The Journal of Emergency Medicine, Vol. 50, No. 1, pp. 198–207, 2016

0736-4679/$ - see front matter

ELSEVIER

http://dx.doi.org/10.1016/j.jemermed.2015.03.043

Clinical Review

REGIONAL CEREBRAL OXIMETRY DURING CARDIOPULMONARY RESUSCITATION: USEFUL OR USELESS?

Cornelia Genbrugge, MD,*† Jo Dens, MD, PHD,†‡ Ingrid Meex, MSC,*† Willem Boer, MD,* Ward Eertmans, MSC,*† Marc Sabbe, MD, PHD,§ Frank Jans, MD, PHD,*† and Cathy De Deyne, MD, PHD*†

*Department of Anaesthesiology, Intensive Care, Emergency Medicine and Pain Therapy, Ziekenhuis Oost-Limburg, Genk, Belgium, †Faculty of Medicine and Life Sciences, Hasselt University, Hasselt, Belgium, ‡Department of Cardiology, Ziekenhuis Oost-Limburg, Genk, Belgium, and §Emergency Department, University Hospitals Leuven, Leuven, Belgium

Corresponding Address: Cornelia Genbrugge, MD, Department of Anaesthesiology, Intensive Care, Emergency Medicine and Pain Therapy, Ziekenhuis Oost-Limburg, Schiepse Bos 6, 3600 Genk, Belgium

☐ **Abstract—Background: Approximately 375,000 people annually experience sudden cardiac arrest (CA) in Europe. Most patients who survive the initial hours and days after CA die of postanoxic brain damage. Current monitors, such as electrocardiography and end-tidal capnography, provide only indirect information about the condition of the brain during cardiopulmonary resuscitation (CPR). In contrast, cerebral near-infrared spectroscopy provides continuous, noninvasive, real-time information about brain oxygenation without the need for a pulsatile blood flow. It measures transcutaneous cerebral tissue oxygen saturation (rSO_2). This information could supplement currently used monitors. Moreover, an evolution in rSO_2 monitoring technology has made it easier to assess rSO_2 in CA conditions. Objective: We give an overview of the literature regarding rSO_2 measurements during CPR and the current commercially available devices. We highlight the feasibility of cerebral saturation measurement during CPR, its role as a quality parameter of CPR, predictor of return of spontaneous circulation (ROSC) and neurologic outcome, and its monitoring function during transport. Discussion: rSO_2 is feasible in the setting of CA and has the potential to measure the quality of CPR, predict ROSC and neurologic outcome, and monitor post-CA patients during transport. Conclusion: The literature shows that rSO_2 has the potential to serve multiple roles as a neuromonitoring tool during CPR and also to guide neuroprotective therapeutic strategies.** © **2016 Elsevier Inc.**

☐ **Keywords—advanced life support; cardiac arrest; cardiopulmonary resuscitation; cerebral tissue saturation; neuromonitoring; NIRS; out-of-hospital cardiac arrest; prehospital**

Reprints are not available from the authors.

INTRODUCTION

Approximately 375,000 people annually experience sudden cardiac arrest (CA) in Europe (1). During the last few decades, major improvements have been introduced in cardiopulmonary resuscitation (CPR) and postresuscitation care. These include an increased emphasis on the lay rescuer with CPR, early defibrillation (especially since the availability of automated external defibrillators [AEDs]), early percutaneous coronary intervention, and the implementation of targeted temperature management (2,3). Despite these efforts, 70% of patients who die during a hospital stay after out-of-hospital cardiac arrest (OHCA) die because of postanoxic brain damage (4).

CPR is currently guided by clinical parameters, such as level of consciousness, breathing pattern, a palpable pulse, continuous electrocardiographic monitoring, and end-tidal capnography (5). However, all these monitoring parameters are characterized by major shortcomings as to

Received: 30 September 2014; Final submission received: 16 January 2015;
Accepted: 14 March 2015

their use in the setting of CPR (i.e., they are nonspecific for the brain, may require interruptions of chest compressions [e.g., electrocardiography], and most importantly, they do not provide direct information about oxygen supply to the vital organs). The absence of specific and reliable monitoring of the brain during CPR leaves the physician or paramedic unaware of the efficiency of his or her CPR efforts.

In order to preserve cerebral viability, a minimum of 20% of normal cerebral blood flow (CBF) is necessary (6,7). From animal studies, it is known that the period of global cerebral ischemia is followed by a no-reflow phenomenon (8–10). In addition, after induced experimental global cerebral ischemia, perfusion defects occur and increase in number and magnitude as the period of ischemia is lengthened because of increasing blood viscosity, perivascular edema, and vasospasm (10–13). When return of spontaneous circulation (ROSC) is achieved, a post-CA syndrome develops. This is characterized by cerebral hyperemia and subsequent increased cerebrovascular resistance and decreased cerebral blood flow (i.e., delayed cerebral hypoperfusion). The potential to obtain data on the exact condition of cerebral perfusion during CPR and in the postresuscitation period would be of extreme interest and relevance. Such techniques are not readily available, let alone validated.

