Cardiac arrest during pregnancy: ongoing clinical conundrum

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While global maternal mortality has decreased in the last 25 years, the maternal mortality ratio in the United States has actually increased. Maternal mortality is a complex phenomenon involving multifaceted socioeconomic and clinical parameters including inequalities in access to health care, racial and ethnic disparities, maternal comorbidities, and epidemiologic ascertainment bias. Escalating maternal mortality underscores the importance of clinician preparedness to respond to maternal cardiac arrest that may occur in any maternal health care setting. Management of maternal cardiac arrest requires an interdisciplinary team familiar with the physiologic changes of pregnancy and the maternal resuscitation algorithm. Interventions intended to mitigate obstacles such as aortocaval compression, which may undermine the success of resuscitation interventions, must be performed concurrent to standard basic and advanced cardiac life support maneuvers. High-quality chest compressions and oxygenation must be performed along with manual left lateral uterine displacement when the uterine size is ≥20 weeks. While deciphering the etiology of maternal cardiac arrest, diagnoses unique to pregnancy and those of the nonpregnant state should be considered at the same time. If initial basic life support and advanced cardiac life support interventions fail to restore maternal circulation within 4 minutes of cardiac arrest, perimortem delivery is advised provided the uterus is ≥20 weeks' size. Preparations for perimortem delivery are best anticipated by the resuscitation team for the procedure to be executed opportunely. Following delivery, intraabdominal examination may reveal a vascular catastrophe, hematoma, or both. If return of spontaneous circulation has not been achieved, additional interventions may include cardiopulmonary bypass and/or extracorporeal membrane oxygenation. Simulation and team training enhance institution readiness for maternal cardiac arrest. Knowledge gaps are significant in the science of maternal resuscitation. Further research is required to fully optimize: relief of aortocaval compression during the resuscitation process, gestational age and timing of perimortem delivery, and other interventions that deviate from nonpregnant standard resuscitation protocol to achieve successful maternal resuscitation. A robust detailed national and international prospective database was recommended by the International Liaison Committee on Resuscitation in 2015 to facilitate further research unique to cardiac arrest during pregnancy that will produce optimal resuscitation techniques for maternal cardiac arrest.

Key words: basic and advanced life support during pregnancy, cardiac arrest during pregnancy, manual left lateral uterine displacement, maternal cardiac arrest, perimortem cesarean delivery, perimortem delivery

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Introduction

The last decade has heralded a paradigm shift in perceptions regarding maternal collapse and cardiopulmonary resuscitation (CPR). Historically, survival was described as poor, and resuscitation futile, because "the causes of cardiac arrest are fatal."[1,2] But new evidence indicates high survival, with a significant proportion of cases attributed to a reversible etiology of arrest. This unique population of young, yet critically ill women can respond to appropriate treatment and may be more salvageable than most patients requiring CPR.[3]

While the global maternal mortality ratio (maternal deaths/100,000 live births) has decreased in the last 25 years from 281.5-195.7, the maternal mortality ratio has actually increased from 16.9-26.4 in the United States. More robust ascertainment systems likely explain some, but not the majority, of this increase. Maternal mortality is a complex multifaceted phenomenon with each etiology of maternal death influenced by population health, comorbid conditions, access to health care, and socioeconomic, racial, and ethnic inequalities. Regardless, cardiac arrest separates survival from death for many forms of maternal critical illness and comorbidities. Institutional preparation for maternal CPR represents an opportunity to optimize maternal survival in many health care settings.[4]

In this article, we aim to provide a comprehensive review of cardiac arrest in pregnancy and outline a practical management algorithm for the clinician in the trenches. Recent guidelines from the Society for Obstetric Anesthesia and Perinatology (SOAP), the American Heart Association (AHA), and the International Liaison Committee on Resuscitation (ILCOR) are reviewed.

Due to the low prevalence and the circumstances of cardiac arrest during pregnancy, randomized clinical trials do not exist to guide management; therefore, we have extrapolated data from simulation studies, expert opinions, small case series, and cohort studies, including new prospectively reported data on maternal cardiac arrest (MCA).[5,6] Given the low frequency of maternal resuscitation, optimal resuscitation practices are poorly described. Most recommendations are based on expert opinion, case reports, and case series. To encourage further research in maternal resuscitation science, this review also highlights existing knowledge gaps.

Recent guidelines

In the past 3 years, several organizations have published new or updated guidelines focusing on maternal resuscitation. Following the publication of several index papers suggesting that MCA is accompanied by better prognoses than believed in the past, and thus merits more focus than it had received,[3,7] SOAP released its first consensus statement on treatment of cardiac arrest in pregnancy in 2014.[8] This practical document provided several important resources to support an optimal team response, including emergency checklists and an alphabetical etiology checklist running from A-H: anesthetic complications (eg, loss of airway, inadvertent spinal injection); bleeding (intrapartum or postpartum); cardiovascular causes (eg, cardiomyopathy, exacerbation of preexisting valve disease, aortic dissection, myocardial infarction); drugs (eg, anaphylaxis, magnesium overdose); embolic events (thrombotic, amniotic fluid); febrile conditions (ie, sepsis); general causes (the regular H's and T's); and hypertension.

