications, risks, and scoring systems that predict the success of percutaneous balloon mitral valvuloplasty.
5. Summarize the risks and feasibility of cardiopulmonary bypass for the pregnant patient and the fetus.
7. Compare the risks and benefits of regional analgesia and anesthesia versus general anesthesia in patients with severe mitral stenosis.
8. Select appropriate hemodynamic monitors for the anesthetic management of a patient with severe mitral stenosis.
9. Identify the particular risks that surgery and delivery of the fetus pose to the patient with severe mitral stenosis.
10. Describe the management of the decompensating patient with severe mitral stenosis.

Case history

A 32-year-old woman was diagnosed with moderate to severe mitral stenosis in week 29 of pregnancy. The presence of placenta previa was noted; there also was a concern for placenta accreta. Sixteen years previously, the patient had undergone a cesarean delivery (outside the United States) that was occasioned by fetal distress.

A healthy fetus was delivered and there were no complications of labor reported at that time. The woman reported having poor exercise tolerance (class 2, New York Heart Association [NYHA] functional classification of heart disease) prior to her current pregnancy, but had no other symptoms. She underwent trans-thoracic echocardiography at 29 weeks of gestation. The findings included a mitral valve pressure half-time of 169 milliseconds (corresponding to an estimated mitral valve area [MVA] of 1.3 cm²), a mean gradient of 17 mm Hg, and a Wilkins mitral valvuloplasty score of 7. Moderate-severe mitral valve regurgitation with an eccentric jet also was observed. Fractional area change in the left ventricle was estimated to be 60%. The patient had mild pulmonary hypertension with systolic pulmonary artery pressure estimated at 36 mm Hg. Moderate tricuspid regurgitation also was noted.

During pregnancy, certain cardiovascular changes are predictable, including an increase in blood volume and heart rate, a decrease in systemic vascular resistance, and increased cardiac output. Left ventricular function is normal and ejection fraction is not significantly altered. These changes are thought to be adaptive in that they improve placental perfusion and also prepare the mother for blood loss at the time of delivery. However, such modifications are not always beneficial—especially in patients with underlying cardiac valvular stenosis—and can be particularly harmful in patients with mitral stenosis because a narrowed mitral valve orifice allows a relatively fixed amount of blood to move across during diastole. Thus, when cardiac output and blood volume increase during pregnancy and the mitral valve is stenotic, left atrial pressure is markedly increased. Additionally, increased cardiac output increases the transmirtal pressure gradient, which worsens symptoms of congestive heart failure and eventually leads to pulmonary edema and respiratory distress. If left atrial pressure becomes severely elevated, pulmonary hypertension and right ventricular heart failure may occur. The pathology is further worsened by tachycardia, which shortens the duration of left ventricular filling.
Echocardiographic Examination for Mitral Stenosis

Normally the area of the mitral valve is between 4 and 6 cm².¹ When the area is reduced to less than 2 cm², the transvalvular pressure gradient is increased. Continuous wave Doppler ultrasound should be used to measure the velocity of blood flow across the mitral valve. (The use of pulse wave Doppler may result in “aliasing” at high-velocity blood flow. Aliasing occurs when the frequency sampled is greater than one-half the pulse repetition frequency delivered from the echo probe. This can lead to an inaccurate estimation of blood flow velocity.) After measuring the velocity, the transvalvular pressure gradient can be estimated by using the modified Bernoulli equation (Figure 1).

\[ P = 4 \times V^2 \]

\( P, \) pressure gradient, mm Hg; \( V, \) blood flow velocity

Figure 1. Modified Bernoulli equation.

Mean gradient is the clinically relevant measurement because it is most precise. Mean gradients in the range of 5 to 10 mm Hg are consistent with moderate mitral stenosis; mean gradients above 10 mm Hg are consistent with severe mitral stenosis (Table 1).²

<table>
<thead>
<tr>
<th>Stenosis</th>
<th>MVA, cm²</th>
<th>Mean Pressure Gradient, mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>&gt;1.5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Moderate</td>
<td>1-1.5</td>
<td>5-10</td>
</tr>
<tr>
<td>Severe</td>
<td>&lt;1</td>
<td>&gt;10</td>
</tr>
</tbody>
</table>

