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# Obstetric Anesthesia and Heart Disease: Practical Clinical Considerations

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## ABSTRACT

Maternal morbidity and mortality as a result of cardiac disease is increasing in the United States. Safe management of pregnancy in women with heart disease requires appropriate anesthetic, cardiac, and obstetric care. The anesthesiologist should risk stratify pregnant patients based upon cardiac disease etiology and severity in order to determine the appropriate type of hospital and location within the hospital for delivery and anesthetic management. Increased intrapartum hemodynamic monitoring may be necessary and neuraxial analgesia and anesthesia is typically appropriate. The anesthesiologist should anticipate obstetric and cardiac emergencies such as emergency cesarean delivery, postpartum hemorrhage, and peripartum arrhythmias. This clinical review answers practical questions for the obstetric anesthesiologist and the nonsubspecialist anesthesiologist who regularly practices obstetric anesthesiology.

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Maternal mortality is increasing in the United States, and cardiovascular disease is now the leading cause.[1,2] According to the Centers for Disease Control and Prevention, cardiovascular disease is currently responsible for one-quarter of maternal deaths in the United States and similar trends are occurring in other high-income countries.[2–4] These trends may be a result of an increasing average age of maternity during the last 4 decades, compounded by increases in known risk factors for cardiovascular disease such as diabetes, hypertension, and obesity.[5–7]

With improvements in the surgical and medical management of congenital heart disease, the number of women with congenital heart disease who survive to childbearing years and present to labor and delivery units in the United States has increased.[8] The European Society of Cardiology's Registry of Pregnancy and Cardiac Disease has recorded more than 5,700 pregnancies in women with cardiovascular disease, 57% of whom had congenital heart disease. Based on the Registry of Pregnancy and Cardiac Disease data, patients with congenital heart disease with appropriate cardiac and obstetric care do well, with relatively low rates of morbidity and mortality compared to other types of heart disease.[3] In contrast, patients at the highest risk of cardiovascular complications and death in pregnancy are women who are older, identify as Black or African American, acquire heart disease in pregnancy, and/or have unrecognized cardiovascular disease and become pregnant.[1,9–11]

There are little data to guide the anesthetic management of women with cardiac disease. Statements by the American Heart Association (Dallas, Texas), European Society of Cardiology (Sophia Antipolis Cedex, France), Society of Maternal–Fetal Medicine (Washington, D.C.), and American College of Obstetricians and Gynecologists (Washington, D.C.) provide valuable guidance regarding the diagnosis and management of cardiovascular disease preconception, in pregnancy, and in the peripartum and postpartum periods.[12–14] These guidelines recommend that a "pregnancy heart team" care for pregnant patients with complex cardiovascular disease. Such a team is defined as cardiologists, obstetricians, perinatologists, and anesthesiologists. Through a nonsystematic literature review with incorporation of national and international guidelines, this Clinical Review answers practical questions for the obstetric anesthesiologist and the nonsubspecialist anesthesiologist who regularly practices obstetric anesthesiology. Besides society statements and guidelines, many of the suggestions in this review are based on hemodynamic and physiologic extrapolation and advice from other experts.

## Discussion

### Where Should Women with Known Heart Disease Deliver?

A woman with cardiovascular disease should deliver at a hospital with the appropriate equipment, resources, and personnel to meet her cardiovascular, obstetric, and anesthetic care needs—both anticipated and emergent. Maternal cardiac risk stratification is a method of using the type of cardiovascular disease along with the medical and surgical history to create a risk-of-event occurrence score. This allows for appropriate delivery location planning. Maternal cardiac disease encompasses a range of diagnoses: congenital heart disease, aortic disease, valvular heart disease, cardiomyopathies, heart failure, coronary artery disease,

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acute coronary syndromes, hypertension, pericardial diseases, pulmonary hypertension, infective endocarditis, and arrhythmias. For each of these diagnoses, the maternal risk at delivery depends upon the severity of the cardiovascular disease, comorbid maternal conditions, and obstetric risk factors.

Several risk stratification systems identify women with cardiovascular disease who are at the greatest risk for maternal and/or neonatal complications during delivery.[15–17] The Modified World Health Organization Classification of Cardiovascular Disease in Pregnancy is a useful tool for the anesthesiologist planning delivery care and is reviewed in table 1.[12,15] The Modified World Health Organization Classification of Cardiovascular Disease in Pregnancy classifies maternal cardiac lesions according to their "risk of a cardiovascular event rate during pregnancy" ranging from group I lesions (*e.g.,* simple repaired atrial or ventricular septal defects, mild mitral valve prolapse, or isolated atrial or ventricular ectopic beats; event rate of 2.5 to 5%) to group IV lesions (*e.g.,* pulmonary arterial hypertension, severe systemic ventricular dysfunction, severe symptomatic aortic stenosis, severe aortic dilation; event rate of 40 to 100%).

In an effort to reduce disparities in care and improve outcomes, the American College of Obstetricians and Gynecologists and Society of Maternal–Fetal Medicine developed the Maternal Levels of Care system to standardize care across hospitals and to create a system that facilitates appropriate transfers when escalation of resources is needed.[18] The Maternal Levels of Care consensus statement defines the capabilities expected at each level: basic care (level I), specialty care (level II), subspecialty care (level III), and regional perinatal healthcare centers (level IV). Through extrapolation, we placed the cardiovascular lesions according to the Modified World Health Organization's Classification of Cardiovascular Disease in Pregnancy into the Maternal Level of Care in table 2. In general, women with lesions in class I and II, according to the Modified World Health Organization's Classification of Cardiovascular Disease in Pregnancy, may be cared for at maternal level I or II centers.[18] Women who require subspecialty care and a cardiologist should, at a minimum, be cared for at level III centers and, should there be a possible need for peripartum cardiac surgery or extracorporeal membrane oxygenation (ECMO), a woman should be transferred to a hospital with

**Table 1.** Modified World Health Organization Classification of Cardiovascular Disease in Pregnancy[1,2]

| Risk Classification | Cardiac Lesions |
|---|---|
| **Class I**<br>No detectable increased risk of maternal mortality and no or minimal increase in maternal morbidity | • Uncomplicated mild pulmonary stenosis<br>• Ventricular septal defect<br>• Patent ductus arteriosus<br>• Mitral valve prolapse with no more than trivial mitral regurgitation<br>• Successfully repaired simple lesions (atrial or ventricular septal defect, patent ductus arteriosus, anomalous pulmonary venous drainage)<br>• Isolated ventricular extra-systoles and atrial ectopic beats |
| **Class II**<br>Small increased risk of maternal mortality or moderate increase in morbidity | • Unrepaired atrial or ventricular septal defect<br>• Repaired tetralogy of Fallot<br>• Most arrhythmias |
| **Class II–III**<br>Moderate increased risk of maternal mortality or morbidity | • Hypertrophic cardiomyopathy<br>• Native or tissue valvular heart disease not considered Modified World Health organization I or IV<br>• Repaired coarctation<br>• Marfan syndrome without aortic dilatation<br>• Bicuspid valve with aorta <45 mm<br>• Mild ventricular impairment<br>• Heart transplantation |
| **Class III**<br>Significantly increased risk of maternal mortality or severe morbidity, and expert cardiac and obstetric prepregnancy, antenatal, and postnatal care are required | • Mechanical valve<br>• Systemic right ventricle<br>• Fontan circulation<br>• Unrepaired cyanotic heart disease<br>• Other complex congenital heart disease<br>• Marfan syndrome with aorta 40–45 mm<br>• Bicuspid aortic valve with aorta 45–50 mm |
| **Class IV**<br>Pregnancy is highly discouraged | • Pulmonary hypertension<br>• Eisenmenger syndrome<br>• Systemic ventricular ejection fraction <30%<br>• Systemic ventricular dysfunction with New York Heart Association class III–IV<br>• Severe mitral stenosis or symptomatic aortic stenosis<br>• Marfan syndrome with aorta >45 mm<br>• Bicuspid aortic valve with aorta >50 mm<br>• Native severe coarctation<br>• Previous peripartum cardiomyopathy with any residual impairment of ventricular function |

**Table 2.** Maternal Levels of Care[3]

| Level | Title | Maternal Health | Hospital Capabilities | Anesthesia Staffing | Modified World Health Organization Patients* |
|---|---|---|---|---|---|
| Birth center | Birth center | Low risk | Not applicable | None | None |
| Level I | Basic care | Low to moderate risk | Limited obstetric ultrasound<br>Blood bank | Anesthesia provider readily available at all times | Modified World Health Organization class I |
| Level II | Specialty care | Moderate to high risk | Computed tomography scanning/magnetic resonance imaging<br>Maternal echocardiogram<br>Nonobstetric ultrasound | Anesthesiologist readily available at all times | Modified World Health Organization class I or II |
| Level III | Subspecialty care | More complex maternal, obstetric and fetal conditions | Interventional radiology<br>In-house capability of all blood components | Board-certified anesthesiologist physically present at all times | Modified World Health Organization class I or II, some III |
| Level IV | Regional perinatal health center | Most complex maternal conditions | ICU care with Maternal Fetal Medicine comanagement<br>Cardiovascular surgery, ECMO, and transplant capabilities | Board-certified anesthesiologist with obstetric anesthesia fellowship or experience in obstetric anesthesia physically present at all times | Modified World Health Organization class I, II, III, or IV |

*The addition of the Modified World Health Organization classifications into the Maternal Levels of Care is an extrapolation based upon Drs. Meng and Arendt's experience, and is not a direct recommendation from the American College of Obstetricians and Gynecologists, Society of Maternal–Fetal Medicine, or Modified World Health Organization.