A year and half later, in November 2015, the AHA also published their first scientific statement on maternal resuscitation.[9] This document, written by interprofessional and multidisciplinary experts in resuscitation science and women's health care, reflects a comprehensive review of available evidence, and offers standardized recommendations for all disciplines to optimize care during MCA. The guideline also highlights the need to improve consensus regarding the optimal sequence of initial resuscitation maneuvers, and the circumstances under which perimortem delivery should be strongly considered. The AHA document also reviews the literature about the causes of MCA.

ILCOR completed another cycle of its 5-year evidence review process of cardiac arrest in 2015, and included a section on cardiac arrest during pregnancy. Following a structured search strategy, the ILCOR review of maternal CPR focused exclusively on left lateral uterine displacement and perimortem delivery. The systematic review found very low-quality evidence for specific interventions for advanced cardiac life support (ACLS) during pregnancy, but suggested perimortem delivery for women in cardiac arrest in the second half of pregnancy.[10]

Subsequently, the 2015 AHA guidelines on CPR drew from the AHA Scientific Statement on Maternal Resuscitation and the more focused results of the systematic review found in the 2015 ILCOR guideline. In summary, priorities for the management of MCA include high-quality chest compressions and manual left uterine displacement. Because evacuation of the gravid uterus relieves aortocaval compression and may improve resuscitative efforts, perimortem delivery may be considered part of standard maternal resuscitation in the second half of pregnancy regardless of the viability of the fetus.[11]

Spectrum of disease

Prevalence of MCA

Large health care utilization databases have sufficient information to describe MCA despite its low prevalence. Recent data from the US Nationwide Inpatient Sample suggest that MCA occurs in 1:12,000 admissions for delivery, based on administrative billing data for diagnostic and procedural codes consistent with cardiopulmonary arrest.[3] The United Kingdom Obstetric Surveillance System (UKOSS) reports a somewhat lower prevalence of 1:16,000 MCA per maternities based on prospectively collected nationwide surveillance data from 2011 through 2014 that relied on active clinician reporting.[5,6] Although prevalence varies by continent paralleling the observed improved global maternal mortality ratio trend cited earlier in the introduction, their respective 95% confidence intervals overlap suggesting insufficient event frequency and statistical power to distinguish these 2 rates. Another retrospective population-based study using data from the discharge abstract database of the Canadian Institute for Health Information reported a prevalence of 1:12,500 deliveries.[12] Most importantly, all of these studies concur that maternal survival after cardiac arrest is >50%.

Etiologies for MCA

Both pregnancy- and nonpregnancy-related diseases and conditions must be considered in the differential diagnosis of MCA. The AHA has proposed an alphabetical listing rather than a specific mnemonic to encourage a broader consideration of etiologies[9] (Table). Familiarity with the etiologies enables the clinician to initiate resuscitation while simultaneously looking for clues leading to a more definitive management that will improve the chance of return of spontaneous circulation (ROSC) and ultimately survival. Hemorrhage remains one of the most common causes of cardiac arrest related to pregnancy.[3] Cardiovascular conditions and sepsis should be considered early; both the Centers for Disease Control and Prevention and UKOSS noted an increase in cardiovascular and infectious etiologies leading to maternal death.[13-15] Anesthetic complications were the most prevalent etiology for MCA in the recent UKOSS Cardiac Arrest in Pregnancy Study (CAPS), accounting for 27% of the arrests, while hemorrhage was the second most common etiology.[5,6] These data confirm the need to prioritize anesthesia care for pregnant women, including airway management, safe neuraxial analgesia and anesthesia, and hemostatic and hemodynamic resuscitation for massive hemorrhage. Notably, the parturient airway is more easily managed by an anesthesiologist at the onset of arrest rather than after several failed intubation attempts. Comorbidities (eg, heart disease), which have also been associated with increased

TABLE

Etiologies for cardiac arrest during pregnancy (adapted from American Heart Association)[9]

Anesthetic causes	High spinal or epidural
	Intravascular injection of local anesthetic
	Airway complications
	Aspiration
Accidents	Trauma
Bleeding	Uterine atony
	Abnormally adherent placentation
	Coagulopathy
Cardiovascular	Valvular disease
	Congenital cardiac disease
	Ischemia and atherosclerosis
	Arrhythmias
	Rupture of dissection
Drugs	Tocolytic agents
	Illicit drugs leading to overdose
	Anaphylaxis
	Uterotonics
	Magnesium
Embolism	Venous embolism
	Amniotic fluid embolism
Fever	Sepsis
	Necrotizing fasciitis
	Viral syndromes
	Acute respiratory distress syndrome
General	Metabolic abnormalities
	Hypocalcemia or hyperkalemia during massive hemorrhage
Hypertension	Stroke (thrombotic or hemorrhagic)
	Preeclampsia/eclampsia/HELLP

Source: American Heart Association, Inc.

