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Management of cardiac arrest in pregnancy

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Cardiac arrest in pregnancy is a rare event in routine obstetric practice, but is increasing in frequency. Resuscitation of cardiac arrest is more complex for pregnant women because of a number of factors unique to pregnancy: the altered physiologic state induced by pregnancy; the requirement to consider both maternal and fetal issues during resuscitation; and the consequent possibility of perimortem caesarean section during resuscitation. These extra considerations create a unique clinical emergency and decision pathway requiring the co-ordinated response of medical, obstetric, and neonatal teams. Although many research questions remain in this area, recent consensus has been reached on appropriate resuscitation of a pregnant woman. Centres offering care for birthing women need to be aware of the changing demographics and resuscitation guidelines in this important area, and implement measures to ensure dependable and optimal team responses to maternal cardiac arrest.

Introduction

The incidence of maternal cardiac arrest appears to be at least 1:12,000 based on recent data from a nationwide study in the United States looking at the incidence of cardiac arrest in patients admitted for delivery [2]. Cardiac disease is the leading cause of maternal mortality, as reported by the Confidential

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Enquiries into Maternal Death in the UK, which is the largest population based study of maternal mortality [1]. Cardiac deaths have been the overall leading cause of death during pregnancy since the 1997–1999 enquiries. Since that time, rates have risen steadily [1]. In a cross-sectional study from the USA [3], the prevalence of chronic heart disease among pregnant women remained unchanged; however, the severity of disease increased between 1995 and 2006. During this period, severe complications (including cardiac arrest) around the time of delivery were found to be more common, as were antenatal hospitalisations; postpartum hospitalisations, however, tripled. Therefore, although still rare, rates of maternal cardiac arrest are rising, mandating appropriate preparation by hospitals and staff.

Managing cardiac arrest in a pregnant woman is more complex than in non-pregnant women. Both the mother and the fetus require consideration during the cardiac arrest. The resuscitation team has two patients, although clearly the mother is the priority. In addition, two specialised teams need to work in conjunction during a maternal cardiac arrest: the 'code blue' maternal resuscitation team, and the obstetrical/neonatal team. The challenge faced by these teams is to work simultaneously but with co-ordinated efficiency. The potential pit-falls in multiple group emergency collaboration are compounded by the rarity of the event and the disappointing levels of skill and knowledge highlighted in all published studies of caregivers of the management of cardiac arrest in pregnancy [4–8]. Education and training on the management of cardiac arrest in pregnancy is, therefore, clearly needed. In this chapter, we review these issues and current guidelines on the management of cardiac arrest in pregnancy.

Pregnancy physiology as it relates to resuscitation

Many changes take place to a woman's physiology during pregnancy. The two changes relating to cardiac resuscitation recommendations, which are particularly important, are aortocaval compression (ACC) and changes to pulmonary physiology.

Aortocaval compression and non-invasive decompression maneuvers

During pregnancy, the gravid uterus compresses the aorta and inferior vena cava. Compression of the inferior vena cava impedes venous return and results in reduced stroke volume and cardiac output, an important factor to consider during resuscitation. Traditionally, 'significant' ACC had been thought to occur at around 20 weeks' gestational age, as an increase in cardiac output in the lateral position compared with the supine position was found at this gestation [9]. It is, however, important to distinguish between two separate issues: AAC that causes problems during a normal pregnancy and the degree of compression that negatively affects resuscitation efforts. The 20-week threshold for significant ACC dates back to 1969 [9]; however, ACC was not examined at earlier gestational ages [9]. A study from as early as 1943 found that ACC occurs even at 12–14 weeks' gestational age [10]. Therefore, from the above data, it can be concluded that ACC occurs even from early in pregnancy and that it results in significant maternal haemodynamic changes.

