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EXPERT PANEL

Recommendations for the Management of High-Risk Cardiac Delivery

ACC Cardiovascular Disease in Women Committee Panel

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ABSTRACT

Maternal mortality is a major public health crisis in the United States. Cardiovascular disease (CVD) is a leading cause of maternal mortality and morbidity. Labor and delivery is a vulnerable time for pregnant individuals with CVD but there is significant heterogeneity in the management of labor and delivery in high-risk patients due in part to paucity of high-quality randomized data. The authors have convened a multidisciplinary panel of cardio-obstetrics experts including cardiologists, obstetricians and maternal fetal medicine physicians, critical care physicians, and anesthesiologists to provide a practical approach to the management of labor and delivery in high-risk individuals with CVD. This expert panel will review key elements of management from mode, timing, and location of delivery to use of invasive monitoring, cardiac devices, and mechanical circulatory support. (JACC Adv 2024;3:100901) © 2024 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Cardiovascular disease (CVD) is a leading cause of maternal mortality and morbidity in the United States.[1] In 2021, the estimated maternal mortality rate in the United States reached an all-time high of 32.9 per 100,000 live births. Data from the 2017 to 2019 Maternal Mortality Review Committee found that over 80% of pregnancy-related deaths were preventable.[2] While there has been growing engagement and expertise in the management of pregnancy in patients with CVD, a significant proportion of patients will not have access to specialized cardio-obstetrics care. There is significant heterogeneity in management, particularly during labor and delivery, due in part to paucity of

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ABBREVIATIONS AND ACRONYMS

ACLS = advanced cardiac life support

aPTT = activated partial thromboplastin time

CVC = central venous catheter

CVD = cardiovascular disease

CS = cardiogenic shock

EHR = electronic health record

EMI = electromagnetic interference

HF = heart failure

ICD = implantable cardioverter-defibrillator

ICU = intensive care unit

LMWH = low-molecular-weight heparin

LV = left ventricular

MCS = mechanical circulatory support

PAC = pulmonary artery catheter

PPCM = peripartum cardiomyopathy

PPM = permanent pacemaker

SVR = systemic vascular resistance

UFH = unfractionated heparin

VKA = vitamin K antagonist

high-quality randomized data to inform best practice. In this context, we were invited to convene a multidisciplinary panel of cardio-obstetrics experts including cardiologists, obstetricians and maternal fetal medicine physicians, obstetric internists, critical care physicians, and anesthesiologists to provide a practical approach to the management of labor and delivery in high-risk patients with CVD (**Central Illustration**).

HIGH-RISK PATIENTS WITH CVD

Labor, delivery, and the immediate postpartum period represent vulnerable periods for all patients with established CVD, especially those with specific high-risk CV lesions. In this review, we consider any individual classified as mWHO category 3 or 4 and/or elevated risk by CARPREG II or ZAHARA risk score[3] as high-risk. While discussion of specific CV lesions is beyond the scope of this review, management of labor and delivery must be highly individualized to the patient's underlying condition and physiology. Ultimately, all high-risk patients should be evaluated by a cardio-obstetrics expert team. If a high-risk individual presents to a site without onsite cardio-obstetrics expertise, rapid triage and communication with a local cardio-obstetrics expert center is critically important as delays in diagnosis and management may contribute to significant maternal morbidity and mortality.

NORMAL HEMODYNAMIC CHANGES DURING LABOR AND DELIVERY

Maternal hemodynamics change in pregnancy to meet the increasing metabolic demands of the mother and to ensure adequate uteroplacental circulation for fetal growth and development.[4] Labor, delivery, and the early postpartum period are associated with marked changes in hemodynamics that are often more dynamic than what is observed during pregnancy itself and may contribute to clinical deterioration among patients with CVD.[5,6] Therefore, understanding and anticipating these changes is critically important for the optimal management of high-risk patients (**Figure 1**). The anticipated changes that occur during labor and delivery are based on a few small observational studies and were assessed using different techniques (eg, echocardiography, minimally invasive and invasive hemodynamic monitoring).[7,8] In singleton pregnancies, the onset of labor is accompanied by ~12% increase in basal cardiac output, based on an echocardiographic measurement of cardiac output, due to repeated uterine contractions and pain. Repeated uterine contractions contribute to rising cardiac output due to increases in stroke volume as uterine blood flow enters the systemic circulation while pain can contribute to significant increases in heart rate and blood pressure. The second stage of labor (from full dilation and effacement of the cervix to delivery) is a dynamic period characterized by further increase in cardiac output above pre-labor values. Details of the hemodynamic changes corresponding to the 4 phases of Valsalva maneuver are displayed in **Figure 1**.[8] Finally, the delivery of the placenta (third stage of labor) and immediate postpartum period are particularly vulnerable periods since relief of caval compression following delivery of the placenta and fetus and autotransfusion of the uteroplacental circulation into the maternal circulation dramatically raise preload and cardiac output as much as 60 to 80%.[9] The delivery of the low resistance placental unit also leads to an abrupt increase in systemic vascular resistance (SVR) in the postpartum period.