ECMO, extracorporeal membrane oxygenator; ICU, intensive care unit.

cardiac surgery capabilities, which is likely to be a level IV center.[12,18] Women who are at high risk of requiring ECMO include women with severe pulmonary hypertension, Eisenmenger syndrome, low systemic ventricular function, or severe right ventricular failure.

The American College of Obstetricians and Gynecologists/Society of Maternal–Fetal Medicine Maternal Level of Care consensus statement, reviewed by the American Society of Anesthesiologists (ASA) and endorsed by the Society for Obstetric Anesthesia and Perinatology, specifies the anesthesia resources required to care for medically-complex pregnant women. For a center to qualify as maternal level III, a board-certified anesthesiologist must be physically present at all times in the hospital. A maternal level IV center must have a board-certified anesthesiologist with obstetric anesthesia fellowship training or experience in obstetric anesthesiology physically present at all times in the hospital.[18]

Choosing the delivery location within a medical center is an essential step in pregnancy heart team planning. This decision is based upon the capabilities of each facility and the specific aspects of care required. Typically, vaginal deliveries are best performed in labor and delivery units and not intensive care units or cardiac operating rooms. This facilitates the response to obstetric emergencies such as urgent cesarean delivery or uterine atony. Medical teams on labor and delivery units at level IV centers are typically capable of administering vasoactive medications, inotropes and utilizing telemetry and invasive monitoring during vaginal delivery. This higher level of care requires either additional training for labor and delivery nurses or a collaboration with intensive care unit nurses. In the level IV center, the anesthesiologist can expect a high degree of bedside involvement in the care of patients with complex cardiac disease undergoing vaginal delivery. Alternatively, an elective cesarean delivery that requires ECMO or cardiothoracic surgical care on standby may best be performed in a cardiothoracic operating room for ease of organizing equipment and personnel.

A predelivery consultation with the anesthesiology service is an opportunity to identify high-risk patients, triage them to an appropriate hospital, and plan peripartum anesthesia management. This step of care management is reviewed in table 3 and offers the anesthesiologist the opportunity to educate the patient about the effects of their cardiac disease on their anesthetic care. This consult also allows the anesthesiologist to obtain the anesthetic, obstetric, and cardiac history; interpret previous cardiac testing records; and highlight aspects of management that may need to be altered at delivery (*e.g.,* anticoagulation regimen) to the multidisciplinary care team. Obstetric anesthesiologists at maternal level III and IV centers should be resources to guide transfers when indicated or to encourage continued care of stable low-risk women at level I or II centers.

## How Does the Physiology of Pregnancy and the Peripartum Period Effect Anesthetic Management?

Understanding the hemodynamic changes of pregnancy and the peripartum period allows anesthesiologists to predict which cardiac lesions may result in peripartum hemodynamic compromise. This informs both the anesthetic care and the response to obstetric emergencies such as emergency cesarean delivery or postpartum hemorrhage. The hemodynamic changes of pregnancy are reviewed in Supplemental Digital Content 1 (http://links.lww.com/ALN/C623).[19] How various cardiac lesions may physiologically interact

**Table 3.** Anesthetic Care Steps for Pregnant Women with Known Cardiovascular Disease

| |
|---|
| **Predelivery Consultation with the Anesthesiology Service** |
| 1. Summarize cardiovascular, obstetric, and anesthesia history and risk factors |
| 2. Cardiac history should focus on: |
| a. Previous surgeries, echocardiograms, electrocardiograms, Holter monitors, stress tests, heart catheterization, *etc.* |
| b. Previous or current episodes of heart failure |
| c. Intracardiac shunting and cyanosis |
| d. Previous arrhythmias |
| e. Left heart obstructive lesions |
| f. Left and right heart function |
| 3. Risk stratify according to the Modified World Health Organization criteria |
| 4. Participate in multidisciplinary planning of labor and delivery |
| 5. With obstetric team, plan appropriate delivery location according to maternal levels of care |
| 6. Partner with pregnancy heart team* for anticoagulation regimen to optimize ability to perform neuraxial techniques |
| 7. Clarify in the consultation note plan for pacemaker or defibrillator (keep automatic implantable cardioverter defibrillator "on" during labor or cesarean delivery |
| 8. Clarify in the consultation notes which obstetric drugs could cause hemodynamic instability (see table 5) |
| 9. Partner with pregnancy heart team* to clarify in the consultation notes postdelivery plans for monitoring |
| **Trial of Labor** |
| 1. Besides standard labor monitoring, also consider monitoring with: |
| a. Pulse oximetry with a wave form |
| b. Five-lead electrocardiography if at risk for tachyarrhythmia or cardiac ischemia |
| c. Intraarterial blood pressure monitoring if at risk for hemodynamic instability with induction of neuraxial or general anesthesia |
| 2. Initiate neuraxial analgesia early in labor (unless contraindication) |
| 3. Do not use a routine preepidural fluid bolus in patients at risk for pulmonary edema |
| 4. Consider modifying epidural test dose to minimize the risk of high spinal or intravascular epinephrine |
| 5. Monitor for hypotension closely during induction of neuraxial labor analgesia and treat with goal-directed fluids and vasopressors (*e.g.,* phenylephrine, norepinephrine, and ephedrine) to maintain normal blood pressure |
| 6. Readily replace suboptimal epidural catheter |
| 7. Keep epidural block dense enough throughout labor such that it eliminates pain and catecholamine release, facilitates operative vaginal delivery, and can quickly be converted to a surgical block in the event of an obstetric emergency |
| **Cesarean Delivery** |
| 1. Low threshold to monitor with intraarterial blood pressure |
| 2. Perform neuraxial anesthesia if no contraindications (choose epidural, sequential combined spinal epidural, or single-shot spinal based upon presumed tolerance of sympathectomy) |
| 3. Titrate vasopressor infusion (*e.g.,* phenylephrine or norepinephrine) to maintain blood pressure |
| 4. Titrate oxytocin on an infusion pump |
| **Postpartum** |
| 1. Titrate oxytocin on an infusion pump |
| 2. Monitor for postpartum hemorrhage and treat rapidly |
| 3. In most cardiovascular patients, risks of methylergonovine and carboprost may outweigh the benefits of these uterotonics medications (see table 5) |
| 4. More intense monitoring postpartum (*e.g.,* five-lead electrocardiographic monitoring, continuous pulse oximetry) may be indicated in patients with Modified World Health Organization class III or IV lesions, or those who experience obstetric or cardiac complications during labor or delivery. This may require intensive care or step-down unit admission. |

*An institution's team of cardiologists, obstetricians, perinatologists, and anesthesiologists focused on the care of pregnant women with cardiovascular disease.

with these changes and the implications for anesthetic management is reviewed in table 4.[20,21]

## Contribution of Preload

Cardiac output (CO) increases in pregnancy. Through pregnancy and the peripartum period, the maternal heart must tolerate increases in preload as a result of: (1) the increased blood volume of pregnancy; (2) uterine contractions; (3) decompression of the inferior vena cava with delivery of the fetal–placental unit; and (4) postdelivery uterine involution. Healthy hearts can tolerate these volume changes well. Women with diminished heart function or preload sensitive lesions may not. If the maternal myocardium cannot augment contractility to accommodate these changes in preload, heart failure will ensue which typically presents in this setting with tachycardia and hypoxemia. An increase in heart rate (HR) occurs to increase CO when stroke volume (SV) cannot be augmented *via* contractility.

The risk of pulmonary edema in pregnant women with heart disease is significant. Pregnancy is associated with a decrease in plasma oncotic pressure which most women tolerate well. This does, however, increase the likelihood of pulmonary edema developing from osmotic pressure gradients pulling water out of the blood plasma and into the pulmonary interstitium. Women with heart failure can also have elevated pulmonary capillary hydrostatic pressure which further increases the risk of transudation of fluid into the pulmonary interstitium. The fluid transduction from

osmotic and hydrostatic pressure gradients can become especially consequential if the pulmonary capillaries gain permeability from endothelial dysfunction from preeclampsia or eclampsia. Hypoxemia must be recognized and treated rapidly to prevent deterioration. In these patients, anesthesiologists should be prepared for potential acute management of pulmonary edema from heart failure including diuresis, inotropic support, and tracheal intubation.