Near infrared spectroscopy (NIRS) is a monitoring technique that is used to measure tissue oxygen saturation continuously in a noninvasive manner (14). The first human study with a commercially available cerebral saturation monitor (INVOS; Covidien) was published in 1991 (15). Several commercial NIRS monitors have since become available, such as SenSmart (Nonin Medical), FORE-SIGHT (CAS Medical Systems), NIRO (Hamamatsu Photonics), and c-FLOW (Ornim Medical Ltd).

In the past few years, NIRS has been introduced as a valuable noninvasive cerebral monitor in adult cardiac surgery in which intraoperative cerebral desaturations have been significantly correlated with postoperative neurocognitive decline and overall outcome (16–20). Most recently, special attention has been given to the use of NIRS during CPR and during the post-CA period (21–25). In this review, we will describe the technical background of different types of devices and discuss the most recent data encompassing the use of cerebral NIRS technology during CPR.

LITERATURE SOURCES

A literature study was conducted to identify published articles concerning cerebral oximetry during CA. Between August 2013 and May 2014, citations in PubMed were searched for a combination of these keywords: cerebral oximetry, cerebral saturation, (out-of-hospital) cardiac arrest, cardiopulmonary resuscitation, and prehospital. The reference lists of all known primary and review articles were consulted for additional relevant citations.

Near Infrared Spectroscopy, Technical Background

A NIRS monitor has a light source, incorporated at 1 side of the sensor, and ≥ 1 detector(s) at various distances on the opposite side of the light source. The sensor is applied to the region of interest (usually the patient's forehead for cerebral saturation monitoring). The detected light (700–1100 nm) flows in a banana-like shape from the light source to the detector (Figure 1) (26). Along its way, the emitted light is partly scattered, reflected, and absorbed as it penetrates through the skin, skull, and brain tissue, after which the remaining light is collected by the detectors (27,28). The difference in absorption of oxygenated and deoxygenated hemoglobin is measured and represents the oxygen saturation of the tissue. By applying the modified Beer–Lambert law, a numerical result of the measurements (i.e., percent of oxygen saturation) is displayed on the monitor (29).

Cerebral saturation values are a representation of oxygenation in the cerebral microcirculation (i.e., the venules, arterioles, and capillaries), but the relative contribution of each compartment to the cerebral saturation value is difficult to predict (30). Nevertheless, the displayed cerebral saturation corresponds well to measured hemoglobin saturations in the arterial and venous compartments if an arterial/venous ratio of 30/70 or 25/75 is used (31–33). However, a significant difference can be found between cerebral saturation and measured weighted blood saturation during induced hypoxia, possibly because of interpatient variability in this arterial/venous distribution (34).

The distance between the light source and the detector determines the depth of tissue saturation monitoring (28,35,36). Most adult sensors have an interoptode distance of around 3 cm, resulting in a penetration depth of approximately 1.5 cm. In children, sensors with a smaller interoptode distance are used. Because of the use of at least 2 detectors, one of which is dedicated to diminishing extracranial contamination, NIRS technology resulted in more accurate measurements (Figure 1) (26,31,36–39).

It must be noted that various cerebral saturation monitors differ extensively from each other in several ways. First, some monitors are more susceptible to ambient light interference, in which values are displayed within the normal range, even when sensors are unattached and completely open to ambient light (40). These findings are remarkable and important to take into account when considering additional research and the use of these

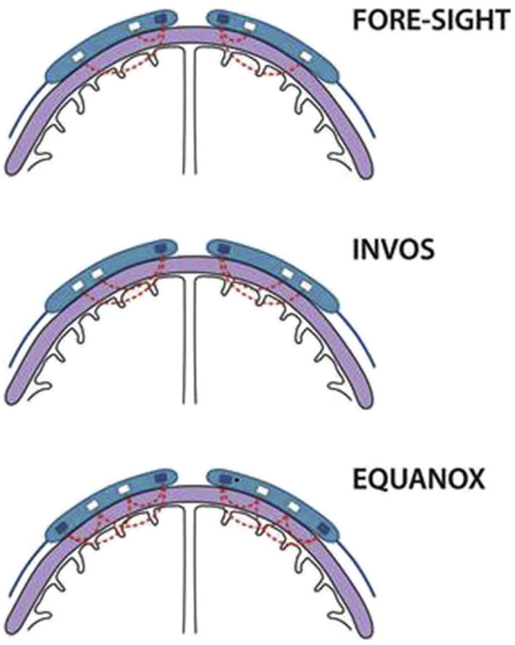

Figure 1. Sensors of different near-infrared spectrophotometry devices. Schematic diagram showing the banana-like shaped pathway through the extracranial and cerebral tissues represented by the different cerebral oximeters. The cerebral oximetry sensor, placed on the subject's forehead, contains light emitters (dark boxes) and light detectors (white boxes). Light (arrows) from the light emitter follows a banana-shaped pathway through both the extracranial tissue and cerebral tissue before resurfacing. The depth of tissue interrogated is proportional to the distance between the optode light emitter and detector. Automated algorithmic subtraction results in the display of the cerebral tissue oxygen saturation. (Reproduced with the permission from Davie and Grocott (26).)

monitors, especially in the prehospital setting. Second, the lower limit in measuring rSO_2 is not 0% in all commercially available devices because of the algorithms used in the different monitors (24). One commercial device cannot measure values < 15% (Table 1). The lowest cerebral tissue oxygen pressure measured during brain death in humans and in cardiac arrest conditions in pigs is 0 mm Hg (41,42). Low measurements (e.g., < 15%) of rSO_2 probably have no clinical relevance, but an rSO_2 between 0% and 15% could provide meaningful information in the setting of CPR research.