Zelop. Maternal cardiac arrest. Am J Obstet Gynecol 2018.

risk of maternal death, are more effectively managed by health care providers before patient collapse.[16,17]

Physiologic changes of pregnancy relevant to MCA

A myriad of multisystem adaptations are required to sustain pregnancy and an understanding of these physiologic changes is required to adequately assess and resuscitate the pregnant patient with cardiopulmonary arrest.[9] Overall, the physiologic changes of pregnancy render pregnant women less tolerant of oxygen deprivation and more susceptible to airway compromise, aspiration, and hypoxemia.[18] Cardiovascular changes are characterized by a 40% increase in cardiac output required to accommodate the metabolic demands of both mother and fetus. As early as the first trimester, stroke volume and heart rate increase while systemic vascular resistance gradually decreases especially in the second trimester. Although the heart is left shifted, it is not significantly elevated in the chest as demonstrated by cardiac magnetic resonance imaging (MRI).[19] The uteroplacental unit "steals" up to 20% of the cardiac output in the third trimester.[20]

Pulmonary changes during pregnancy must supply a 20% increase in oxygen consumption to accommodate the increased metabolic rate. Estrogen and progesterone produce vascular engorgement of the upper pharynx and larynx leading to changes in landmarks and narrowing of the airway passages; collectively, these changes magnify the difficulty in intubation and airway management. Thoracic compliance is diminished although respiratory muscle function is preserved. Functional residual capacity decreases mainly due to a smaller residual volume and intrapulmonary shunting increases from 5-15% by the third trimester resulting in a more rapid desaturation during hypoxia. Increased minute volume mainly due to a larger tidal volume creates a respiratory alkalosis that requires a compensatory metabolic acidosis to maintain pH balance. Therefore, blood gas parameters are altered with a P_{CO_2} in the 28-32 mm Hg range; pH ranging from 7.40-7.45; and a slightly higher P_{O_2} ranging from 101-106 mm Hg.[21,22] Progesterone also promotes relaxation of gastroesophageal sphincter and slowing of gastric emptying. These gastrointestinal alterations predispose to potential aspiration of gastric contents on loss of maternal consciousness.[23]

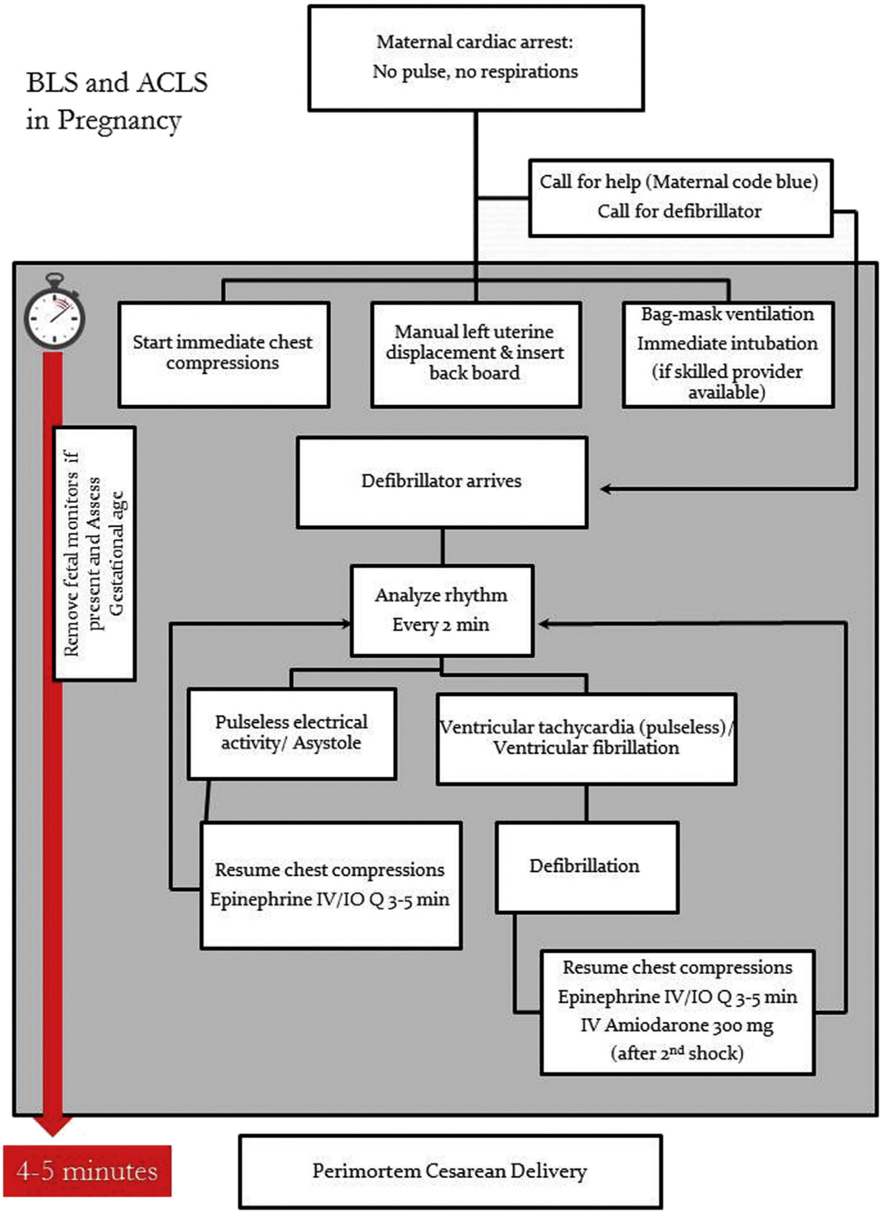
Growth of the uteroplacental unit leads to aortocaval compression as early as the second trimester as demonstrated by classic physiology experiments.[24,25] MRI data assessing right and left cardiac function at 20 weeks and at 32 weeks in the supine vs a left lateral 30-degree tilted position emphasize that cardiac output is compromised as early as 20 weeks in the supine position with some amelioration in the left lateral position.[26] Aortocaval compression decreases venous return and increases afterload. While aortic compression may improve blood flow to the maternal heart and brain in the short term, ongoing compression compromises cardiac output and overwhelms the myocardium with increased workload. Aortocaval compression can be so profound that it can undermine the resuscitation process requiring definitive amelioration. This concept will be revisited below in the section addressing left lateral uterine displacement and perimortem delivery delineated in the resuscitation algorithm below.

