Review article

Maternal cardiac arrest and perimortem caesarean delivery: Evidence or expert-based?∗, ∗∗

Sharon Einav a,∗, Nechama Kaufman a, b, Hen Y. Sela c

a The General Intensive Care Unit of the Shaare Zedek Medical Centre, Jerusalem, Israel
b The Department of Emergency Medicine of the Shaare Zedek Medical Centre, Jerusalem, Israel
c The Department of Obstetrics and Gynaecology, Division of Maternal Fetal Medicine, Columbia University Medical Center, New York, USA

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A B S T R A C T

Aim: To examine the outcomes of maternal cardiac arrest and the evidence for the 4-min time frame from arrest to perimortem caesarean delivery (PMCD) recommended in current resuscitation and obstetric guidelines.

Data sources and methods: Review and data extraction from all reported maternal cardiac arrests occurring prior to delivery (1980–2010). Cases were included if they provided details regarding both the event and outcomes. Outcomes of arrest were assessed using survival, Cerebral Performance Category (CPC) and maternal/neonatal harm/benefit from PMCD. Outcome measures were maternal and neonatal survival.

Results: Of 1594 manuscripts screened, 156 underwent full review. Data extracted from 80 relevant papers yielded 94 included cases. Maternal outcome: 54.3% (51/94) of mothers survived to hospital discharge, 78.4% (40/51) with a CPC of 1/2. PMCD was determined to have been beneficial to the mother in 31.7% of cases and was not harmful in any case. In-hospital arrest and PMCD within 10 min of arrest were associated with better maternal outcomes (ORs 5.17 and 7.42 respectively, p<0.05 both). Neonatal outcome: mean times from arrest to delivery were 14 ± 11 min and 22 ± 13 min in survivors and non-survivors respectively (receiver operating area under the curve 0.729). Neonatal survival was only associated with in-hospital maternal arrest (OR 13.0, p < 0.001).

Conclusions: Treatment recommendations should include a low admission threshold to a highly monitored area for pregnant women with cardiorespiratory decompensation, good overall performance of resuscitation and delivery within 10 min of arrest. Cognitive dissonance may delay both situation recognition and the response to maternal collapse.

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1. Introduction

Maternal cardiopulmonary arrest with resultant death or disability carries devastating consequences. Studies of cardiac arrest in the general adult population demonstrate that improving patient outcomes may be possible even in an arrest situation but the efficacy of implementing similar strategies in maternal cardiac arrest remains unknown. The extreme rarity and highly uncontrolled circumstances of cardiopulmonary arrest during pregnancy render study of this medical situation very difficult.

Modern cardiopulmonary resuscitation (CPR) was first introduced in 1961. Obstetric resuscitation first appeared in the guidelines only 30 years later; less than a page was dedicated to the subject. Today, as evidenced by current resuscitation guidelines and appearance of the first green-top guidelines on maternal collapse in pregnancy of the UK-based Royal College of Obstetricians and Gynaecologists (RCOG), there is growing awareness that the physiological and anatomical changes of pregnancy may necessitate modification of standard practice.

Both resuscitation and obstetric guidelines suggest that perimortem caesarean delivery (PMCD) be considered within 4 min of maternal collapse if there is no return of spontaneous circulation (ROSC). Delivery within 5 min in women beyond 20 weeks of gestation is endorsed in order to facilitate maternal resuscitation (Grade D recommendation). This recommendation is based on the assumption that compression of the vena-cava by the gravid uterus may interfere with maternal haemodynamics. The 4-min interval theoretically benefits both mother and neonate by minimizing ischaemic neurological damage in both, but its veracity has never been studied.

The 4-min rule has been perpetuated in the literature due to two papers. The first described a greater likelihood of neonatal survival with early PMCD in cases collected from 1875 to 1985. Since CPR was first introduced in 1961, clearly the large majority of women described in this paper did not undergo CPR. The second paper described the cases published between 1986 and 2004; time from arrest to PMCD was described only for the majority of women described in this paper did not undergo CPR. Where the expression “term” was used to describe the gestational age, we assumed 40 weeks gestation. One paper did not detail the gestational age of each case but described the minimal age for inclusion, thus the earliest possible gestational age (26 weeks) was assumed for all cases described. Cases where the presenting rhythm was not detailed but the patient was described as going “into cardiac arrest” were grouped together as a separate category (i.e. “cardiac arrest”).