Table 1. Echocardiographic Evaluation of Mitral Stenosis

MVA, mitral valve area

At least 2 other echocardiographic evaluations are useful in estimating the severity of mitral stenosis. First is the measurement of mitral valve pressure half-time (ie, the time it takes for the transvalvular pressure gradient to decrease to 50% of its maximum value). An MVA may be estimated using the following equation: \( MVA, \) cm² = \( \frac{220}{\text{pressure half-time, milliseconds}}. \)

MVAs of 1 to 1.5 cm² are consistent with moderate mitral stenosis and areas less than 1 cm² are consistent with severe mitral stenosis. The area of the mitral valve orifice also can be estimated using planimetry. The opening of the mitral valve can be visualized and the area traced to provide an estimation of the MVA. Severe calcification of the mitral valve may interfere with a determination of its
area by planimetry, and in patients with significant subvalvular stenosis, the degree of hemodynamic compromise may be underestimated.

**Minimally Invasive Valvuloplasty**

Percutaneous balloon mitral valvuloplasty (PBMV) is a minimally invasive procedure that has been performed in the cardiac catheterization suite since the mid-1980s. The procedure involves left-sided heart catheterization and inflation of a balloon across a stenotic mitral valve to increase the orifice area. Significant mitral regurgitation and left atrial thrombus are contraindications to PBMV.

The procedure has a high level of efficacy when patients are selected appropriately. In one case series of 74 patients, valve area increased by at least 50% in 73% of participants. Unfortunately, the procedure is not successful in all patients. Serious complications include death, cardiac tamponade, systemic embolism, and worsening mitral regurgitation; emergent surgery also may be necessary. In the previously mentioned case series, the death rate was 3%.

A number of scoring systems have been developed to help predict the success of PBMV. The Wilkins score, first described in 1988, is one of the oldest and most widely accepted systems based solely on echocardiographic criteria (Table 2). The Wilkins scoring system uses 4 echocardiographic criteria to determine an overall score between 4 and 16: mitral valve mobility, subvalvular thickening, valve thickening, and valve calcification. Using this system, patients with a lower score are more likely to have an optimal outcome, whereas a high score is more likely associated with a suboptimal outcome. In the original study, 7 was the mean score in the optimal outcome group and 11 was the mean score in the suboptimal outcome group.

<table>
<thead>
<tr>
<th>Score</th>
<th>Mobility</th>
<th>Subvalvular Thickening</th>
<th>Thickening</th>
<th>Calcification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Highly mobile; only leaflet tip is restricted</td>
<td>Minimal thickening just below valve leaflets</td>
<td>Leaflets near normal in thickness (4-5 mm)</td>
<td>Single area of increased echo brightness</td>
</tr>
<tr>
<td>2</td>
<td>Leaflet mid and base have normal mobility</td>
<td>Thickening of chordal structures extending up to one-third of chordal length</td>
<td>Midleaflets normal; considerable thickening of margins (5-8 mm)</td>
<td>Scattered areas of brightness confined to leaflet margins</td>
</tr>
<tr>
<td>3</td>
<td>Valve continues to move forward in diastole, mainly from base</td>
<td>Thickening extending to distal one-third of chords</td>
<td>Thickening extending through entire leaflet (5-8 mm)</td>
<td>Brightness extending into mid-lower portion of leaflets</td>
</tr>
<tr>
<td>4</td>
<td>No or minimal forward movement in diastole</td>
<td>Extensive thickening and shortening of all chordal structures extending to the papillary muscles</td>
<td>Considerable thickening of all leaflet tissue (&gt;8-10 mm)</td>
<td>Extensive brightness throughout much of leaflet tissue</td>
</tr>
</tbody>
</table>

* Based on echocardiographic criteria alone; predicts the success of intervention.4
Recently, other scoring systems that incorporate clinical variables with echocardiographic variables have been developed. One such multifactorial scoring system developed by Cruz-Gonzalez and colleagues showed higher success with PBMV in males, patients classified as NYHA class 1 or 2, and patients less than 55 years old. This multifactorial scoring system also showed that patients with high-grade mitral regurgitation were less likely to have an optimal outcome. In the case presented here, the Wilkins score for the patient was 7; however, because of her significant mitral regurgitation, we believed the procedure would not improve her symptoms.