Previous work has shown that lack of recognition of heart failure in pregnancy contributes significantly to maternal deaths in the United States.[9] This lack of recognition may be due to the fact that symptoms present during

**Table 4.** Hemodynamic Effects of Pregnancy and Anesthetic Management Considerations in Specific Cardiovascular Diseases[21]

| | Effects of Pregnancy and Delivery | Management Considerations |
|---|---|---|
| Coronary artery disease | (-) Decrease in SVR can result in reduced diastolic blood pressure and thereby decreased coronary perfusion pressure<br>(-) Increase in heart rate can result in decreased coronary filling time<br>(-) Cardiac work can increase significantly during labor | Normal heart rate (avoid tachycardia):<br>➢ Maintain effective neuraxial labor analgesia<br>➢ Continue β-blockade through labor and delivery<br>➢ Avoid β-agonist agents (*e.g.,* terbutaline)<br>Maintain afterload:<br>➢ Consider intraarterial blood pressure monitoring<br>➢ Consider phenylephrine for vasopressor of choice<br>➢ Carefully titrate neuraxial anesthesia onset for labor or cesarean delivery<br>➢ Consider prophylactic phenylephrine infusion for cesarean delivery<br>➢ Titrate oxytocin carefully<br>➢ Early recognition and aggressive response to hemorrhage<br>Monitor for and avoid ischemia:<br>➢ Five-lead electrocardiographic monitoring for cesarean delivery or labor<br>➢ Avoid methylergonovine<br>➢ Recognize and carefully treat hypertensive disorders of pregnancy (*e.g.,* consider intraarterial monitoring)<br>Postpartum monitoring:<br>➢ Monitor for postpartum ischemia or heart failure |
| Severe left ventricular dysfunction (*e.g.,* dilated or peripartum cardiomyopathy) | (-) Increase in cardiac output and blood volume can result in heart failure and pulmonary edema<br>(-) Decrease in oncotic pressure can result in pulmonary edema<br>(-) Patients with previous episode of peripartum cardiomyopathy are at risk for further deterioration in left ventricular function with subsequent pregnancies<br>(-) Angiotensin-converting enzyme inhibitors are discontinued due to teratogenicity | Normal heart rate (avoid bradycardia):<br>➢ Treat bradycardia with ephedrine or glycopyrrolate<br>Maintain afterload (avoid hypertension or hypotension):<br>➢ Consider intraarterial blood pressure monitoring<br>➢ Maintain effective neuraxial labor analgesia<br>➢ Carefully titrate neuraxial anesthesia onset for labor or cesarean delivery<br>➢ Treat hypotension with ephedrine or norepinephrine<br>➢ Titrate oxytocin carefully<br>➢ Recognize and carefully treat hypertensive disorders of pregnancy (*e.g.,* consider intraarterial monitoring)<br>➢ Early recognition and aggressive response to hemorrhage<br>Maintain contractility:<br>➢ Consider ephedrine for vasopressor of choice<br>➢ If low cardiac output syndrome develops, consider milrinone or dobutamine with the addition of epinephrine or norepinephrine to maintain blood pressure<br>Prevent and monitor for pulmonary edema:<br>➢ Careful fluid balance<br>➢ Continuous pulse oximetry throughout labor and peripartum (including postpartum)<br>Manage pulmonary edema:<br>➢ Consider diuresis<br>➢ Administer supplemental oxygen<br>➢ Labor in upright position<br>➢ If necessary, consider intubation with positive end expiratory pressure and controlled ventilation<br>Monitor for and avoid ischemia or arrythmia:<br>➢ Five-lead electrocardiographic monitoring for cesarean delivery or labor<br>Manage automatic implantable cardioverter defibrillator, if present:<br>➢ Keep antitachyarrhythmia function of automatic implantable cardioverter defibrillator active in labor and may be kept active in the event of emergent cesarean delivery<br>Minimize pulmonary vascular resistance:<br>➢ Administer supplemental oxygen<br>➢ Avoid oversedation<br>➢ Assure well-controlled ventilation if intubated<br>➢ Avoid carboprost<br>Postpartum monitoring:<br>➢ Monitor for postpartum heart failure |

(*Continued*)

**Table 4.** (Continued)

| | Effects of Pregnancy and Delivery | Management Considerations |
|---|---|---|
| Pulmonary hypertension | (-) Increased cardiac output may not be accommodated by the fixed pulmonary vasculature resulting in right heart failure<br>(-) Decrease in SVR can result in reduced diastolic blood pressure and thereby decreased coronary perfusion pressure especially in a dilated and failing right ventricle<br>(-) Hypercoagulable state can result in pulmonary emboli which can exacerbate pulmonary hypertension | Minimize pulmonary vascular resistance:<br>➢ Administer supplemental oxygen<br>➢ Avoid oversedation, hypercapnia<br>➢ Maintain effective neuraxial labor analgesia<br>➢ Assure well-controlled ventilation if intubated<br>➢ Avoid carboprost<br>Maintain adequate blood volume and venous return:<br>➢ Strict monitoring of fluid balance<br>➢ Recognize and carefully treat hypertensive disorders of pregnancy (*e.g.,* consider intraarterial monitoring)<br>➢ Early recognition and aggressive response to hemorrhage<br>Avoid myocardial depressants:<br>➢ Avoid β-blockade if possible<br>Monitor for and avoid ischemia or arrythmia:<br>➢ Five-lead electrocardiographic monitoring for cesarean delivery or labor<br>Maintain afterload:<br>➢ Consider intraarterial blood pressure monitoring<br>➢ Careful titration of onset of neuraxial anesthetic for labor or cesarean delivery<br>➢ Consider phenylephrine for vasopressor of choice<br>➢ Titrate oxytocin carefully<br>Invasive pulmonary artery catheter monitoring as well as vasoactive agents may be necessary:<br>➢ Consider partnership with cardiovascular anesthesiologist<br>Postpartum monitoring:<br>➢ Monitor for postpartum heart failure |
| History of unstable arrhythmia | (-) Pregnancy, labor, and delivery can incite tachyarrhythmias which can be associated with poor fetal outcome | Minimize maternal plasma catecholamines:<br>➢ Maintain effective neuraxial labor analgesia<br>➢ Consider avoiding epinephrine-containing local anesthetics (including in a test dose)<br>➢ Avoid ephedrine and terbutaline<br>➢ Recognize and carefully treat hypertensive disorders of pregnancy (*e.g.,* consider intraarterial monitoring)<br>➢ Early recognition and aggressive response to hemorrhage<br>Identify arrhythmias rapidly:<br>➢ Five-lead electrocardiographic monitoring for labor, cesarean delivery, and postpartum<br>Cardiovert unstable tachyarrhythmias rapidly:<br>➢ Cardioversion can be performed in pregnancy<br>➢ With tachyarrhythmia, consider fetal distress an indication for cardioversion<br>Manage pacemaker/automatic implantable cardioverter defibrillator, if present:<br>➢ Keep antitachyarrhythmia function of automatic implantable cardioverter defibrillator active in labor and may be kept active in the event of emergent cesarean delivery<br>Postpartum monitoring:<br>➢ Monitor for postpartum arrhythmia |
| Aortopathy (*e.g.,* Marfan syndrome) | (-) Pregnancy, labor, and delivery may increase dilation of aortic root and increase the risk of aortic dissection<br>(-) Maternal Valsalva maneuver may result in increased arterial sheer stress | Minimize aortic wall tension:<br>➢ Maintain effective neuraxial labor analgesia<br>➢ Continue β-blockade through labor and delivery<br>➢ Cardio-Obstetrics may recommend cesarean delivery or no Valsalva during second stage<br>Minimize hemodynamic fluctuations:<br>➢ Carefully titrate neuraxial anesthesia onset for labor or cesarean delivery<br>➢ Consider intraarterial blood pressure monitoring<br>➢ Avoid methylergonovine and carboprost<br>➢ Titrate oxytocin carefully<br>➢ Recognize and carefully treat hypertensive disorders of pregnancy (*e.g.,* consider intraarterial monitoring)<br>➢ Early recognition and aggressive response to hemorrhage<br>Postpartum monitoring:<br>➢ Monitor for postpartum hemodynamic instability |

(*Continued*)