Finally, some monitors use only 2 wavelengths (primarily the monitors that were first commercially available). Nowadays, several monitors use 3 or even 4 wavelengths, enabling absolute measurements without the need for calibration (43–45). Because no baseline value can be obtained, a trend-only monitor, which uses only 2 wavelengths, is of limited value in the CPR setting.

In a CPR setting, the ideal rSO_2 monitor would be small, lightweight, and have a sustainable battery; it would measure absolute real-time values with trend displays and would not require calibration. Moreover, the ideal monitor would have no detection limits, no sensitivity to ambient light, and not be influenced by extracranial contamination. None of the currently available devices is equipped with the aforementioned characteristics of an ideal prehospital rSO_2 monitor. The properties of all available devices are listed in Table 1. Each monitor recommends the use of a different abbreviation for cerebral oxygen saturation value (e.g., rSO_2, resting cerebral oximetry, or tissue oxygenation index). We will continue to use rSO_2 as the abbreviation for cerebral tissue oxygen saturation throughout this article.

DISCUSSION

Near-Infrared Spectroscopy and Cardiopulmonary Resuscitation

CA is characterized by the absence of pulsatile flow. Therefore, most hemodynamic monitors currently in use, such as noninvasive blood pressure and pulse oximetry, do not reliably detect the presence of a pulsatile flow, and cannot provide reliable information during CA. In contrast, cerebral NIRS is able to monitor cerebral oxygenation during CPR and post-CA, and could be used as an indirect indicator of impaired cerebral perfusion or low arterial oxygen content (Table 2).

Feasibility of Measuring rSO_2 During CPR

Newman et al. were the first to assess the feasibility of measuring rSO_2 during CPR (24). They used a INVOS 3000 monitor (Covidien). In 1 of 15 patients, no reliable reading could be generated. Fourteen other patients were initially below the predefined detection limit (< 15%). ROSC occurred in 3 patients, accompanied by progressively detectable rSO_2 values. The authors concluded that measuring rSO_2 in OHCA patients is feasible, while taking into consideration that in 14 of 15 patients, rSO_2 during CPR was ≤ 15%. More recently, the feasibility of rSO_2 measurements during CPR conditions has been confirmed in both inhospital CA (IHCA) patients and OHCA patients, with different cerebral saturation monitors (EQUANOX, FORE-SIGHT, or INVOS) (23,45,46). No reliable data could be obtained in only 2 of 11 patients measured with EQUANOX and in 4 of 19 patients measured with INVOS. Nevertheless, aside from Newman et al., only 1 study measured cerebral saturation prehospital during CPR—all others measured cerebral saturation in the hospital environment (45). Albeit dependent on which device is used, most recently performed studies succeeded in obtaining reliable rSO_2 values, even before ROSC. None of the reported studies described a delay in standard CPR care by applying the sensor. Placement of 1 sensor on the patient's forehead

Table 1. Characteristics of Different Cerebral Near-Infrared Spectrophotometry Devices

	INVOS 5100C (Covidien)	FORE-SIGHT (CAS Medical Systems)	EQUANOX SenSmart Model X-100 and EQUANOX Advance Model 8004CA Sensor (Nonin Medical)	c-FLOW (Ornim Medical Ltd)	NIRO-200NX (Hamamatsu Photonics)
Dimensions (cm)					
Height	24	20.3	18	NA	27.9
Width	29	33	30.5	NA	26.4
Depth	19	20.3	13	NA	19.9
Weight (kg)	4.95	9.8	0.9	NA	6
Light source	LED	Laser	LED	Laser + pulses of ultrasound	LED
No. of light sources	1	1	2	1	1
Emitter–diode spacing (mm)	30–40	15–50	20–40	12	37–43
No. of wavelengths (nm)	2 (730–810)	4 (690/780/805/850)	4 (730/760/810/880)	3 (780–830)	3 (735/810/850)
Range cerebral saturation	15–95%	0–99%	0–100%	0–100%	0–100%
Value update (seconds)	5–6	2	1.4	5	NA
Battery (hour)	2	1.5	> 3	1	0.5
Absolute or relative values	Relative	Absolute	Absolute	NA	Absolute
Extracranial contamination (mean ± SD)*	16.6% ± 9.6	11.8% ± 5.3	6.8% ± 6	NA	NA
Sensitivity to ambient light when sensor is detached (40)	Sensitive	Not sensitive	Sensitive	NA	NA
Abbreviation	rSO_2	$SctO_2$	rSO_2	StO_2	TOI
FDA approval for the use of cerebral saturation	Yes	Yes	Yes	Yes	No

FDA = U.S. Food and Drug Administration; LED = light-emitting diode; NA = not available; rSO_2 = cerebral oxygen saturation; $SctO_2$ = regional cerebral tissue oxygen saturation; SD = standard deviation; StO_2 = tissue oxygen saturation; TOI = tissue oxygenation index.

* Extracranial contamination was determined as a decrease in rSO_2 during inflation of a pneumatic head cuff compared to baseline values (26).

