Cardiac arrest occurs in pregnant women for a variety of reasons, and perimortem cesarean delivery may be necessary to improve both maternal and fetal outcomes.1-3 There is agreement that if return of spontaneous circulation does not occur in response to resuscitative measures, perimortem cesarean delivery should ideally occur within 5 minutes of maternal cardiac arrest.2,4-6 However, the optimal location to perform perimortem cesarean delivery is unknown. Some clinicians have performed perimortem cesarean delivery immediately at the site of the arrest, whereas others have first moved the patient to the operating room (OR).7

Performing perimortem cesarean delivery in the OR has potential surgical advantages, including better equipment, lighting, and familiarity. However, if the decision is to transport the patient to the OR, providers must perform cardiopulmonary resuscitation (CPR) on a patient with a gravid uterus in challenging circumstances and while running alongside or riding on top of the gurney. Relocation may therefore have adverse effects on CPR rendered during patient transport. No previous studies in obstetric patients have specifically investigated the effect of transport on the quality of CPR.

Our study objective was to compare the quality of maternal CPR rendered during transport to the OR versus that rendered while stationary in the labor room. Logistic and ethical concerns preclude the study of actual patient events, so we assessed CPR performed on a mannequin during simulated maternal cardiac arrests. We hypothesized that transport would cause a deterioration in the quality of CPR performed by teams randomized to transport as compared with those randomized to remain stationary in the labor room where the arrest occurred.

**METHODS**

From July through August 2011, 26 two-person teams were recruited for this randomized, controlled study of...
CPR at Lucile Packard Children’s Hospital, Palo Alto, CA. Because the teams were participating in ward drills that are part of the ongoing quality improvement process at Lucile Packard Hospital, and there was no potential for patient harm, this study was deemed exempt by the IRB at Stanford University School of Medicine. The teams were composed of 2 providers (obstetricians, obstetric nurses, or anesthesiologists working in the Labor and Delivery Unit) randomly assigned to the teams. Providers were excluded if they had concerns that compressions and ventilations would be too physically strenuous, if they had overuse or other injuries that might be exacerbated by performing CPR, or if, for any reason, they did not feel comfortable participating in the study.

The Laerdal Resusci Anne SkillReporter™ mannequin (Laerdal, Stavanger, Norway) was used for the study. The mannequin allows for the practice of CPR skills and provides real-time feedback to individuals performing compressions or ventilations, but cannot be intubated. The pulmonary compliance during mask ventilation is 20 to 40 mL/cm H2O per Laerdal Advanced Technical Support. The mannequin measures and stores data on compressions (rate, depth, sternal hand position, release) and ventilations (peak flow rate, tidal volume), and this information is downloadable for analysis. The same simulated cardiac arrest drill and mannequin were used for all 26 participating teams.

Study teams were randomized to either the “stationary” or “transport” group using computer-generated random number allocation. Teams were informed that we were studying the effects of transport on the quality of CPR, and to which group they had been assigned. The study hypothesis (CPR quality will deteriorate during transport) was not discussed. Participants then practiced CPR on the mannequin using the real-time feedback feature to perfect their CPR skills before the start of the drill. After the participants had consistently administered correct compressions and ventilations and indicated they were ready to begin, the drill commenced. To study any decrements in quality that occurred over time, to evaluate differences between providers on the same team, and to evaluate differences before, during, and after transport, it was necessary to divide the drill into 3 main phases which, taken together, comprised five 2-minute cycles, or 10 minutes in total. Of the five 2-minute cycles, the first 2 comprised phase I of the study. Phase I therefore consisted of 4 minutes of CPR performed on the Laerdal SkillReporter mannequin while stationary on a gurney in a labor room before any transport. The third 2-minute cycle comprised phase II of the study, and consisted of 2 minutes of CPR performed on the mannequin while either remaining stationary or while the mannequin was transported on the gurney to the OR, depending on group allocation. To standardize phase II, multiple trial runs were performed before commencing the study to determine the gurney transport route that would consistently result in arrival to the OR at the 2-minute mark. For those groups randomized to transport, the gurney and mannequin were pushed from the labor room to the OR by 2 individuals not involved in the CPR. The fourth and fifth 2-minute cycles comprised phase III of the study, and consisted of 4 minutes of CPR performed while the mannequin was stationary on the gurney.

