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## Review

# Update: Focus in-hospital maternal cardiac arrest



C. Fischer<sup>a,\*</sup>, M.P. Bonnet<sup>a,b</sup>, A. Girault<sup>b,c</sup>, C. Le Ray<sup>b,c</sup>

<sup>a</sup> Department of Anesthesiology and Critical Care, Hôpital Cochin, Hôpitaux Universitaire Paris Centre, Assistance Publique- Hôpitaux de Paris, France

<sup>b</sup> INSERM U1153, Obstetrical, Perinatal and Pediatric Epidemiology Research team (EPOPé), Center for Epidemiology and Statistics Sorbonne Paris Cité, DHU Risks in Pregnancy, Paris Descartes University, Paris, France

<sup>c</sup> Port-Royal Maternity Unit, Cochin Hospital, Hôpitaux Universitaires Paris Centre, Assistance Publique-Hôpitaux de Paris, DHU Risks in Pregnancy, Paris Descartes University, Paris, France

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## ABSTRACT

The incidence of maternal cardiac arrest ranges from 1/55,000 to 1/12,000 births. It is due most frequently to cardiovascular, hemorrhagic, and anesthesia-related causes, as well as to amniotic fluid embolism. The basic principles of resuscitation remain applicable in this situation, but the physiological modifications of pregnancy must be taken into account, in particular, the aortocaval compression syndrome. After 24 weeks of gestation, a salvage cesarean delivery must be performed immediately, without transfer to the operating room, if resuscitation maneuvers have failed 4 min after arrest, because this interval conditions the mother's neurological prognosis and improves neonatal survival.

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## Introduction

The principles of modern cardiopulmonary resuscitation (CPR) of adults were introduced in the 1960s, but their application to

pregnant women appeared only 30 years later and occupied only a few lines in the text of clinical practice guidelines. The particularities of maternal CPR are better known today and are covered in specific guideline sections [1,2]. Consideration of the physiological modifications of the cardiopulmonary system associated with pregnancy is essential for effective CPR of pregnant women. These changes involve cardiac output, blood volume, ventilation, and oxygen consumption, all of which increase during pregnancy. Moreover, the gravid uterus causes compression of the

\* Corresponding author at: Department of Anesthesiology and Critical Care, Hôpital Cochin, 27, rue du Faubourg St Jacques, 75014, Paris, France.  
 E-mail address: [catherine.fischer2@aphp.fr](mailto:catherine.fischer2@aphp.fr) (C. Fischer).

abdominal and iliac vessels, especially in the dorsal decubitus position, where this results in decreased cardiac output and blood pressure. The standard initial management of cardiorespiratory arrest must therefore be adapted to these physiological modifications. Nonetheless, if cardiac activity does not resume within 4 min after maternal cardiac arrest (MCA), even after appropriate basic or advanced cardiac life support (BLS and ACLS), a perimortem cesarean delivery (PMCD) is an essential part of fetal but especially maternal salvage.

Cardiac arrest during pregnancy is extremely rare but maternal and fetal outcome depend on the speed and effectiveness of the resuscitation procedures. This extraordinary situation requires coordinated intervention by obstetrics, anesthesiology, and neonatology teams, which must share the same management objectives. These objectives and the algorithm for maternal resuscitation must be known beforehand by all participants to implement optimal management.

## Epidemiology

### Incidence of maternal cardiac arrest

Because of the rarity of this event, the incidence of MCA is difficult to calculate. Several recent population-based studies in Canada and the United States (US) have assessed the incidence of MCA at around 1/12,000 hospitalizations for delivery [3,4]. A retrospective nationwide study in Canada identified 286 cases of MCA between 2002 and 2015 among 3,568,597 admissions, for an incidence of 8/10,000 hospitalizations and a maternal survival rate of 71% [3]. In a US study, Mhyre et al. found a similar incidence, with 4843 cases of MCA between 1998 and 2011 among 56,900,512 hospitalizations and a 59% maternal survival rate [4].

Moreover, enquiries that monitor and analyze maternal deaths have shown a significant increase in the number of PMCDs during this century: 52 cases were reported in the United Kingdom (UK) in 2003–2005, double the number reported during the preceding three-year period [5]. Similarly, a retrospective study in the Netherlands showed that this procedure increased over a 15-year period [6].