Table 2. Overview of Published Papers About Cerebral Near-Infrared Spectrophotometry and Cardiopulmonary Resuscitation

Authors	Year	Type of Study	rSO_2 Device Used	OHCA/IHCA	Measured IH or OH	No. of Patients	Feasibility	Quality or Effect of CPR	Prediction of ROSC	Prediction of Neurologic Outcome* or Survival	Monitoring Function†
Müllner et al.	1995	Observational	INVOS 3100	OHCA	IH	18	+	NA	NA	+	±
Newman et al.	2004	Observational	INVOS 3000	OHCA	OH	16	+	±	NA	NA	NA
Parnia et al.	2012	Observational	INVOS	IHCA	IH	19	+	±	+	+	NA
Ito et al.	2012	Observational	INVOS	OHCA	IH	92	+	NA	+	+	NA
Weatherall et al.	2012	Observational	FORE-SIGHT	OH, healthy volunteers	OH	65	+	NA	NA	NA	NA
Kämäräinen et al.	2012	Observational	INVOS 5100c	IHCA	IH	9	+	+	NA	NA	NA
Meex et al.	2013	Observational	FORE-SIGHT; Equanox	OHCA + IHCA	OH + IH	14	+	±	NA	NA	±
Ahn et al.	2013	Observational	Equanox 7600	OHCA + IHCA	IH	50	+	+	+	NA	NA
Asim et al.	2013	Observational	INVOS 5100c	OHCA	IH	30	+	NA	+	+	±
Koyama et al.	2013	Observational	NIRO	OHCA	IH	15	+	+	+	NA	NA
Parnia et al.	2013	Observational	Equanox 7600	IHCA	IH	34	+	+	±	NA	NA
Singer et al.	2014	Retrospective observational study	Equanox	OHCA	IH	59	+	NA	+	NA	NA
Ito et al.	2014	Observational	INVOS 5100c	OHCA	IH	672	+	NA	NA	+	NA
Pilkington et al.	1995	Case report	INVOS 3100	IHCA	IH	1	+	±	NA	NA	±
Nagdyman et al.	2003	Case report	NIRO 300	IHCA	IH	1	+	±	NA	NA	±
Paarmann et al.	2010	Case report	INVOS 5100	IHCA	IH	1	+	±	NA	NA	±
Martens et al.	2010	Case report	FORE-SIGHT	IHCA	IH	1	+	±	NA	NA	±
Mayr et al.	2011	Case report	INVOS 5100c	IHCA	IH	1	+	±	NA	NA	±
Ito et al.	2012	Letter	INVOS 5100c	OHCA	IH	33	+	NA	±	+	NA
Ito et al.	2012	Letter	INVOS	OHCA	IH	186	+	+	±	+	NA

+ = Yes; ± = it is mentioned; CPR = cardiopulmonary resuscitation; IH = in-hospital; IHCA = in-hospital cardiac arrest; NA = not applicable/not mentioned; NIRS = near-infrared spectroscopy; OH = out-of-the hospital; OHCA = out-of-hospital cardiac arrest; ROSC = return of spontaneous circulation.

* Neurologic outcome defined as cerebral performance category.

† Monitoring function is compared to current hemodynamic monitoring.

took an average of approximately 15 seconds (± 10 seconds) without interrupting basic life support or advanced life support (23).

Monitoring Function during Transport

Weatherall et al. tested the feasibility of rSO_2 monitoring during transportation of patients (road and helicopter) (47). Absolute rSO_2 was registered (FORE-SIGHT) during 33 road and 32 helicopter transports of healthy volunteers. Movements generated by transport or patients themselves did not affect the quality of the measured rSO_2 data. These observations suggest that rSO_2 value could become a valuable monitoring parameter during transport. During difficult transport conditions, conventional monitoring may not always give accurate signals. Especially during transport of patients with pulseless electrical activity, rSO_2 monitoring could complement electrocardiographic monitoring.

Cerebral Saturation as a Measure of Quality of CPR

Only 1 study measured rSO_2 (INVOS) in IHCA patients (n = 9) in combination with a CPR quality feedback monitor (Q-CPR; Laerdal Medical) (22). Four episodes of suboptimal quality of CPR were recognized by the Q-CPR in 4 different patients. Optimization of these suboptimal CPR periods did not result in significant changes in rSO_2. Despite the quality of CPR was readily at the start of CPR in 3 of them.

Another study concluded that rSO_2 could reliably assess the quality of chest compressions, although the efficiency of chest compressions was based solely on visual inspection and no quantifiable measurements of the chest compressions were obtained (48). Therefore, the relationship between reduced quality of chest compression and rSO_2 could not be determined, because rSO_2 values before the suboptimal CPR period were not available.

Quality of chest compressions can be improved by using an automated chest compression device (49–51). When comparing rSO_2 in patients resuscitated with manual vs. mechanical chest compressions, a higher mean rSO_2 was observed in the patients treated with mechanical chest compressions (52). In addition, a higher cerebral cortical blood flow was found in pigs resuscitated with mechanical chest compressions. These findings support the hypothesis that rSO_2 can measure the quality of chest compressions (53).