The effect of maternal position on ACC is important as it shows how it can significantly affect maternal haemodynamics [11]. Traditionally, tilt has been used to relieve ACC. A recent magnetic resonance imaging study found that, at 20 weeks' gestational age, stroke volume in the left lateral decubitus position increased by 27% compared with the supine position; by 32 weeks, stroke volume increased by 35% and cardiac output increased by 24% in the left lateral decubitus position compared with the supine position [12]. Other studies have found that tilt results in improved maternal haemodynamics, including blood pressure, cardiac output, and stroke volume [13]. Fetal parameters also improve, including oxygenation, non-stress test, and fetal heart rate [14–16].

In studies on cardiac arrest in pregnant women, the benefit of maternal tilt during the management of cardiac arrest has been questioned for several reasons. First, no physiologic data show that chest compressions are effective on a tilted woman [17]. Second, the maximum resuscitative force that can be applied during chest compression in a tilted woman declines as the degree of tilt increases [18]. High-quality chest compressions are an essential part of maximizing the chance of successful resuscitation [19,20], and require proper positioning (supine) placing the patient on a firm surface e.g

backboard, proper depth, of at least 2 inches/5 cm, and rate of chest compression, at least 100/min, allowing full recoil of the chest wall and, importantly, minimize interruption to < 10 seconds except for specific intervention such as defibrillation and intubation [21,22]. The importance of chest compression quality is supported by the decision of the American Heart Association (AHA) to replace the long-standing 'A-B-C' with 'C-A-B', indicating that chest compressions are the most important action of the rescuer [23]. Any action that may delay, interrupt, or affect the quality of chest compression could negatively affect outcomes. Efforts at maternal lateral tilt may result in delays, interruptions, and reduced force of chest compressions, and therefore are not ideal in the arrest situation. Moreover, even if caregivers attempt tilt during resuscitation, ACC may not be completely relieved at the degrees of tilt that can be reasonably achieved. At tilt angles of 30° or more, the unconscious woman will slide or roll off the incline plane [18]. At 15°, 30°, and 45° of tilt, ACC can still be found [24–26]. One study found that maximal cardiac index was only achieved with the full left lateral position [26], a position that is incompatible with resuscitation. Any degree of ACC could affect maternal haemodynamics enough to negatively affect resuscitation efforts. In a recent study, cardiac output was reported to be on average 5% higher when tilted 15° or more compared with less than 15° [27]. In a subgroup of women, cardiac output decreased by over 20% without a change in blood pressure when they were tilted less than 15° [27]. Furthermore, even experienced clinicians have been shown to be inaccurate when estimating the degree of tilt and, commonly, overestimate tilt [28]. Finally, even though studies have found that chest compression can practically be carried out in the tilted position [29], these studies are not physiologic and, therefore, lack critical information about the use of tilt during cardiopulmonary resuscitation. Therefore, many concerns are valid about the use of tilt for the purpose of relieving ACC when resuscitating a pregnant woman with cardiac arrest [30]. In the pre- and post-arrest phases, when chest compressions are not required, placing the pregnant woman in a full left lateral decubitus position at 90° is recommended to help prevent haemodynamic deterioration [31].

Aortocaval compression can also be relieved by manual left uterine displacement (LUD) [32]. In healthy pregnant woman undergoing caesarean section, LUD resulted in less hypotension and a significant reduction in mean ephedrine requirements in women undergoing caesarean section [32]. When manual LUD is used, the woman can remain supine, which allows for high-quality chest compression and easier access for defibrillation and airway management (Fig. 1). Therefore, manual LUD is the preferred method of relieving ACC during resuscitation in a pregnant woman. Manual LUD can be carried out from either the left or right side of the woman. The left side is preferred as the uterus can be cupped and lifted upwards and leftward off the maternal vessels (Fig. 2, received permission to use from AHA) [31]. If the rescuer must be on the right side of the woman, manual LUD can be carried out by pushing the uterus upwards and to the left (Fig. 3, received permission to use from AHA) [31]. It

Fig. 1. Tilt with chest compressions from above and left uterine displacement (LUD).

Fig. 2. Left uterine displacement (LUD) from left side of patient.

is important that the rescuer uses the proper technique for manual LUD so as not to inadvertently push the uterus down, thereby causing increased ACC. Manual LUD should be the first and preferred method of relieving ACC during resuscitation for a maternal cardiac arrest [31].

