A Feasibility Study of Cerebral Oximetry During In-Hospital Mechanical and Manual Cardiopulmonary Resuscitation

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Objective: A major hurdle limiting the ability to improve the quality of resuscitation has been the lack of a noninvasive real-time detection system capable of monitoring the quality of cerebral and other organ perfusion, as well as oxygen delivery during cardiopulmonary resuscitation. Here, we report on a novel system of cerebral perfusion targeted resuscitation.

Design: An observational study evaluating the role of cerebral oximetry (Equanox; Nonin, Plymouth, MI, and Invos; Covidien, Mansfield, MA) as a real-time marker of cerebral perfusion and oxygen delivery together with the impact of an automated mechanical chest compression system (Life Stat; Michigan Instruments, Grand Rapids, MI) on oxygen delivery and return of spontaneous circulation following in-hospital cardiac arrest.

Setting: Tertiary medical center.

Patients: In-hospital cardiac arrest patients (n = 34).

Main Results: Cerebral oximetry provided real-time information regarding the quality of perfusion and oxygen delivery. The use of automated mechanical chest compression device (n = 12) was associated with higher regional cerebral oxygen saturation compared with manual chest compression device (n = 22) (53.1% ± 23.4% vs 24% ± 25%, p = 0.002). There was a significant difference in mean regional cerebral oxygen saturation (median % ± interquartile range) in patients who achieved return of spontaneous circulation (n = 15) compared with those without return of spontaneous circulation (n = 19) (47.4% ± 21.4% vs 23% ± 18.42%, p < 0.001). After controlling for patients achieving return of spontaneous circulation or not, significantly higher mean regional cerebral oxygen saturation levels during cardiopulmonary resuscitation were observed in patients who were resuscitated using automated mechanical chest compression device (p < 0.001).

Conclusions: The integration of cerebral oximetry into cardiac arrest resuscitation provides a novel noninvasive method to determine the quality of cerebral perfusion and oxygen delivery to the brain. The use of automated mechanical chest compression device during in-hospital cardiac arrest may lead to improved oxygen delivery and organ perfusion. (Crit Care Med 2013; 42:00–00)

Key Words: cardiac arrest; cerebral oximetry; cerebral perfusion; near-infrared spectroscopy; resuscitation; return of spontaneous circulation

Although in-hospital resuscitation leads to return of spontaneous circulation (ROSC) in up to 50%, survival to discharge remains poor at 18% (1). Pathophysiologically, cardiac arrest reflects an injury process that begins with the cessation of heartbeat and reflects a state of imbalanced oxygen delivery relative to tissue oxygen requirements, which if left unrecognized and untreated can lead to progressive and irreversible organ damage (2). Even though one of the major goals of cardiopulmonary resuscitation (CPR) is maintaining adequate cerebral perfusion and oxygen delivery, to date there have been no standard noninvasive “real-time” clinical methods available to determine the balance between oxygen delivery and requirements in the brain during cardiac arrest resuscitation. Although jugular venous oxygen saturation (SjO2) monitoring can determine the balance between cerebral oxygen delivery and oxygen requirements, it is an invasive test, which greatly limits its practical application during cardiac arrest resuscitation. A noninvasive technology that has emerged and is not susceptible to motion artifact during cardiac arrest is cerebral oximetry using near-infrared spectroscopy (NIRS).
NIRS measures the fall in optical intensity, expressed as the change in optical density per centimeter of tissue, and when applied to the brain, it provides real-time continuous information regarding regional cerebral oxygen saturation (\(rSO_2\)) in the frontal lobe, which reflects the balance between oxygen delivery and consumption in cerebral tissue (3).

Although the quality of chest compression delivery is of prime importance during cardiac arrest resuscitation, many studies have demonstrated significant variability in the delivery of chest compressions in hospitals (4–6). Analysis of the quality of CPR using a quantitative system of CPR (Real CPR; Zoll, Chelmsford, MA) during simulation training at our institution demonstrated that staff were able to achieve the rate and depth recommended by the American Heart Association guidelines less than 50% of the time. However, the use of an automated mechanical chest compression (A-CPR) device (Life Stat; Michigan Instruments, MI) demonstrated the correct delivery of depth and rate 100% of the time. Thus, to standardize the delivery of chest compression across the hospital, we introduced A-CPR. Furthermore, building on an earlier feasibility study in which NIRS was incorporated into a small series of in-hospital manual cardiac arrest resuscitations at our institution (7), we compared the quality of cerebral oxygen delivery using A-CPR device with conventional manual chest compression (M-CPR) device at our specific institution. We hypothesized that standardizing the rate and depth of CPR delivery using A-CPR would lead to improved brain oxygen delivery. The primary outcome measure for this study was the mean \(rSO_2\) level during CPR in the A-CPR group compared with the M-CPR group.