All 3 phases were performed continuously with no breaks between the phases. A drill proctor (JYW) timed the drill using a stopwatch. The proctor instructed the providers when to switch roles and, for those teams allocated to transport, when to begin and end transport. During phases I and III, individuals performing compressions changed after 2-minute cycles to performing ventilations (in accordance with current American Heart Association Advanced Cardiac Life Support [ACLS] guidelines to change compressors after 2 minutes). The exception was the 2-minute interval during phase II, at which time the participants changed compressors after 1 minute. This was necessary to measure the performance of both compressions and ventilations provided by each team member during transport. It was not possible to tilt the mannequin to simulate left uterine displacement because the mannequin consists only of a torso and a head. A backboard was placed under the supine mannequin before the start of the study.

The primary outcome measure in this study was the percentage of correctly delivered compressions. These data were derived directly from the Laerdal SkillReporter mannequin, which uses several criteria to assess for correct compressions, including compression rate ≥100 beats per minute, compression depth ≥1.5 inches (2.8 cm), correct sternal hand placement (mid sternum), and proper release. Secondary outcomes measured directly by the mannequin included compression rate, interruptions during compression, and ventilation variables (tidal volume and peak flow rate). Interruptions were defined as pauses in compressions (>1 second) during the course of the 30 compression cycles in accordance with current guidelines. The pauses were both witnessed and recorded by the study proctor (JYW) and confirmed by the mannequin data. Breaths between the 30 compression cycles were not considered interruptions. If the participant stopped mid-cycle because it was time to switch over after 2 minutes, the pause was not considered an interruption. The specific manner (e.g., ran alongside or rode on top of the gurney) by which the teams performed CPR during the transport phase was also recorded.

Demographic information was obtained from the participating personnel regarding their medical specialty, years of experience, whether they had received basic cardiac life support and ACLS training and were currently certified, and whether they had ever rendered CPR during an actual cardiac arrest, obstetric or nonobstetric.

**Statistical Analysis**

On the basis of pilot data collected during provider CPR training on the mannequin, a priori sample-size analysis predicted that we required 24 participants per study arm to detect a 33% relative reduction in the percentage of correct compressions (power = 0.8, α = 0.05, 10% data capture failure, 2-sided Student t test). The percentage of correct compressions was the percentage of compressions that each individual performed correctly during their resuscitation cycle, and not the percentage of individuals who did compressions correctly. For the purposes of this study, a 33% decrease was considered a practical and clinically
significant value by study investigators and was derived from our observed correct compressions mean ± SD of 70%±25% from our pilot data. Demographic and outcome data are summarized with descriptive statistics. Results are expressed as the mean ± SD, median (interquartile range) and percentages, as appropriate.

The primary end point was considered percentage correct compressions. Outcome measures of interest between the 2 groups were compared using the Student t test for normally distributed variables (compression rate, tidal volume, self-reported fitness) and the Mann-Whitney test for nonparametric comparisons (experience, correct compressions). Outcome measures within groups were compared using paired Student t test (compression rate, tidal volume) and Wilcoxon rank test (correct compressions) as appropriate. Normal distribution was determined using quantile–quantile plots and the Kolmogorov-Smirnov test, with any value above 0.05 indicating normality. Associations between discrete outcome variables (age, gender, specialty, certification, interruptions) were investigated using the Pearson χ² and Fisher exact test 2×2 table comparisons where appropriate. The 95% confidence interval of the difference in proportions between the groups was calculated using the Wilson score method.8,9 Analyses were performed with IBM SPSS Version 20.0 for Windows statistical package (Armonk, NY). P < 0.05 was considered statistically significant. No mathematical corrections for multiple comparisons were made for any individual P values and confidence intervals of secondary outcome measures, and all measured outcomes were reported.

RESULTS

Fourteen teams (28 participants) were randomized to the stationary group, and 12 teams (24 participants) participated in the transport group. The uneven number of teams in each group was due to a randomization error. Data from all 26 teams (52 participants) were analyzed for primary and secondary outcome measures. No teams were excluded from the analysis, and no protocol violations occurred. Demographic data of the participants are outlined in Table 1.

The percentage of correctly rendered compressions during each phase of the study is shown in Figure 1. The median (interquartile range, range) percentage of correctly rendered compressions during phase II was 32% (10%–63%, 0%–86%) in the transport group and 93% (58%–100%, 1%–100%) in the stationary group (P = 0.002, 95% confidence interval of mean difference = 22%–58%). The reasons for incorrect compressions during phase II are outlined in Table 2. Insufficient compression depth was the primary reason for incorrect compressions.