**Cardiac Surgery in the Obstetric Patient**

Cardiac surgery performed in obstetric patients entails relatively low risk for the mother. However, the risk for fetal mortality has been estimated as high as 33%—which may be unacceptably high unless surgery is absolutely necessary and there is no alternative. Cardiopulmonary bypass (CPB), especially when performed under conditions of maternal hypothermia, can lead to tonic contraction of the uterus and compromise uterine blood flow.

The mechanism by which hypothermia leads to tonic contraction of the uterus during CPB is not well described. A prolonged decrease in uterine blood flow leads to fetal acidosis and hypoxemia. Typically, this is displayed on the fetal heart tracing as a late deceleration. When compared with normothermic CPB, hypothermic CPB has been shown to increase the risk for fetal mortality; the lower the temperature the greater the risk to the fetus.

At least 2 other factors may account for an increased risk to the fetus during CPB. First, it has been postulated that dilution of maternal progesterone levels in the CPB circuit may increase uterine contractions. Second, animal studies have shown that nonpulsatile blood flow during CPB causes severe placental dysfunction and vasoconstriction leading to fetal acidosis, and even fetal death. This effect may be negated by pulsatile CPB, but no human studies corroborate the findings in animal studies.

If CPB is performed on a woman carrying a viable fetus, fetal monitoring should be carried out during surgery; however, it can be technically challenging and heart rate abnormalities are common. Fetal bradycardia is the most common response to the initiation of CPB, and a normal heart rate typically returns after resumption of normal circulation. The significance of bradycardia and its effects on the fetus has not yet been fully elucidated. However, attempts should be made to increase placental perfusion if mean arterial pressure is low. This usually is accomplished through the use of vasopressors or by increasing CPB flow rates.

In the case presented here, the cardiac surgeon believed that valve repair was indicated because the patient was classified as NYHA class 4 and there was echocardiographic evidence of severe mitral stenosis and regurgitation. However, after discussing all options, the multidisciplinary team decided that the risks associated with valve repair during pregnancy outweighed the maternal benefit. In addition, the patient was not willing to consent for cardiac surgery with a risk for fetal mortality as high as 33%. Instead, valve repair 3 months after delivery was planned—unless the patient required emergent sternotomy and CPB at the time of delivery.
Hemodynamic Goals in Mitral Stenosis

The hemodynamic goals for any patient can be divided into 4 categories: preload, afterload, heart rate, and contractility goals. In a patient with mitral stenosis, the anesthesiologist should aim to maintain a normal preload, high afterload, slow heart rate, and normal contractility.

Tachycardia is especially detrimental to the patient with mitral stenosis because it decreases left ventricular diastolic filling time and myocardial perfusion time during diastole. Tachycardia can also increase left atrial pressure, leading to subsequent pulmonary hypertension and pulmonary edema. Myocardial contractility should be kept in the normal range. Excessive increases in myocardial contractility may lead to ischemia by increasing oxygen demand while output from the left ventricle is compromised. Systemic vascular resistance (afterload) should be kept in the higher range because it improves myocardial perfusion pressure. Preload should be kept in the normal range to maintain stroke volume, but the anesthesiologist must be cautious because excessively high preload can lead to pulmonary edema and rapid decompensation.

Achieving these goals is a challenge, but is possible with the use of appropriate monitors and well-planned anesthesia. In order to maintain preload in the normal range, the anesthesiologist should administer IV crystalloid in a goal-directed manner. Volume status can be accurately assessed using pulse pressure variation on the arterial waveform or transesophageal echocardiography (TEE). High afterload can be achieved and maintained by avoiding the administration of anesthetics that cause significant vasodilation and also by administering vasoconstricting drugs during periods of hypotension. A pure α-1 adrenergic agonist, such as phenylephrine, is an excellent choice for treating hypotension because it increases afterload while decreasing heart rate.

To maintain the patient at a slow heart rate, the anesthesiologist must induce a sufficient depth of anesthesia. The short-acting opioid, remifentanil, can be very helpful in achieving this goal because it induces deep anesthesia during surgery, but is rapidly eliminated. The anesthesiologist also should avoid anesthetics that commonly lead to tachycardia, such as ketamine. If tachycardia develops, the β-blocker esmolol is an excellent choice for treatment because of its β-1 selectivity and short duration of action. Finally, anesthetics that significantly decrease myocardial contractility, such as volatile agents in high doses, should be avoided because of their detrimental effects.