MATERIALS AND METHODS

Institutional review board approval was obtained for this study following modification to the clinical method used to resuscitate cardiac arrest patients at Stony Brook Medical Center. We conducted an observational study in a convenience sample of 34 adult patients (age > 21) who underwent in-hospital cardiac arrest resuscitation during a 1-year clinical evaluation period. This was set up to examine the utility of incorporating cerebral oximetry using NIRS (Equanox 7600; Nonin, Plymouth, MI, and Invos; Somanetics, Troy, MI) during cardiac arrest. Each sensor consists of an adhesive strip, a near-infrared light transmitter, and two sensors. The emitted light is scattered by tissues in two parabolic curves: one corresponding with hemoglobin saturation from the skin and skull and the other from the skin, skull, and frontal cortex. Using specific algorithms, the hemoglobin saturation in the frontal cortex is calculated (8–11).

After a cardiac arrest was announced through the paging system in the hospital, the cerebral oximeter was taken by a predesignated member of staff from the medical ICU (MICU) to the site of cardiac arrest, where an on-call MICU physician and nurse trained in its use also attended. The placement of a single sensor on either the right or left lateral aspect of the forehead was considered sufficient for the purpose of measuring the overall quality of cerebral oxygen delivery, since cerebral blood flow during cardiac arrest is predominantly dependent on the quality of the circulation. The cerebral oximeter recorded continuous data. After each cardiac arrest, the data were downloaded (by universal serial bus or blue-tooth) onto a computer. For each event, the overall \(rSO_2\) for each patient was determined by calculating the mean of the continuous data (sampled every 4 s) from the time the sensor had been placed on the patient until either ROSC had been achieved or until CPR had been terminated as documented on the cardiac arrest records. ROSC was determined whenever (after a 2-minute period of CPR) a palpable pulse was elicited. The cerebral oximeter was then marked to indicate ROSC. We only analyzed the data from the start of CPR until that point. Artifact values were recognized by either an absent value or a single value obtained during a given 4-second period that was markedly different to the 4-second cycle either before or after it. There were thus 15 values routinely measured per minute, and any artifact was deleted. We did not have a warm-up or run-in period. The calculations of the mean value for each patient was carried out by A.N. and A.A. who were not blinded to ROSC outcome or mode of chest compression.

Although staff were not specifically blinded to the cerebral oximetry values, the monitor was routinely placed away from the actual cardiac arrest and staff did not have any specific understanding regarding the interpretation of \(rSO_2\) values. Thus, values were not used for the purpose of clinical decision making. The decision to use either M-CPR or A-CPR was at the discretion of the cardiac arrest team. Patients in A-CPR and M-CPR groups were totally separated.

At the time of this study, neither end-tidal \(CO_2\) (Petco2) monitoring nor quantitative methods aimed at determining the quality of chest compressions were routinely available on the hospital wards, and we were thus unable to compare data derived from cerebral oximetry with these resuscitation variables.

Statistical Analysis

Patients’ characteristics between those using M-CPR and A-CPR were compared using Fisher exact test or chi-square test for categorical variables and Wilcoxon rank-sum test for continuous variables. The mean \(rSO_2\) comparison between patients who achieved ROSC and those who did not achieve ROSC and also between patients who used A-CPR and those who used M-CPR was further assessed in a two-way analysis of variance model. Normality assumption was confirmed. Statistical significance level was set at 0.05, and \(p\) values from two-sided test were reported. All analyses were performed in SAS 9.3 (SAS Institute, Cary, NC).

RESULTS

In a 1-year period, a total of 34 patients were studied. Twenty-two underwent M-CPR and 12 underwent A-CPR. Patients were not randomly assigned and the decision to use either A-CPR or M-CPR was left at the discretion of the cardiac arrest team. In general, the decision to use oximetry and/or A-CPR seemed to reflect the overall level of familiarity with these
technologies. They were used predominantly more toward the later stages of the clinical evaluation as staff felt more comfortable integrating these into their usual practice. Decisions were not made based on the team's perception regarding a patient's chance of survival. There were no significant differences in age, initial rhythm, duration of cardiac arrest, dose of epinephrine, or dose of atropine between patients receiving M-CPR and A-CPR (Table 1).

In patients receiving cerebral oximetry monitoring, a significant difference was noted in the rsO₂, in those who achieved ROSC compared with those without ROSC (median ± interquartile range: 47.4% ± 21.4% vs 23% ± 18.4%, p < 0.001) (Fig. 1A). Comparing the results between the two different CPR delivery methods, a significantly higher mean rsO₂, was observed in the A-CPR group compared with the M-CPR group (53.1% ± 23.4% vs 24% ± 25%, p = 0.002) (Fig. 1B). There was still strong statistical evidence to support this finding after adjusting for patients who had achieved ROSC or not (p < 0.001).