Compression rates and tidal volumes during each phase of the drill are shown in Figures 2 and 3. The mean ± SD compression rate per minute during phase II was 127±19...

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**Table 1. Demographics of Study Participants**

<table>
<thead>
<tr>
<th>Age breakdown (%)</th>
<th>Transport group, n = 24</th>
<th>Stationary group, n = 28</th>
</tr>
</thead>
<tbody>
<tr>
<td>20–40 y</td>
<td>20 (83)</td>
<td>16 (57)</td>
</tr>
<tr>
<td>41–60 y</td>
<td>2 (8)</td>
<td>11 (39)</td>
</tr>
<tr>
<td>&gt;60 y</td>
<td>2 (8)</td>
<td>1 (4)</td>
</tr>
<tr>
<td>Gender (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>19 (79)</td>
<td>18 (64)</td>
</tr>
<tr>
<td>Male</td>
<td>5 (21)</td>
<td>10 (36)</td>
</tr>
<tr>
<td>Female/male team</td>
<td>3 (25)</td>
<td>4 (29)</td>
</tr>
<tr>
<td>Female/female team</td>
<td>8 (67)</td>
<td>7 (50)</td>
</tr>
<tr>
<td>Male/male team</td>
<td>1 (8)</td>
<td>3 (21)</td>
</tr>
<tr>
<td>Specialty breakdown (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Registered nurses</td>
<td>11 (46)</td>
<td>13 (46)</td>
</tr>
<tr>
<td>Obstetricians</td>
<td>4 (17)</td>
<td>4 (14)</td>
</tr>
<tr>
<td>Anesthesiologists</td>
<td>9 (38)</td>
<td>11 (39)</td>
</tr>
<tr>
<td>Current BLS and ACLS certification (%)</td>
<td>22 (92)</td>
<td>24 (85)</td>
</tr>
<tr>
<td>Prior CPR code experience (%)</td>
<td>17 (71)</td>
<td>24 (86)</td>
</tr>
<tr>
<td>Years of experience</td>
<td>4 (2–11, 0–26)</td>
<td>6 (2–18, 1–37)</td>
</tr>
<tr>
<td>Self-reported fitness (%)</td>
<td>3±2</td>
<td>3±2</td>
</tr>
</tbody>
</table>

Values presented as number (percentage); median (interquartile range, range); mean ± SD.

No significant differences between groups (P > 0.05).

BLS = basic life support; ACLS = advanced cardiac life support; CPR = cardiopulmonary resuscitation.

*One participant did not respond to this question.

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**Table 2. Reasons for Incorrect Chest Compressions**

<table>
<thead>
<tr>
<th>Reason</th>
<th>Transport group, n = 24</th>
<th>Stationary group, n = 26</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insufficient depth (%)</td>
<td>21 (5–37, 2–83)</td>
<td>1 (0–8, 0–71)</td>
<td>0.03</td>
</tr>
<tr>
<td>Sternal hand placement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Too low (%)</td>
<td>11 (0–75, 0–99)</td>
<td>0 (0–0, 0–99)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Too high (%)</td>
<td>0 (0–0, 0–27)</td>
<td>0 (0–0, 0–83)</td>
<td></td>
</tr>
<tr>
<td>Too right (%)</td>
<td>0 (0–0, 0–15)</td>
<td>0 (0–0, 0–33)</td>
<td></td>
</tr>
<tr>
<td>Too left (%)</td>
<td>0 (0–0, 0–69)</td>
<td>0 (0–0–0, 0–4)</td>
<td></td>
</tr>
<tr>
<td>No release/leaning (%)</td>
<td>3 (0–9, 9–47)</td>
<td>0 (0–0, 0–93)</td>
<td>0.006</td>
</tr>
<tr>
<td>Rate &lt; 100 beats/min</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Values presented as median (interquartile range, range). Insufficient depth defined as <1.5 inches (2.8 cm); No release/leaning is defined as persistent weight applied to the mannequin’s chest between compressions, caused by the participant leaning on the mannequin and preventing adequate chest recoil. All teams generated compression rates >100 beats per minute.
DISCUSSION

