42 Evaluation of the Quality of Chest Compression with Oxyhemoglobin Level by Near-Infrared Spectroscopy in a Rat Asphyxia Cardiac Arrest Model

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Abstract

The real-time evaluation of chest compression during cardiopulmonary resuscitation is important to increase the chances of survival from a cardiac arrest (CA). In addition, cerebral oxygen level measured by near-infrared spectroscopy (NIRS) plays an important role as an indicator of return of spontaneous circulation. Recently, we developed a new method to improve the quality of chest compression using a thoracic pump in conjunction with the classic cardiac pump in a rat asphyxia CA model. This study evaluated the quality of chest compression using NIRS in male Sprague-Dawley rats. NIRS was attached between the nasion and the upper cervical spine, and rats underwent 10 minute asphyxia CA. After CA, we alternately performed three different types of chest compression (cardiac, thoracic, and cardiac plus thoracic pumps) every 30 seconds for up to 4 and a half minutes. We measured the oxyhemoglobin (Oxy-Hb), deoxyhemoglobin (Deoxy-Hb), and tissue oxygenation index (TOI) and compared these values between the groups. Oxy-Hb was significantly different among the groups (cardiac, thoracic, and cardiac plus thoracic, 1.5 ± 0.9, 4.4 ± 0.7, and 5.9 ± 2.1 μmol/L, $p < 0.01$, respectively), while Deoxy-Hb and TOI were not (Deoxy-HB −2.7 ± 1.2, −1.1 ± 3.2, and −1.6 ± 10.1 μmol/L; TOI, 1.8 ± 1.8, 5.5 ± 1.3, and 9.5 ± 8.0%, respectively). Oxy-Hb showed potential to evaluate the quality of chest compression in a rat asphyxia CA model.

Keywords

Cardiac arrest · Oxyhemoglobin (Oxy-Hb) · Cerebral blood oxygenation (CBO) · Near-infrared spectroscopy (NIRS) · Quality of chest compression

42.1 Introduction

Recent guidelines for cardiopulmonary resuscitation (CPR) state that high-quality CPR is the key to improving survival from a cardiac arrest (CA) [1]. Therefore, the real-time evaluation of chest

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E. M. Nemoto et al. (eds.), *Oxygen Transport to Tissue XLII*, Advances in Experimental Medicine and Biology 1269, https://doi.org/10.1007/978-3-030-48238-1_42

compression plays an important role in CA [2]. Cerebral blood oxygenation (CBO) has been discussed as a promising indicator of return of spontaneous circulation [3, 4], and CBO measured by near-infrared spectroscopy (NIRS) is used for real-time evaluation of the quality of CPR in clinical settings [5]; however, guidelines have not yet recommended the use of CBO by NIRS for CA due to the lack of clear evidence of its utility [6]. This study was conducted to test the evaluation of quality of chest compression with CBO using NIRS in a rat model. This study is a continuation of a recent study, in which we developed a new method to improve the quality of chest compression using the thoracic pump in conjunction with the classic cardiac pump in a rat asphyxia CA model.

42.2 Methods

42.2.1 Animal Preparation

The Institutional Animal Care and Use Committee (IACUC) of the Feinstein Institute for Medical Research approved these study protocols (2016-047). The details of methods for a rat asphyxia CA model have been described previously [7, 8]. In brief, adult male Sprague-Dawley rats (450–550 g, Charles River Laboratories) were anesthetized with 4% isoflurane (Isosthesia, Butler-Schein AHS) and intubated with a 14-gauge plastic catheter (Surflo, Terumo Medical Corporation). The animals were mechanically ventilated. Anesthesia was maintained with isoflurane 2% at a fraction of inspired O_2 (FIO_2) of 0.3. The left femoral artery was cannulated (sterile polyethylene-50 catheter inserted for 20 mm) for continuous arterial pressure monitoring. A temperature probe was placed in the esophagus for continuous temperature monitoring. The core temperature was maintained at 36.5 ± 1.0 °C during the surgical procedure. The left femoral vein was cannulated with a polyethylene-50 catheter, which was advanced into the inferior vena cava for drug infusion. We attached NIRS (NIRO-200NX, Hamamatsu Photonics, Japan) from the nasion to the upper cervical spine of the rats. The distance between the emission and the detection probes was 3 cm. We examined the mean arterial pressure (MAP), end-tidal carbon dioxide ($ETCO_2$), and oxyhemoglobin (Oxy-Hb)/Deoxyhemoglobin (Deoxy-Hb), and tissue oxygen index (TOI). The NIRS device records the oxygen saturation level (TOI) and the changes in concentration of Oxy-Hb and Deoxy-Hb in real time (100 Hz). We analyzed averaged values over 30 second periods. Oxy-Hb and Deoxy-Hb were collected by modified Beer-Lambert (MBL), and TOI was collected by spatially resolved spectroscopy (SRS) [5]. After instrumentation, neuromuscular blockade was achieved by slow intravenous administration of 2 mg/kg of vecuronium bromide (Hospira, USA). Asphyxia was induced in the rats by switching off the ventilator, and CA occurred 3–4 minutes after asphyxia started. Mechanical ventilation was restarted at an FIO_2 of 1.0, and manual CPR was delivered to CA animals. Chest compressions were performed at a rate of 240–300 per minute.