**Table 4.** (Continued)

| | Effects of Pregnancy and Delivery | Management Considerations |
|---|---|---|
| Valvular lesions | | |
| Mechanical prosthetic valve | (-) Hypercoagulable state of pregnancy increases risk of valve thrombosis<br>(-) Vitamin K antagonists (most effective way to prevent valvular clot formation) are teratogenic. Suboptimal anticoagulation regimens may be used during pregnancy | Balance risk of anticoagulation therapy and anesthesia technique:<br>➢ Perform general anesthesia for cesarean delivery in patients who are anticoagulated<br>Recognize anticoagulation also increases risk of intrapartum and postpartum hemorrhage:<br>➢ Select and/or titrate uterotonics carefully depending on underlying cardiac disease recognizing that oxytocin decreases SVR, methylergonovine behaves as an adrenergic alpha agonist and carboprost increases pulmonary vascular resistance significantly<br>➢ Postpartum monitoring<br>➢ Monitor for postpartum valvular clotting or obstetric bleeding |
| Mitral stenosis | (-) Elevation in blood volume and heart rate increases left atrial pressure which may lead to atrial fibrillation and pulmonary edema<br>(-) Because of relatively fixed preload to the left ventricle, the heart may not adequately generate increased cardiac output<br>(-) Decreased oncotic pressure further increases risk of pulmonary edema | Normal heart rate (avoid tachycardia):<br>➢ Maintain effective neuraxial labor analgesia<br>➢ Continue β-blockade through labor and delivery<br>➢ Five-lead electrocardiographic monitoring for cesarean delivery or labor<br>➢ Avoid β-agonist agents (*e.g.,* terbutaline)<br>➢ Early recognition and aggressive response to hemorrhage<br>➢ Avo Atrial fibrillation<br>➢ In new-onset atrial fibrillation, cardioversion should be considered<br>➢ In failed cardioversion and in cases with chronic atrial fibrillation, treat rapid ventricular rate with medical therapy<br>Prevent and monitor for pulmonary edema:<br>➢ Careful fluid balance<br>➢ Continuous pulse oximetry throughout labor and peripartum (including postpartum)<br>➢ Recognize and carefully treat hypertensive disorders of pregnancy (*e.g.,* consider intraarterial monitoring)<br>Manage pulmonary edema:<br>➢ Consider diuresis<br>➢ Administer supplemental oxygen<br>➢ Labor in upright position<br>➢ If necessary, consider intubation with positive end expiratory pressure and controlled ventilation<br>Postpartum monitoring:<br>➢ Monitor for postpartum pulmonary edema |
| Aortic stenosis/hypertrophic obstructive cardiomyopathy | (-) Decrease in SVR can result in reduced diastolic blood pressure and therefore decreased coronary perfusion pressure to the thickened left ventricle myocardium<br>(-) Left ventricle diastolic dysfunction and excess volume can lead to pulmonary edema | Maintain afterload (avoid hypotension and hypovolemia):<br>➢ Consider intraarterial blood pressure monitoring<br>➢ Carefully titrate neuraxial anesthesia onset for labor or cesarean delivery<br>➢ Treat hypotension with phenylephrine<br>➢ Avoid nonspecific β-agonist agents (*e.g.,* terbutaline)<br>➢ Titrate oxytocin carefully<br>➢ Early recognition and aggressive response to hemorrhage<br>Normal heart rate (avoid tachycardia):<br>➢ Maintain effective neuraxial labor analgesia<br>➢ Prevent and monitor for ischemia<br>➢ Five-lead electrocardiographic monitoring for cesarean delivery or labor<br>➢ Recognize and carefully treat hypertensive disorders of pregnancy (*e.g.,* consider intraarterial monitoring)<br>Maintain normovolemia:<br>➢ Strict monitoring of fluid balance<br>➢ Postpartum monitoring<br>➢ Monitor for postpartum hypotension or ischemia |
| Mitral/aortic insufficiency | (+) Decreased SVR results in a lower regurgitant volume<br>(-) Pregnancy can worsen ventricular dilation | Avoid increases in SVR and decreases in contractility:<br>➢ Maintain effective labor analgesia<br>➢ Avoid bradycardia<br>➢ In cesarean delivery under spinal anesthesia, if prophylactic phenylephrine administered, carefully titrate and treat bradycardia. Alternatively, consider norepinephrine<br>Maintain sinus rhythm:<br>➢ Maintain effective neuraxial labor analgesia<br>➢ Consider afterload reduction<br>➢ Neuraxial analgesia/anesthesia typically well tolerated if preserved ventricular function<br>➢ Recognize and aggressively treat hypertensive disorders of pregnancy (*e.g.,* consider intraarterial monitoring) |

(*Continued*)

**Table 4.** (Continued)

| | Effects of Pregnancy and Delivery | Management Considerations |
|---|---|---|
| Shunt lesions | | |
| Right-to-left shunt (*e.g.,* tetralogy of Fallot, Eisenmenger syndrome) | (-) Decreased SVR increases right-to-left shunting and possible cyanosis<br>(+) In unrepaired tetralogy of Fallot and normal right ventricle function, the increase in blood volume is beneficial because adequate right ventricular preload is necessary to eject blood past the outflow obstruction and increase pulmonary blood flow* | Maintain afterload and recognize worsening cyanosis:<br>➢ Continuous pulse oximetry throughout labor and peripartum (including postpartum)<br>➢ Treat cyanotic episodes with phenylephrine<br>➢ Consider intraarterial blood pressure monitoring<br>➢ Carefully titrate neuraxial anesthesia onset for labor or cesarean delivery<br>➢ Titrate oxytocin carefully<br>➢ Minimize pulmonary vascular resistance<br>➢ Administer supplemental oxygen throughout labor and delivery<br>➢ Avoid oversedation<br>➢ Maintain effective neuraxial labor analgesia<br>➢ Assure well-controlled ventilation if intubated<br>➢ Avoid carboprost<br>Maintain adequate blood volume and venous return:<br>➢ Strict monitoring of fluid balance<br>➢ Avoid supine position<br>➢ Early recognition and aggressive response to hemorrhage<br>Avoid myocardial depressants because any decrease in right ventricular contractility can decrease pulmonary circulation:<br>➢ Avoid β-blockade if possible<br>➢ Five-lead electrocardiographic monitoring for cesarean delivery or labor<br>If pulmonary vascular disease is present, invasive pulmonary artery catheter monitoring, as well as vasoactive agents, may be necessary:<br>➢ Consider partnership with cardiovascular anesthesiologist<br>Avoid paradoxical embolism:<br>➢ Place filters on intravenous lines<br>➢ Perform epidural loss of resistance technique with saline not air<br>➢ Postpartum monitoring<br>➢ Monitor for postpartum cyanosis |
| Left-to-right shunt (*e.g.,* ventricular septal defect or atrial septal defect) | (+) Decrease in SVR decreases left-to-right shunting<br>(-) Increase in blood volume can precipitate failure because the patient is in a state of compensatory hypervolemia | Avoid excessive fluid administration, overtransfusion, and Trendelenburg position:<br>➢ Strict monitoring of fluid balance<br>➢ Early recognition and careful response to hemorrhage<br>➢ Avoid increases in afterload<br>➢ Maintain effective neuraxial labor analgesia<br>Avoid paradoxical embolism:<br>➢ Place filters on intravenous lines<br>➢ Perform epidural loss of resistance technique with saline and not air |

Modified from Arendt[20] and Arendt and Lindley.[21]

*Cyanotic congenital heart disease, Eisenmenger syndrome, and all pulmonary vascular hypertensive diseases carry a high mortality rate in pregnancy, labor, delivery, and the postpartum period.

(-) indicates deleterious physiologic change; (+) indicates favorable physiologic change; SVR, systemic vascular resistance.

a normal pregnancy such as fatigue, shortness of breath and edema, can overlap with the symptoms of heart failure. The American College of Obstetricians and Gynecologists Practice Bulletin on pregnancy and heart disease emphasized this with a table of reported symptoms, vital signs, and physical exam signs which, when reported in pregnancy, should lead to a prompt cardiac evaluation.[14] These are summarized in table 5.

The National Partnership for Maternal Safety has published the Maternal Early Warning Criteria which is a list of abnormal parameters designed to expedite recognition, diagnosis, and treatment of women who may be developing critical illness.[22] These include a systolic blood pressure less than 90 or greater than 160 mmHg; a diastolic blood pressure greater than 100 mmHg; HR less than 50 or greater than 120 beats/min; respiratory rate less than 10 or greater than 30 breaths/min; oxygen saturation on room air less than 95%; urine output less than 35 ml/h during the span of 2 h; and women presenting with agitation, confusion, or unresponsiveness, or patients with preeclampsia reporting a nonremitting headache or shortness of breath. Women who present with any of the signs or symptoms from the American College of Obstetricians and Gynecologists Practice Bulletin on pregnancy and heart disease or the Maternal Early Warning Criteria should undergo immediate assessment to determine the cause. If any of the patient's signs or symptoms are suspicious for heart disease of any sort, there should be a low threshold to obtain echocardiography, chest imaging, and electrocardiography.

**Table 5.** Signs and Symptoms Indicating a Prompt Evaluation by the Pregnancy Heart Team*

| Vital Signs | Physical Exam Signs | History and Symptoms |
|---|---|---|
| Heart rate ≥ 120 beats/min | Jugular venous pressure visible 2 cm above clavicle at 45° | History of cardiovascular disease |
| Systolic blood pressure ≥ 160 mm Hg | Loud systolic murmur or S4 | Shortness of breath at rest, paroxysmal nocturnal dyspnea, orthopnea, refractory pneumonia, or bilateral chest infiltrates on chest radiography |
| Symptomatic low blood pressure | Wheezing | Chest pain at rest or minimal exertion |
| Respiratory rate ≥ 25 breaths/min | Lung crackles | Exertional or unprovoked syncope or palpations associated with near syncope or syncope |
| Oxygen saturation < 95% | Marked peripheral edema | Extreme fatigue |

Modified from American College of Obstetricians and Gynecologists.[14]

*An institution's team of cardiologists, obstetricians, perinatologists, and anesthesiologists focused on the care of pregnant women with cardiovascular disease.