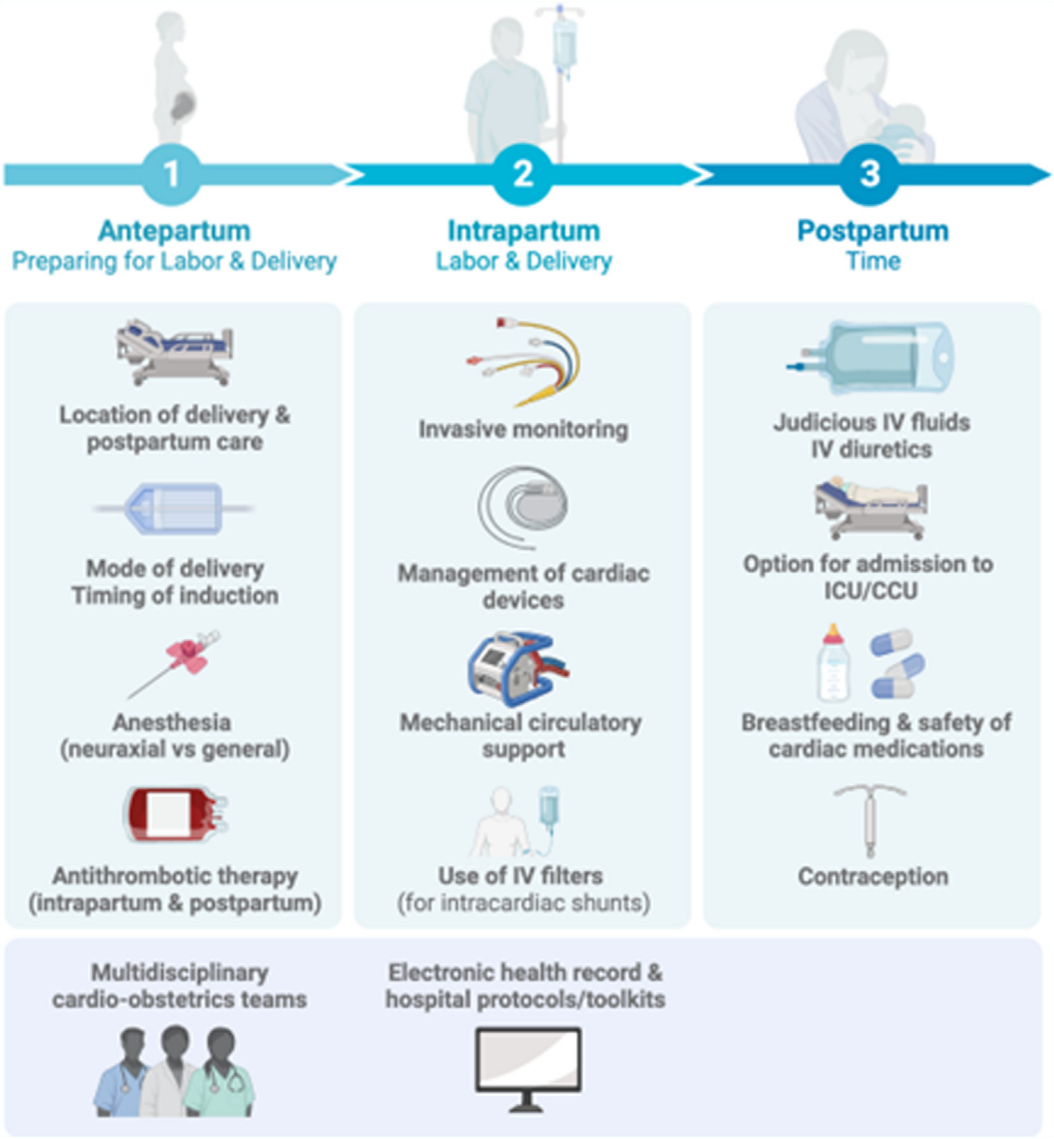
HIGHLIGHTS

- Labor and delivery is a vulnerable time for high-risk patients, characterized by with significant heterogeneity in management.
- For high-risk individuals, management should be individualized with multidisciplinary team input.
- Rapid triage and communication with a local cardio-obstetrics expert center is critical to delay diagnosis and management.
- Inclusion of pregnant individuals into trials and registries is essential to define best practice and improve maternal outcomes.

LOCATION OF LABOR AND DELIVERY

Recognizing that maternal care is fragmented across the United States, the Society for Maternal Fetal Medicine and the American College of Obstetricians and Gynecologists introduced a standardized classification system that establishes level of maternal care

CENTRAL ILLUSTRATION **Key Considerations for Intrapartum and Immediate Postpartum Management of Pregnant Patients With High-Risk Cardiovascular Disease**