Algorithm for resuscitation with pregnancy modifications

The cornerstone of basic life support and ACLS is predicated on sequential coordinated interventions. Maternal CPR is characterized by multiple simultaneous interventions, which are best accomplished with early activation of the maternal code blue emergency alert (Figure 1). High-quality chest compressions at a rate of 100-120 depress the sternum 5-6 cm with good recoil to provide circulatory function. Hand placement for compressions is over the mid-lower sternum similar to the nonpregnant state. Prior to tracheal intubation, CPR is performed at a ratio of 30 compressions to 2 breaths using a bag mask with 100% oxygen. Following intubation, ventilations should be given at a rate of 8-10 per minute, taking care to avoid hyperinflation, which will increase intrathoracic pressure and impede blood flow. Pads should be used to assess initial rhythm and determine the need for immediate biphasic defibrillation.[9]

Resuscitation during pregnancy requires simultaneous concerted interventions that accommodate the physiologic changes of pregnancy. The maternal code blue responders typically incorporate a multidisciplinary team of health care providers including obstetrician/maternal-fetal medicine specialist, anesthesiologist, cardiologist, neonatologist, intensivist, and cardiovascular surgeon. Chest compressions are initiated as left lateral uterine displacement is performed. Oxygenation is the overall goal, but ideally an advanced airway should be secured as quickly as possible to minimize interruption in chest compressions and prevent aspiration. A smaller endotracheal tube (6-7 mm) is utilized as a

FIGURE 1
Algorithm for maternal resuscitation



Algorithm for maternal cardiac arrest resuscitation with data from American Heart Association[9] basic life support (BLS) and advanced cardiac life support (ACSL).

IO, intraosseous; *IV*, intravenous.

Zelop. Maternal cardiac arrest. Am J Obstet Gynecol 2018.

result of pregnancy-related narrowed airway and an experienced laryngoscopist is best to perform intubation in anticipation of a "difficult airway." Failed intubation during pregnancy approaches 1/250 vs 1/2000 in nonpregnant population.[27] While the most recent study[28] did not demonstrate a benefit from intubation during resuscitation for in-hospital cardiac arrest, this study may not have generalizability relevant to the pregnant population because of pregnant physiology. Several unique circumstances of pregnancy suggest that timely intubation remains important to decrease the

FIGURE 2
Left lateral uterine displacement

One-handed left lateral uterine displacement that enables access to abdomen if perimortem delivery is required. Not shown is alternative 2-handed technique that displaces uterus by pulling it toward rescuer positioned on left side of patient.

Zelop. Maternal cardiac arrest. Am J Obstet Gynecol 2018.

risk of aspiration and provide therapeutic treatment when MCA is attributed to anesthetic complications such as respiratory depression.[6] However, what becomes evident is that interruption to quality CPR must be minimized to enable successful resuscitation whenever any other intervention such as intubation is performed. Intravenous access obtained above the diaphragm will prevent trapping below the gravid uterus remembering that an intraosseous approach is a valid alternative to achieve access. If fetal monitors are in place, they should be removed or disconnected expeditiously to minimize time spent on nonresuscitative procedures in preparation for perimortem delivery. While electrocution of mother, fetus, or staff is most likely a theoretical concern, the focus is driven by the maternal status.[9]

Rhythm analysis and defibrillation are similar to the nonpregnant patient with utilization of the same levels of energy.[29] Automated external defibrillators may be more appropriate in clinical settings where staff is less familiar with rhythm analysis. Determination of gestational age is initiated as left lateral uterine displacement is performed. A combination of physical exam and rapid ultrasound assessment may provide the most useful estimate again minimizing interruption of chest compressions for no more than 10 seconds.