Maintaining sinus rhythm can be essential because loss of atrial contraction may not be well tolerated by patients with preload-dependent lesions or by patients with diastolic dysfunction. Epinephrine and norepinephrine can incite tachyarrhythmias and these catecholamines have been shown to increase significantly throughout labor.[23] The onset of effective labor analgesia has been associated with a decrease in these catecholamines.[24] Therefore, effective neuraxial labor analgesia is a key component of obstetric anesthetic care for patients with cardiac disease, especially those at risk for cardiac arrhythmias.

### *Contribution of Afterload*

Systemic vascular resistance (SVR) decreases with pregnancy, as does mean arterial pressure and diastolic pressure. This is primarily a result of the vasodilatory effects of progesterone, estrogen, prostaglandins, relaxin, and nitric oxide. As the placenta develops, it further contributes to low vascular resistance by adding a high-flow, low-resistance shunt to the maternal circulation.

Patients with afterload-dependent lesions, such as left ventricular outflow tract obstructive lesions, can be at high risk for cardiovascular complications during pregnancy and delivery. Decreases in afterload can happen quickly during delivery as a result of anesthetic or obstetric management choices, or as a result of complications (*e.g.,* obstetric hemorrhage). For example, in a patient with severe aortic stenosis, a postpartum hemorrhage can result in decreased preload and consequently, decreased mean arterial and aortic diastolic pressure that results in decreased coronary perfusion to the thickened myocardium and thereby myocardial ischemia. The ischemic myocardium may not be able to effectively pump against the stenotic aortic valve, which can result in a decrease in CO, further ischemia, and death. To prevent this, it is critical that the anesthesiologist recognize the event early and provide rapid vasopressor support to maintain coronary perfusion until adequate volume resuscitation can occur. In lesions that can spiral quickly from inadequate aortic diastolic pressure, general anesthesia induction medications and vasopressor medications should be titrated carefully to avoid hypotension. The risks and benefits of the administration of medications commonly used for obstetric indications that cause a rapid drop in SVR, such as terbutaline or intravenous boluses of oxytocin, should be weighed carefully. Further, the onset of neuraxial anesthesia should involve careful blood pressure monitoring and treatment to mitigate the effects of the sympathectomy that can result from neuraxial local anesthetics.

## How Do I Manage a Planned Vaginal Delivery in Heart Disease?

### *Monitoring and Intravenous Access*

The ASA guidelines state that "neuraxial anesthesia for labor and/or vaginal delivery requires that the parturient's vital signs and the fetal HR be monitored and documented by a qualified individual. Monitoring technique, frequency of recording, and additional monitoring should be chosen with regard to the clinical condition of the parturient and fetus and in accordance with institutional policy.[25] The Association of Women's Health, Obstetric, and Neonatal Nurses suggests a baseline pulse oximetry, temperature, HR, and blood pressure, with the subsequent frequency of assessment depending on the clinical circumstances.[26] Likewise, according to the Association of Women's Health, Obstetric, and Neonatal Nurses, upon the initiation of labor analgesia, the blood pressure frequency minimum is every 5 min for the first 15 min, and then repeated at 30 min and 1 h after the procedure.[26] For some women with cardiac disease, these minimums are not adequate. The frequency of vital sign monitoring may depend on the type and severity of heart disease. Continuous pulse oximetry and HR monitoring should occur throughout labor on a monitor that provides a visible waveform with audible alarms dedicated to alert for maternal bradycardia, tachycardia, or oxygen desaturations. Frequent blood pressure monitoring should occur with assessments every 2 to 5 min immediately after initiation of neuraxial analgesia or after bolus dosing of neuraxial analgesia. We also recommend the employment of the Maternal Early Warning Criteria in all units to facilitate

timely recognition, diagnosis, and treatment for women developing critical illness.[22]

Indications for electrocardiography include a history of a tachyarrhythmia, a cardiac lesion at high risk for arrhythmia, or a patient at risk for myocardial ischemia. Because many labor and delivery nurses are not qualified for electrocardiographic monitoring nor administration of vasopressor or inotropic medications, predelivery staffing coordination with the nursing leadership team may be necessary.

Invasive blood pressure monitoring, especially when placed before initiation of neuraxial analgesia, may be useful to more rigorously maintain maternal blood pressure. Moreover, intraarterial blood pressure monitoring can be critically important in the case of obstetric or cardiac emergencies. For a patient with severe aortic stenosis needing an emergent cesarean delivery, for example, the beat-to-beat blood pressure measurements can guide the anesthesiologist though the hemodynamic fluctuations of a rapid induction of neuraxial or general anesthesia. Lesions for which intraarterial blood pressure monitoring during labor can be helpful include moderate to severe left-sided outflow tract obstructive lesions, severe mitral stenosis, cardiomyopathy with significantly reduced ejection fraction, right heart dysfunction, pulmonary hypertension, or preeclampsia with heart failure.

Central venous pressure monitoring has low utility in labor. A central venous line should be placed if vasoactive medications or inotropes are anticipated to be required or as a conduit for a pulmonary artery catheter. Pulmonary artery catheters may be considered to assist in monitoring the response to pulmonary vasodilator therapy in patients with severe pulmonary hypertension who are anticipated to require inhaled and intravenous pulmonary vasodilators as a result of the anticipated fluid shifts during delivery causing fluctuations in pulmonary pressure. Transthoracic echocardiogram can be a useful tool for assessing the maternal cardiac tolerance to labor and delivery during the peripartum period and may be employed if the patient shows signs of hemodynamic instability such as unexplained tachycardia, hypotension, or hypoxia. Noninvasive CO monitors are not yet well validated in pregnant women.

## Labor Analgesia

Vaginal deliveries are associated with a reduced risk of blood loss, infection, and venous thromboembolism compared to cesarean delivery.[27–29] Therefore, a vaginal delivery with effective neuraxial analgesia is the preferred mode of delivery for most women with cardiovascular disease.[14] Epinephrine and norepinephrine have been shown to increase significantly throughout labor, and the onset of effective labor analgesia has been associated with a decrease in these catecholamines.[23] An epidural catheter also provides a conduit for conversion to surgical anesthesia should cesarean delivery be necessary. The fluctuations in CO during labor are thought to be a result of an increase in central blood volume during uterine contractions from autotransfusion, as well as a result of pain and catecholamine release. As contractions begin, so do fluctuations in CO, and as labor progresses, these CO fluctuations increase in amplitude.[30] Therefore, in a patient with cardiac disease, neuraxial labor analgesia should be initiated upon the onset of labor discomfort and the epidural catheter should be replaced if analgesia is suboptimal.

There is little evidence that a routine intravenous crystalloid bolus prevents hypotension after neuraxial labor analgesia initiation. Therefore, for patients with cardiovascular disease at risk for pulmonary edema, it is reasonable for the anesthesiologist to avoid a routine fluid bolus before the initiation of neuraxial labor analgesia. At the onset of neuraxial analgesia, small fluid boluses (*e.g.,* 200 ml) can be used to treat blood pressures that are below baseline. Vasopressors, such as small doses of intravenous phenylephrine (*e.g.,* 50 to 100 mcg), can be used in patients who need augmentation of SVR, and small doses of intravenous ephedrine (*e.g.,* 5 to 10 mg) can be used in patients who may benefit from the vasoactive peptides that are indirectly released by ephedrine for augmentation of SVR, contractility, and HR. Norepinephrine 0.02 to 0.08 mcg · kg$^{-1}$ · min$^{-1}$ or 1 to 6 mcg/min may be used when β-adrenergic agonism is necessary beyond the solely α-adrenergic agonism provided by phenylephrine. These doses of norepinephrine can be administered safely through peripheral intravenous lines.[31] Women with reduced cardiac function may benefit from an inotropic medication to augment contractility that facilitates increased volume through cardiopulmonary circulation. Dobutamine (5 to 10 mcg · kg$^{-1}$ · min$^{-1}$) provides mostly β1 and some β2 agonism and works rapidly with few side effects. Milrinone, a phosphodiesterase-3 inhibitor (0.125 to 0.375 mcg · kg$^{-1}$ · min$^{-1}$), is typically initiated with a loading dose that can cause decreased SVR. Therefore, in laboring women with preeclampsia, if time allows, a slow load titration instead of a loading dose may be optimal. Dopamine has varied actions depending on the dose range (dopamine receptor 1: 1 to 2 mcg · kg$^{-1}$ · min$^{-1}$), β2 agonism (2 to 10 mcg · kg$^{-1}$ · min$^{-1}$), and α1 agonism (greater than 10 mcg · kg$^{-1}$ · min$^{-1}$). Epinephrine (0.02 to 0.1 mcg · kg$^{-1}$ · min$^{-1}$), with its α1, β1, and β2 agonism, reliably provides cardiac contractile augmentation when necessary.