### Risk factors

Although maternal mortality has remained stable in most countries that have been analyzing these data for several decades by appropriate methods, severe maternal morbidity is rising. A higher incidence of cardiovascular comorbidity in pregnant women, associated in part with the increase in maternal age, explains this phenomenon in part. African ancestry and social and economic vulnerability are other risk factors of maternal cardiovascular morbidity described in the US [7].

Among the 4843 cases of in-hospital MCA reported by Mhyre et al., the most frequently associated comorbidities were pulmonary arterial hypertension, cancer, cardiovascular and liver disease, and systemic lupus erythematosus [4]. The obstetric risk factors included fetal death, cesarean delivery, severe preeclampsia, and placenta previa.

In the Canadian study, Balki et al. reported the following risk factors for MCA: maternal age (with an OR of 1.8 for women aged 35–39 years and 3.1 for those 40 years or older), grand multiparity (> 4, OR 2.08), as well as gestational age younger than 32 weeks (OR between 14 and 16) [2]. The obstetric risk factors were abnormal placental insertion and polyhydramnios. Associated maternal comorbidities were cancer (OR 8.4), neurological and respiratory diseases, hypertensive disorders of pregnancy, and gestational diabetes. Contrary to the study by Mhyre et al., cardiovascular diseases did not appear to be risk factors in the

Canadian study, but we must note that it included substantially fewer cases of MCA than the US study: 286 vs 4843 [4].

## Maternal cardiac arrest: CAUSES and PROGNOSSES

### Causes and maternal prognosis

Among the causes of MCA, hemorrhage – antepartum or postpartum – remains the most frequent. Nonetheless the incidence of MCA in women with a hemorrhage is below 1/1000. Amniotic fluid embolism is the disorder most frequently often complicated by MCA, followed by myocardial infarction and thromboses. Table 1 reports the frequencies of the causes of MCA reported by these two studies and survival rates by cause [3,4].

Between 2011 and 2014, a prospective study in the UK identified 66 MCAs among 2,347,670 pregnancies, for an incidence of 2.8/100,000 pregnancies and a maternal survival rate of 58% [8]. In this study, the leading cause of MCA was anesthesia-related (17 of 59 cases), with a survival rate of 100%, followed in order of decreasing frequency by hypovolemia (13 cases, survival 38%), amniotic fluid embolism (8 cases, survival 62%), venous thrombosis (8 cases, survival 12%), cardiac causes (6 cases, survival 83%), cerebral hemorrhage (3 cases, survival 0%), aortic dissection (2 cases, survival 0%), cardiac tamponade, asthma, and pulmonary artery rupture (1 case each). Besides the anesthesia-related causes, which had an unexpectedly high incidence in this study, the other causes of MCA were essentially those found in surveys of maternal mortality [5]: 38 women (58%) survived after their initial cardiac arrest. Among the complications, 6 were neurological, 5 hemorrhages, 2 coagulopathies, 2 renal, and 1 cardiac. Details of intermediate- to long-term maternal outcomes were not provided.

The specific place that MCA occurs and the speed of its management are crucial prognostic factors. In the study by Beckett et al., the group of women who died was characterized by its higher proportions of MCA at home and of women who were moved for a cesarean delivery, as well as by a longer delay between MCA and the start of resuscitation. MCA from anesthesia-related causes, corresponding to cardiovascular complications of regional anesthesia, was associated with excellent maternal survival, explained in large part by their occurrence in a place where rapid management, especially surgery, was possible, due to the nearly immediate presence of anesthetists and obstetricians (operating suite, delivery room) (8).

Globally, the survival rates for MCAs reported in the literature are lower than those for cardiac arrest in the general population of adults [9,6].

**Table 1**

Causes of maternal cardiac arrest and survival rates according to cause (nonexclusive categories).