Relief of aortocaval compression and optimizing force vectors are paramount to generate effective chest compressions. There are no studies that evaluate this phenomenon in the pregnant patient receiving chest compressions. Mannequin simulation studies have demonstrated that tilt of 27 degrees prevented the mannequin from falling off but generated only 80% of the body weight force produced when the mannequin was supine.[30] Full lateral decubitus provides total relief of aortocaval compression, but does not allow for the performance of chest compressions. A recent study using virtual gastroscopy demonstrated that left lateral tilt can shift the heart more laterally, thereby interfering with pump mechanism during chest compression possibly offsetting the preservation of venous return.[31] MRI was recently utilized to examine aortocaval compression in singleton parturients compared to nonpregnant women. The inferior vena cava was compressed in the supine position and only partially relieved with 30-degree tilt.[32] MRI provides information about function and physiologic state at a specific moment in time limiting its ability to assess an evolving process. Initial aortic compression could provide benefit by increasing diastolic perfusion of maternal organs. However, over time the increase in afterload would elevate cardiac workload leading to decreased cardiac output to both mother and fetus. Kundra et al[33] in 2007 evaluated blood pressure and ephedrine requirements in those patients undergoing cesarean under spinal anesthesia randomized to tilt (15 degrees) or manual uterine displacement of the uterus 1.5 in from the midline to the left. Those treated with manual uterine displacement required less ephedrine for hypotension. Manual uterine displacement theoretically optimizes the vectors for chest compressions by preserving a supine position of the thorax (Figure 2). Although current guidelines recommend manual uterine displacement to relieve aortocaval compression, clearly decompression of the uterus via delivery provides the most comprehensive relief.

Gestational age is not always known to the resuscitation team, but can be estimated at the time of manual left lateral uterine displacement. A uterus that extends to the umbilicus is usually sufficiently large to cause aortocaval compression, and should be displaced laterally. Among morbidly obese women, the uterus may be more difficult to palpate. A combination of physical exam and rapid ultrasound may provide the most useful estimate, again minimizing interruption of chest compressions for no more than 10 seconds.

Medications utilized during MCA

While the physiologic changes of pregnancy affect drug metabolism, volume of distribution and clearance of medications, medication dosages utilized during cardiac arrest are not altered in this acute setting.[34] Concerns regarding fetal toxicity due to medication exposure should be superseded by the gravity of the maternal condition. Epinephrine administered as 1 mg intravenous/intraosseous every 3-5 minutes is utilized as the vasopressor of choice. As presented at ILCOR 2015, even in nonpregnant cardiac arrest scenarios, vasopressin does not provide any superior advantage over epinephrine.[35] Calcium (10 mL of 10% calcium gluconate) should be administered early during the resuscitation whenever magnesium sulfate toxicity or hyperkalemia are part of the differential diagnosis. Amiodarone may be considered for ventricular fibrillation or pulseless ventricular tachycardia that is not responsive to CPR, defibrillation, and epinephrine. Sodium bicarbonate is not routinely recommended, according to the 2015 AHA guidelines for CPR,[11] but may be indicated for toxic ingestion during any cardiac arrest including MCA. Early administration could theoretically lead to shift in the carbon dioxide (CO_2) gradient, causing pooling of CO_2 in the fetus and worsening of fetal acidemia if maternal acidosis is overcorrected.[36]

When local anesthetic toxicity is suspected as the etiology for MCA, rescue with low-dose epinephrine (<1 μg/kg) and 20% lipid emulsion (1.5 mL/kg bolus followed by 0.25-0.5 mL/kg/min infusion) should be administered. Local anesthetic agents possess unique properties as a result of their biochemical structure exhibiting both lipophilic and hydrophilic components. Excess concentrations of these amphipathic molecules poison voltage-gated sodium channels and block oxidative phosphorylation. The greatest susceptibility occurs in tissues with high-energy aerobic requirements such as cardiac, central nervous system, and skeletal muscle leading to seizures and arrhythmias. Two mechanisms have been proposed for the effect of 20% lipid emulsion rescue: as a lipid sink to purify the blood and remove excess local anesthetics and/or as a modulator at the level of the cell membrane.[37]