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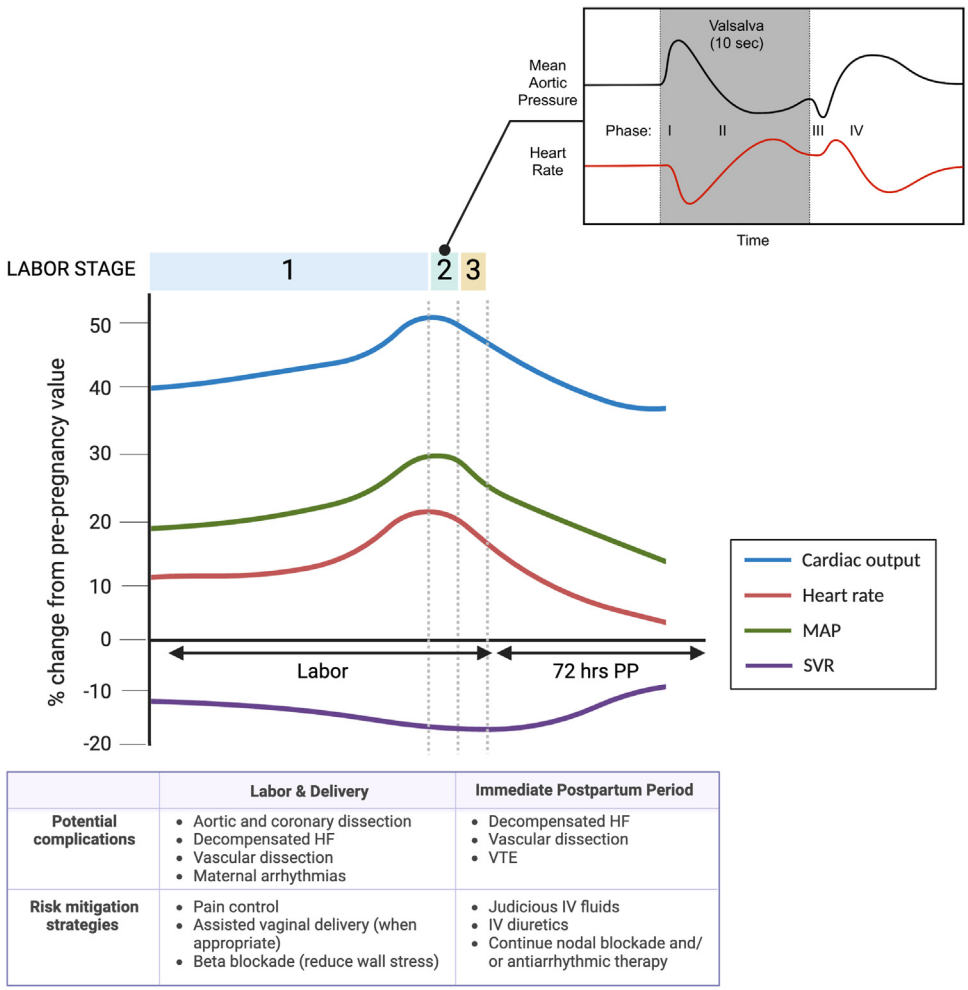
Prior to labor and delivery, mode of delivery, timing of induction, and location of intrapartum and postpartum care should be discussed. Anesthetic and antithrombotic therapy strategies should also be determined prior to labor and delivery. During labor and delivery, use of invasive monitoring, cardiac devices, and mechanical circulatory support are guided by the patient's cardiac risk profile and clinical hemodynamic status. Postpartum management should focus on optimization of fluid status, breastfeeding, and establishment of a postpartum contraception plan. Multidisciplinary cardio-obstetrics teams and electronic health record/hospital algorithms, protocols, and toolkits are critical for the optimal management of these high-risk individuals.

to help guide the optimal maternal care delivery site for patients.[10] This classification schema establishes 4 levels of maternal care: level 1 center (basic care), level 2 (specialty care), level 3 (subspecialty care), and level 4 (regional perinatal health care centers).[10] This system would facilitate on-demand transfer to appropriate facilities when needed and reduce disparities in access. Patients with CVD, particularly those classified as mWHO category 3 or 4 and/or elevated risk by the CARPREG II or ZAHARA risk

FIGURE 1 Hemodynamic Changes of Labor, Delivery, and Immediate Postpartum Period



	Labor & Delivery	Immediate Postpartum Period
Potential complications	• Aortic and coronary dissection • Decompensated HF • Vascular dissection • Maternal arrhythmias	• Decompensated HF • Vascular dissection • VTE
Risk mitigation strategies	• Pain control • Assisted vaginal delivery (when appropriate) • Beta blockade (reduce wall stress)	• Judicious IV fluids • IV diuretics • Continue nodal blockade and/or antiarrhythmic therapy

Changes in cardiac output, heart rate, mean arterial pressure, and systemic vascular resistance that occur during labor/delivery (by stage of labor) and the first 72 hours postpartum are displayed. Stage 2 of labor is characterized by repeated Valsalva maneuvers. Phase I of the Valsalva maneuver corresponds to an increase in thoracic pressure due to strain, resulting in transient increase in blood pressure. In phase 2, maintenance of the Valsalva maneuver leads to decrease venous return, decrease in blood pressure, and reflex tachycardia. With release of the Valsalva in Phase 3, there is a brief drop in blood pressure with normalization of intrathoracic pressure. Finally, phase 4 is characterized by restoration of LV preload, increase in blood pressure, and decrease in heart rate. MAP = mean arterial pressure; SVR = systemic vascular resistance; VTE = venous thromboembolism.

scores, as well as other patients deemed high risk for noncardiac reasons, should receive care at a level 4 maternal care center, when possible, with access to on-site intensive care, cardio-obstetrics and maternal fetal medicine expertise, nursing staff with expertise in the management of critically ill patients, obstetric anesthesia, and cardiac surgery if possible.

Labor and delivery are typically best managed on labor and delivery units although intensive care unit (ICU) delivery can be considered based on individual risk and institutional resources. Choice of delivery location should be based on the environment that can best offer invasive monitoring and ICU level care if needed. Options include the labor and delivery floor, labor and delivery operating room, cardiac care unit, hybrid operating room with ability for interventional procedures, or cardiac operating room. Cesarean deliveries that require cardiothoracic surgeons on standby may be best performed in a cardiothoracic operating room. When deliveries are performed outside of the labor and delivery unit, it is critical to have a mobile delivery cart including medication and equipment to manage cardiovascular complications such as arrhythmias and hemodynamic instability,

access to catheterization laboratory for acute coronary syndromes, and advanced heart failure (HF) and critical care teams in case of urgent need for mechanical support. Postpartum recovery location (ICU, stepdown/telemetry unit, obstetric floor) will also depend on availability and need for specialized resources (telemetry, invasive monitoring, more intensive nursing services). Nurses who are trained in both critical care and obstetrics provide a valuable resource to patients with cardiac disease in labor. More commonly, patients are co-managed collaboratively by nurses from both cardiac care and labor and delivery units. Finally, for high-risk patients, particularly those with existing CVD, home births are strongly discouraged.