2. Materials and methods

Prior to study initiation, an internal protocol outlining the research question, outcome measures, search strategy, study selection, methods of data abstraction and analysis was developed.

2.1. Definitions and coding

PMCD was defined as “a caesarean delivery performed after initiation of cardiopulmonary resuscitation”.

Where the expression “term” was used to describe the gestational age, we assumed 40 weeks gestation. One paper did not detail the gestational age of each case but described the minimal age for inclusion, thus the earliest possible gestational age (26 weeks) was assumed for all cases described. Cases where the presenting rhythm was not detailed but the patient was described as going “into cardiac arrest” were grouped together as a separate category (i.e. “cardiac arrest”).

2.2. Types of participants

Pregnant women described as experiencing any one of the following occurrences prior to delivery: (1) “cardiac arrest” or a specific non-perfusing rhythm at any time and/or (2) report of treatment with chest compression and/or receipt of advanced life support medications and/or defibrillation. Cases with a presenting rhythm described as “cardiac arrest” were included only if this was followed by a description of the administration of basic and advanced life support. Cases describing administration of resuscitative medications only, with no description of a prior non-perfusing rhythm or the subsequent performance of chest compression/defibrillation, were not included in the study.

2.3. Types of studies

Published original articles, case series, case reports and letters to the editor were included, as well as reports from databases, provided that they met inclusion/exclusion criteria (listed below). Review papers were excluded. No language restrictions were applied for the search; however, for detailed data extraction, only papers in English, French, Japanese or German were included.

2.4. Inclusion criteria

Papers were included if they described cases for which the following data were provided: (1) At least five clinical details regarding the case (e.g. patient age, gravidity, parity, obstetric and medical history, presenting rhythm, location of arrest) and the care provided (e.g. chest compression, ventilation, monitoring,
drug administration); (2) At least one of the following outcomes: (a) maternal non-return/return of spontaneous circulation or non-survival/survival to hospital discharge (SHD); (b) foetal/neonatal outcome.

2.5. Exclusion criteria

Papers were excluded if they described cases of maternal arrest occurring post-delivery, if there was no provision of data enabling relation of individual case details to outcome or if both outcomes were unclear. Appropriateness for inclusion was adjudicated by two reviewers (SE and HYS). If either was unsure regarding fulfillment of inclusion criteria, the paper was excluded from the analysis.

2.6. Outcome measures

The primary outcome measures were maternal and neonatal survival to hospital discharge and the relationship between PMCD and this outcome. Secondary outcome measures included maternal and neonatal neurological outcomes and the feasibility of performance of PMCD within the advocated time frame.

Outcomes were assessed through independent judgment by two reviewers (SE and HYS). PMCD was determined to have a beneficial effect on maternal outcome when a clear association between PMCD and maternal haemodynamic improvement was described. PMCD was determined to have a harmful effect on maternal outcome if it had led to a complication associated with maternal death. PMCD was determined to have a beneficial effect on neonatal outcome when there was no maternal ROSC (i.e. without PMCD the neonate would have died as well); exceptions to this rule were cases where the neonate survived with severe residual neurological damage. In general, the tendency was towards conservatism: if benefit was not obvious, there was judged to be no benefit.

The instrument used to assess neurological outcome was the Cerebral Performance Category (CPC) score. For the purpose of this study, the score was dichotomized to 1/2 for good to moderate neurological outcomes and 3/4 for poor to severe neurological outcomes. This clinical instrument is often used to assess the extent of brain damage after cardiac arrest in adults\(^\text{20,21}\) as well as in pediatric populations\(^\text{22}\) and has demonstrated inter-rater reliability\(^\text{23}\); furthermore, with a high CPC score, the likelihood of a good Health Utilities Index score is very low.\(^\text{24}\)

Both maternal and neonatal CPC results were determined by two independent reviewers (SE and HYS) based on the description in the publication.