In this study of simulated maternal cardiac arrest, transport negatively affected the overall quality of resuscitation. During phase II of the study in teams randomized to transport, correctly rendered compressions decreased significantly, with degradations noted in compression depth, sternal hand placement, and proper release. The “operational reality” of performing CPR during transport is characterized by unfavorable mechanics, unavoidable interruptions, task saturation, and misallocation of attention. Insufficient compression depth during transport was the most common reason for incorrect compressions, suggesting that provider mechanics may be the key factor. The mannequin used in this study was configured according to the 2005 ACLS specifications (1.5-inch [3.81-cm] compression depth) rather than the 2010 guidelines (2-inch [5.1-cm] compression depth). Had the mannequin been configured according to the 2010 standards, our teams might have had an even lower percentage of correct compressions than our data indicated. High-quality compressions with minimal interruptions are now considered so important that the 2010 ACLS guidelines contained a major paradigm shift: first responders are now taught to perform compressions, airway, breathing rather than airway, breathing, compressions.2 Recent articles on a simulation-based educational intervention for maternal–fetal medicine staff10 and on strategies to more effectively use the 2010 American Heart Association guidelines for resuscitation during maternal cardiac arrest11 support our findings and suggest that transport may negatively affect the quality of CPR. The fraction of time spent without compressions has also been found to increase during transport.12 There is little information in the literature addressing the logistics of transport during CPR. No standard of care exists with respect to emergency responder positioning while rendering CPR during transport. Our participants were not given instructions on how to best position themselves during transport. The majority of providers (20 of 24) climbed on the gurney and kneeled next to, or straddled the mannequin. Our impression was that riding atop the gurney resulted in a less negative effect on CPR efficiency than running alongside it; however, this study was not adequately powered to analyze differences among CPR techniques. Although no injuries occurred during this study, concerns regarding provider safety during rapid transport remain.

We observed significantly more interruptions during compressions in groups randomized to transport. In addition, the transport groups also had more episodes of multiple interruptions. The majority of interruptions during transport occurred as the gurney moved past hallway obstacles or through doorways. The dynamic setting of a busy labor and delivery unit may increase the likelihood of interruptions in CPR during transport compared with other clinical settings. Of interest, the groups randomized to transport demonstrated a nonstatistically significant trend toward more incorrect compressions in phase I (before transport) and in phase III (after transit) compared with the stationary group. In phase I, it is possible that anticipation of patient transport resulted in provider distraction, resulting in the trend toward more incorrect compressions. In phase III, it is possible that provider exhaustion resulted in the trend toward more incorrect compressions. In that case, we would expect

in the transport group and 124±15 in the stationary group (P = 0.53). Mean ± SD tidal volume during phase II was 273±155 mL in the transport group and 385±167 mL in the stationary group (P = 0.03).

Interruptions in CPR during phase II were observed in 92% (22/24) of transport and 7% (2/28) of stationary groups (P < 0.001, 95% confidence interval of difference = 61%-92%). Multiple (>2) interruptions occurred in 11 of the 24 drills in the transport group compared with none in the stationary group. During phase II, teams randomized to transport provided CPR as follows: 18 providers kneeled next to the mannequin on top of the gurney, 2 providers straddled the mannequin, and 4 providers ran alongside the gurney.

Figure 2. Figure showing the mean (95% confidence interval) of the compression rate administered during each phase of the study. * = Transport (phase III) versus stationary (phase III) group (P = 0.04); and within transport group phase III versus phases I (P < 0.001) and II (P = 0.001). † = Stationary group phase I versus stationary group phases II (P = 0.001) and III (P < 0.001).

Figure 3. Figure showing the mean (95% confidence interval) tidal volume administered during each phase of the study. * = Transport (phase II) versus stationary (phase II) group (P = 0.03); and within transport group phase II versus phases I (P = 0.004) and III (P = 0.04).
CPR Degrades During Maternal Transport

compression rates to decrease secondary to muscular fatigue. However, the compression rates of the transport groups increased after the move (phase III) in comparison with the rates before the move (phase I), perhaps as a result of residual excitatory effects from transit. This awareness, combined with a “study examination” mentality, may partly explain the supranormal compression rates both groups generated (>120 beats per minute) throughout all study phases. All of our participants practiced CPR to perfection immediately before the study by using the task trainer functionality of the mannequin. Despite studying experienced providers, who had the advantages of practice immediately before the study, teams randomized to transport still had unacceptably high percentages of incorrect compressions compared with the stationary teams. These data suggest that the act of transport may be fundamentally incompatible with high-quality CPR.