During a maternal cardiac arrest, consideration for possible ACC should be given at any gestational age, and aortocaval decompression should be carried out when technically possible. Other factors, such as multiple pregnancy or polyhydramnios may cause ACC at earlier gestational ages than usually expected. If the woman is 20 weeks' gestational age or over, the uterus is at or above the umbilicus, aortocaval decompression manoeuvers as discussed above should always be implemented immediately.

When aortocaval decompression and usual resuscitation measures do not result in return of spontaneous circulation (ROSC), then a perimortem caesarean section should be considered at 20 weeks gestational age or over. Perimortem caesarean section is the only method that completely relieves ACC by decompressing the uterus with delivery of the fetus. Perimortem caesarean section before 20 weeks' gestational age is, in most circumstances, not required and not encouraged. Reports of

Fig. 3. Left uterine displacement (LUD) from right side of patient.

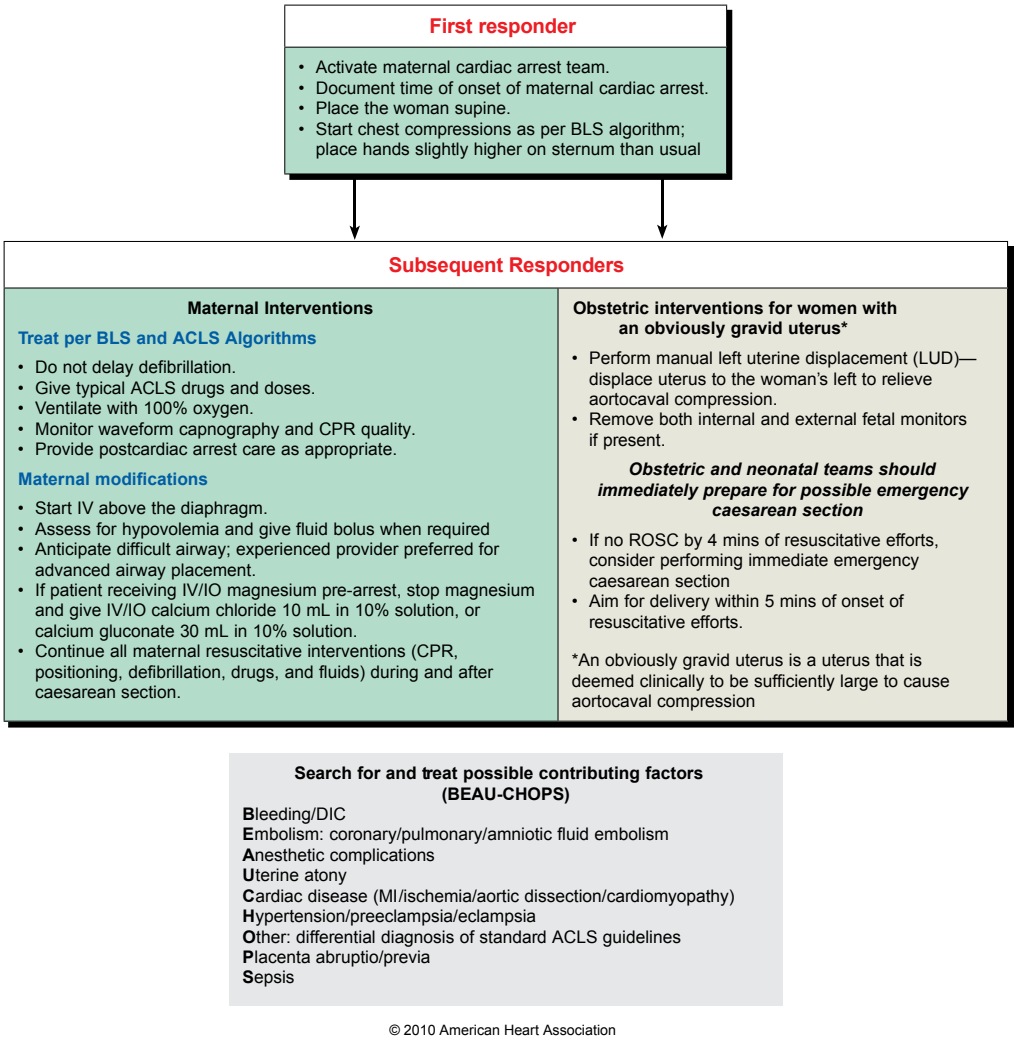

Fig. 4. American Heart Association (AHA) algorithm for the management of cardiac arrest in pregnancy.

successful resuscitation without perimortem caesarean section at earlier gestation ages have been published [33,34], and non-invasive methods of aortocaval decompression should be adequate.

Perimortem caesarean section

Many case reports have been published of sudden and dramatic ROSC in women at later gestational ages only after perimortem caesarean section had been carried out [30,35–39]. Therefore, if non-invasive methods of relieving ACC prove inadequate, perimortem caesarean section can be life saving for both mother and baby, and should be considered as one of the important treatment options for the management of cardiac arrest in pregnancy. Perimortem caesarean section should be considered when ROSC does not result after 4 min of resuscitation, so that hypoxic brain injury can be avoided [31] and to improve the chance of fetal and maternal survival [40–43]. Perimortem caesarean section should be carried out at the site of the maternal cardiac arrest; the woman should not be transported to an operating room, as this causes delays and results in decreased cardiopulmonary resuscitation (CPR) quality [44,45].

Table 1
Recommended equipment in high risk areas.