3. Search methods for identification of studies

3.1. Electronic databases

From Dec 2010 to Jan 2011 publications in the Cochrane and MEDLINE electronic databases were sought using the terms “pregnancy” or “pregnant” and “cardiac arrest” or “perimortem” or “postmortem” or “cardiopulmonary arrest” or “cardiopulmonary resuscitation” or “fatal outcome” or “maternal mortality” or “death” and “delivery” or “caesarean section” or “caesarean delivery”. Citation lists were independently searched by two of the authors (SH and HYS) to identify relevant studies. Titles and abstracts were screened and articles were retrieved if they were either clearly relevant or believed to be relevant.

3.2. Reference lists

The reference lists of included and non-included papers (e.g. reviews) that had been retrieved in the search were searched manually for further references.

3.3. Hand searches

The main journals most likely to contain publications in this area (e.g. Resuscitation, Circulation, Critical Care Medicine, Intensive Care Medicine, Annals of Emergency Medicine, and the American, British and International Journals of Obstetrics and Gynecology) were identified using MEDLINE and content experts in the area. These were hand searched if they were locally available and had not already been included. Specialist publications\(^\text{1,19,34}\) were similarly searched.

3.4. Selection of studies

If the title or abstract suggested presentation of a case eligible for inclusion, the full article was retrieved and reviewed against the inclusion and exclusion criteria. Critical appraisal of eligible cases was performed independently by two of the authors (SE and HYS). Only cases meeting inclusion criteria based on the assessment of both reviewers were kept for data extraction. Of the 1594 manuscripts screened through the title and abstract of the paper, 156 also underwent full review. From these papers, 108 cases underwent full data extraction and 94 cases were included in the final analysis (Fig. 1).
3.5. Assessment of risk of bias

All papers were either case reports or case series. As the level of evidence was considerably lower than that demanded of a systematic review, it was impossible to assess the risk of bias through accepted quality ratings of clinical trials.

3.5.1. Data management

Once included, data regarding each case were extracted using a pre-constructed list of variables. Information regarding each case, including potential triggers, sequence of events, arrest characteristics, pre-hospital (where relevant) and in-hospital case management and maternal and foetal/neonatal outcomes were independently extracted by two authors (SE and HYS). Differences were resolved by external consultation.

3.5.2. Data analysis

In the first step, descriptive statistics were used to characterize the study population. Continuous variables (e.g. maternal age, gestational age, parity, gravidity, time from arrest to delivery and cord blood pH) were described with their means, standard deviations, medians, ranges and interquartile ranges (IQRs); these were examined for their distributions. Categorical variables (e.g. type of pregnancy [singleton or not], causes and locations of arrest, witnessed status, presenting maternal rhythms, foetal heart rates, rates of maternal and neonatal survival and neurological outcomes) were described with proportions and percentages.

In the second step, descriptive statistics were used to study both outcome measures. The prevalence of the maternal outcome measure (i.e. maternal SHD) with/without PMCD was examined, including the reviewers’ impression regarding the relationship between PMCD and maternal outcome (beneficial/unclear/harmful). The prevalence of the neonatal outcome measure (i.e. neonatal survival to hospital discharge) was appraised in relation to potential independent predictors (e.g. witnessed status, location of arrest, foetal heart rate monitor findings).

The proportions of survivors/non-survivors for both mothers and neonates in relation to the relevant categorical independent variables were examined using either Chi-square or Fishers exact test (for tables with cells with a small expected number of cases).

The relationship between the outcome measures (maternal/neonatal SHD) and the independent variables potentially predicting these outcomes were examined using logistic regression modeling. In the first step, univariate associations between the outcome and the potential confounders were examined. Due to the small number of cases and the amount of unreported data, few variables were included in each model: witnessed status, location of the arrest, maternal presenting rhythm, gestational age and the amount of time from arrest to delivery were included in both maternal and neonatal models. Foetal heart rate was added to the neonatal model. Maternal presenting rhythm was first examined with ANOVA (data not presented) and then dichotomized when no between-group differences were found. The amount of time from arrest to delivery was examined both as a continuous variable (data not presented) and with cutoffs of 5, 10 and 15 min based on the recommendations and the median time observed in survivors. Similarly, foetal heart rate was first examined with ANOVA and then dichotomized. No collinearity was found between the two variables thought to be conceptually related: pre-hospital arrest and unwitnessed status. A choice was made to examine gestational age rather than birth weight because the number of cases with missing data was greater with the latter variable. The variables found to be statistically significant at the 0.10 level were entered in a multiple logistic regression model using the enter procedure.