Women with cardiac disease are often prescribed anticoagulation therapy; therefore, neuraxial techniques must be timed according to the anticoagulation medication and dose to minimize the risk of spinal epidural hematoma. Women with low-flow states, Fontan physiology, pulmonary hypertension, mechanical heart valves, or atrial fibrillation are likely to be on anticoagulant therapy.[13] Because thrombotic events can cause major morbidity and mortality for pregnant patients with cardiovascular disease, and because anticoagulation can affect the timing and safety

of neuraxial anesthesia, decisions about the management of peripartum anticoagulation should be a made by the multidisciplinary team. The American Society of Regional Anesthesia Guidelines and the Society for Obstetric Anesthesia and Perinatology consensus statement can help guide decision-making.[32,33] According to these societies, neuraxial analgesia may be safely administered for women who are on low-dose (5,000 units two or three times daily) unfractionated heparin and who are more than 4 to 6 h from their last dose. If the low-dose heparin was administered within the last 4 to 6 h; if intermediate-dose heparin (7,500 or 10,000 units twice daily) was administered more than 12 h before; or if high-dose heparin (daily dose greater than 20,000 units; any single dose greater than 10,000 units) was administered more than 24 h before, then an activated partial thromboplastin time should be within normal range or an anti–factor Xa level undetectable. If the activated partial thromboplastin time is abnormal, an anti–factor Xa is detectable, or a patient received high-dose heparin with the last 24 h, the patient may be at increased risk for spinal epidural hematoma. Neuraxial procedures should be avoided for at least 12 h after subcutaneous low-dose low–molecular weight heparin (*e.g.,* enoxaparin less than or equal to 40 mg once daily or 30 mg twice daily) and at least 24 h for high-dose, low–molecular weight heparin (*e.g.,* enoxaparin 1 mg/kg twice daily or 1.5 mg/kg once daily).

### Neuraxial Labor Analgesia Technique

Epidural catheters can be placed *via* an epidural, dural puncture epidural, or combined spinal epidural technique. In cardiac disease, an opioid-only intrathecal drug administration may provide rapid analgesia while avoiding the sympathectomy effects from neuraxial local anesthetic administration. An epidural or dural puncture epidural technique may allow for a slow onset of the sympathectomy. A dural puncture epidural technique may provide greater assurance that the tip of the epidural needle is correctly sited in the epidural space.[34] A combined spinal epidural with intrathecal local anesthetic or a dural puncture epidural may facilitate coverage of the sacral nerve roots.[34] Superior coverage of sacral nerve roots can be beneficial in patients in whom the pregnancy heart team has chosen to delay maternal expulsive maneuvers, avoid pushing altogether, and/or perform an assisted vaginal delivery (*e.g.,* forceps or vacuum). Whichever neuraxial technique is performed, the most important aspect is to safely site the epidural catheter in the epidural space so that it facilitates complete labor analgesia and can be used for surgical anesthesia for cesarean delivery if necessary.

Of note, in patients with intracardiac shunting, a loss-of-resistance with saline technique instead of air may decrease the chance of paradoxical air embolism in the event of intravascular needle placement.[35,36] Whether a combined spinal epidural, dural puncture epidural, or epidural technique is chosen, the anesthesiologist should monitor the maternal hemodynamics carefully after placement and augment the blood pressure with vasopressors as needed. Even if no intrathecal local anesthetics are utilized (*e.g.,* combined spinal epidural initiated with intrathecal opioid), the act of relieving pain with neuraxial analgesia may decrease the release of endogenous catecholamines which could potentially result in a decrease in maternal blood pressure.

When an epidural catheter is placed, a test dose of epidural medication is often used to indicate unintentional intravascular or intrathecal placement. A traditional test dose has been described as 3 ml of lidocaine 1.5% or 2.0% (45 mg or 60 mg) with 1:200,0000 dilution of epinephrine (total 15 mcg). In patients with cardiac disease, thought should be given to whether the risks outweigh the benefit of a traditional test dose. The epinephrine "tests" for an intravascular catheter *via* expected changes in the HR or blood pressure. This intravascular test dose of epinephrine 15 mcg in women with a history of arrhythmias, stenotic heart lesions, or severe aortopathies could be harmful. In these scenarios, fentanyl 50 to 100 mcg may be a more prudent intravascular test dose, with the anesthesiologist asking patients to report any effects of intravascular opioid administration.[37,38] In patients with cardiovascular disease, the intrathecal test dose should also be carefully considered because high spinal anesthesia has been reported after intrathecal test doses which would be poorly tolerated in a woman with cardiovascular disease.[39,40] Here, instead of lidocaine, the anesthesiologist may choose to administer 5 ml aliquots of the epidural labor analgesia solution (*e.g.,* bupivacaine 0.0625 to 0.125% with 1 to 2 mcg/ml fentanyl) and assess the patient for intrathecal placement every 5 min until the block is established.[41] A slow titration of the initial epidural medication bolus during a span of 10 to 20 min, with careful monitoring of vital signs and motor block, is important to detect a misplaced catheter and to prevent and treat hypotension. Labor analgesia may be maintained with standard local anesthetic and opioid infusions, either *via* continuous epidural medication infusions with patient controlled boluses or programed intermittent boluses. Neither of these delivery modes is contraindicated in women with cardiac disease.

Valsalva maneuvers in women with severely enlarged aortic aneurysms theoretically increase the risk of rupture as fluctuations in preload cause an increase in sheer stress to the aorta. A modified Valsalva maneuver with an open glottis may reduce the changes in intrathoracic pressure that occur with a closed-glottis Valsalva maneuver.[42,43] In women undergoing assisted vaginal deliveries (*e.g.,* forceps or vacuum), the anesthesiologist may need to augment labor analgesia with epidural local anesthetic medication to provide a dense sacral neuraxial block to prevent pain from assisted vaginal delivery or to prevent involuntary maternal expulsive maneuvers. Augmentation of the epidural block

can usually be performed with 5- to 10-ml doses of lidocaine 2% or 5- to 10-ml doses of chloroprocaine 3% with minimal hemodynamic consequences. Continuous pulse oximetry, HR, and frequent blood pressure monitoring with treatment of hypotension with vasopressor medications (*e.g.,* phenylephrine, norepinephrine, or ephedrine) should occur throughout an assisted vaginal delivery. It is important to note that women who require an assisted vaginal delivery may be more prone to bleeding at the time of delivery.[44]

## How Do I Manage a Cesarean Delivery in Heart Disease?

### *Indications for Cesarean Delivery*

Cesarean delivery is typically reserved for obstetric, not cardiovascular, indications.[14] Exceptions include large expanding or dissecting aortic aneurysms and maternal anticoagulation with warfarin. Mechanical valves occasionally require warfarin anticoagulation during pregnancy, and while warfarin crosses the placenta, warfarin reversal therapies (vitamin K, fresh frozen plasma, coagulation factor concentrates) do not. Therefore, the anticoagulated fetus can have cerebral hemorrhage as a result of vaginal birth.[12] Cesarean delivery may also be indicated in critical valvular stenosis, severe decompensated pulmonary hypertension, or any women requiring tracheal intubation for acute heart failure.

### *Anesthetic Technique for Cesarean Delivery*

Neuraxial anesthesia is preferred for cesarean delivery whenever possible, including in women with Modified World Health Organization Classification of Cardiovascular Disease in Pregnancy class III or IV lesions. The hemodynamic changes from the onset of a spinal anesthetic for cesarean delivery are more rapid and pronounced than for an epidural anesthetic.[45] Nonetheless, women with Modified World Health Organization Classification of Cardiovascular Disease in Pregnancy class I or II cardiac disease typically tolerate a typical intrathecal dose of local anesthesia for cesarean delivery.[45] If the cesarean section is anticipated to be uncomplicated, then a lower dose of bupivacaine can be considered because lesser intrathecal doses have been associated with reduced hemodynamic fluctuations.[46,47] Depending on the lesion, women with Modified World Health Organization Classification of Cardiovascular Disease in Pregnancy class III or IV lesions may benefit from a more gradual onset sympathectomy. Options include an epidural technique, a combined spinal epidural technique with intrathecal opioids and epidural local anesthetic, or a sequential combined spinal epidural technique in which intrathecal opioids and low-dose bupivacaine (2.5 to 5 mg) are administered, followed by a slow epidural medication titration with 2% lidocaine or other appropriate local anesthetic (bupivacaine, ropivacaine, or levobupivacaine) to a T4 to 6 surgical level.[48] Many anesthesiologists prefer the sequential combined spinal epidural technique in cardiac disease because it theoretically combines the greater block reliability, symmetry, and consistency of intrathecal local anesthesia with the more gradual onset sympathectomy of epidural local anesthesia.[21]

Monitoring for a cesarean delivery includes standard ASA monitors and, often, intraarterial blood pressure monitoring.[49] The beat-to-beat blood pressure measurements assist in titration of vasopressors (typically phenylephrine, norepinephrine, and ephedrine) during induction of a neuraxial or general anesthetic. Central venous and pulmonary artery pressure monitoring are reserved for patients with cardiopulmonary decompensation or right ventricular failure requiring titration of vasopressors and pulmonary vasodilators.