Preoperative Assessment and Anesthetic Planning

When taking the preoperative history of a patient with mitral stenosis, the anesthesiologist should ask him or her about exercise tolerance and ability to lie comfortably in the supine position. Patients who have low exercise tolerance or difficulty lying supine are likely to have severe disease. The NYHA classification system provides a simple way to classify severity of heart failure and is useful in determining prognosis (Table 3). In general, patients with symptoms classified as 3 or 4 and in whom there is echocardiographic evidence of significant dysfunction of the mitral valve may require optimization or intervention.

<table>
<thead>
<tr>
<th>Class</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No limitation of activities</td>
</tr>
<tr>
<td>2</td>
<td>Slight, mild limitation of activities</td>
</tr>
<tr>
<td>3</td>
<td>Marked limitation of activities</td>
</tr>
<tr>
<td>4</td>
<td>Unable to carry out any physical activity without discomfort; symptoms at rest; complete rest required; patient confined to bed or chair</td>
</tr>
</tbody>
</table>

NYHA, New York Heart Association
In any patient with known mitral stenosis, the anesthesiologist must review the echocardiography report preoperatively. In particular, the mean pressure gradient across the mitral valve and the estimated mitral valve area must be considered to estimate the severity of mitral stenosis. Right and left ventricular function and the degree of pulmonary hypertension should also be considered. The anesthesiologist also should review the chest x-ray for evidence of pulmonary edema and cardiomegaly to help gauge the severity of disease. Obtaining a complete blood count may be helpful in evaluating anemia and the potential need for blood products during surgery.

Regional anesthetic techniques are the mainstay of obstetric anesthesia and have an excellent safety record. However, these techniques may not be safe in all patients with mitral stenosis. Regional techniques are associated with hemodynamic changes that are opposite to the previously stated hemodynamic goals in patients with mitral stenosis. Also, patients commonly develop tachycardia when undergoing labor, which can be detrimental.

Nevertheless, the evidence indicates that epidural anesthesia can be a safe and effective technique in patients with severe mitral stenosis. In one retrospective study in South Africa, 128 consecutive patients with mitral stenosis were followed. In all, 49% of these women had an MVA less than 1.2 cm². The rate of maternal complications during pregnancy was high (51%). By far, the most common complication was pulmonary edema. Twenty women in the study underwent PMBV during pregnancy, with good results. The remainder were managed medically until time of delivery. In 60% of the patients, epidural anesthesia was successful and without complications. There were no maternal deaths and fetal outcome was satisfactory in 91% of the cases.

Alternatively, spinal anesthesia with local anesthetics is not advisable in patients with severe mitral stenosis. The rapid sympathectomy that occurs with spinal anesthesia with these agents can lead to cardiac arrest if myocardial ischemia develops after a fall in pre-load and afterload. Additionally, no large case series studies have been published to support the safe use in this group of patients.

Spinal anesthetic techniques that are purely opioid based, however, may provide adequate labor analgesia. In fact, placement of an intrathecal catheter and continuous opioid infusion is an excellent method for providing labor analgesia for the patient with severe mitral stenosis, because it does not significantly decrease preload and afterload and tends to maintain a slow heart rate. In the case presented, this technique was not an option because cesarean delivery was indicated and intrathecal opioids alone were unlikely to provide adequate anesthesia.

The obvious alternative to regional anesthesia is general anesthesia. Inherent risks and periods of instability associated with general anesthesia include induction, laryngoscopy, and emergence. Tachycardia commonly develops at such times and a severe drop in preload or afterload can occur after induction. Etomidate is the induction agent of choice because it offers the most hemodynamic stability. Remifentanil may be a good choice to blunt the hemodynamic response during laryngoscopy because of its rapid elimination, which leads to minimal residual effect on the fetus. Remifentanil also can be given by infusion during the case to maintain a slow heart rate and adequate depth of anesthesia.