MODE AND TIMING OF DELIVERY

Timing of delivery must consider the risks of prematurity balanced with the benefit of delivery. The American College of Obstetricians and Gynecologists guidelines support vaginal delivery from 39 to 40 weeks gestational age for the general population but there is scant literature to guide delivery timing for women with existing CVD and available data are heavily confounded. Maternal indication for cardiac surgery may influence timing of delivery. Cardiac surgery in pregnant individuals is associated with high fetal mortality but is lowest when performed after fetal viability (approximately 24 weeks gestation). However, if fetal viability can be safely achieved, fetal survival is highest if cesarean delivery is performed prior to cardiac surgery.[11]

Vaginal delivery is the preferred mode of delivery for most patients due to lower risk of obstetric/surgical complications and more gradual hemodynamic shifts when compared to cesarean delivery. An assisted second stage (forceps or vacuum-assisted) has been proposed for preload dependent lesions (eg, moderate-to-severe aortic stenosis, systolic dysfunction) to reduce prolonged Valsalva which has the theoretical risk of reducing preload and increasing aortic wall stress. However, the definition of what constitutes a prolonged Valsalva is unclear. Assisted second stage has been associated with increased risk of pelvic floor trauma and postpartum hemorrhage. There are specific circumstances, however, when cesarean delivery should be considered including labor in the setting of therapeutic anticoagulation with warfarin (owing to risk of fetal intracranial hemorrhage during vaginal delivery), acute or chronic aortic dissection, specific aortopathies (including bicuspid aortic valve with aorta >5.0 cm, Turner syndrome and an aortic size index >2.5 cm/m^2, aorta >4.5 cm in the setting of Marfan's syndrome or Loeys-Dietz syndrome, and all patients with vascular Ehlers-Danlos syndrome, and intractable HF/maternal shock (Table 1).[12,13] Ultimately, mode of delivery should be arrived at through patient-centered counseling, taking into consideration available data, multidisciplinary team input, and patient preferences.

TABLE 1 Recommended Delivery Management for Aortopathy[12]

Condition	Aortic Diameter	Delivery Mode	COR LOE
Aorta[a] not significantly dilated	<4 cm	Vaginal[b]	1 C-EO
Aortic enlargement[a]	4-4.5 cm	Vaginal reasonable[c]	2b C-EO
Syndromic (Marfan syndrome, Ehler-Danlos, Loeys-Dietz syndrome) or ns-HTAD	4-4.5 cm	Cesarean reasonable[d]	2a C-EO
Aortic diameter	≥4.5 cm	Cesarean reasonable	2a C-EO
Chronic aortic dissection	NA	Cesarean recommended	1 C-EO
Acute type A dissection T1-T2		Urgent aortic surgery[e]	1 C-LD
Acute type A dissection T3		Urgent cesarean delivery followed by aortic surgery	1 C-LD
Acute type A dissection 24-28 wk		Individualized decision may be required	
Type B dissection		Medical therapy with endovascular repair if possible and required. Cesarean mode delivery	1 C-LD
Progressive aortic growth		Prophylactic aortic surgery may be considered.	2 b C-EO

For all patients with aortopathy, beta-blockade therapy titrated to maximum tolerated dose is recommended. [a]Aortic root diameter, ascending aortic diameter, or both. [b]In absence of obstetric indication for cesarean mode of delivery. [c]With regional anesthesia, expedited second stage, assisted delivery. [d]Patients with vascular Ehlers-Danlos syndrome should always undergo cesarean delivery due to risk of uterine rupture with labor. [e]Surgery should be performed with fetal monitoring and modification of bypass to reduce fetal loss.

COR = class of recommendation; EO = expert opinion; LD = limited data; LOE = level of evidence; ns-HTAD = nonsyndromic heritable.

ANESTHESIA CONSIDERATIONS DURING LABOR AND DELIVERY

Pain control during labor and delivery is an important consideration in the management of high-risk cardiac patients. Reducing labor pain mitigates catecholamine surges and accompanied risk of tachycardia and arrhythmias.[14,15] Neuraxial anesthesia (epidural or spinal anesthesia) can significantly reduce SVR and blood pressure, particularly spinal anesthesia in patients undergoing cesarean delivery, where the onset of anesthetic block is rapid and pronounced.[14,16,17] The decrease in SVR can lead to decreased aortic diastolic pressure, reduced coronary perfusion, and increase in LV end-diastolic pressure, predisposing these high-risk patients to acute ischemia and volume overload. Therefore, maintaining maternal SVR and blood pressure throughout delivery and the immediate postpartum period is particularly important. Slow infusion of anesthetic via small incremental doses

rather than a single spinal dose is recommended to modulate the drop in SVR. Usually, vasopressor support with phenylephrine or norepinephrine is required to support maternal SVR.

General anesthesia should be reserved for patients undergoing cesarean delivery who are currently therapeutically anticoagulated, require intubation for cardiopulmonary decompensation, and/or decline neuraxial anesthesia.[14] However, it is important to anticipate that laryngoscopy and endotracheal intubation can cause tachycardia, hypertension, and arrhythmias. Rapid sequence induction and intubation are usually employed in obstetric patients to minimize the risks of aspiration and rapid desaturation, but patients with high-risk CVD may not tolerate the reduction in preload and afterload related to the rapid sequence induction strategy. Certain induction medications may cause a decrease in SVR which may be mitigated with vasopressor support. Induction medications that have less profound hemodynamic effects should be considered. Expert consultation with cardiothoracic and obstetric anesthesiologists should be obtained when planning induction of anesthesia in patients with the highest risk cardiovascular conditions.[18,19]