The effect—but not the quality—of bystander CPR on rSO_2 was assessed by Ito et al. (54). They included 186 OHCA patients who were still in CA on arrival at the emergency department (ED); rSO_2 measured on hospital arrival was 33% ± 20 in the group with bystander CPR (76 patients) and 22% ± 13 in the other group ($p = 0.00003$). The authors concluded that bystander-initiated CPR resulted in a significantly higher rSO_2. However, the authors found only an association between bystander CPR and higher cerebral oximetry values and could not demonstrate a causal relationship.

Others observed a decrease in rSO_2 with a switch of caregivers and an increase in rSO_2 values when CPR efforts were optimized (23,45). Three case reports measured rSO_2 during accidental CA in patients undergoing transcatheter aortic valve implantation (TAVI), and 1 arterial switch procedure with transposition of the great arteries. These case reports provide interesting information on the effect of chest compressions on cerebral saturation (55–58). During loss of pulsation, a decrease in rSO_2 was observed, with a subsequent increase or status quo of rSO_2 values during chest compressions. When ROSC was achieved or cardiopulmonary bypass was initiated, a further increase in rSO_2 was seen. These observations during TAVI procedures clearly illustrate the influence of chest compressions on rSO_2 and the sensitivity of rSO_2 to hemodynamic instability. However, none of the authors described the latency between onset of loss of pulse, interruption of chest compressions, and decline in rSO_2. Therefore, it is still unclear how quickly rSO_2 values change after hemodynamic (in)stability.

These results provide some support to the conceptual premise that rSO_2 can detect a change in quality of CPR; nevertheless, the quality of CPR has not been measured.

Cerebral Saturation during CPR as a Predictor of ROSC and Neurologic Outcome

The role of cerebral saturation as a predictor of ROSC and neurologic outcome has been investigated at different time points during CPR and after CA, but almost exclusively in a hospital environment.

Three studies suggested that rSO_2 measured on arrival can play a role in predicting neurologic outcome 1 week after CA or at hospital discharge (59–61). Ito et al. included 92 OHCA patients in whom rSO_2 (using INVOS) was measured during CPR for a 1-min period on arrival at the ED (61). None of the patients with rSO_2 values < 25% survived, whereas 50% of patients with rSO_2 values > 40% survived ($p < 0.0001$). A significant positive correlation was observed between these first rSO_2 values on hospital admission and good neurologic outcome (cerebral performance category 1–2) at hospital discharge. Despite the positive correlation, the causality between rSO_2 values at ED admission and neurologic outcome was still not established. In their multicenter study (620 patients), they confirmed that rSO_2 at ED arrival, with ongoing CPR efforts, could predict neurologic outcome at 90 days after OHCA (60).

However, the value of this first rSO_2 measurement was not confirmed in a prospective study conducted by Ahn et al., in which it was shown that first measured rSO_2 at the ED did not significantly differ between patients who achieved ROSC vs. patients with no ROSC (14 OHCA and 36 IHCA patients) (25).

Overall mean rSO_2 during CPR (after ED admission) was significantly higher in patients achieving ROSC compared to patients not achieving ROSC (59 OHCA patients and 15 IHCA patients) (23,46). In a study by Singer et al., mean rSO_2 was 43.8% in the ROSC group vs. 34.2% in the no ROSC group ($p = 0.001$) (46). In a smaller study, in which only IHCA patients were included, overall mean rSO_2 was 35% $\pm$ 5 in the ROSC group, which was significantly higher than in the no ROSC group (18% $\pm$ 0.4 [$p < 0.001$]) (23). In this small sample size study, a positive predictive value of 1.0 for ROSC was obtained as well if mean rSO_2 value was 48% during 5 min of CPR.

A higher increase in rSO_2 from baseline was observed in patients who achieved ROSC compared to patients who did not achieve ROSC (23,62). In contrast, Koyama et al. observed no significant difference between initial rSO_2 and rSO_2 measured at the time of ROSC or at the time of death between patients achieving ROSC vs. no ROSC (48). If IHCA and OHCA patients were divided into subgroups according to initial rhythm, a significant difference in median rSO_2 values was observed between survivors and nonsurvivors in the group with pulseless electrical activity (PEA) and asystole ($p = 0.02$ and $p < 0.002$) (25). These results suggest a main benefit of rSO_2 monitoring in determining ROSC in CA patients with PEA or asystole as initial heart rhythm.

Currently, no general threshold has been set at which ROSC will be achieved. In the nonsurvivor group, it was observed that rSO_2 values never exceeded 30% during the majority of CPR, whereas none of the patients with a mean $rSO_2 \leq 30\%$ achieved ROSC (23,25). In a study by Ito et al., no patients with $rSO_2 < 15\%$ on hospital arrival survived to hospital discharge, suggesting that rSO_2 values < 25% could be an indicator of futile resuscitation attempts (61,63). However, this could not be confirmed in their multicenter trial (60). Others found a significant difference between patients who achieved ROSC or no ROSC when the threshold of initial rSO_2 was set at 40% (48). However, there was still 1 patient with an initial $rSO_2 < 40\%$ who achieved ROSC.

At the present time, there is no consensus on the remaining question of whether NIRS could play a role as a predictor of ROSC and survival. Moreover, a possible threshold to determine the chance of ROSC has not yet been defined. Clearly, more extensive studies using larger study populations are greatly needed and should be conducted in an out-of-hospital setting from the start of advanced life support.