Ventilation tidal volumes were also significantly affected by transport. The optimal volume for ventilation of the pregnant cardiac arrest victim has not been defined, but 600 mL delivered over 1 second is recommended for the resuscitation of nonpregnant adults.13 We suspect ventilation was challenging for both groups because: (1) mask ventilation is more technically difficult than positive pressure ventilation via an endotracheal tube, and (2) the pulmonary compliance of the Laerdal Resusci Anne SkillReporter is poor (20–40 mL/cm H₂O) to approximate the poor compliance likely encountered during CPR.

There are a number of potential limitations to this study. Although CPR “prompt and feedback devices” have been endorsed by international organizations and improve CPR skill acquisition and retention,14 such devices may not precisely replicate the compressions and ventilations required or obtained during an actual event. Current recommendations for cardiac arrest associated with pregnancy include early, definitive airway control such as placement of an endotracheal tube, whenever possible. However, the mannequin used for this study was not designed for intubation, and therefore mask ventilation was electively used throughout the drill. Our results should, however, be applicable to the initial phase of a cardiac arrest before intubation. If a parturient is moved to the OR for perimortem cesarean delivery within 5 minutes of arrest, an anesthesiologist or other provider with intubating skills may not yet have arrived to perform definitive airway control.

Our teams may have experienced advantages not likely to occur during a real maternal arrest. For example, the mannequin consisted of just a head and a torso. A full mannequin or a real patient would have been more difficult to position and move because of larger size and greater weight. A near-term gravid uterus would likely complicate the effective provision of compressions from both a technical (increased abdominal girth) and physiologic perspective (decreased venous return secondary to caval compression), as well as further complicate ventilation.15–17 It was not possible to use a full-sized mannequin with gravid uterus because there are no current models available that measure rate, compression depth, and other variables of CPR. As a result, we were not able to study the effects of left uterine displacement with pelvic tilt or manual displacement, although current ACLS guidelines recommend such maneuvers to relieve aorticaval compression.2 Two earlier mannequin studies suggested that pelvic tilt could decrease the effectiveness of chest compressions compared with the supine position.18,19

In conclusion, transport significantly decreased the overall quality of CPR during simulated maternal arrests. We previously demonstrated that transport to the OR during simulated perimortem cesarean delivery significantly delayed delivery and recommended that perimortem cesarean delivery be performed at the site of the arrest.6 The current findings strengthen these recommendations. Because effective CPR in the first 5 minutes may be critical for intact maternal and neonatal survival, obstetric units, emergency medicine departments, and intensive care units should be prepared to perform perimortem cesarean delivery at the site of maternal arrest should such an emergency arise.

DISCLOSURES:

Name: Steven S. Lipman, MD.
Contribution: This author helped develop the scenario, conceptualize and design the study, draft the manuscript, perform critical analysis, and revise the manuscript.
Attestation: Steven S. Lipman approved the final manuscript. Steven S. Lipman attests to the integrity of the original data and the analysis reported in this manuscript. Steven S. Lipman is the archival author.
Name: Jocelyn Y. Wong, BA.
Contribution: This author helped develop the scenario, recruit staff, conduct the scenario, conceptualize and design the study, acquire the data, interpret the data, draft the manuscript, perform critical analysis, and revise the manuscript.
Attestation: Jocelyn Y. Wong approved the final manuscript. Jocelyn Y. Wong attests to the integrity of the original data and the analysis reported in this manuscript.
Name: Julie Arafeh, RN, MSN.
Contribution: This author helped develop the scenario, conceptualize and design the study, perform critical analysis, and revise the manuscript.
Attestation: Julie Arafeh approved the final manuscript. Julie Arafeh attests to the integrity of the original data and the analysis reported in this manuscript.
Name: Sheila E. Cohen, MBChB, FRCA.
Contribution: This author helped develop the scenario, conceptualize and design the study, perform critical analysis, and revise the manuscript.
Attestation: Sheila E. Cohen approved the final manuscript. Sheila E. Cohen attests to the integrity of the original data and the analysis reported in this manuscript.
Name: Brendan Carvalho, MBBCCh, FRCA.
Contribution: This author helped develop the scenario, conceptualize and design the study, perform critical analysis, and revise the manuscript.
Attestation: Brendan Carvalho approved the final manuscript. Brendan Carvalho attests to the integrity of the original data and the analysis reported in this manuscript.

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