USE OF INTRAPARTUM HEMODYNAMIC MONITORING

Hemodynamic monitoring is an important adjunct for the management of high-risk cardiac deliveries. Noninvasive monitoring with continuous electrocardiogram monitoring with intrapartum telemetry is useful for patients with a history of arrhythmia. However, patient discomfort from additional monitoring devices during active labor should be weighed against potential benefit of monitoring for women with known risk of malignant arrhythmia. Data for use of invasive hemodynamic monitoring (including intra-arterial blood pressure monitoring, central venous catheter [CVC], and pulmonary artery catheters [PACs]) are limited and poorly validated in pregnant patients.[20] We agree with expert opinion that CVC and PAC monitoring in pregnancy should be reserved for patients with: 1) cardiopulmonary decompensation; 2) right ventricular failure requiring titration of vasopressors and/or pulmonary vasodilators; or 3) high risk of decompensation in setting of large volume shifts.[19] CVCs may also be used as a conduit for intravenous access particularly for patients for whom prolonged access is required or with challenging access. PAC may be helpful to accurately assess hemodynamic status in patients failing to respond to standard therapies. The routine use of PAC is not recommended in pregnant patients and should be individualized. The estimated risks of complications are low and on par with the general nonpregnant population (0.3%-3.8%).[21] Invasive arterial line blood pressure monitoring is recommended for pregnant patients when: 1) immediate beat-to-beat blood pressure monitoring would guide vasopressor and inotrope management; 2) changes in SVR could lead to rapid decompensation (eg, severe cardiomyopathy, dynamic outflow tract obstruction, high-risk aortopathy, and hypertensive emergencies); and 3) rapid and frequent arterial blood gases are needed. Whenever CVC and/or PAC are being utilized, concomitant arterial line use is generally recommended. Finally, some have advocated for the use of peripherally inserted central catheters or midline catheters for central venous pressure monitoring, but data are limited. Peripherally inserted central catheters and midlines are associated with low insertion risk and catheter-based blood stream infections, and may offer a less invasive alternative to CVC for central venous pressure monitoring, but the theoretical risk of upper extremity thrombosis has limited their widespread use in pregnant women.[22]

MANAGEMENT OF CARDIAC DEVICES DURING LABOR AND DELIVERY

Management of cardiovascular implantable electronic devices including permanent pacemakers (PPMs) and implantable cardioverter-defibrillators (ICDs) during labor and delivery closely follows the device management strategies used for other operative procedures and should be documented in the medical record prior to delivery. Possible delivery complications include electromagnetic interference (EMI) resulting in oversensing with inhibition of appropriate therapy, false detection of arrhythmias with unnecessary antitachycardia therapy, or stimulation of rate responsive pacing.[23,24] Risk of EMI is higher with ICDs vs PPMs and can occur with the use of monopolar electrosurgery (eg, Bovie) that is utilized in most cesarean deliveries for coagulation and tissue dissection.[23,24] EMI is considered a significant risk when it occurs <15 cm from the generator.[24] It is not usually necessary to reprogram or deactivate a device in a routine cesarean delivery with a low transverse incision as EMI below the umbilicus is unlikely to disturb device function.[24] Having an available magnet to deactivate shock therapies in ICD and switch to asynchronous mode in PPMs is usually sufficient. For patients with abdominal generator placement and/or subcutaneous ICDs, risk of EMI exists with cesarean delivery, so modification of device settings (either to

asynchronous mode or via magnet placement) is recommended to diminish risk of severe bradycardia or asystole.[25] For all patients who undergo device reprogramming, continuous rhythm monitoring is mandatory until the device is reprogrammed to desired settings.

INTRAPARTUM CONSIDERATIONS IN PREGNANT PATIENTS REQUIRING MECHANICAL CIRCULATORY SUPPORT

While rare, cardiogenic shock (CS) during pregnancy can be devastating with an estimated mortality rate of 18.8% compared with 0.02% in the pregnant population without CS.[26] Data from the National Inpatient Sample (2002-2013) showed an increased incidence over time, with the greatest risk of CS during delivery (23.5%) and postpartum period (58.8%). CS in pregnancy is most commonly observed in the context of acute HF related to peripartum cardiomyopathy (PPCM).[26,27] Other etiologies include acute worsening of chronic HF, stress-induced cardiomyopathy, spontaneous coronary artery dissection and other mechanisms of myocardial infarction, myocarditis, or acute massive pulmonary embolism.[26,28]

Mechanical circulatory support (MCS) is an important therapeutic option for pregnant patients presenting with refractory CS. However, inotropic support can certainly be utilized and is often sufficient as less invasive support in many individuals with structural heart disease. In the specific setting of PPCM, a report from the German PPCM registry suggested adverse effects of dobutamine in these patients thought to be due in part to excessive adrenergic stimulation leading to downstream myocardial energy depletion, oxidative stress, and ultimately myocardial dysfunction.[29] As such, utilization of MCS in the pregnant population has increased over time in line with trends in MCS use in the general population.[30] While there are no randomized clinical trials or prospective studies to guide utilization of MCS devices during pregnancy, MCS may be initiated in patients with CS as a bridge to recovery, durable support, or heart transplantation.[31] The severity of CS and magnitude of hemodynamic derangement should guide the choice of MCS device support that is most likely to promptly restore tissue perfusion with the lowest risk of complications. Intra-aortic balloon counterpulsation and percutaneous microaxial pumps (Impella devices) are feasible and have been shown to be safe in pregnancy, but provide modest hemodynamic support (intra-aortic balloon counterpulsation: ≤1 L/min, Impella: ≤6 L/min) and primarily offload the LV.[27,32,33] Venoarterial extracorporeal membrane oxygenation provides the most robust biventricular hemodynamic support, but at the expense of greater risk of thrombotic and hemorrhagic complications.[34-36] Bleeding, including intrauterine, intra-abdominal, access site, and cannula-related bleeding, was the most common maternal complication among pregnant individuals requiring MCS.[34,36] Rate of bleeding varies widely between studies, but risk of bleeding is consistently highest in the immediate postpartum period. Other potential complications of MCS including vascular complications (eg, limb ischemia, deep vein thromboses) were infrequent.[36] Collectively, the limited data on venoarterial extracorporeal membrane oxygenation during pregnancy suggest that it is feasible during pregnancy and labor/delivery.[36]