The 4-minute rule for perimortem cesarean delivery and neonatal outcomes

The term "perimortem cesarean delivery" (PMCD) was introduced in 1986 in a publication describing outcomes following MCA. This first analysis of neonatal survival in the setting of PMCD retrospectively reviewed published cases from the preceding 20 years and noted that neonatal survival was better if delivery occurred within 4-5 minutes of MCA. This finding substantiated the dogma that irreversible anoxic brain injury occurs within 4-5 minutes from MCA. Consequently, the 4-minute rule was proposed. This tenet advocated for initiation of a PMCD within 4 minutes from MCA if resuscitative efforts are unsuccessful, allowing delivery by 5 minutes.[38]

Twenty years later, the authors published a follow-up study reviewing published reports of PMCD since the introduction of the 4-minute rule.[2] This follow-up publication supported the recommendation for delivery within 4 minutes of MCA to maximize neonatal outcome. Neonatal outcomes were similar to the previous publication. Interestingly, in this study 25 of the 38 cases provided maternal physiologic information postcesarean delivery. In 12 of the 25 mothers for whom data were provided, "sudden and profound" improvement in the maternal condition is described. Additional case reports and case series describe ROSC immediately after performing a PMCD without evidence of worsened maternal status.[2,3,7] Because the available evidence supports early delivery of the fetus and potential improvement in maternal condition following delivery, the AHA and SOAP recommend that PMCD be initiated by 4 minutes after cardiac arrest with delivery of the fetus by 5 minutes.[8,39] However, the vast majority of PMCD fall outside of this window.[2,40] Neonatal survival with acceptable outcomes has been reported, even when delivery took place following prolonged cardiac arrest. PMCD should still be considered after prolonged resuscitation if the patient is undelivered.[7] In certain circumstances, such as when the patient has a nonsurvivable injury, the arrest is not witnessed, or resuscitative efforts appear futile, it may be advisable to perform PMCD immediately rather than waiting for 4 minutes of resuscitative efforts.[2,39]

Is it reasonable to establish a clinical guideline to perform perimortem delivery within 5 minutes? The pathophysiologic rationale is guided by the principle to minimize maternal neurological compromise from cerebral hypoperfusion. When normal cardiac and respiratory function cease, a brief critical period of time exists prior to the onset of anoxic brain injury. If chest compressions are initiated within 4 minutes, prognosis is generally more favorable.[41] Prognosis is more variable when initiated within the 4- to 6-minute window. However, after 6 minutes irreversible brain injury occurs. These principles are based on conclusions from a study that evaluated survival of out-of-hospital cardiac arrest stratified by initiation of CPR.[41] There are no human or animal models that have been examined to date specifically for pregnancy, so the process of cellular compromise and death may actually be accelerated underlining the small window of time required for successful intervention.[41] If ROSC is not achieved with conventional rescue efforts within 4-5 minutes, there remains little time for seeking an alternative approach to improve maternal circulation. This observation underlies both the SOAP and the AHA decision to support a 4- to 5-minute resuscitation attempt between onset of arrest to perimortem delivery.

Finally, data through 2017 demonstrated that shorter intervals from MCA to delivery have favorably impacted maternal and fetal survival. Einav et al[7] reported that the time interval from MCA to PMCD was shorter for both maternal survivors compared to nonsurvivors (10 $\pm$ 7.2 vs 22.6 $\pm$ 13.3 minutes) and for neonatal survivors compared to nonsurvivors (14 $\pm$ 11 vs 22 $\pm$ 13 minutes). In 2016, Benson et al[42] demonstrated that maternal and neonatal injury-free survival diminished steadily as the time interval from MCA to PMCD increased. However, their data did not reveal a specific survival threshold at the 4 minutes from MCA to initiation of delivery. Moreover, the 50% threshold for injury-free maternal and neonatal survival was 25 and 26 minutes, respectively. The CAPS UKOSS data[6] substantiate the 4- to 5-minute rule. Reporting a 58% maternal survival for MCA, the time from MCA to PMCD in survivors was 7 minutes compared to 16 minutes in nonsurvivors. Overall, 61% (30/49) underwent PMCD by 5 minutes. In all, 24 of 25 (96%) neonates survived when PMCD was performed within 5 minutes vs 70% when PMCD occurred >5 minutes, $P = .059$. Analyzing median time from collapse to delivery, women who survived (N = 38) MCA to PMCD was a median of 3 minutes compared to a median of 12 minutes in those who died, $P = .01$.[6]

Gestational age and PMCD

Both SOAP and the AHA guidelines from 2015 strongly support the performance of PMCD when the uterine size is ≥20 weeks' size.[9,11] The implementation of PMCD as a resuscitative strategy for the patient 20-24 weeks remains an area of ongoing controversy where clinicians may have to individualize for the clinical scenario. Certainly, the classic physiologic studies[24,25] and more recent cardiac MRI data[26] substantiate the potential maternal benefit. Close analysis of the data of Beckett et al[6] reveals that PMCD was implemented as early as 20 weeks. Because of the small numbers at each gestational age, the study does not indicate a specific gestational age at which survival is improved. Further investigation is required.