Finally, the relationship between both neonatal and maternal survival and the time that elapsed between arrest to delivery was first examined using the $t$-test to compare between the groups (surviving and non-surviving) and then through ROC modeling. Data were analyzed using SPSS 18.0 (SPSS Inc., Chicago, Illinois).

4. Results

The literature search yielded 94 reported cases of maternal cardiac arrest during pregnancy (Fig. 1, Utstein). Average maternal age was 30.5 ± 6.5 years (median 32, range 17–44, IQR, 26.5–35.5, $n$ = 80), gravidity 2.5 ± 1.5 (median 2, range 1–7, IQR 1–4, $n$ = 59) and parity 1.1 ± 1.3 (median 1, range 0–6, IQR 0–2, $n$ = 57). Most pregnancies were singleton (90.4%, $n$ = 85) with an average gestational age at the time of the arrest of 33 ± 7 weeks (median 35, range 10–42, IQR 31–39, $n$ = 85). Eight cases (8.5%) described arrest during twin pregnancy and one case described arrest during pregnancy with triplets.

4.1. Arrest characteristics

The most common causes of arrest were trauma, maternal cardiac problems, severe preeclampsia and amniotic fluid embolism. Most arrests occurred in-hospital (67.0%, $n$ = 63) in highly monitored admission areas and most were witnessed (89.4%, $n$ = 84); despite these facts, most of the women were not intubated prior to arrest (75.5%, $n$ = 71). The most common presenting rhythm was asystole (25.5%, $n$ = 24), followed closely by VT/VF (Ventricular Tachycardia/Ventricular Fibrillation) (24.5%, $n$ = 23) and “cardiac arrest” (20.2%, $n$ = 19). Patient outcome has been shown to be determined to a great extent by initial presenting rhythm; patients presenting with shockable rhythms (i.e. Ventricular Tachycardia [VT]/Ventricular Fibrillation [VF]) fare far better than those with initial non-shockable rhythms (i.e. asystole).25 Further arrest characteristic are presented in Table 1.

4.2. Perimortem caesarean delivery

PMCD was performed in the majority of viable pregnancies (87.2%, 76/86). In 9 cases (10.5%), the mother was transported for this purpose to the operating room whilst undergoing CPR. Only 57 cases (75%) reported the time from arrest to delivery; the average time was 16.6 ± 12.5 min (median 10, range 1–60, IQR 8–25), with only 4 cases making it under the advocated 4-min time limit.

4.2.1. Maternal outcomes

4.2.1.1. ROSC. ROSC was achieved more often than not (60.6%, $n$ = 57, data missing in 3 cases); of these women, 89.5% survived to hospital discharge (51/57). Overall survival to hospital discharge was 54.3% ($n$ = 51). Maternal survival rates within each presenting rhythm are presented in Fig. 2A. Death occurred during the index arrest in 34 cases (36.2%), within 24 h in 4 cases (4.3%), within a week in one case (1.1%) and after more than a week in 2 cases (2.1%). Information regarding the time of death was not provided in three cases (3.2%). The variables predicting maternal survival are shown in Table 2: in multivariable analysis only in-hospital arrest location (OR = 7.42, 95% CI 1.3–41.6, $p$ = 0.023) and PMCD occurring within <10 min (OR = 5.17, 95% CI 1.06–25.15, $p$ = 0.042) achieved statistical significance.

4.2.2. Neurological outcomes

Outcomes of surviving mothers ($n$ = 51) were described as CPC 1/2 in 78.4% (40/51), CPC 3/4 in 11.8% (6/51) and “good” in 9.8% (5/51) of the cases. Descriptions of residual neurological damage in surviving mothers included amnesia,26 hemiparesis and dysarthria,27 hemiplegia and speech impairment,28
impaired short-term memory,29,30 neuropathic leg pain,30 intention tremor31 and visual field defects.32

4.2.2. PMCD. There were more cases of maternal ROSC without PMCD than with PMCD [93.8% (15/16) vs. 54.2% (39/72), \( p = 0.005 \)], and there were more cases of SHD without PMCD compared to those with PMCD [87.5% (14/16) vs. 45.3% (34/75), \( p = 0.002 \)]. In cases undergoing PMCD the average time elapsing from arrest to PMCD was significantly different between surviving (27/57) and non-surviving (30/57) mothers [10.0 ± 7.2 min (median 9, range 1–37) and 22.6 ± 13.3 min (median 20, range 4–60) respectively (\( p < 0.001, 95\% CI 6.9–18.2 \))]. The area under the receiver operating curve (ROC) for prediction of maternal death by the time that elapsed from arrest to delivery was 0.827 (Fig. 3).