MCS use during pregnancy usually requires continuous anticoagulation therapy and hemodynamic monitoring (with PAC and arterial line) to guide weaning and escalation of hemodynamic support.[37] Given the complexity of MCS management, pregnant patients who are at risk for developing CS should be cared for at a center with expertise in advanced HF, critical care, MCS, and maternal-fetal-medicine. The European Society of Cardiology guidelines recommend urgent delivery via cesarean delivery regardless of the gestational age for pregnant patients in CS who are hemodynamically unstable.[37]

MANAGEMENT OF CARDIAC ARREST DURING LABOR AND DELIVERY

Although rare, cardiac arrest during labor and delivery is associated with significant maternal morbidity and mortality. Standard advanced cardiac life support (ACLS) protocol should be promptly initiated with a few unique considerations for pregnant individuals (**Table 2**).[38] Following return of spontaneous circulation, the mother should be placed in the left lateral decubitus position to relieve compression of the gravid uterus on the inferior vena cava if the position does not interfere with other vital treatments. Finally, initiation of targeted temperature management should be considered in all pregnant individuals who have suffered a cardiac arrest. Although the data on targeted temperature management in pregnancy are limited, several case reports have reported favorable outcomes.[39-42]

MANAGEMENT OF PERIPARTUM ANTITHROMBOTIC THERAPY

Peripartum anticoagulation management is centered on the careful balance of thrombotic and bleeding

TABLE 2 Management of Cardiac Arrest During Labor and Delivery

ACLS protocol
• Identify team leader for: 1) maternal resuscitation; 2) obstetrics care; and 3) fetal care. • Call for obstetric anesthesia (pregnant individuals have a higher likelihood of a difficult airway). • Call for mechanical circulatory support if at center with MCS capabilities. • Obtain IV access above the diaphragm. • Provide manual left lateral uterine displacement after 20 weeks gestation. • Consider hypermagnesemia if patient administered IV magnesium. Stop IV magnesium and give calcium regardless of Mg level. • Do not hold ACLS medications for concern for teratogenicity. • No dose-adjustment of ACLS medication required. • Standard defibrillation technique is recommended for all pregnant patients. • Targeted temperature management should be considered.
Fetal considerations
• Fetal assessment should not be performed during ACLS as focus is maternal resuscitation. • If singleton pregnancy >20 wk or uterus at level of umbilicus, manual left uterine displacement is required. • Standard defibrillation technique is recommended for all pregnant individuals. • Delivery of fetus via resuscitative hysterotomy should be strongly considered at 4 min or sooner if there is no chance of maternal survival. • Resuscitative hysterotomy should be performed at site of cardiac arrest without strict attention to aseptic technique.

ACLS = advanced cardiac life support; IV = intravenous; MCS = mechanical circulatory support.

risks. It should be planned ahead of delivery with multidisciplinary team input, and include discussion of anticipated timing and mode of delivery.[43] For patients on therapeutic anticoagulation and/or antiplatelet P2Y12 inhibitors, induction of labor is recommended so that interruption of anticoagulation can be planned safely. Induction is not routinely indicated for patients on prophylactic low-molecular-weight heparin (LMWH) and/or aspirin.[43,44]

Antithrombotic medications should be interrupted to minimize bleeding events, including postpartum hemorrhage and spinal epidural hematoma in those who receive neuraxial anesthesia.[45] Published guidelines for the management of anticoagulation medications in preparation for neuraxial analgesia are summarized in **Table 3**.[45,46] While the optimal timing to reinitiate antithrombotic therapy following delivery is not known, resumption of therapeutic anticoagulation following delivery and neuraxial analgesia removal should be guided by individual bleeding risks, indications for anticoagulation, and multidisciplinary team input (**Table 3**). For most patients, reinitiation of anticoagulation can begin between 6 and 24 hours following delivery.

Peripartum management of patients on therapeutic anticoagulation for mechanical heart valves requires additional considerations, including the peripartum management of vitamin K antagonists (VKAs). Fetal metabolism of VKA is delayed, resulting in a prolonged anticoagulant effect on the fetus.[47,48] As such, discontinuation of VKAs at 36 weeks of gestation with transition to therapeutic LMWH or intravenously (IV) unfractionated heparin (UFH) is recommended in preparation for delivery.[37] Judicious monitoring to ensure therapeutic anticoagulation must occur (target anti-Xa levels = 0.8 U/mL to 1.2 U/mL at 4-6 hours post-LMWH dose or activated partial thromboplastin time (aPTT) = 2 times control for IV UFH).[49] In addition, for patients on therapeutic anticoagulation for mechanical heart valves using LMWH, bridging with IV UFH (starting 36 hours prior to planned delivery until 4-6 hours before delivery) is recommended by expert consensus by both the European Society of Cardiology and the American College of Cardiology/American Heart Association.[37,49] In the opinion of this expert panel, the decision to bridge with IV UFH can be individualized based on the valve type, position, presence of atrial fibrillation, or prior thromboembolic events/thrombosis.