Equipment contents of the emergency caesarean section tray	Equipment for neonatal resuscitation and stabilisation
Scalpel with number 10 blade	Over-bed warmer
Lower end of Balfour retractor	Neonatal airway supplies
Pack of sponges	Umbilical access
Two Kelly clamps	Medications (e.g. epinephrine 1: 10,000 (0.1 mg/ml))
Needle driver	
Russian forceps	
Sutures and suture scissors	

Respiratory physiologic changes and resuscitation

During pregnancy, several important changes occur to the upper airway and pulmonary physiology. These changes result in more rapid desaturation [46] and an increased risk of failed intubation, even for elective procedures in the normal women undergoing caesarean section [1,47,48]. All members of the resuscitation team should be educated in the changes in airway and pulmonary physiology, and have heightened concern about airway management.

Changes to the upper airway include oedema, hypersecretion, and hyperaemia, which result in possible impaired visualisation and increase the risk of bleeding during airway manipulations [49,50]. The upper airway is smaller during pregnancy [51]. Therefore, the most experienced anaesthetist should attempt intubation, multiple attempts should be avoided, and a smaller endotracheal tube than normal should be used. Specific airway management protocols for pregnant women are beyond the scope of this chapter; however, excellent resources are available [50,52].

During pregnancy, functional residual capacity reduces and oxygen consumption increases, which results in a reduction in oxygen reserve [46,53–55]. Reduced oxygen reserve contributes to the rapid desaturation seen during pregnancy. In addition, during pregnancy, increased intra-pulmonary shunting is observed, so ventilation-perfusion mismatch is poorly tolerated [56]. During pregnancy, the fetus can be affected by the physiologic effects of ventilation. With maternal over-ventilation and the resultant respiratory alkalosis, there is a risk of uterine vasoconstriction and fetal hypoxaemia [57]. Finally, with the elevated diaphragm in pregnancy, ventilation volumes may need to be reduced.

Lower oesophageal sphincter dysfunction occurs in pregnancy, which increases the risk of aspiration [58–60]. The use of cricoid pressure, however, may not reduce the risk of aspiration and may have a negative effect on laryngoscopy and ventilation [61,62]. Therefore the routine use of cricoid pressure is no longer recommended [62].