The reviewers agreed that PMCD had led to a clear maternal survival benefit in 19/60 cases (31.7%). The Lambda score achieved by the reviewers in correlation of outcome benefit was 0.617. There were no cases for which both reviewers agreed that PMCD may have been deleterious in terms of maternal survival.

4.2.3. Neonatal outcomes

Neonatal outcome is described for all cases not occurring during termination of pregnancy (\( n = 92 \)), although only 86 pregnancies were viable at the time of the arrest.

4.2.3.1. Neonatal condition prior to PMCD and at birth. Reporting of foetal heart rate (FHR) monitoring would have been relevant in the
Table 1
Descriptive statistics of the study population arrest characteristics (n = 94). Percentages are among all the reported cases, including those with missing data.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary cause of arrest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maternal cardiac complications (e.g. structural heart disease, cardiomyopathy)</td>
<td>18</td>
<td>19.1</td>
</tr>
<tr>
<td>Trauma</td>
<td>19</td>
<td>20.2</td>
</tr>
<tr>
<td>Complications of severe preeclampsia (incl. treatment complications, e.g. magnesium toxicity)</td>
<td>17</td>
<td>18.1</td>
</tr>
<tr>
<td>Amniotic fluid embolism</td>
<td>12</td>
<td>12.8</td>
</tr>
<tr>
<td>Toxicity (e.g. iatrogenic, complications of drug abuse)</td>
<td>8</td>
<td>8.5</td>
</tr>
<tr>
<td>Venous air embolism</td>
<td>4</td>
<td>4.3</td>
</tr>
<tr>
<td>Infection/sepsis</td>
<td>3</td>
<td>3.2</td>
</tr>
<tr>
<td>Aortic/coronary dissection</td>
<td>2</td>
<td>2.1</td>
</tr>
<tr>
<td>Uterine rupture</td>
<td>2</td>
<td>2.1</td>
</tr>
<tr>
<td>Primary pulmonary problem</td>
<td>2</td>
<td>2.1</td>
</tr>
<tr>
<td>Aortocaval compression syndrome</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>Unknown</td>
<td>5</td>
<td>5.3</td>
</tr>
<tr>
<td>Location of arrest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-hospital</td>
<td>27</td>
<td>28.7</td>
</tr>
<tr>
<td>In-hospital</td>
<td>63</td>
<td>67.0</td>
</tr>
<tr>
<td>Unknown</td>
<td>4</td>
<td>4.3</td>
</tr>
<tr>
<td>Location of in-hospital resuscitation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour and delivery</td>
<td>25</td>
<td>26.6</td>
</tr>
<tr>
<td>Emergency department</td>
<td>24</td>
<td>25.5</td>
</tr>
<tr>
<td>Operating room</td>
<td>14</td>
<td>14.9</td>
</tr>
<tr>
<td>Intensive care unit</td>
<td>5</td>
<td>5.3</td>
</tr>
<tr>
<td>Antepartum ward</td>
<td>2</td>
<td>2.1</td>
</tr>
<tr>
<td>Ultrasound unit</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>Medical ward</td>
<td>1</td>
<td>1.1</td>
</tr>
<tr>
<td>Unknown</td>
<td>22</td>
<td>23.4</td>
</tr>
<tr>
<td>Witnessed status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Witnessed</td>
<td>84</td>
<td>89.4</td>
</tr>
<tr>
<td>Unwitnessed</td>
<td>3</td>
<td>3.2</td>
</tr>
<tr>
<td>Unknown</td>
<td>7</td>
<td>7.4</td>
</tr>
<tr>
<td>Time of intubation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>After arrest</td>
<td>71</td>
<td>75.5</td>
</tr>
<tr>
<td>Before arrest</td>
<td>11</td>
<td>11.7</td>
</tr>
<tr>
<td>Unknown</td>
<td>12</td>
<td>12.8</td>
</tr>
</tbody>
</table>