Indications for general anesthesia include cardiopulmonary decompensation, current anticoagulation, severe thrombocytopenia, and maternal refusal of neuraxial anesthesia.[32,33] In women at risk of heart failure, there is a theoretical risk of decompensation immediately after delivery because aortocaval decompression and uterine involution at the time of delivery can acutely increase preload. It is our opinion that if a woman with cardiac disease can lie flat without dyspnea or hypoxemia, acute decompensation from heart failure at the time of delivery is rare. If a patient with cardiac disease is dyspneic or hypoxemic lying flat before cesarean delivery, then we believe general anesthesia with intubation may be prudent to prepare for potential decompensation immediately after delivery. Precordial Doppler changes consistent with venous micro air emboli have been reported in up to 65% of women undergoing cesarean delivery.[50] The usual practice of some obstetricians is to exteriorize the uterus to facilitate closure of the hysterotomy. This uterus exteriorization may contribute to micro air emboli which can be deleterious in women with right ventricular compromise or pulmonary vascular disease. While formal recommendations do not yet exist regarding this practice, it seems theoretically beneficial for the obstetricians to leave the uterus *in situ* for hysterotomy closure, if possible, in women with right ventricular compromise or pulmonary vascular disease.

## How Do I Manage Obstetric Emergencies in Patients with Cardiovascular Disease?

### *Fetal Distress and Emergency Cesarean Delivery*

Clear plans for obstetric emergencies should be established before delivery. Obstetric drugs that may be administered during obstetric emergencies that have hemodynamic effects are reviewed in table 6. In the event of fetal bradycardia caused by uterine tachysystole, the obstetricians may administer terbutaline, a β2-adrenergic receptor agonist, as a tocolytic agent to decrease the force of uterine contractions to allow improved uteroplacental perfusion. Terbutaline is

**Table 6.** Side Effects of Medications Commonly Used for Obstetric Care

| Medication (Class) | Cardiopulmonary Effects | Lesions for Which Medication Is Relatively Contraindicated | Notes |
|---|---|---|---|
| Oxytocin (uterotonic) | ↓ SVR and MAP<br>Slight ↑pulmonary vascular resistance and PAP | Most cardiac patients tolerate oxytocin if carefully titrated | Effective uterotonic agent<br>Administer slowly *via* infusion pump in patients intolerant of ↓ MAP<br>Consider counteracting ↓ MAP with phenylephrine infusion<br>Do not administer in bolus intravenous form in patients with cardiac disease |
| Misoprostol (uterotonic) | None | None | Least effective uterotonic agent<br>Can be used prophylactically |
| Methylergonovine (uterotonic) | ↑ SVR<br>↑Pulmonary vascular resistance | Hypertension<br>Preeclampsia<br>Pulmonary hypertension<br>Ischemic disease<br>Intracardiac shunts<br>Aortopathy | Mechanism similar to an α-adrenergic agent<br>Generally avoided in cardiac patients |
| Carboprost (uterotonic) | ↑ PAP<br>Bronchospasm resulting in ventilation perfusion mismatch | Fontan circulation<br>Intracardiac shunt<br>Pulmonary hypertension | Prostaglandin F2α<br>Do not use in patients who cannot tolerate increased PAP |
| Terbutaline (uterine relaxant) | ↑ Heart rate<br>↑ Myocardial contractility<br>↓ SVR | Hypertrophic obstructive cardiomyopathy<br>History of tachyarrhythmias | β-agonist |

MAP, mean arterial pressure; PAP, pulmonary artery pressure; SVR, systemic vascular resistance.

contraindicated in some women with cardiovascular disease. For example, the increase in HR and myocardial contractility and the decrease in SVR from terbutaline could cause hemodynamic collapse in a patient with hypertrophic obstructive cardiomyopathy. Likewise, patients who would not tolerate tachycardia or patients with a history of tachyarrhythmias should not receive β-adrenergic agonist drugs in labor. Nitroglycerine administered sublingually or intravenously is a uterine relaxant that can be used for acute tocolysis of uterine tachysystole. However, nitroglycerine can also cause an acute decrease in SVR and subsequent tachycardia and should therefore be used with caution in women who could have hemodynamic compromise from these changes.

A laboring woman is always at risk of requiring an emergent intrapartum cesarean delivery. Placental abruption, umbilical cord prolapse, uterine rupture, or persistent uteroplacental insufficiency can result in the need for rapid conversion from neuraxial labor analgesia to surgical anesthesia. For this reason, an arterial line placed during labor to be prepared for emergency cesarean delivery, if necessary, can be helpful in patients categorized as Modified World Health Organization Classification of Cardiovascular Disease in Pregnancy classes III and IV. When an epidural catheter is *in situ*, local anesthetic can be dosed for cesarean delivery and maintenance of SVR can be maintained with phenylephrine or norepinephrine if necessary. Maternal physiology and fetal status will dictate whether epidural medications can be dosed rapidly, whether slow titration is prudent, or whether rapid conversion to general endotracheal anesthesia is required.

### *Postpartum Hemorrhage and Uterotonic Agents*

Postpartum hemorrhage is a risk to all women after delivery and is twice as common in women with heart disease.[51,52] Prophylactic uterotonics are typically administered to decrease the risk of uterine atony and postpartum hemorrhage. While all women should have excessive bleeding identified early in order to initiate resuscitation without delay, it is especially important for women with cardiovascular disease. Oxytocin should be titrated *via* an infusion pump because bolus dosing can rapidly decrease SVR.[53] Further, doses of oxytocin greater than the ED95 dose generally do not provide more benefit because lower doses (16.2 U/h in nonlaboring women undergoing cesarean section and 44.2 U/h in laboring women undergoing cesarean section) appear effective and higher doses have been associated with greater side effects.[54,55]

Uterotonics beyond oxytocin may be requested if uterine tone remains inadequate. It is essential to weigh the risks associated with the side effects of specific uterotonics with the benefit provided by the uterotonics to prevent uterine atony and hemorrhage. The side effect profile of carboprost and methylergonovine precludes safe usage in many cardiovascular lesions. For example, carboprost has been shown to increase pulmonary vascular resistance by more than 100% and pulmonary artery pressures by 125%.[56] It has been described as precipitating bronchospasm, abnormal ventilation perfusion ratios, increased intrapulmonary shunt fraction, hypoxemia, and death.[57–59] In patients with preexisting asthma, pulmonary hypertension, or right heart compromise, carboprost is relatively contraindicated.

Methylergonovine is thought to interact with α-adrenergic receptors as an agonist and has been described to increase SVR, resulting in hypertension, seizure, and stroke,[60] as well as causing coronary vasospasm, resulting in myocardial ischemia and death.[61,62] Methylergonovine is relatively contraindicated in patients with hypertension, preeclampsia, aneurysms, or coronary artery disease.[60–63] Typically, methylergonovine is administered for postpartum hemorrhage in a single 200-mcg intramuscular injection. Of note, in cases of severe, life-threatening hemorrhage, methylergonovine can be diluted and titrated slowly as an intravascular medication rather than an intramuscular injection so as to control the dose and effect and allow for antihypertensive medications to be given if needed.[64,65] If methylergonovine is administered by the intravenous route, extreme caution must be employed with vigilant monitoring and treatment of a possible hypertensive response.[64,65]

## How Do I Manage Cardiac Emergencies in Obstetric Patients?

### *Arrhythmias*

The overall prevalence of cardiac arrhythmias in pregnant women is rising,[66] and tachyarrhythmias in the antepartum period have been associated with poor fetal outcome.[67] Echocardiography should be performed in any pregnant woman presenting with a newly diagnosed tachyarrhythmia to investigate the presence of structural disease.[12] Patients with a history of tachyarrhythmia are at risk of experiencing arrhythmia during the peripartum period which can result in fetal compromise.[67] These women should be monitored with five-lead electrocardiography during labor with central telemetry when possible.

Atrial fibrillation and paroxysmal supraventricular tachycardia are the most common arrhythmias in pregnancy, while ventricular tachycardia, ventricular fibrillation, and heart block are rare in the pregnant population.[12,67] These arrythmias should be managed similarly to nonpregnant patients.[12] Pacemakers and automatic implantable cardioverter defibrillators should be left "on" in labor as these devices provide a rapid response to a tachyarrhythmia. A cesarean delivery occurs below the umbilicus, therefore, disabling the defibrillation function of the automatic implantable cardioverter defibrillator is not necessary.[68]

The 2018 European Society of Cardiology's guidelines for the management of cardiovascular diseases during pregnancy outline the management of arrythmias in pregnant women.[12] Overall, the acute management of arrythmias in pregnancy is unchanged from the nonpregnant state. If new-onset atrial fibrillation occurs during pregnancy, cardioversion is advised.[12] Chemical or electrical cardioversion can be performed in pregnancy; however, transesophageal echocardiography is required to ensure there is not thrombus in the left atrial appendage. Adenosine can be used safely in pregnancy in women with paroxysmal supraventricular tachycardia; β-adrenergic blockers or calcium channel blockers can be used to slow the ventricular rate in atrial fibrillation. The fetus should be monitored during chemical cardioversion. In unstable patients, electrical cardioversion should be performed immediately. The American Heart Association states that if rapid electrical therapy is indicated, the presence of fetal monitors (even a fetal scalp electrode) should not delay the shock.[69] The risk to the mother in delaying this therapy outweighs potential concern for electrical arcing *via* the fetal monitors.