Aetiology of maternal cardiac arrest

During a maternal cardiac arrest, the aetiologic considerations differ from those in non-pregnant women. Mnemonics can be useful for clinicians to help remember the possible causes of a maternal arrest. 'BEAUCHOPS' as listed in the care algorithm (Fig. 4) of the AHA 2010 guidelines [31] on cardiac arrest in pregnancy is one possible mnemonic: **B**leeding/DIC; **E**mbolism (coronary/pulmonary/amniotic fluid embolism); **a**nesthetic complications; **U**terine atony; **C**ardiac disease (myocardial infarct/ischemia/aortic dissection/cardiomyopathy); **H**ypertension/pre-eclampsia/eclampsia; **O**ther: differential diagnosis of standard Advanced Cardiac Life Support (ACLS); **P**lacenta abruptio/previa; **S**epsis.

The Confidential Enquiries into Maternal Death report [1] highlighted the importance of cardiac disease in maternal mortality and discussed its risk factors: women are having babies at older ages, and the frequency of cardiac risk factors among pregnant women is on the rise; [1] women with more complex health problems are attempting pregnancy [1]. The most common cardiac causes of maternal arrest include sudden adult death syndrome (SADS), peripartum cardiomyopathy, aortic dissection, myocardial infarction or ischaemic heart disease [1]. Amniotic fluid embolism is a dramatic event, but with rapid response successful resuscitation has been reported [63,64]. Magnesium toxicity is another important consideration during cardiac arrest [65], and treatment should include stopping the infusion and administering calcium [31].

The resuscitation team and equipment

The team and equipment required to properly manage a maternal cardiac arrest differs greatly from those required in routine adult resuscitation [66]. Suggested members of the resuscitation team include (1) the adult resuscitation team; (2) the obstetrical team, including one doctor and one nurse or midwife; (3) the anaesthesia team, including one doctor and one adult respiratory therapist; and (4) the neonatal team, including one neonatologist, one nurse, and one neonatal respiratory therapist [66]. Those centres without an obstetrical service should make contingency plans [66]. Suggested minimum equipment that should be brought to every maternal arrest is outlined in Table 1 (received permission to use from JOGC) [66], and should be placed on code carts, high risk areas, or brought to the cardiac arrest scene by maternal cardiac arrest team members without delay.

Current science

Research into the science behind maternal resuscitation guidelines is sparse. Research on the management of maternal resuscitation is difficult given the rarity of the event, the individual circumstances of each case, and medico-legal issues of research during pregnancy and at the time of cardiac arrest. The most comprehensive publications include work by The International Liaison Committee on Resuscitation (ILCOR), which examines the science of resuscitation [67–69] and a recent publication of the first systematic review of maternal resuscitation [70]. The major findings of these publications include several important concepts. Chest compression feasibility has been researched in mannequin, non-physiologic studies [18,29]. As discussed above, these studies have found that, although chest compressions are feasible in the tilted patient, it is hard on the rescuers, and the force of compression diminishes as the angle of inclination increases [18,29]. When it comes to defibrillation energy requirements, one study found that the transthoracic impedance does not change with pregnancy and therefore concluded that the energy requirement for defibrillation in pregnancy should not change from the non-pregnant recommendations [71]. Perimortem caesarean section has been evaluated in two studies. One retrospective cohort study found that implementation of a training course on managing maternal emergencies resulted in an increased awareness of the potential maternal benefit of perimortem caesarean section and also an increase in the number of perimortem caesarean section carried out [37]. This retrospective cohort reported poor outcomes with perimortem caesarean section, and also many time-consuming delays to carrying out perimortem caesarean section. The perimortem caesarean sections that were carried out were not within the recommended 4–5 min window [37]. The second study was a case study [42]. It showed that few perimortem caesarean sections were carried out within the recommended 4–5 min time-frame from maternal cardiac arrest. Despite delays, positive neonatal and maternal outcomes after perimortem caesarean section still occurred [42]. When delays to perimortem caesarean sections beyond the recommended 4–5 min timeframe occurred, it was the older neonates that had better outcomes. This study found that often the mother has a sudden improvement in haemodynamics after perimortem caesarean section, a finding described in many case reports [42].