Causes of MCA	Canada 2002-2015 N = 286		USA 1998-2011 N = 4843	
	MCA	Survival	MCA	Survival
Postpartum hemorrhage	39%	70%	28%	55%
Antepartum hemorrhage	20%	65%	17%	53%
Heart failure	31%	70%	28%	55%
Anesthesia	13%	100%	8%	82%
Amniotic fluid embolism	13%	67%	13%	52%
Trauma	12%	56%	3%	23%
Sepsis	9%	60%	11%	47%
Eclampsia	7%	85%	6%	76%
Pulmonary embolism	6%	53%	7%	41%
Stroke	5%	46%	4%	40%
Acute pulmonary edema	5%	77%	2%	71%
Myocardial infarction	1%	33%	3%	56%
Aortic dissection	1%	25%	0.3%	0

## Fetal prognosis

Fetal prognosis is closely linked to that of the mother and thus to the speed of resuscitation.

In the UK prospective study with 66 cases of MCA, 46 fetuses were liveborn (32 to mothers who survived and 14 to mothers who died). When cesareans were performed within 5 min of MCA, neonatal survival was 96%, compared with 70% for delays exceeding 5 min. The other factors associated with better neonatal survival were maternal survival, birth weight, and gestational age, as well as reassuring neonatal markers (Apgar score and pH). The rates of complications and sequelae among the surviving "newly borns" were similar among those whose mothers did and did not survive [8]. These data confirm that maternal resuscitation is the most important element of fetal salvage.

In another series of 94 cases of MCA published in 2012, the neonatal survival rate among the 66 viable fetuses delivered by PMCD was 64% [10]. The time between MCA and PMCD – 14 +/-11 min among the survivors and 22+/-13 min for the non-survivors – underlines the importance of the speed of the cesarean delivery in this context.

## Medical management

Cardiac arrest is defined as the cessation of cardiac activity. Nonetheless verifying the absence of a palpable pulse is not essential for this diagnosis. All the guidelines stipulate that a patient who does not respond and is not breathing or is breathing abnormally requires immediate resuscitation, that is, chest compression and, if possible, ventilation.

### Basic life support

Initial management is based on the principles of basic CPR or life support (BLS), known to all. All major steps of BLS are reported in Table 2.

**Table 2**  
Principles of MCA management.

<b><u>MATERNAL CARDIAC ARREST</u></b>		
<b>BLS</b> <i>(4 staff members)</i>	<ul style="list-style-type: none"> <li>▪ Call for help</li> <li>▪ Note the timing</li> <li>▪ Start ECM at 100/min on a firm surface</li> <li>▪ Manual lateral uterine displacement</li> <li>▪ Free the upper airways</li> </ul>	Anesthetist Obstetrician Neonatologist
Prepare simultaneously for an onsite cesarean		
<b>ACLS</b> <i>(Specific team)</i>	<ul style="list-style-type: none"> <li>▪ Ventilation FiO<sub>2</sub> 100%</li> <li>▪ Orotracheal intubation</li> <li>▪ Supradiaphragmatic venous access</li> <li>▪ Epinephrine IVD 1 mg/3-5 min</li> <li>▪ DCC (except for asystole)</li> </ul>	<i>No fetal sensors</i>  <i>Stop MgSO<sub>4</sub></i>
<i>If failure and term &gt; 20 weeks</i>  <b>Cesarean without transfer at 4 minutes</b>		

BLS: basic life support, ACLS: advanced cardiac life support.  
IVD: intravenous direct, DCC: Direct current cardioversion.

The objective of chest compression is to press the chest down hard to a depth of 5–6 cm (2–2.4 inches) at a frequency of 100/min and a 1/1 relaxation/compression ratio. Any interruption of ECM compromises coronary vascularization and reduces the chances of survival. If ventilation can be provided (with an external mask), the ratio of chest compressions to insufflations must be 30/2, without any interruption of ECM. This should enable, at best, the return of spontaneous circulation (ROSC) at 20% of the normal level. Coronary perfusion is not assured because diastolic pressure cannot be restored by ECM alone, and cerebral perfusion remains mediocre, < 20% of normal. These initial procedures should be done until advanced cardiac life support (ACLS) is delivered. Particular attention must be paid to the time, which must be noted very precisely: time of MCA occurrence and of the start and duration of ECM.