86 cases with a viable pregnancy; however, in almost half of the cases, (48.8%, n = 42) FHR was either not assessed or not reported prior to PMCD. Among those cases where FHR was reported, the most common FHRs were bradycardia or decelerations (29.1%, n = 25) followed equally by “positive cardiac activity” and asystole (9.3%, n = 8 respectively). In four cases (3.5%), the FHR was described as “normal/reassuring” prior to PMCD. Cord blood pH was not reported in 81.4% of the cases (70/86) thus precluding any analysis using this variable.

Table 2
Logistic regression analysis of variables potentially predictive of maternal survival.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Univariable</th>
<th>Multivariable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Witnessed arrest</td>
<td>84/87</td>
<td>2.80 (0.24–32.10)</td>
<td>0.408</td>
</tr>
<tr>
<td>In-hospital arrest location</td>
<td>63/90</td>
<td>6.14 (2.23–16.88)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Presenting rhythm (alternative models)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT/VF</td>
<td>23/83</td>
<td>1.25 (0.46–3.40)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PEA</td>
<td>72/83</td>
<td>7.56 (0.92–62.23)</td>
<td>0.060</td>
</tr>
<tr>
<td>Not asystole</td>
<td>59/83</td>
<td>1.95 (0.74–5.12)</td>
<td>0.175</td>
</tr>
<tr>
<td>Time from arrest to PMCD (alternative models)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes, at any time</td>
<td>57/57</td>
<td>1.146 (1.06–1.24)</td>
<td>0.001</td>
</tr>
<tr>
<td>Within &lt;5 min</td>
<td>4/57</td>
<td>3.625 (0.35–37.14)</td>
<td>0.278</td>
</tr>
<tr>
<td>Within &lt;10 min</td>
<td>18/57</td>
<td>11.25 (2.74–46.26)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Within &lt;15 min</td>
<td>32/57</td>
<td>8.80 (5.57–30.18)</td>
<td>0.001</td>
</tr>
<tr>
<td>Gestational age &lt;28 weeks</td>
<td>16/85</td>
<td>1.28 (0.42–3.92)</td>
<td>0.663</td>
</tr>
<tr>
<td>Gestational age &lt;30 weeks</td>
<td>20/85</td>
<td>1.135 (0.41–3.15)</td>
<td>0.808</td>
</tr>
</tbody>
</table>

4.2.3.2. Singleton pregnancies with a potentially viable baby (n = 77). PMCD was performed in most cases (66/77, 85.7%) but neonatal outcome was not reported in two of these cases. In cases with PMCD which reported outcome, the overall neonatal survival rate was 63.6% (42/66). Outcomes of surviving neonates were described as CPC 1/2 in 52.3% (22/42), CPC 3/4 in 21.4% (9/42) and “good” in 26.2% (11/42) of the cases. Neonatal deaths (22/66, 33.3%) were declared shortly after PMCD in 54.5% (12/22), within 24 h in 22.7% (5/22), within a week in 9.1% (2/22) and more than a week after the event in 13.3% (3/22) of the cases.

PMCD was not performed in 11 viable singleton pregnancies. In one such case the mother died still carrying the fetus. The neonatal survival rate in this cohort was therefore 90.9% (n = 10). Among the survivors, neurological outcomes were CPC 1/2 in 5 cases (50%) and “good” in 5 cases (50%). None of the surviving neonates had a CPC of 3/4.

4.2.3.3. Multiple pregnancies (n = 9) with potentially viable babies (n = 19). PCMD was performed in all cases with a multiple pregnancy. Overall neonatal survival was 63.1% (12/19). CPC was described as 1/2 for 25.0% (3/12) of the surviving neonates and 3/4
which neonatal survival was not described. Overall, 57 of the 84 firstborn neonates whose outcome was described also survived.