In addition to the above considerations, research has also addressed a number of other issues. Simulation-based research is an important area that has been highlighted in recent years. Studies have found that transporting the mother in cardiac arrest decreases the quality of CPR [45] and increases the time to perimortem caesarean section [44]. These studies, together with a retrospective cohort study [37], which found that transport resulted in delays to perimortem caesarean section, support the recommendation that perimortem caesarean section should be carried out at the site of the maternal cardiac arrest [37,44,45]. Another study introduced the idea of having a cognitive aid reader to assist the team leader for a simulated obstetric cardiac arrest, and found that all critical actions were only executed when such a reader was introduced [72]. Simulation-based research has shown that simulation can also be used to improve knowledge, confidence and performance for the management of maternal cardiac arrest [73]. Finally, a more recent case study was conducted of all maternal cardiac arrests that occurred in pregnancy before a caesarean section [43]. This study found that 60.6% of mothers achieved ROSC, and that 51 out of 94 mothers (54.3%) survived to hospital discharge [43]. Variables predicting maternal survival included in-hospital location of arrest and perimortem caesarean section less than 10 min [43]. Perimortem caesarean section was beneficial in 31.7% of cases

and not determined to be of harm in any case [43]. Neonatal outcomes were better with earlier delivery times, and only found in cases of in-hospital arrest [43].

In conclusion, no randomised-controlled trials on the management of cardiac arrest in pregnancy have been published. Guidelines are based on the few studies available that examine specific areas within the management of a maternal cardiac arrest, known maternal physiology as it relates to resuscitation, case studies, and expert opinion, which are then combined with the knowledge base of resuscitation science in non-pregnant woman. The most recent AHA guidelines for cardiac arrest in pregnancy were published in 2010 [31].

Current guidelines

The 2010 AHA guidelines provide healthcare professionals with an up-to-date response plan for a maternal cardiac arrest [31]. The first responder must activate the maternal cardiac arrest team, note (and later document) the time of onset of the maternal arrest (for purposes of when to consider perimortem caesarean section), and start chest compressions. Subsequent responders will provide the additional resuscitation actions. The second responder should provide aortocaval decompression, ideally with manual left uterine displacement. The adult resuscitation team will manage the usual measures for adult resuscitation. Importantly, the responders should not delay defibrillation or administration of the usual resuscitation drugs recommended in non-pregnant woman, during management of a maternal arrest. Waveform capnography, when available, should be used to assess CPR quality. Modifications to adult resuscitation in the pregnant woman include placing the hands slightly higher on the sternum for chest compression, making sure intravenous access is above the diaphragm, assess for hypovolaemia with a higher index of suspicion, and then treat aggressively with fluid bolus, and finally for those women receiving magnesium, the magnesium should be immediately stopped and empiric treatment given in the form of calcium gluconate [31]. The airway should be managed by the most experience clinicians available. The obstetrical team should immediately prepare for a perimortem caesarean section and remove fetal monitors to expedite delivery should perimortem caesarean section be required. The neonatal team should be ready to receive the infant should perimortem caesarean section be carried out.

Cardiac arrest algorithm

As part of the 2010 AHA guidelines, the first algorithm for the management of cardiac arrest in pregnancy was published (Fig. 4, received permission to use from AHA) [31]. After the first responder activates the maternal cardiac arrest team, the algorithm depicts two simultaneous columns representing the simultaneous actions of the maternal arrest team and the obstetrical and neonatal teams. To carry out a perimortem caesarean section within 5 min after the onset of the maternal cardiac arrest, the teams must work in a co-ordinated fashion. The algorithm highlights the important modifications to resuscitation in the pregnant woman, the need for aortocaval decompression manoeuvers, and the rapid preparation and decision making required for a perimortem caesarean section should ROSC not be achieved within 4 min. In addition, the algorithm provides a mnemonic to help responders remember the various causes of maternal arrest. The algorithm can be laminated and kept on code carts, given to maternal arrest clinicians, or provided in poster form in high-risk areas. The algorithm can be used as a cognitive aid for responders.