Logistics and technical aspects of PMCD

While it may be tempting to move the patient to a more familiar location conducive to surgery (eg, the operating room) for PMCD, this procedure should be performed on location of the arrest. ROSC without delivery has been described, but requires high-quality CPR. The quality of chest compression is significantly reduced during transfer of the patient.[9,43,44] The mother deserves an optimal resuscitation attempt prior to the decision of PMCD. Once the decision for PMCD is made, relocating the patient also delays performance of PMCD.[44] Time is of the essence in these situations. New data from CAPS[6] appear to substantiate that patients transported during their resuscitation are less likely to survive even when adjusted for an out-of-hospital event. In their data, transportation delayed PMD and most likely compromised the quality of chest compressions. This remains an ongoing area of research. While most of the perimortem deliveries will be surgical procedures, vaginal delivery is an acceptable alternative if delivery is imminent.[9]

Contrary to most surgical procedures, bleeding will most likely not be an issue when performing PMCD because of the lack of uterine perfusion. If ROSC occurs, obtaining surgical hemostasis will still be required especially since coagulopathy may be a cofactor. Similarly, efforts to cleanse and prepare the abdomen will likely lead to delays and should be minimized. Once CPR has begun, attention should be directed to preparing for PMCD in the event that initial resuscitative efforts are unsuccessful. Fetal monitoring and ultrasound to confirm presence of fetal heart tones are not necessary. The determinant of whether or not to perform PMCD is not the fetal condition, it is the condition of the mother. If ROSC does not occur and the uterus is ≥20-week size, then PMCD is recommended. The gestational age, or more precisely the uterine size, was chosen based on the physiologic premise that aortocaval decompression through delivery optimizes chances of ROSC as discussed above.

The only necessary equipment for initiating a PMCD is a scalpel. A vertical laparotomy incision has been advocated for PMCD. This approach is useful to facilitate additional interventions such as abdominal exploration to evaluate for intraabdominal and retroperitoneal hemorrhage and provides access to the upper abdomen and aorta. However, many providers are much more comfortable performing an emergency cesarean delivery through a Pfannenstiel incision. We recommend the provider use the incision that he/she is most comfortable with that will allow the most expeditious delivery of the fetus. Time is best spent on the rapid performance of a cesarean delivery with no efforts on careful sharp dissection or cautery of vessels. CPR should continue throughout the procedure.

Once the fetus and placenta are delivered, then attention should be focused on additional resuscitative interventions. Palpation of the aorta may assist in determining whether spontaneous circulation has returned. Compression on the aorta (ideally below the level of the renal arteries) may be performed to redirect vital circulation cephalad during compressions. The decision of whether to close the uterus and abdomen will be dictated by maternal condition. If ROSC occurs, the abdomen can be packed, and the patient transported to the operating department for closure of the hysterotomy and laparotomy incisions. Suspicion of amniotic fluid embolism should prompt activation of massive transfusion protocol. If resuscitation is ongoing and ROSC appears less likely in the minutes following delivery, then the surgeon may opt to close the incisions in situ. The uterus should be closed using absorbable suture in a running interlocking fashion. The suturing technique should be performed with the idea of tissue reapproximation that minimizes the risk of inadvertent needle injury to the surgical team. The abdomen is closed using a mass closure. If the abdomen remains open, be aware of crucial heat loss, which may occur and make efforts to minimize it by packing and covering the abdomen. If not already in place, a urinary catheter should be inserted. Placement of the catheter should not create an unnecessary delay. We suggest that institutions develop their own PMCD kit that contains all of the necessary items in a centralized location, such as with the code cart. Suggested items to include in the kit include scalpel(s) with a 10 blade, surgical gloves and gowns, masks, skin preparation, laparotomy sponges, 2 Kelly clamps, suture scissors, retractor, cord clamps, needle driver, Russian forceps, suture, and items for the neonate such as resuscitation supplies.[8,9,40,45]

The role of simulation in MCA

Because of the low prevalence of MCA, it is likely that most or all of the team members responsible for responding to the acute arrest will have no prior experience with MCA or PMCD. The SOAP guidelines and the AHA Scientific Statement in 2015 recommends multidisciplinary drills and specific courses concentrating on maternal resuscitation for staff members.[9] In one study, maternal-fetal medicine staff and fellows who received simulation-based training on MCA demonstrated improved response in initiating CPR and performing a PMCD.[46] In a recent Canadian study involving anesthesiology residents, didactic or electronic teaching regarding MCA followed by high-fidelity simulation reduced the time to perform PMCD and increased the likelihood of performing the PMCD in situ. Whether the residents received didactic or electronic teaching presimulation did not appear to be a significant factor in this study.[47] In the Netherlands in 2003, the Managing Obstetric Emergencies and Trauma (MOET) course was introduced. This course includes education on performing PMCD. A recent publication assessed PMCD incidence and factors in the 11 years before and the 5 years after introduction of the MOET course. As expected, PMCD was more likely to be performed after education was provided (4 PMCD in 11 years preceding MOET vs 8 in 5 years subsequent to MOET). Of note, none of the 12 PMCD were performed within a 5-minute window from MCA. Unnecessary delay is described as the primary reason this threshold was not met, including inability to locate a scalpel, relocating to an operating room, and/or performing fetal monitoring.[48]