Logistic regression analysis of variables potentially predictive of firstborn neonatal survival in viable pregnancies. Among the 86 viable pregnancies there were two cases in Table 3; the only variable found to be significant on multivariable analysis was in-hospital arrest location (OR = 13.02, CI 2.85–59.54, p = 0.001).

4.2.3.4. Neonatal outcome by variable. Firstborn neonatal survival rates within each presenting maternal rhythm are presented in Fig. 2B. Firstborn neonatal mortality was higher in pre-hospital (17/23, 73.9%) compared to in-hospital arrests (8/57, 14.0%). The variables that were thought to predict neonatal survival are shown in Table 3; the only variable found to be significant on multivariable analysis was in-hospital arrest location (OR = 13.02, CI 2.85–59.54, p = 0.001).

4.2.3.5. Time from arrest to delivery. The time elapsing from arrest to delivery was described in 57 cases, and was <4 min in only four cases. Mean times were 14 ± 11 min (median = 10, range = 1–47) and 22 ± 13 min (median = 20, range = 4–60) in neonatal survivors and non-survivors respectively (p = 0.016). The area under the receiver operating curve (ROC) for prediction of neonatal death by the time that elapsed from arrest to delivery was 0.729 (Fig. 4).

4.2.3.6. Neonatal survival and PMCD. The reviewers agreed that PMCD had led to a clear neonatal survival benefit in 31/62 cases (50%). The Lambda score achieved by the reviewers in correlation of the neonatal outcome benefit of PMCD was 0.615. Both reviewers agreed that there were no cases where PMCD was deemed deleterious in terms of neonatal survival.

5. Discussion

The current study, based on analysis of pooled data from the published literature to date, highlights several important findings: maternal outcomes may not be as poor as those of other cardiac arrest populations, mortality rates were higher among women who underwent PMCD compared with those who did not, the 4-min time frame advocated for PMCD usually remains unmet yet neonatal survival is still likely if delivery occurs within 10 or even 15 min of arrest and neonatal survival was most-powerfully associated with maternal arrest occurring in-hospital, regardless of the cause of arrest.

The causes of maternal arrest described in the published cases comprising our study cohort were similar to those observed elsewhere; however, survival rates within all rhythms were unusually high when compared to other cardiac arrest populations. Either maternal cardiac arrest is a different entity than “regular” in- and out-of hospital cardiac arrests, or the published cases do not represent the entire population. Since the causes of arrest in this paper are reminiscent of those described elsewhere, we assume that the majority of the difference should be attributed to the young and healthy baseline condition of most of the study population, the physiology of pregnancy, the unique precipitating causes and the high incidence of witnessed status.

The relationship between PMCD and maternal outcome remains unclear. There were higher mortality rates among women who underwent PMCD compared with those who did not, but this finding could be due to confounding (e.g. prolonged arrests having poorer outcomes and a higher likelihood of PMCD) or true causation. Although PMCD led to clear maternal survival benefit in only 31.7% of the cases, multivariate analysis suggests that this might be a powerful association. We therefore suggest that in the event of cardiac arrest, delivery should realistically occur within 10 min of arrest; by this time, the likelihood of maternal resuscitation is significantly decreased and there may well remain neonatal benefit. To date, approximately one-third of the women who die during pregnancy remain undelivered at the time of death. Future research should determine the circumstances under which PMCD would maximally benefit both mothers and their children.