Recommendations for peripartum management of antiplatelet therapy are guided by the number and class of antiplatelet agents. For patients on antiplatelet monotherapy with aspirin, aspirin may be continued throughout delivery.[44,45] For pregnant patients on dual antiplatelet therapy, discontinuation of P2Y12 inhibitor is recommended in anticipation of labor and need for neuraxial anesthesia. Optimal timing of antiplatelet therapy discontinuation is guided by principles used in the nonpregnant population which recommends discontinuation of clopidogrel 5 to 7 days prior to noncardiac surgery.[44,46]

BREASTFEEDING RECOMMENDATIONS FOR THE CARDIAC PATIENT

The American Academy of Pediatrics recommends that infants are exclusively breastfed for the first 6 months of life with the introduction of solid food along with breast milk for the next 2 years as mutually desired by the mother and child. Breastfeeding benefits both the mother and infant pair. Long-term benefits of breastfeeding to mothers include reduced rates of ovarian cancer, premenopausal breast cancer, obesity, type 2 diabetes mellitus, and CVD. Infants who are breastfed have decreased rates of infection, type II diabetes, childhood obesity, and mortality.[50] Theoretical risks of breastfeeding have been raised in the context of aortic dissection as mouse model data show that risk for aortic dissection was reduced by prevention of lactation or use of an oxytocin receptor antagonist.[51] However, human data are limited.

While many cardiovascular medications have well established safety profiles, others lack robust data as to their use in breastfeeding. Use of cardiovascular medications during breastfeeding and consideration

TABLE 3 Interruption and Resumption of Anticoagulation According to American Society of Regional Anesthesia and Pain Medicine Guidelines and the Society for Obstetric Anesthesia and Perinatology Consensus Statement[45,46]

	Before Placing a Neural Anesthetic	Before Initiating or Resuming Anticoagulation
UFH SC low dose (5,000 U twice or 3 times daily)	Consider holding the dose >4-6 h or assessing coagulation status[a]	Wait ≥1 h after neuraxial procedure (if no signs of postpartum hemorrhage) and ≥1 h after epidural catheter removal
UFH SC intermediate dose (7,500 U or 10,000 U twice daily, ≤20,000 U)	Consider holding the dose ≥12 h and assessing coagulation status[a]	
UFH SC high dose (individual dose >10,000 U per dose, total daily dose >20,000 U)	Consider holding the dose ≥24 h since last dose and assessing coagulation status[a]	
UFH IV	Consider stopping the infusion 4-6 h and assessing coagulation status[a]	Wait ≥1 h after neuraxial block (if no signs of postpartum hemorrhage)
Low-dose LMWH SC (eg, enoxaparin <40 mg once daily or 30 mg twice daily or dalteparin 5,000 U once daily)	Consider holding the dose ≥12 h	Wait ≥12 h after neuraxial procedure and ≥4 h after epidural catheter removal
Intermediate-dose LMWH SC (eg, enoxaparin >40 mg once daily or 30 mg twice daily and <1 mg/kg twice daily or 1.5 mg/kg once daily or dalteparin >5,000 U once daily and <120 U/kg twice daily or 200 U/kg once daily)	Insufficient published data to recommend a specific interval between 12 and 24 h to delay neuraxial anesthesia. *Expert panel recommends: consider holding the dose ≥24 h* (in keeping with recommendations for therapeutic dose LMWH).	Wait ≥24 h after neuraxial procedure and ≥4 h after epidural catheter removal
High-dose LMWH SC (eg, enoxaparin: 1 mg/kg twice daily or 1.5 mg/kg once daily or dalteparin: 120 U/kg twice daily or 200 U/kg once daily	Consider holding the dose ≥24 h	

[a]Current guidelines do not specify the preferred coagulation test or cutoff for assessment of coagulation status in patients receiving UFH. The aPTT is the laboratory test most frequently used to assess the coagulation status of patients receiving UFH. Some limitations of aPTT include variable reference ranges and the impact of untested coagulant factors (eg, lupus anticoagulant). Anti-Xa may also be used; however, its availability remains limited. Results of the aPTT or anti-Xa must be interpreted in the context of clinical information of the patient to decide on timing of neuraxial procedures.

aPTT = activated partial thromboplastin time; IV = intravenously; LMWH = low-molecular-weight heparin; SC = subcutaneously; UFH = unfractionated heparin.

of cardiovascular pharmacotherapy during lactation should be guided by careful consideration of risks and benefits and counseling as to patient preferences. Among commonly used cardiovascular medications, amiodarone, factor Xa inhibitors, and direct thrombin inhibitors are generally considered to be contraindicated. Data on angiotensin receptor blockers and angiotensin receptor/neprilysin inhibitors, statins, direct oral anticoagulants, sodium-glucose cotransporter-2 inhibitors, and endothelin receptor antagonists are either limited or conflicting. As data continue to emerge, the most common information regarding safety of all medications can be reviewed using the LactMed database.[52,53] Patients should be counseled on risks and benefits, acknowledging limitations of the available data, and the lowest effective dose should be used. Breastfeeding should be encouraged for the desiring patient whenever possible. For individuals for whom breastfeeding is not an option, donor milk remains a safe, increasingly available alternative.

THE IMPORTANCE OF CARDIO-OBSTETRICS TEAMS

The success of cardiovascular multidisciplinary team-based care has led to the emergence of the cardio-obstetrics team, a multidisciplinary team of cardiologists, obstetricians, maternal-fetal-medicine specialists, geneticists, neonatologists, obstetric internists, anesthesiologists, nurses, and pharmacists with specialized expertise in the care of pregnant patients with CVD.[54-56] These teams are vital to the optimal management of labor and delivery for pregnant persons with CVD.[55] While the structure of the team may vary by institution, cardio-obstetrics teams generally meet regularly (either in person or virtually) to discuss high-risk pregnancies and offer recommendations, with the shared input of the patient's values, to guide the management of these patients to optimize maternal and neonatal outcomes. During these meetings, we recommend discussing patients using a standardized protocol to guide testing and assessment throughout pregnancy to standardize care for these high-risk patients. For example, the Standardized Outcomes in Reproductive Cardiovascular Care (STORCC) initiative used a simple color code of red, yellow, and green to characterize cardiac, obstetric, and anesthetic risk. Color codes were assigned through multidisciplinary discussion at a monthly meeting where each patient is reviewed and color codes modified. Specifically, delivery planning is an essential component of cardio-obstetrics meetings and should include identification of key providers for delivery,

discussion of optimal location of delivery and postpartum care, need for invasive monitoring and/or telemetry, and options for second stage of labor.