42.2.2 Cardiopulmonary Resuscitation

The one-side method (cardio pump) involved chest compression vertically performed over the sternum with two fingers at a rate of 240–300 per minutes. The chest compression rate was calculated retrospectively from the record of pressure waveforms of the femoral arterial catheter. The two-side method (thoracic pump) was performed with two fingers horizontally squeezing the chest wall from both sides at the same rate. The three-side chest compression (cardiac plus thoracic pump) was carried out with two fingers of the right hand over the sternum in synchrony with two fingers of the left hand squeezing the chest wall from both sides ([8] Okuma Y – supplement for review only). The three sets of these chest compressions were alternately and randomly tested every 30 seconds, and CPR was performed for up to 4.5 minutes (nine sets of CPR, three for each group). CBO including TOI, Oxy-Hb, and Deoxy-Hb during CPR were compared to the values measured at the end of 10 minutes of asphyxia (baseline). In this experiment, adrenaline was not

Table 42.1 Relationship between mean arterial pressure (MAP), end-tidal carbon dioxide ($EtCO_2$), and cerebral blood oxygenation (CBO) including oxyhemoglobin (Oxy-Hb), Deoxy-Hb, and tissue oxygenation index (TOI)

		Cerebral blood O_2 (CBO)		
	MAP	Oxy-Hb	Deoxy-Hb	TOI
EtCO2	0.48**	0.23**	0.06	0.02
MAP		0.22**	−0.42**	0.31**
Oxy-Hb			−0.93**	0.02
Deoxy-Hb				−0.15*

**$p < 0.01$; *$p < 0.05$

given to the animal to avoid obtaining return of spontaneous circulation (ROSC) from the animals ($n = 5$).

42.2.3 Statistical Analysis

Data are presented as mean and standard deviation (SD). These values were compared between the groups by one-way analysis of variance (ANOVA) with post hoc analysis of the Tukey test. In multiple parameter's comparisons, correlation coefficient (r) values were collected. All statistical analyses were performed with JMP (version 10.1 software; SAS Institute, Cary, NC, USA). p-values less than 0.05 were considered significant.

42.3 Results

ROSC was not achieved in any animals. Oxy-Hb showed a significant correlation with both MAP ($r = 0.218$, $p < 0.0001$) and $EtCO_2$ ($r = 0.2294$, $p < 0.0001$), while Deoxy-Hb and TOI correlated with MAP ($r = -0.4193$, $p < 0.0001$; $r = 0.3125$, $p < 0.0001$, respectively) but not with $EtCO_2$ ($r = 0.0584$, $p = 0.302$; $r = 0.0239$, $p = 0.673$, respectively) (Table 42.1). Likewise, Oxy-Hb identified the differences of three groups (1-side, 2-side, and 3-side, 1.5 ± 0.9, 4.4 ± 0.7, and 5.9 ± 2.1 mmol/L, $p = 0.0008$, respectively), while Deoxy-Hb (1-side, 2-side, and 3-side, −2.7 ± 1.2, −1.1 ± 3.2, and −1.6 ± 10.1 mmol/L, $p = 0.952$, respectively) and TOI (1-side, 2-side, and 3-side, 1.8 ± 1.8, 5.5 ± 1.3, and 9.5 ± 8.0%, respectively, $p = 0.064$) did not (Fig. 42.1).

42.4 Discussion

In our preliminary data, three-side chest compression showed the best performance of CPR compared to the other methods, since the combination of the cardiac and thoracic pumps increased the thoracic pressure [8]. This increased cardiac output and carotid arterial pressure in a rat asphyxia CA model. In the present study, we found that Oxy-Hb identified the differences of the CPR methods and three-side chest compression demonstrated the highest Oxy-Hb level during CPR. This could suggest that Oxy-Hb can serve as an indicator to evaluate the quality of CPR. In addition, Oxy-Hb had a significant correlation with MAP and $EtCO_2$, which are also important indicators of the quality of CPR.

Two different mechanisms of chest compression have been proposed, cardiac pump theory and thoracic pump theory, and both cardiac and thoracic pumps may synergistically contribute to high-quality CPR and subsequently improve survival from cardiac arrest. The three-side method increases intrathoracic pressure and likely stabilizes cardiac hemodynamic status, which may be beneficial to improving the brain function. It is inferred that all CBO parameters including Oxy-Hb, Deoxy-Hb, and TOI increase because of improved cardiac pump effect likewise MAP. On the other hands, only Oxy-Hb reflected thoracic pump effect likewise $EtCO_2$ does. We currently have no data to support this hypothesis, and so future study with larger gyrencephalic species (swine, nonhuman primate, etc.) and measuring the pressure and blood gas in the carotid artery and jugular vein may be crucial to test this hypothesis [8].