<table>
<thead>
<tr>
<th>Variable</th>
<th>n</th>
<th>Unvariable</th>
<th>Multivariable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OR (95%CI)</td>
<td>p-Value</td>
</tr>
<tr>
<td>Witnessed arrest</td>
<td>75/77</td>
<td>1</td>
<td>&lt;0.000</td>
</tr>
<tr>
<td>In-hospital arrest location</td>
<td>57/80</td>
<td>17.35 (5.26–57.25)</td>
<td>&lt;0.001</td>
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<tr>
<td>Presenting rhythm (alternative models)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VT/VF</td>
<td>17/73</td>
<td>3.27 (0.67–15.9)</td>
<td>0.142</td>
</tr>
<tr>
<td>Not PEA</td>
<td>64/73</td>
<td>1.5 (0.34–6.7)</td>
<td>0.596</td>
</tr>
<tr>
<td>Not asystole</td>
<td>50/73</td>
<td>1.89 (0.64–5.61)</td>
<td>0.251</td>
</tr>
<tr>
<td>Time from arrest to PMCD (alternative models)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;5 min</td>
<td>4/57</td>
<td>1.68 (0.16–17.26)</td>
<td>0.664</td>
</tr>
<tr>
<td>&lt;10 min</td>
<td>18/57</td>
<td>6.86 (1.39–33.93)</td>
<td>0.018</td>
</tr>
<tr>
<td>&lt;15 min</td>
<td>32/57</td>
<td>3.87 (1.23–12.2)</td>
<td>0.021</td>
</tr>
<tr>
<td>FHR detected</td>
<td>73/81</td>
<td>3.86 (0.85–17.6)</td>
<td>0.081</td>
</tr>
<tr>
<td>Gestational age &gt;28 weeks</td>
<td>67/75</td>
<td>3.19 (0.71–14.22)</td>
<td>0.129</td>
</tr>
<tr>
<td>Gestational age &gt;30 weeks</td>
<td>63/75</td>
<td>2.37 (0.63–8.27)</td>
<td>0.208</td>
</tr>
</tbody>
</table>

^a Unwitnessed arrest synonymous with death.

Fig. 4. ROC for predicting the death of the firstborn neonate by time from maternal arrest to delivery (n = 57). The area under the curve was 0.729 (95%CI 0.594–0.864).
The 4-min time frame advocated for PMCD remained unmet in 93% of the cases, yet there was neonatal survival benefit in 50% of cases, even when delivery occurred >10 min after the arrest. Further research should focus on the role of cognitive dissonance in recognition and treatment delays in this situation. Fixation on specific time frames for PMCD may not be ideal. It may be more important to focus on event recognition and good overall performance. Training aimed at improving the teamwork and skills of all sectors of the obstetric resuscitation team have been advocated by many.12,37–39 In a study recently performed in the Netherlands,40 the frequency of PMCD increased after physicians participated in specialized courses, although the 4-min time frame remained elusive for them as well. It may be wise to advocate a short time frame for performance of PMCD in order to achieve better outcomes; however, blanket endorsement of an unrealistic time frame may well create a defeatist attitude when that time frame cannot be met.

Neonatal survival was most-powerfully associated with maternal arrest occurring in-hospital most likely because the likelihood of extrication of the neonate is improved if the mother cannot be resuscitated. Since elimination of un witnessed arrests in hospitalized patients would improve both survival and subsequent neurological function,41 treatment recommendations should include a low threshold of admission to a highly monitored environment for pregnant women showing early signs of cardiovascular decompensation. Further research should clarify the indications for admission and the relationship between highly monitored environments and patient outcomes in these cases.

The current study had several limitations, the key one being the need for a larger sample size to generate stable models and probability estimates; however this study encompassed most, if not all, of the literature on maternal cardiac arrest and PMCD published in the last 30 years. It may be prudent in the future to also consider other sources such as Embase, the grey literature and Web of Knowledge. As the results of this study rely entirely on previous publications, its conclusions should be interpreted with caution in light of possible recall bias, under-reporting and publication bias. Several studies have suggested that maternal mortality in general remains greatly under-reported, with rates of under-reporting ranging from 22% to 67%.42–44 Finally, CPC estimates were performed indirectly by the authors based on the descriptions provided; however this assessment tool is a priori a very coarse assessment of patient condition.

6. Conclusions
Maternal cardiac arrest is a rare but haunting event. The National Registry of CPR (NRCPR) data demonstrates that such events occur at a reported rate of approximately 14 per year even within the United States.41 To date, our ability to learn from these unfortunate occurrences, derive meaningful conclusions and optimize treatment is limited by poor reporting quality and possible reporting bias. The data from these cases should be systematically collected so that they may guide future preventive and therapeutic efforts.1,45 Several countries have established systems to organize and collect such data.46–48 Promulgation of maternal resuscitation guidelines would be much easier if the recommendations were evidence-based rather than expert-based. Considering the rarity of maternal arrest and the impact of such an event on all involved, international collaboration is warranted to advance knowledge of this subject and prevent the untimely deaths of young mothers and their children.

Conflict of interest statement
The authors state that there are no conflicts of interest, nor have they received any source of funding for this study.

References