CONCLUSION

During recent decades, major improvements have been introduced in CPR and postresuscitation treatment. However, the absence of a tool to reflect the perfusion of the brain and oxygenation makes it impossible to monitor the brain during CPR in order to assess the hemodynamic effects of CPR efforts and to take adequate neuroprotective measures. Neuromonitoring, such as electroencephalography, transcranial Doppler ultrasonography, and jugular bulb saturation cannot be used in OHCA conditions. Cerebral NIRS, previously used in other areas, such as anesthesiology, has now been introduced into the domain of CPR and has the potential to open new dimensions for fine-tuning therapy and predicting outcome.

rSO_2 seems sensitive to hemodynamic changes and changes in cardiac rhythm. These measurements are noninvasive, continuous, and real-time, and changes are immediately registered. Because of these characteristics, rSO_2 could become a monitoring parameter during CPR and after ROSC is achieved. Moreover, rSO_2 could potentially guide neuroprotective treatment during and after CA. However, there are still many unresolved questions. It is still unclear whether 1 measurement is sufficient or if trends are more important in predicting ROSC and survival. If 1 value is sufficient, what timepoint during CPR would be the best for measuring it? Or is it more meaningful if rSO_2 remains above a threshold value during a defined time period? What threshold would that be? Can we use the measured cerebral saturation values without a previous baseline?

Future research should focus on the role of rSO_2 in decision-making during CPR, possibly limiting futile CPR efforts, prognostication of outcome, improving clinical outcome, and comparing rSO_2 with traditional measurements for predicting outcome, with longer follow-up. It is too early to promote the standard use of cerebral oximetry during (prehospital) CPR.

However, a new era has begun in the field of resuscitation. Measuring perfusion of the brain and assessing efficiency of CPR efforts by rSO_2 is no longer impossible but holds promise; large observational and interventional studies are necessary to provide more insight into the possibilities of using rSO_2 during CPR.

Acknowledgments—This manuscript is part of the Limburg Clinical Research Program (LCRP) UHasselt-ZOL-Jessa, supported by the foundation Limburg Sterk Merk, Hasselt University, Ziekenhuis Oost-Limburg, and Jessa Hospital. We want to thank Professor Caers for the English grammar advice.