### *Anesthesia for Termination of Pregnancy*

A Modified World Health Organization Classification of Cardiovascular Disease in Pregnancy Class IV lesion is associated with high maternal mortality with consensus that pregnancy should be discouraged. When these very high-risk women present pregnant in the first or early second trimester, a termination of pregnancy may be offered. Termination carries risk and, just as with delivery, should occur at a hospital with the level of maternal care consistent with the Modified World Health Organization's Classification of Cardiovascular Disease in Pregnancy as outlined in table 2. The European Society of Cardiology's guidelines state that for pregnancy termination in cardiac disease, dilatation and evacuation is the safest procedure in both the first and second trimesters.[12] However, in patients up to 7 weeks' gestation, the European Society of Cardiology does state that medical termination with mifepristone, an antiprogestin compound, is an optional alternative to surgery.[12] Alternatively, if a medical termination is induced with a prostaglandin E1 or E2 compound or misoprostol, then continuous pulse oximetry should be employed throughout and the unit should have the ability to initiate a norepinephrine infusion to support any decrease in SVR. Prostaglandin F compounds such as carboprost should be used with caution in women with cardiac disease. Healthy patients are often sent home overnight after the prostaglandin is administered for a medical abortion, but patients with cardiac disease may need to be monitored in the hospital during this time.

For surgical dilation and curettage or evacuation, neuraxial anesthesia, general anesthesia, and deep sedation with and without paracervical block may all be options in women with cardiac disease. If the patient's anticoagulation regimen does not prevent neuraxial anesthesia and the patient is willing to remain awake for the procedure, a single shot spinal anesthetic with a goal dermatomal block to T10 is an option for many patients,[70] and could be considered in select patients with cardiac disease. Intraarterial blood pressure monitoring and prophylactic intravenous phenylephrine or norepinephrine infusions should be considered in patients with cardiac lesions in whom sympathectomy would be poorly tolerated. Obstetric considerations that favor general anesthesia include gestational age beyond first

trimester, ossification of the fetus (and thereby the need for instrumental evacuation beyond suction curettage), and any other factor that increases the likelihood of blood loss (*e.g.,* molar or scar pregnancy).[70] Cardiac considerations favoring general anesthesia include heart failure or hypoxia precluding supine or lithotomy positioning or concerns regarding the safety of administering any sedative medications in a patient who desires to be asleep for the procedure.

### *Cardiovascular Surgery and Cardiopulmonary Arrest*

Should a pregnant woman present with the dissection of a major vessel or other cardiovascular emergency requiring immediate surgery, an emergent need for cardiac surgery should not be delayed due to pregnancy. If the fetus is term or if there are signs of fetal distress in a preterm viable fetus, a cesarean delivery can be performed concurrent with the vascular or cardiac surgery. The decision to deliver a fetus must be made on an individual basis, weighing the risk of prematurity with the benefits of delivering a fetus before cardiopulmonary bypass. If a pregnancy is maintained through a surgery requiring cardiopulmonary bypass, high-flow normothermic perfusion during cardiopulmonary bypass is shown to most optimally maintain uteroplacental perfusion.[71–75]

ECMO may be required during pregnancy for pulmonary or cardiopulmonary failure. The most common indication for venovenous ECMO support during pregnancy is adult respiratory distress syndrome from influenza, and it has more recently been employed in pregnant women with COVID-19.[76,77] Venoarterial ECMO has been used during pregnancy for pulmonary embolism, pulmonary hypertension, and cardiac failure.[78] ECMO during cardiopulmonary resuscitation has been employed for amniotic fluid embolism and cardiac failure.[76] Women with right heart compromise, severe left heart dysfunction, or pulmonary hypertension are the highest risk of requiring mechanical support during pregnancy termination, labor and delivery, or cesarean delivery.[69,78,79] In these extremely high-risk patients, venous and arterial micropuncture catheters can be placed before delivery so as to facilitate rapid exchange to ECMO cannulas and deployment of ECMO support in the event that it is necessary.

Maternal arrest is a rare event occurring in 1 in 12,000 delivery hospitalizations per year in the United States.[80] The most common etiologies of maternal arrest are hemorrhage, heart failure, amniotic fluid embolism, sepsis, and complications from anesthesia.[80] Point-of-care ultrasound and transthoracic echocardiography can narrow the diagnosis in undifferentiated shock or cardiac arrest. In hemorrhage, the heart will be hyperdynamic and the inferior vena cava collapsible. In cardiogenic shock, ventricular function will be decreased, the inferior vena cava will be noncollapsible, and B lines will be present on lung ultrasound. In obstructive shock, the right ventricle will be dilated and the inferior vena cava will be noncollapsible. In sepsis, the heart may be hyperdynamic or display decreased function and the inferior vena cava will range from collapsible to dilated.

Improved outcomes are seen when simulation is used to prepare labor floor teams for the rare event that requires advanced cardiac life support in a pregnant patient.[81,82] A cardiac arrest response team should include the hospital's code team, along with clinicians from the anesthesia, obstetrics, and neonatology teams. The resuscitation should occur at the site of the arrest, and the patient should not be moved to an operating room.[82,83] If return of spontaneous circulation does not occur in 4 min, a perimortem cesarean delivery is indicated to release aortocaval compression, improve maternal hemodynamics, reduce maternal oxygen demand, and improve survival of the mother and fetus.[82,83] If available, personnel capable of performing transesophageal echocardiography and ECMO during cardiopulmonary resuscitation should also be called.[84] Chest compressions should be performed with the pregnant woman supine at the usual 100/min rate with a second provider performing manual left uterine displacement to remove aortocaval compression.[69,82] Defibrillation should proceed and Advanced Cardiac Life Support medications be dosed as usually indicated.[69,82]

## How Do I manage the Postpartum Care of Women with Cardiac Disease?

Postpartum monitoring is dependent upon the patient's cardiovascular disease state and the events of delivery. Postpartum cardiovascular care may include titrating diuresis in heart failure, monitoring for arrhythmias, and monitoring for postpartum preeclampsia. Women with pulmonary hypertension or reduced ventricular function often benefit from acute use of inotropic medications, in addition to diuretic medications, to facilitate this transition back to prepregnancy volume status. It is also critically important to monitor for postpartum hemorrhage or postpartum preeclampsia and to also allow for typical breastfeeding support and newborn care education.

## What Are the Next Steps in Research and Development in the Anesthetic Care of Women with Cardiac Disease in Pregnancy?

While the cardiac, obstetric, and anesthetic care of women with cardiac disease in pregnancy has advanced in the last 3 decades, there is still much work to be done to improve outcomes. Work is needed to validate noninvasive hemodynamic monitoring technology in pregnancy. Peripartum cardiomyopathy remains difficult to identify and treat. Tools to more accurately identify heart failure in pregnancy and predict decompensation, such as simple multivariable alert systems integrated into the electronic record, or even artificial intelligence specific to hospitals, should be employed. Artificial intelligence could incorporate activity levels from personal wearable activity trackers to identify

at-risk patients, and inexpensive screening tests such as routine 12-lead electrocardiograms, could flag pregnant patients with early signs of heart failure and allow for earlier optimal management.[85] The role of bromocriptine in postpartum management of patients with peripartum cardiomyopathy remains controversial and needs to be clarified.[12] Moreover, little improvement has been made in the survival of women with pulmonary hypertension in pregnancy. Considering the poor survival outcomes, there is minimal research addressing the timing, delivery mode, and anesthetic care of these patients.[86] Finally, guidelines have been published from multiple societies, and a Patient Safety Bundle on cardiac conditions in obstetric care is in development through the Alliance for Innovation on Maternal Health program.[87] The next step will be studying compliance and the clinical effect of implementation of these recommendations for care across populations. We can hope that such efforts reverse the trend of cardiac disease causing an increasing proportion of maternal deaths in developed countries.[1,2,88–90]

## Conclusion

The American Heart Association, European Society of Cardiology, Society of Maternal–Fetal Medicine, and American College of Obstetricians and Gynecologists all recognize the vital role of anesthesiologists on pregnancy heart teams.[12–14] Obstetricians generally do not focus on hemodynamic optimization in heart disease and cardiologists rarely are immediately available in labor and delivery units. Optimizing hemodynamics in heart disease is daily work to an anesthesiologist, yet may be uncomfortable and novel to those who work regularly in labor and delivery units. The anesthesiologist can embrace the role of providing excellent labor analgesia, superb surgical anesthesia, prevention of adverse cardiac events, early recognition of critical events, and rapid and precise resuscitation. The anesthesiologist can embrace the role of a peridelivery physician leader[91] who unites multiple teams for the safe care of the pregnant woman with cardiac disease.

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The authors declare no competing interests.

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