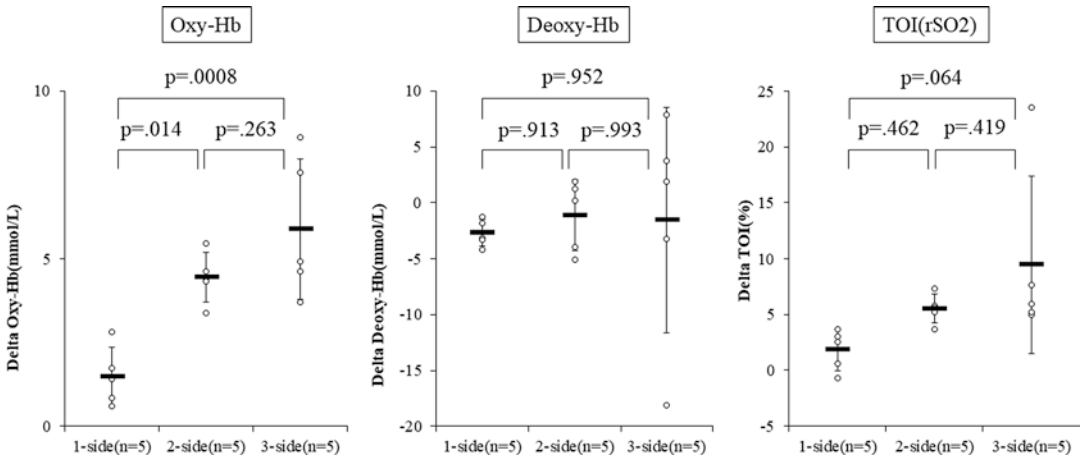

Fig. 42.1 The comparison of differences of cerebral blood oxygenation (CBO) including oxyhemoglobin (Oxy-Hb), Deoxy-Hb, and tissue oxygenation index (TOI) during our original three types of chest compression. The delta is the difference between the current average and the average of the end of the asphyxial period regarded as a baseline. rSO2 regional cerebral tissue oxygen saturation, 1-side one-side chest compression, 2-side two-side chest compression, 3-side three-side chest compression. ##$p < 0.01$; #$p < 0.05$; n.s. not significant

One of the reasons why the current guidelines do not recommend CBO by NIRS during CPR is the lack of evidence showing that CBO can effectively evaluate the quality of CPR. Several parameters of CBO are available by NIRS; however, there is a paucity of data supporting which parameter needs to be used for the evaluation of the quality of CPR.

In this study, we used NIRO instead of the other NIRS devices such as INVOS and regional oximetry. This system does not need to be adjusted for body weight. This is required by other systems, such as SenSmart™, which limits its use to subjects with a body weight over 40 kg. Moreover, in addition to measuring TOI/regional cerebral tissue oxygen saturation (rSO_2), NIRO calculates Oxy-Hb and Deoxy-Hb separately without blood collection at the same time [9]. Oxy-Hb measurement is becoming a hot topic in resuscitation science. The data from a previous Japanese prospective, multicenter observational study suggested that Oxy-Hb might be an indicator of neuroprotection in CA patients, which performance was better than rSO_2 [10]. Our results are consistent with these data, revealing that Oxy-Hb had performed better than TOI or Deoxy-Hb in evaluation of the quality of CPR.

$EtCO_2$ is one of the only indicator suggested to be used during CPR in the guidelines even though multiple studies support the potential use of CBO by NIRS [1]. This opposition is likely due to the fact that TOI/rSO_2 has not shown a good correlation with $EtCO_2$ [11, 12]. Our results are consistent, and TOI/rSO_2 did not have a correlation with $EtCO_2$; however, Oxy-Hb did.

One of the difficulties of NIRS measurements in critically ill patients is a large variability of CBO between individual patients [13, 14]. Taking this into consideration, we adjusted for differences between individuals by comparing the values of CBO in each animal with itself during CA (asphyxiation). This method is applicable in a real clinical setting with patients who have more variability than experimentally controlled animals.

The current study has several limitations. First, our study was preliminary, and larger sample size would be required. Second, the quality of CPR needs to be evaluated by blood flow measurements by other independent systems; however, a real-time measurement of the blood flow is difficult in small rodent models. Therefore, it would be necessary to monitor the blood flow using other animal models such as swine or macaque.

42.5 Conclusion

Oxy-Hb during CPR compared to that of during CA showed the potential to evaluate the quality of CPR in a rat CA model.

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