REFERENCES

1. Gräsner JT, Herlitz J, Koster RW, et al. Quality management in resuscitation – towards a European Cardiac Arrest Registry (EuReCa). Resuscitation 2011;82:989–94.
2. Berg RA, Hemphill R, Abella BS, et al. Part 5: Adult basic life support 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2010;122(18 suppl 3):S685–705.
3. Peberdy MA, Callaway CW, Neumar RW, et al. Part 9: Post–cardiac arrest care 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2010;122(18 suppl 3):S768–86.
4. Laver S, Farrow C, Turner D, et al. Mode of death after admission to an intensive care unit following cardiac arrest. Intensive Care Med 2004;30:2126–8.
5. Neumar RW, Otto CW, Link MS, et al. Part 8: Adult advanced cardiovascular life support 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2010;122(18 suppl 3):S729–67.
6. Symon L. Flow thresholds in brain ischaemia and the effects of drugs. Br J Anaesth 1985;57:34–43.
7. Powers WJ, Grubb RL Jr, Darriet D, et al. Cerebral blood flow and cerebral metabolic rate of oxygen requirements for cerebral function and viability in humans. J Cereb Blood Flow 1985;5:600–8.
8. Lee SK, Vaagenes P, Safar P, et al. Effect of cardiac arrest time on cortical cerebral blood flow during subsequent standard external cardiopulmonary resuscitation in rabbits. Resuscitation 1989;17: 105–17.
9. Shaffner DH, Eleff SM, Brambrink AM, et al. Effect of arrest time and cerebral perfusion pressure during cardiopulmonary resuscitation on cerebral blood flow, metabolism, adenosine triphosphate recovery, and pH in dogs. Crit Care Med 1999;27:1335–42.
10. Fischer M, Hossmann KA. No-reflow after cardiac arrest. Intensive Care Med 1995;21:132–41.
11. Chiang J, Kowada M, Ames A 3rd, et al. Cerebral ischemia. III. Vascular changes. Am J Pathol 1968;52:455–76.
12. Ames A 3rd, Wright RL, Kowada M, et al. Cerebral ischemia. II. The no-reflow phenomenon. Am J Pathol 1968;52:437–53.
13. Fischer EG, Ames A 3rd. Studies on mechanisms of impairment of cerebral circulation following ischemia: effect of hemodilution and perfusion pressure. Stroke 1972;3:538–42.
14. Murkin JM, Arango M. Near-infrared spectroscopy as an index of brain and tissue oxygenation. Br J Anaesth 2009;103(suppl 1):i3–13.
15. McCormick PW, Stewart M, Goetting MG, et al. Regional cerebrovascular oxygen saturation measured by optical spectroscopy in humans. Stroke 1991;22:596–602.
16. Slater JP, Guarino T, Stack J, et al. Cerebral oxygen desaturation predicts cognitive decline and longer hospital stay after cardiac surgery. Ann Thorac Surg 2009;87:36–44.
17. Yao F-SF, Tseng C-CA, Ho C-YA, et al. Cerebral oxygen desaturation is associated with early postoperative neuropsychological dysfunction in patients undergoing cardiac surgery. J Cardiothorac Vasc Anesth 2004;18:552–8.
18. Murkin JM, Adams SJ, Novick RJ, et al. Monitoring brain oxygen saturation during coronary bypass surgery: a randomized, prospective study. Anesth Analg 2007;104:51–8.
19. Fischer GW, Lin H-M, Krol M, et al. Noninvasive cerebral oxygenation may predict outcome in patients undergoing aortic arch surgery. J Thorac Cardiovasc Surg 2011;141:815–21.
20. Tang L, Kazan R, Taddei R, et al. Reduced cerebral oxygen saturation during thoracic surgery predicts early postoperative cognitive dysfunction. Br J Anaesth 2012;108:623–9.
21. Meex I, Dens J, Jans F, et al. Cerebral tissue oxygen saturation during therapeutic hypothermia in post-cardiac arrest patients. Resuscitation 2013;84:788–93.
22. Kämäräinen A, Sainio M, Olkkola KT, et al. Quality controlled manual chest compressions and cerebral oxygenation during in-hospital cardiac arrest. Resuscitation 2012;83:138–42.
23. Parnia S, Nasir A, Shah C, et al. A feasibility study evaluating the role of cerebral oximetry in predicting return of spontaneous circulation in cardiac arrest. Resuscitation 2012;83:982–5.
24. Newman DH, Callaway CW, Greenwald IB, et al. Cerebral oximetry in out-of-hospital cardiac arrest: standard CPR rarely provides detectable hemoglobin-oxygen saturation to the frontal cortex. Resuscitation 2004;63:189–94.
25. Ahn A, Nasir A, Malik H, et al. A pilot study examining the role of regional cerebral oxygen saturation monitoring as a marker of return of spontaneous circulation in shockable (VF/VT) and non-shockable (PEA/Asystole) causes of cardiac arrest. Resuscitation 2013;84:1713–6.
26. Davie SN, Grocott HP. Impact of extracranial contamination on regional cerebral oxygen saturation: a comparison of three cerebral oximetry technologies. Anesthesiology 2012;116:834–40.
27. Dobriner K, Kritchevsky TH, Fukushima DK, et al. Infrared spectrometry in metabolic studies with deuterium-labeled steroids. Science 1949;109:260–1.
28. Scheeren TWL, Schober P, Schwarte LA. Monitoring tissue oxygenation by near infrared spectroscopy (NIRS): background and current applications. J Clin Monit Comput 2012;26:279–87.
29. Pellicer A, Bravo M del C. Near-infrared spectroscopy: a methodology-focused review. Semin Fetal Neonatal Med 2011; 16:42–9.
30. Daubeney PE, Pilkington SN, Janke E, et al. Cerebral oxygenation measured by near-infrared spectroscopy: comparison with jugular bulb oximetry. Ann Thorac Surg 1996;61:930–4.
31. MacLeod DB, Ikeda K, Vacchiano C, et al. Development and validation of a cerebral oximeter capable of absolute accuracy. J Cardiothorac Vasc Anesth 2012;26:1007–14.
32. Henson LC, Calalang C, Temp JA, et al. Accuracy of a cerebral oximeter in healthy volunteers under conditions of isocapnic hypoxia. Anesthesiology 1998;88:58–65.
33. Pollard V, Prough DS, DeMelo AE, et al. Validation in volunteers of a near-infrared spectroscope for monitoring brain oxygenation in vivo. Anesth Analg 1996;82:269–77.
34. Bickler PE, Feiner JR, Rollins MD. Factors affecting the performance of 5 cerebral oximeters during hypoxia in healthy volunteers. Anesth Analg 2013;117:813–23.
35. Bonner RF, Nossal R, Havlin S, et al. Model for photon migration in turbid biological media. J Opt Soc Am A 1987;4:423–32.
36. Germon TJ, Evans PD, Barnett NJ, et al. Cerebral near infrared spectroscopy: emitter-detector separation must be increased. Br J Anaesth 1999;82:831–7.
37. Franceschini MA, Fantini S, Paunescu LA, et al. Influence of a superficial layer in the quantitative spectroscopic study of strongly scattering media. Appl Opt 1998;37:7447–58.
38. Choi J, Wolf M, Toronov V, et al. Noninvasive determination of the optical properties of adult brain: near-infrared spectroscopy approach. J Biomed Opt 2004;9:221–9.
39. Zhang Y, Sun JW, Rolfe P. RLS adaptive filtering for physiological interference reduction in NIRS brain activity measurement: a Monte Carlo study. Physiol Meas 2012;33:925–42.
40. Zaouter C, Arbeid E. Influence of ambient light on cerebral oximeters. Br J Anaesth 2010;105:873–4.
41. Bein B, Cavus E, Stadlbauer KH, et al. Monitoring of cerebral oxygenation with near infrared spectroscopy and tissue oxygen partial pressure during cardiopulmonary resuscitation in pigs. Eur J Anaesthesiol 2006;23:501–9.
42. Palmer S, Bader MK. Brain tissue oxygenation in brain death. Neurocrit Care 2005;2:17–22.
43. Wolf M, Naulaers G, van Bel F, et al. A review of near infrared spectroscopy for term and preterm newborns. J Infrared Spectrosc 2012; 20:43.
44. Hemmerling TM, Bluteau MC, Kazan R, et al. Significant decrease of cerebral oxygen saturation during single-lung ventilation measured using absolute oximetry. Br J Anaesth 2008; 101:870–5.
45. Meex I, De Deyne C, Dens J, et al. Feasibility of absolute cerebral tissue oxygen saturation during cardiopulmonary resuscitation. Crit Care 2013;17:R36.