**DISCUSSION**

While acknowledging that our study has a number of significant inherent limitations which predominantly relate to the observational nature of the work and the use of a convenience sample of patients, our results suggest that a higher level of rsO₂, may be associated with ROSC. Furthermore, the observation that in our hospital patients were more likely to achieve ROSC using A-CPR than M-CPR may reflect the challenges that exist in ensuring staff assigned to provide CPR can maintain consistent chest compressions, rather than a specific benefit with respect to the mode of CPR delivery. Because of the limitation in sample size, other possible confounders such as age and patient’s disease could not be considered to estimate the odds ratio of achieving ROSC using A-CPR or M-CPR. We further acknowledge that the patient’s underlying condition is of paramount importance in determining whether ROSC is achieved and we cannot exclude potential bias in this evaluation. Therefore, larger studies are needed to determine the relationship between rsO₂ and ROSC, as well as the role of A-CPR and M-CPR in achieving higher levels of rsO₂.

Our results further suggest that cerebral oximetry may also provide information regarding the quality of oxygen delivery to the heart. This observation may simply reflect the reality that achieving higher levels of oxygen delivery and perfusion to the brain depends on the overall quality of the circulation, which will most likely impact other organs too.

In previous studies, it has been shown that cerebral oximetry may potentially be useful as a predictor of survival and neurological outcomes following cardiac arrest (12–15). In one small study, it was demonstrated that a mean rsO₂ of 17% or less achieved during out-of-hospital cardiac arrest appeared to predict nonsurvival (12). This was supported by a larger study in which patients arriving in the emergency department following out-of-hospital cardiac arrest with an rsO₂ of less than or equal to 15% were found not to survive (14). Furthermore, it has been demonstrated that in a similar patient population, an rsO₂ less than 25% on arrival to the emergency room corresponds with poor outcomes (15).

The results of our study complement these findings but additionally indicate that rsO₂ monitoring can potentially be used as a dynamic rather than a static measure during cardiac arrest. Thus, an effective intervention (such as standardizing the quality of chest compressions) may increase oxygen delivery as indicated by rsO₂. Furthermore, the use of cerebral oximetry during cardiac arrest may compliment the use of Petco₂ monitoring, which has been proposed as a marker of the quality of oxygen delivery and ROSC (16). Petco₂ monitoring is impacted by underlying pulmonary pathology and

**TABLE 1. Patient Demographics and Characteristics**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Automated Mechanical Chest Compression Device (n = 12)</th>
<th>Manual Chest Compression Device (n = 22)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (mean ± sd)</td>
<td>67.67 ± 9.58</td>
<td>72.77 ± 15.27</td>
<td>0.2409</td>
</tr>
<tr>
<td>Male, %</td>
<td>7 (58.33)</td>
<td>15 (68.18)</td>
<td>0.7113</td>
</tr>
<tr>
<td>Initial rhythm, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulseless electrical activity</td>
<td>5 (41.67)</td>
<td>15 (68.18)</td>
<td>0.3206</td>
</tr>
<tr>
<td>Asystole</td>
<td>4 (33.33)</td>
<td>5 (22.73)</td>
<td></td>
</tr>
<tr>
<td>Ventricular fibrillation/ventricular tachycardia</td>
<td>3 (25)</td>
<td>2 (9.09)</td>
<td></td>
</tr>
<tr>
<td>Duration (min) (mean ± sd)</td>
<td>15.92 ± 10.87</td>
<td>20.64 ± 13.74</td>
<td>0.2812</td>
</tr>
<tr>
<td>Epinephrine dose (mg) (median ± IQR)</td>
<td>5.00 ± 5.00</td>
<td>5.00 ± 3.00</td>
<td>0.8257</td>
</tr>
<tr>
<td>Atropine dose (mg) (median ± IQR)</td>
<td>2.00 ± 2.00</td>
<td>1.00 ± 2.00</td>
<td>1</td>
</tr>
<tr>
<td>Time to start of oximetry measurements (min) (median ± IQR)</td>
<td>9.5 ± 3.00</td>
<td>4.5 ± 7.00</td>
<td>0.2596</td>
</tr>
</tbody>
</table>

IQR = interquartile range. 

p value is based on Wilcoxon rank-sum test for continuous variables and Fisher exact test or chi-square test for categorical variables.
REFERENCES


CONCLUSIONS

The integration of cerebral oximetry into cardiac arrest resuscitation provides a novel noninvasive method to determine the quality of cerebral perfusion and oxygen delivery to the brain. The use of A-CPR device during in-hospital cardiac arrest may lead to improved oxygen delivery and organ perfusion.