The multidisciplinary cardio-obstetrics team should also establish a standardized mechanism to urgently convene multiple key specialists to discuss rapid evaluation and management and mobilize resources (eg, catheterization laboratory, cardiac operating room, mechanical support) for decompensating patients or those at risk for decompensation. An accessible rapid response protocol is especially crucial for individuals managing high-risk patients in maternal care deserts or institutions without cardio-obstetrics expertise. An ideal future state could include virtual group meetings and could be modeled after established Pulmonary Embolism Response Team (PERT) protocols.

STANDARDIZING MATERNAL CARE DELIVERY THROUGH HOSPITAL AND ELECTRONIC MEDICAL RECORD PROTOCOLS

Despite numerous international, national, state, and local efforts to standardize care and outcome reporting for pregnant patients with CVD, maternal care remains heterogeneous and fragmented. Early identification of high-risk patients during pregnancy is critical for the prevention of adverse pregnancy outcomes. Current risk stratification tools are utilized in individuals with established CVD and do not address the risks for those who develop de novo, or previously undetected disease.

TABLE 4 Key Knowledge Gaps and Strategies to Address Knowledge Gaps

Key knowledge gaps
• Optimal mode of delivery for high-risk patients, including mWHO III/IV, and patients at elevated risk for maternal morbidity and mortality due to noncardiac risk factors. • Hemodynamic monitoring strategies for cardiovascular patients at the time of labor and delivery. • Ideal location for delivery and postpartum recovery for WHO III/IV patients. • Inotrope and vasopressor selection during delivery and postpartum period for patients in CS. • Timing of delivery for patients at risk for late pregnancy cardiovascular complications. • Impact of labor and delivery management strategies on the quality of life of patients with CVD. • Impact of breastfeeding on maternal outcomes, specifically those with vascular disorders.
Strategies to address knowledge gaps
• Enroll pregnant and postpartum patients into multicenter randomized clinical trials. • Advocate for increased federal funding and broad institutional commitment dedicated to basic, translational, epidemiologic, and clinical research in pregnant patients with CVD. • Mandate hospital and state systems to participate in clinical registries that report pregnancy outcomes. • Develop formalized training programs to train the next generation of cardio-obstetrics experts and leaders.

CS = cardiogenic shock; CVD = cardiovascular disease.

Screening algorithms that include assessment of cardiac biomarkers, cardiac imaging, and consultation by subspecialty providers have the potential to provide streamlined care for pregnant or recently pregnant patients evaluated in outpatient clinics or emergency departments. The Cardiovascular Disease in Pregnancy and Postpartum Toolkit developed for the California Maternal Quality Care Collaborative is one example of a screening algorithm that correctly identified 93% of patients at increased risk for CVD in a small internal cohort.[57,58] Converting toolkits and care paths into electronic health record (EHR) provider alerts has potential to decrease preventable pregnancy-related deaths. Tailored EHR alerting systems have been shown to be effective in increasing guideline-directed medical therapy for outpatients with systolic HF.[59,60] Whether integration of cardiovascular pregnancy screening tools into the EHR can translate to reduction in pregnancy-related complications and deaths is not known, but currently under investigation.[57]

KNOWLEDGE GAPS AND STRATEGIES TO NARROW THE GAPS

Evidence-based guidelines for pregnant patients with high-risk cardiovascular conditions are limited by the frequent exclusion of pregnant and breastfeeding patients from clinical studies and substantial heterogeneity of patients.[61] As a result, most recommendations are guided by expert opinion and observational cohort studies. While pregnant patients represent a medically complex group of study participants, careful and diligent planning by a multidisciplinary team dedicated to considering pregnancy-related complexities of trial design can increase their successful inclusion.[62] Pregnant patients are fully capable of making informed, autonomous decisions related to participation in clinical research studies.[61] The opportunity to participate in clinical research provides justice for both mother and baby in delivering the full scope of advanced health care.[61]

Presently, there is a varied spectrum of care delivery for pregnant patients with CVD, even at high-volume experienced cardio-obstetrics centers driven in large part by differences in local expertise and institutional capabilities. Many obstetrical centers may have limited expertise in forceps delivery prompting increased use of unnecessary cesarean delivery in this patient population.[63,64] We highlight several key knowledge gaps that require further study and key strategies to address these important gaps in **Table 4**.

CONCLUSIONS

CVD is a leading cause of maternal morbidity and mortality. The optimal management of pregnant patients with CVD begins at preconception, continues through the duration of pregnancy, labor and delivery, and the postpartum period. Despite the vulnerabilities associated with labor and delivery for patients with CVD, there is presently no standardized approach to labor and delivery. Moreover, the systematic exclusion of pregnant patients from randomized trials further limits the pool of evidence available to guide the pregnancy care of these high-risk patients and existing recommendations are based on expert consensus and cohort studies. In this review, we offer a summary of the current practices for the management of labor and delivery for pregnant patients. Notably, our recommendations are most pertinent to tertiary care centers in high-income countries, and generalizability to lower resourced centers and/or countries may be limited. Much work remains to define the standard of care, develop guidelines, and increase consistency in care delivery for this high-risk population and to ultimately improve maternal outcomes.

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