Table 2 shows these modified principles, applicable to pregnant woman:

- first, the call for help must include a call for an obstetrician and a pediatrician, ideally a neonatologist
- the operator's hand position for ECM must be mediosternal (a little higher) because of the ascension of the diaphragm
- as soon as the uterus size is above the umbilic, manual displacement of the uterus to the left must begin immediately, as well as preparation for a cesarean, in case resuscitation does not succeed rapidly [1].

### Advanced cardiac life support

This stage of MCA management must also be adapted to the physiological modifications of pregnancy.

- The pregnant uterus, responsible for aortocaval compression syndrome, severely compromises the efficacy of ECM. One member of the team must be assigned to continuously displace the uterus laterally leftward. The procedure consists in cupping the uterine

fundus with both palms and pushing to the left while lifting it as much as possible to free the vena cava and the aorta. It was initially recommended that ECM be performed with the woman in left lateral decubitus, by using various types of objects to keep her on her side (inclined plane, a side block, a chair, etc.). But simulation tools have shown that ECM in a lateral decubitus position is much less effective than in dorsal decubitus. The force developed by the operator is stronger when he or she is vertically above the chest (67% of body weight) and diminishes with the slope of the surface (36% at 90°) [11]. Manual lateral displacement is more effective than a 12° slant for maternal hemodynamics during cesarean delivery [12].

- The position of the hands during ECM must be more or less mediosternal because of the pregnancy-related elevation of the diaphragm.
- Although procedures for maternal BLS and ACLS follow the standard guidelines for adults, steps to restore ventilation must be started earlier for MCA. Intubation by an expert (senior anesthesiologist) is recommended when possible, as well as the use of a small-diameter tube. End tidal CO<sub>2</sub> should be continuously monitored as soon as possible in order to assess the efficacy of chest compressions and to confirm correct endotracheal tube placement. Indeed, end tidal CO<sub>2</sub> above 10 mmHg or rising during resuscitation may correlate with the return to spontaneous circulation [2].- Early intravenous or intraosseous vascular access must be rapidly established; it must be supradiaphragmatic, to reduce delay in the time for drugs to reach the heart in case of caval compression.

The medical principles of ACLS for adults apply without modification for pregnant women concerning:

- Use of epinephrine: 1-mg bolus every 3–5 minutes
- Direct current cardioversion (DCC) (for shockable rhythm), at the same frequency and intensity as usual. A study showing that pregnancy does not modify thoracic impedance suggests that the same intensity of DCC should be used for pregnant women [13]. The only precaution is that the electrodes should be placed such that the current does not pass by the uterine cavity, that is, one anterior chest electrode and one left posterolateral, placed adequately high. A case report reviewing the literature counted 40 women treated by DCC for severe arrhythmias during pregnancy and reported in nearly all the cases (38/40) that the fetus was not harmed by this treatment. On the contrary, maternal ROSC was accompanied by improvement in fetal condition. On the other hand, DCC directed at the fetus is associated with neonatal mortality of 75% [14].

Fetus condition should not be considered at this stage, except for assessing gestational age (before or after 24 weeks). No monitoring (ultrasound or FHR/CTG) should be established; indeed it should be removed or disconnected after MCA. First, the metal sensor can be dangerous during cardioversion shocks. Second, assessment of fetal condition must not modify or delay execution of the algorithm for maternal resuscitation.

In the specific case of MCA due to excess magnesium sulfate for the treatment of severe preeclampsia, the magnesium sulfate infusion should be stopped and its antidote, calcium (1 g), injected.

#### **Perimortem cesarean at 4 min after MCA**

As mentioned above, maternal and neonatal survival both depend closely on the speed of maternal management and the performance of a so-called perimortem cesarean delivery (PMCD), ideally 4 min at most after the MCA.

#### *Rationale*

In the 1980s, despite modernization of the principles of CPR, cases of unexpected failure of resuscitation after MCA during pregnancy were reported [15]. During that decade, several authors also reported ROSC after cesarean deliveries performed after maternal resuscitation had apparently failed [16]. A review of the literature published in 2005 identified 38 cases of PMCDs published between 1985 and 2004. In more than half of the cases documenting subsequent maternal condition (12/22), authors reported spectacular and immediate improvement in maternal hemodynamics after the PMCD. Cesarean delivery was performed within 4–5 minutes in only 8 of the 38 cases in this series [17].