Institutional preparation for MCA

Because MCA is an infrequent event, few providers have experience in handling this situation. It is often not covered during routine ACLS certification courses. Emergency preparedness through regular performance of multidisciplinary team training simulations is recommended to improve interdepartmental communication and to identify local barriers to optimal care.[8] Additionally, because equipment needed for PMCD may not be immediately available in an emergency, the development of a specific PMCD kit (as described above) that can be transported by the code team to the maternal code may help decrease delays in performing a PMCD.[45]

Additional interventions

End tidal CO_2 levels >10 mm Hg may correlate with ROSC, but are not predictive of survival or long-term outcome.[9] A palpable aortic pulse appreciated during PMCD can also signify ROSC. If ROSC has not occurred following perimortem delivery, additional interventions including direct cardiac massage, cardiopulmonary bypass (CPB), and extracorporeal membrane oxygenation (ECMO) may be considered. Direct cardiac massage can be performed via diaphragmatic approach during PMCD and may enhance organ perfusion when ROSC has not yet occurred.[49-51] Direct cardiac massage has also been utilized during thoracotomy performed in the setting of trauma or cardiothoracic surgery.[52-54]

CPB and ECMO can be utilized when the suspected etiologies of cardiac arrest are potentially reversible during a limited period of mechanical cardiorespiratory support. Etiologies that may be conducive to these interventions include: local anesthetic toxicity, drug overdose, respiratory failure, and acute respiratory distress syndrome or amniotic fluid embolism.

In some patients, the etiology of the arrest may be potentially reversible if external hemodynamic and or respiratory support is provided through CPB or ECMO. CPB is more commonly utilized for intraoperative support. When support is required for a prolonged period of time in an intensive care unit setting, for example, ECMO or extracorporeal life support are utilized. Venovenous ECMO provides respiratory support while venoarterial ECMO additionally provides hemodynamic support. The most common indication for extracorporeal life support in pregnancy thus far is acute respiratory distress syndrome and not cardiac arrest. When utilized in undelivered patients, maternal survival is reported to be 77.8% for mother and 65.1% in fetuses.[55] When postpartum patients are included, maternal survival is similar at 80%.[56]

Post-ROSC management

If resuscitation is successful and ROSC occurs, management will be dictated by the specific clinical scenario. A multidisciplinary team in an intensive care unit setting is best equipped to optimize management of these cases. Neurophysiological and imaging modalities should be used to assess prognosis as they are in the nonpregnant population. If the patient is undelivered, fetal assessment guided by gestational age will determine further management. Planned delivery may be appropriate after successful maternal resuscitation and/or if maternal hemodynamic instability recurs. Positioning in full left lateral decubitus whenever possible will optimize maternal hemodynamics. The risk for post resuscitation arrhythmia is elevated and therefore pharmacologic therapy as well as pacing may be necessary to stabilize the patient.

Because of the uncertain benefit of targeted temperature therapy in pregnancy, decisions for its implementation should be made on a case-by-case basis.[9] Hypothermia may aggravate an already fragile coagulation system. Fetal heart rate monitoring usually reveals a low baseline with decreased variability. Targeted temperature management at 36°C rather than lower degrees of targeted hypothermia may be favored to combat reperfusion injury in the nonpregnant population.[57]

Conclusion

Maternal mortality is paradoxically increasing in the new millennium. Resuscitation for MCA requires a multidisciplinary team well versed in the physiologic adaptations of pregnancy and the core principles of maternal CPR. Resuscitative interventions are concurrent rather than sequential, emphasizing manual left uterine displacement to mitigate aortocaval compression. Perimortem delivery provides ultimate relief of aortocaval compression performed to optimize maternal outcomes. Shorter times from arrest to delivery appear to improve both maternal and neonatal outcomes, yet the precise delivery time point estimate requires further evaluation. Initiation of PMCD by 4 minutes with delivery by 5 minutes may be an unrealistic clinical expectation. However, establishing a longer time frame may only lead to further delays.

Simulation training can be implemented to ensure emergency preparedness to improve systems of care and to foster collaborative communication, a fundamental component of successful multidisciplinary medical teams. As demonstrated by the ILCOR 2015 review of maternal resuscitation, knowledge and evidence gaps remain considerable. While the recent CAPS provides detailed prospective data regarding MCA, it is clear that more data are required to refine areas of clinical uncertainty. Establishment of a national and international prospective registry would promote better understanding of how best to mitigate aortocaval compression during resuscitation and refine the impact of perimortem delivery and its optimal timing for best maternal and neonatal outcomes. ■

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