Post-arrest care

Preparing for the post-arrest mother after resuscitation is equally important. If ROSC has been achieved without perimortem caesarean section, the woman should be placed in full left lateral decubitus position as a recovery position to prevent ACC and possible deterioration in haemodynamic status or even re-arrest. The use of therapeutic hypothermia should be considered on a case-by-case basis when indicated for the non-pregnant woman, as pregnancy is a relative contraindication and has not been studied. Therapeutic hypothermia can significantly improve the maternal neurological recovery after cardiac arrest (as extrapolated from research on non-pregnant women); however, fetal effects are unknown [62]. Some case reports have been published on the successful use of therapeutic

hypothermia in pregnancy [34,74], including one case report of fetal demise in a case where therapeutic hypothermia was used; however, emergency medical services arrived 22 min after being called, so fetal outcome could have been affected by other factors [75]. The use of therapeutic hypothermia has not been reported after perimortem caesarean section, and concern about coagulopathy with the use of hypothermia should be considered in this situation. Women receiving therapeutic hypothermia who have not had their babies delivered should be monitored for fetal bradycardia [34].

Other factors to consider after maternal cardiac arrest include adequate pain control should perimortem caesarean section be carried out, consideration for delivery if the woman is still pregnant when ROSC is achieved, and ongoing multi-disciplinary care (e.g. intensive care, anaesthesia, obstetrics, and neonatology).

Implementation and training

The implementation of maternal cardiac arrest guidelines and emergency preparedness requires a proactive approach [66]. Emergency preparedness committees should have an organised approach to the response to a maternal cardiac arrest. First, there should be a universal call to action for all members of the cardiac arrest team, for example 'Code Blue Obstetrics' could be considered as one option [66]. This call to action should activate a response by all required maternal code members and ensure that all the necessary equipment arrives at the scene of the arrest without delay [66]. A recent consensus statement on the management of cardiac arrest in pregnancy provides important and useful point of care instruments. [78]. Areas considered at particularly high risk for a maternal arrest include emergency departments, obstetrical units, and intensive care units. Women who are at risk for cardiac arrest should have the necessary resuscitation equipment kept in close proximity to their hospital bed. Every case of maternal arrest should be reviewed expeditiously, with feedback and support provided to team members [66]. Simulation can be used to help identify deficiencies and help improve the response for a maternal cardiac arrest within hospital settings [45].

Training programs for the management of a maternal arrest should be available for staff but also institution-specific training, implementation and response plans should be developed. Training courses aimed specifically at managing maternal cardiac arrest have been developed, as traditional adult cardiac-arrest training programmes inadequately prepare for a maternal cardiac arrest [73,76,77].

Conclusions

Maternal cardiac arrest is rare but is increasing in frequency. Resuscitation of these mothers requires a well-coordinated, multi-team response. Research into resuscitation techniques and an understanding of the physiological changes of pregnancy have allowed the development of guidelines specifically for maternal cardiac arrest. Health services that provide care for women who may suffer a cardiac arrest during pregnancy can avail of these guidelines when developing the integrated teams and processes necessary for optimal survival rates.

Practice points

- Left lateral tilt is no longer recommended during active resuscitation of maternal cardiac arrest during pregnancy.
- Left uterine displacement is currently the preferred method of minimizing ACC during active resuscitation in pregnancy.
- Defibrillation and all usual resuscitation medications should be used as they would be in non-pregnant resuscitation.
- Perimortem caesarean section should be used at the resuscitation site if there has been no response after 4 min.
- Multidisciplinary team training should be undertaken to optimise team preparation for resuscitation of cardiac arrest during pregnancy.

Research agenda

- Continue physiological studies to further explore the ideal positioning of pregnant women during resuscitation.
- Study preventative measures that might halt, or reverse, the growing incidence of maternal cardiac arrest in pregnancy.
- Explore optimal training strategies for implementation of published guidelines.
- Research post-resuscitation measures, such as therapeutic hypothermia, which might reduce morbidity.
- Develop an international registry for cardiac arrest in pregnancy.

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