A retrospective Dutch study analyzed 55 MCAs in the 1993–2008 period; PMCD was performed in only 12 of them, but the authors noted that this rate increased substantially after the initiation of the MOET (Managing Obstetric Emergencies and Trauma) program, which recommended the performance of PMCD (the PMCD rate rose from 0.36/year to 1.6/year). In those 12 cesareans, 67% (n=8) of the women had recovered spontaneous cardiac output at the end of the delivery, but maternal mortality remained very high (83%) and the only two survivors had severe neurological sequelae. No PMCD was performed within 5 min of MCA; delays were attributed to the transfer of women to the operating room and/or assessment of fetal condition [6].

The principal benefit expected from operative fetal intervention when maternal resuscitation fails is improvement of the effectiveness of ECM; potential fetal salvage is only a secondary aim. This decision is, nonetheless, justified only after 22–24 weeks, or when the gravid uterus extends beyond the umbilicus. That is, effective ECM that follows standard guidelines does not enable the restoration of the cardiac output to more than 15–30% of normal. Moreover, caval compression by the gravid uterus reduces the filling volume of the right heart and the global flow proportionally to the uterine volume; this compression is maximum in the dorsal decubitus position and can result in complete occlusion of the inferior vena cava (which accounts for two thirds of total venous return). In the mid-third trimester, in dorsal decubitus position, cardiac output is thus reduced by 30 to 40%. The combination of these two factors (low restoration by ECM and aortocaval compression syndrome) severely impairs the performance of maternal resuscitation. Overall, only 10–15% of cardiac output can be obtained in these conditions. This very low blood flow is expressed by low maternal cerebral blood flow that, when maintained for more than 4 to 6 min can lead to irreversible anoxic neurological sequelae. For the same reasons, neonatal survival also depends on the duration of this low flow.

Manual lateral uterine displacement can certainly improve this result. Nonetheless if initial maneuvers fail past this 4-minute deadline on which maternal neurological prognosis depends, the uterus must be emptied to relieve this compression and enable ECM to continue in the best conditions.

Other potential benefits accompany the PMCD: improvement of lung compliance by reducing intra-abdominal pressure and fetal oxygen needs, restitution of the uterine portion of the total blood flow (10–20%) and, later, the mechanism of vascular flow associated with uterine contractions.

On the other hand, ECM must not in any case be interrupted, because that will worsen the mother's survival and functional prognosis. Moving her (by stretcher, elevator, etc.) for a cesarean delivery in the operation room impairs the effectiveness of ECM and of DCC. It is therefore recommended that the cesarean be performed, like the resuscitation, where the MCA occurred, even in the absence of aseptic conditions. In the CAPS prospective study in the United Kingdom, 41 PMCDs were performed among the 66 antepartum MCAs, including 11 cesareans in the ER, not in the OR.

In the survivors' group (38 women), the delay between MCA and PMCD was significantly shorter (7 min (2.5–17.5)) than in the group of women who died (16 min (6.5–43.5)). For women who had a cesarean without being moved (n=25), survival was 72%, compared with 36% for the women who were transferred. PMCD was not performed at all for the other 17 women, because cardiac output was restored (n=6), or gestational age was < 20 weeks (n=6), or for another reason (n=5) [8].

#### *In practice*

The recent international guidelines unanimously recommend a rapid cesarean: once the uterine volume reaches or extends past the umbilicus (20–24 weeks), a cesarean is indicated to save the mother's life between 20 and 24 weeks and for both the mother and fetus at and after 24 weeks [1]. Nonetheless, although PMCD is recognized as a key intervention on which maternal and fetal survival depend, many providers do not appear to know this, given that it is actually performed in only around one third of the maternal deaths after 24 weeks [18].

The 4-minute rule is an objective to strive for; it requires that the obstetric team be ready to perform a cesarean delivery once the MCA is observed and to perform a hysterotomy > 4 min later, in the absence of return to spontaneous circulation. Nonetheless, even after this delay, the cesarean delivery must be performed: on the one hand, a live newly born baby can be delivered even after 30 min of maternal resuscitation; on the other hand, even though the maternal neurological prognosis is associated with the duration of cerebral anoxia, this duration can only be assessed retrospectively.