One benefit of general anesthesia is that it allows for emergent sternotomy and initiation of CPB in a patient who undergoes acute decompensation. It also allows for the use of TEE, intraoperatively. If possible, a cesarean delivery should be performed in a cardiac operating room (OR) with a cardiac surgery team available.
Selection of Hemodynamic Monitors

Appropriate hemodynamic monitors can be very helpful in guiding therapy to achieve hemodynamic goals. Arterial cannulation is advisable in the obstetric patient with severe mitral stenosis, regardless of the anesthetic technique chosen. If general anesthesia is selected, an arterial line should be placed prior to induction so that hemodynamic changes during induction can be monitored closely. Central venous access also is advisable to permit the rapid administration of vasoactive drugs as necessary.

In patients with severe mitral stenosis and evidence of pulmonary hypertension, the placement of a pulmonary artery catheter can be helpful for allowing measurement of pulmonary artery pressures. If pulmonary artery pressures are greater than 50% of systemic pressure and right-sided heart failure is a concern, the pulmonary artery catheter measurements can help to guide therapy with drugs that lower pulmonary artery pressures—such as milrinone, nitric oxide, and iloprost. It should be noted, however, that no evidence-based medical guidelines exist to support the use of pulmonary artery catheterization to reduce morbidity or mortality.

TEE—which can be performed when the patient is under general anesthesia—allows for a relatively rapid assessment of both systolic and diastolic heart function in the hands of an experienced echocardiographer. It also helps to differentiate the common etiologies of hypotension, such as cardiac failure, decreased preload, and decreased afterload. If tricuspid regurgitation is detected, pulmonary artery pressures can be estimated using TEE without the need for pulmonary artery catheterization.

Management of the Case Presented

Initial Evaluation of Patient

The patient was transferred from a community hospital to an academic medical center. She was experiencing considerable dyspnea during any physical activity, and was unable to lie comfortably in the supine position (NYHA classification 4). She was immediately admitted to the cardiac care unit. She was started on metoprolol for heart rate control, and received the diuretic furosemide as needed. Soon after, a multidisciplinary team met to discuss a plan for her delivery and options for disease treatment during the remainder of her pregnancy.

A cardiologist who evaluated the patient did not believe she was a candidate for PBMV due to the presence of significant mitral regurgitation. A cardiothoracic surgeon who also evaluated the patient was of the opinion that a valve replacement or repair was indicated; however, the surgeon felt that in this case such a procedure would involve an unacceptably high risk to the fetus. Finally, a plan was agreed for continued medical management and a planned cesarean delivery at 32 weeks gestational age.

Induction of labor was not an option because of the presence of placenta previa. The plan allowed time to administer antenatal steroids with maximal benefit. Cesarean delivery was to be performed in the cardiac OR with a cardiac surgeon available, so that the patient could be placed on CPB emergently in the event of rapid decompensation. The plan was explained in detail to the patient and she gave informed consent. The high-risk obstetrics team requested an anesthesia consult.
Cesarean Delivery

A general anesthetic technique was selected and cesarean delivery performed in the cardiac OR with a cardiac surgery team on standby. The patient had been made aware of the unlikely possibility of an emergent sternotomy and valve repair. Preoperatively, the patient received 30 cc of sodium bicitrate.

In the OR, the patient was placed on the operating table in a semirecumbent position with left uterine displacement (45 degrees). The obstetricians monitored the fetal heart during anesthetic preparation. IV midazolam 2 mg was administered. A radial arterial line and pulmonary artery catheter were placed under local anesthesia. The patient’s initial systemic blood pressure was 125/65 mm Hg, with a mean pressure of 76 mm Hg. Heart rate was 105 beats per minute. Initial pulmonary pressures were 90/60 mm Hg, with mean pulmonary artery pressure of 62 to 68 mm Hg. The central venous pressure was 14 mm Hg, with a prominent v wave. Thermodilution cardiac output was not measured because of tricuspid regurgitation; however, initial mixed venous oxygen saturation was 34%. The patient was preoxygenated in the sitting position (at 45 degrees) to minimize discomfort.

Etomidate, remifentanil, and succinylcholine were administered for a modified rapid-sequence induction. The trachea was intubated successfully. An infusion of remifentanil 0.15 mcg/kg per minute was started. Isoflurane at less than 0.5 minimum alveolar concentration was administered. Depth of anesthesia was monitored, with a value maintained between 40 and 60 on the bispectral index.