46. Singer AJ, Ahn A, Inigo-Santiago LA, et al. Cerebral oximetry levels during CPR are associated with return of spontaneous circulation following cardiac arrest: an observational study. Emerg Med J 2015;32:353–6.
47. Weatherall A, Skowno J, Lansdown A, et al. Feasibility of cerebral near-infrared spectroscopy monitoring in the pre-hospital environment. Acta Anaesthesiol Scand 2012;56:172–7.
48. Koyama Y, Wada T, Lohman BD, et al. A new method to detect cerebral blood flow waveform in synchrony with chest compression by near-infrared spectroscopy during CPR. Am J Emerg Med 2013;31:1504–8.
49. Sunde K, Wik L, Steen PA. Quality of mechanical, manual standard and active compression-decompression CPR on the arrest site and during transport in a manikin model. Resuscitation 1997;34: 235–42.
50. Olasveengen TM, Wik L, Steen PA. Quality of cardiopulmonary resuscitation before and during transport in out-of-hospital cardiac arrest. Resuscitation 2008;76:185–90.
51. Stapleton ER. Comparing CPR during ambulance transport. Manual vs. mechanical methods. J Emerg Med Serv 1991;16:63–4. 66, 68.
52. Parnia S, Nasir A, Ahn A, et al. A feasibility study of cerebral oximetry during in-hospital mechanical and manual cardiopulmonary resuscitation. Crit Care Med 2014;42:930–3.
53. Rubertsson S, Karlsten R. Increased cortical cerebral blood flow with LUCAS; a new device for mechanical chest compressions compared to standard external compressions during experimental cardiopulmonary resuscitation. Resuscitation 2005;65:357–63.
54. Ito N, Nanto S, Nagao K, et al. Bystander-initiated cardiopulmonary resuscitation can curb the deterioration of regional cerebral oxygen saturation on hospital arrival in patients with cardiac arrest. Resuscitation 2012;83:e167–8.
55. Paarmann H, Heringlake M, Sier H, et al. The association of noninvasive cerebral and mixed venous oxygen saturation during cardiopulmonary resuscitation. Interact Cardiovasc Thorac Surg 2010;11:371–3.
56. Mayr NP, Martin K, Kurz J, et al. Monitoring of cerebral oxygen saturation during closed-chest and open-chest CPR. Resuscitation 2011;82:635–6.
57. Martens PR, Dhaese HLA, Van den Brande FG, et al. External cardiac massage improved cerebral tissue oxygenation shown by near-infrared spectroscopy during transcatheter aortic valve implantation. Resuscitation 2010;81:1590–1.
58. Pilkington SN, Hett DA, Pierce JM, et al. Auditory evoked responses and near infrared spectroscopy during cardiac arrest. Br J Anaesth 1995;74:717–9.
59. Müllner M, Sterz F, Binder M, et al. Near infrared spectroscopy during and after cardiac arrest—preliminary results. Clin Intensive Care Med 1995;6:107–11.
60. Ito N, Nishiyama K, Callaway CW, et al. Noninvasive regional cerebral oxygen saturation for neurological prognostication of patients with out-of-hospital cardiac arrest: a prospective multicenter observational study. Resuscitation 2014;85:778–84.
61. Ito N, Nanto S, Nagao K, et al. Regional cerebral oxygen saturation on hospital arrival is a potential novel predictor of neurological outcomes at hospital discharge in patients with out-of-hospital cardiac arrest. Resuscitation 2012;83:46–50.
62. Asim K, Gokhan E, Ozlem B, et al. An assessment of the use of near infrared spectrophotometry (cerebral oximetry) in predicting the return of spontaneous circulation in out-of-hospital cardiac arrest. Am J Emerg Med 2014;32:14–7.
63. Ito N, Nanto S, Nagao K, et al. Regional cerebral oxygen saturation predicts poor neurological outcome in patients with out-of-hospital cardiac arrest. Resuscitationtpdel 2010;81:1736–7.

ARTICLE SUMMARY

1. Why is this topic important?

Brain monitoring possibilities are limited during cardiopulmonary resuscitation, with no way to receive any direct information from the brain. Cerebral saturation has potential as a monitor during cardiopulmonary resuscitation, and possibly also as a predictor of return of spontaneous circulation or neurologic outcome early in the resuscitation phase.

2. What does this study attempt to show?

This article presents an objective overview of the current literature about cerebral saturation in the setting of cardiopulmonary resuscitation.

3. What are the key findings?

Cerebral saturation can be measured in cardiopulmonary resuscitation settings both in-hospital and out-of-hospital. It has the potential to predict return of spontaneous circulation and neurologic outcome.

4. How is patient care impacted?

At the present time, it is too early to introduce cerebral saturation monitoring as the standard monitoring during prehospital cardiopulmonary resuscitation efforts because of the lack of large observational studies with long-term outcome data.