Hesitancy and its many reasons are nonetheless obstacles to the performance of an immediate onsite cesarean in this context: nonsterile environment, minimal equipment, fear of a hemorrhage or legal consequences, and an erroneous belief that the cesarean is performed exclusively for the fetus's benefit. But these considerations may be offset by the failure of resuscitation past the time when maternal neurological prognosis and fetal survival seem unlikely.

The decision to perform a cesarean must not interrupt the resuscitation procedure, ECM in particular. No fetal assessment (ultrasound or monitoring) should be performed at this stage; the PMCD decision depends only on the failure of resuscitation. Any supplementary examination necessarily delays management and/or interrupts ECM, even if only for several seconds. Rapid and shared decision-making is facilitated if the scenario has been envisioned in advance, by simulation for example. The use of checklists or cognitive aids (posters, cards) read by one of the participants (who also announces the timing) is also useful in this context [19].

The cesarean must be performed in the same place as the MCA and CPR insofar as possible, generally by a midline laparotomy, while continuing ECM, epinephrine injections, and DCC if indicated. The placenta must be removed immediately after the fetus; nonetheless the risk of hemorrhage is not at the forefront since by definition there is no spontaneous cardiac output. If ROSC occurs, physicians should be aware of the risk of major bleeding. Thus, the woman should then be transferred to the operating room, especially for hemostatic procedures

In practice, the only essential equipment is a scalpel, but some authors recommend equipping emergency carts in obstetric