Pure oxygen was used to ventilate the patient. Normocarbia was vigilantly maintained to optimize pulmonary vascular resistance. TEE was performed intraoperatively, showing a mean pressure gradient of 16 mm Hg across the mitral valve, a mitral valve pressure half-time of 154 milliseconds, and an estimated mitral valve area of 1.43 cm² (Figure 2).

An explanation was given to the pediatric team—unfamiliar with the pharmacokinetics of remifentanil—that some opioid-induced respiratory depression would be observed immediately after birth, but the effects would be of short duration because of the predictable and short elimination half-life of the drug. As expected, after delivery the neonate required several minutes of positive pressure ventilation. Shortly thereafter, spontaneous respiration resumed and respiratory effort of the neonate was satisfactory. Apgar scores were 4 at 1 minute and 9 at 5 minutes.

**Figure 2.** Mid-esophageal 4-chamber view of mitral valve. Continuous wave Doppler across the valve allows for calculations of transvalvular pressure gradient, mitral valve pressure half-time, and estimated MVA.

Mean PG, mean transvalvular pressure gradient; MVA, mitral valve area (estimated from P1/2T); P1/2T, mitral valve pressure half-time, milliseconds
The obstetrics team completed the cesarean delivery, with the patient remaining hemodynamically stable throughout the procedure. She did not need any vasoactive infusions or blood transfusion. After the procedure, her trachea was extubated in the OR. Her postpartum course was uneventful. Three months after her delivery, the woman underwent a complex mitral valve repair with an excellent outcome.

**Summary**

Mitral stenosis commonly manifests for the first time during pregnancy because of normally occurring hemodynamic changes that can exacerbate symptoms. When severe, the condition increases risks to the parturient and fetus. A multidisciplinary plan should be in place early because patients can decompensate at any time. Some patients may be candidates for PBMV during pregnancy; however, the procedure is not successful in all cases and carries significant risk. Cardiac surgery can be performed during pregnancy with low risk to the mother, but the risk for fetal mortality is high. Epidural anesthesia, general anesthesia, or continuous intrathecal opioid techniques can be appropriate during delivery, but the advantages and disadvantages of each must be considered. Anesthesiologists should choose appropriate hemodynamic monitors and have a plan in place to manage rapid decompensation in the patient. With a well-coordinated and executed plan, the outcome is generally excellent for both mother and fetus.
References


Post-test

1. Which of the following is not a normal cardiovascular change during pregnancy?
   a. Increase in heart rate
   b. Decrease in systemic vascular resistance
   c. Decrease in ejection fraction
   d. Increase in blood volume

2. Which echocardiographic finding is consistent with severe mitral stenosis?
   a. Estimated MVA of 0.9 cm²
   b. Mean transmitral gradient of 6 mm Hg
   c. Estimated MVA of 1.4 cm²
   d. Mean transmitral gradient of 8 mm Hg

3. Which type of Doppler should be used to measure blood velocity across the mitral valve in a patient with mitral stenosis?
   a. Pulse wave
   b. Continuous wave
   c. Color flow
   d. M-mode

4. Which of the following is a reported complication of percutaneous balloon mitral valvuloplasty?
   a. Cardiac tamponade
   b. Death
   c. Systemic embolus
   d. All of the above
5. **Which of the following is not a feature of the Wilkins mitral valvuloplasty score?**
   a. Mobility
   b. Thickening
   c. Calcification
   d. Degree of mitral regurgitation

6. **Hemodynamic goals in mitral stenosis include which of the following?**
   a. Tachycardia
   b. Normal to high systemic vascular resistance
   c. Low preload
   d. High contractility

7. **The approximate risk for fetal mortality during cardiopulmonary bypass is:**
   a. 5%
   b. 20%
   c. 33%
   d. 50%

8. **A patient with mitral stenosis can walk up 2 flights of stairs, but then has to stop for rest. She can walk approximately 4 blocks, but then becomes short of breath. In which New York Heart Association class would the patient be assigned?**
   a. 1
   b. 2
   c. 3
   d. 4

9. **Which hemodynamic monitor is appropriate for a patient with severe mitral stenosis?**
   a. Pulmonary artery catheter
   b. Transesophageal echocardiography
   c. Arterial catheter
   d. All of the above

10. **In pregnant women with severe mitral stenosis, the most common complication is:**
    a. fetal loss
    b. pulmonary embolus
    c. pulmonary edema
    d. death