### Check list for the management of the first minutes of maternal cardiac arrest

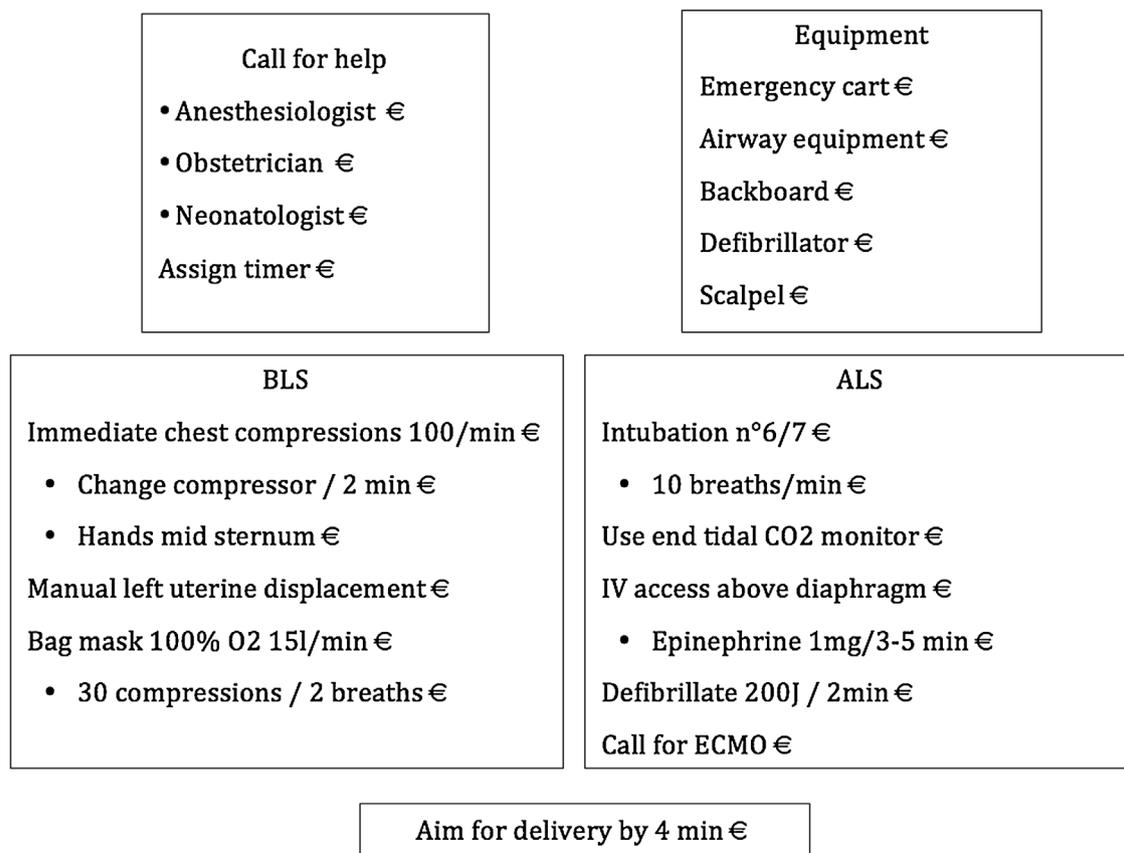


Fig. 1. Check list for the management of the first minutes of maternal cardiac arrest.

departments with a minimum set of surgical equipment, in particular, cord clamps, retractors, and sutures [19,20].

In the prospective CAPS study, 12 PMCDs were performed with no aseptic measures (no gloves, no skin preparation, no fields . . . ). A scalpel was available in the resuscitation cart in 55% of cases [8].

Table 2 summarizes the principles of management for MCA: basic life support, advanced cardiac life support, and a cesarean at 4 min.

### Extracorporeal life support

Following delivery, if return to spontaneous circulation has not been achieved, cardiopulmonary bypass or extracorporeal membrane oxygenation (ECMO) should be systematically considered [22]. A call number for ECMO referral center should be identified and mentioned in a check list (Fig. 1).

### Utility of simulation

Numerous studies have shown that simulation programs are excellent educational tools for interns and residents, but also important as techniques to improve the skills of more experienced providers for rare and serious situations [21,24]. Emergency decision-making, team leadership, organization, and communication, the use of checklists, cognitive aids and protocols, identification of errors, assessment of individual and group performance — all of these are aspects that can be enhanced by simulation exercises, especially as a team. While individual continuing education about MCA resuscitation is generally provided regularly within hospitals, the specificities of the management of pregnant women and the aspects of multidisciplinary coordination within a team are covered only rarely.

Assessments of knowledge and performance most often show the inadequacy of the preparation of obstetric and neonatal teams to manage maternal MCA [10,23]. The comparative before-and-after evaluation of a group simulation exercise showed significant improvement of all performance indicators, especially for PMCD decision-making [21]. Analysis of the videotape of an MCA simulation exercise makes it possible to document the points requiring improvement. In one study of this type conducted in an unprepared obstetric team (nurses, obstetricians, and anesthesiologists), the authors found that ECM was performed correctly in only 56% of cases, ventilation in 50%, and lateral uterine displacement was performed in only 56% of cases [24]. Delays in management are shortened, especially ECM initiation and PMCD decision-making, after a team simulation program [25]. Establishing immersion training and simulation program within multidisciplinary teams that may face this type of crisis situation makes it possible to improve the recognition of signs of life-threatening maternal distress, the practice of survival procedures (ECM, defibrillation, ventilation, lateral uterine displacement), the reflexes and organization of PMCD in 4–5 minutes, the coordination and implementation of multidisciplinary codes and procedures [24]. All members of obstetrical and anesthesiologist teams should have an easy access to cognitive aids and check lists for MCA management and be regularly trained through simulation sessions (Fig. 1). The establishment of this type of program is recommended by international guidelines on this topic [1,2].

### Conclusion

In-hospital MCA is a rare and serious event that healthcare providers in obstetrics must prepare themselves to face. The maintenance of skills as part of a training and simulation program must be organized regularly. The specific maneuvers of resuscitation must be coordinated and implemented in a multidisciplinary manner: the particularities of management associated with

aortocaval compression by the gravid uterus, which requires manual lateral uterine displacement during ECM, and the risk of early hypoxia, which must lead to rapid oxygenation. For the first minutes, and regardless of gestational age, the objectives of management aim solely for maternal ROSC and follow the algorithms for adult BLS and ACLS. If the initial attempt at resuscitation fails and after 20 weeks of gestation, cesarean delivery performed at the MCA site, without interrupting the cardiac massage, can improve maternal prognosis by releasing the aortocaval compression. After 24 weeks, it may allow enable fetal salvage. The 4-minute rule conditions the maternal neurological prognosis.

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