ARTICLE IN PRESS

Journal of Critical Care xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Journal of Critical Care

journal homepage: www.jccjournal.org

Noninvasive assessment of hemodynamic variables using near-infrared spectroscopy in patients experiencing cardiogenic shock and individuals undergoing venoarterial extracorporeal membrane oxygenation ☆

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ARTICLE INFO

Keywords:
Cardiogenic shock
Extracorporeal membrane oxygenation
Hemodynamics
Near-infrared spectroscopy
Oximetry

ABSTRACT

Purpose: The relationship between near-infrared spectroscopy cerebral oximetry ($CrSO_2$), peripheral oximetry ($PrSO_2$) and hemodynamic variables is not fully understood.
Methods: The relationship between $CrSO_2$/$PrSO_2$ and cardiac index (CI), systemic vascular resistance index (SVRI) and mean arterial pressure (MAP) in patients experiencing cardiogenic shock and those undergoing venoarterial extracorporeal membrane oxygenation (ECMO) was retrospectively analyzed; in patients on ECMO, total circulatory index (TCI) was calculated from the sum of CI and extracorporeal blood flow index.
Results: In patients experiencing cardiogenic shock (n = 10), significant correlations between $PrSO_2$ values and CI (Spearman $r = 0.81$; $P < .0001$), SVRI ($r = -0.45$; $P < .0001$), and MAP ($r = 0.58$; $P < .0001$) were found. Significant correlations between $CrSO_2$ and CI ($r = 0.55$; $P < .0001$) and SVRI ($r = -0.47$; $P < .0001$), but not MAP, were observed. Linear regression analysis revealed that CI could be calculated using the following equation: CI = $PrSO_2$/24.0.
In patients on VA ECMO (n = 12), significant correlations were found between $PrSO_2$ and TCI ($r = 0.68$; $P < .0001$), SVRI ($r = -0.47$; $P < .0001$), and MAP ($r = 0.27$; $P = .025$). Significant correlations were also found between $CrSO_2$ and TCI ($r = 0.68$; $P < .0001$) and SVRI ($r = -0.51$; $P < .0001$), but not MAP.
Conclusions: Results of the present study suggest that $CrSO_2$ and $PrSO_2$ in particular can be used for noninvasive estimation and monitoring of global circulatory status in patients experiencing cardiogenic shock and individuals undergoing ECMO.

1. Introduction

Measurement of hemodynamic variables is often valuable in many critical conditions, especially in patients experiencing cardiogenic shock. However, current methods for cardiac output (CO) measurement are often invasive and limited in their ability to continuously monitor; furthermore, they are not applicable in some cases such as patients undergoing venoarterial extracorporeal membrane oxygenation (VA ECMO). The criterion standard for CO measurement in intensive care—thermodilution using pulmonary artery catheterization (PAC)—does not allow proper measurement of global hemodynamic status in patients on VA ECMO because (i) a substantial portion of blood flow bypasses the lungs and (ii) thermodilution with PAC often losses accuracy in these patients when pulmonary artery flow falls below 2 L/min. Frequently used minimally invasive or noninvasive methods such as pulse-wave analysis are not suitable in substantial part of these individuals, for example, because of continual blood flow. Furthermore, transpulmonary thermodilution is inappropriate for CO measurements in patients with extracorporeal circulation. Similarly, although echocardiography provides important data regarding cardiac functions, it does not enable continuous monitoring and assessment of global circulatory status in patients undergoing VA ECMO.

Near-infrared spectroscopy (NIRS) oximetry has recently emerged as a promising method for the noninvasive measurement of cerebral and tissue oxygenation and perfusion. Several studies have demonstrated its use in the assessment of perioperative brain perfusion in cardiac [1] and noncardiac [2] surgery, in carotid interventions [3], and for monitoring brain and tissue perfusion in several critical conditions [4–7]. To date, however, there are only limited data regarding measurement of cerebral regional oxygen saturation ($CrSO_2$) and peripheral regional oxygen saturation ($PrSO_2$) using NIRS in patients experiencing cardiogenic shock and those undergoing VA ECMO [8,9]. In the present study, we tested the hypothesis that NIRS oximetry can be used to estimate global circulatory status in patients experiencing cardiogenic shock and in patients with cardiogenic shock undergoing

☆ The present study was supported by a grant from the Czech Ministry of Health, No. 12153.

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http://dx.doi.org/10.1016/j.jcrc.2014.02.003

VA ECMO, in whom standard methods of hemodynamic measurement cannot be easily used.

2. Materials and methods

2.1. Study overview

The present study was approved by the Na Homolce Hospital Ethics Committee (Prague, Czech Republic). Written informed consent for data collection from patient's medical records was not required for this retrospective study, and all data were collected and analyzed in a de-identified form. We performed a retrospective analysis of medical records from patients experiencing cardiogenic shock hospitalized at the Cardiology Intensive Care Unit, Na Homolce Hospital in Prague, in whom both $CrSO_2$ and $PrSO_2$ 4-channel NIRS oximetry (INVOS, Covidien, Dublin, Ireland) was monitored simultaneously with hemodynamic monitoring using PAC (CCOmbo Pulmonary Artery Catheter and Vigilance II Monitor; Edwards Lifesciences, Irvine, California). The indication for PAC was insufficient response to inotropic and vasopressor therapy (defined as norepinephrine dose >0.2 $\mu g\ kg^{-1}\ min^{-1}$ and dobutamin dose >5 $\mu g\ kg^{-1}\ min^{-1}$). Since 2010, $CrSO_2$ and $PrSO_2$ NIRS oximetry monitoring has been routinely used at the Na Homolce Hospital in most patients experiencing cardiogenic shock and in almost all patients undergoing VA ECMO. Cerebral oximetry has been performed using two forehead sensors, and peripheral oximetry using 2 sensors placed at the calves. Cerebral oximetry (>50%) became also one of the major therapeutic goals in these patients, besides mixed venous oxygen saturation and mean arterial pressure (MAP). The medical records of these patients contained oximetry and hemodynamic data collected at 1-hour intervals. In the present analysis, we included values obtained at the beginning of measurement and subsequently at 6-hour intervals for a maximum of 2 days (ie, a maximum of 9 data sets per patient). The reason for selection only data recorded at 6-hour intervals for the analysis was to reflect more different global circulatory status.

In patients experiencing cardiogenic shock, values of CO, MAP, central venous pressure, and body surface area were obtained from the medical records; cardiac index (CI) and systemic vascular resistance index (SVRI) were then calculated.

In patients undergoing VA ECMO, total circulatory index (TCI) was calculated according to the following formula:

$$\mathrm{TCI} = \mathrm{CI} + \text{extracorporeal blood flow index (EBFI)};$$
$$\mathrm{EBFI} = \text{extracorporeal blood flow}/\mathrm{BSA}$$

In VA ECMO patients, SVRI was then calculated from TCI instead of CI:

$$\mathrm{SVRI} = (\mathrm{MAP{-}CVP}) * 80/\mathrm{TCI}$$

In patients on ventilation support, ventilator parameters were set to maintain a target partial pressure of oxygen in arterial blood ($Pa{O_2}$) of 10.0 to 13.0 kPa and partial pressure of carbon dioxide ($Pa{CO_2}$) of 4.0 to 6.5 kPa. Similarly, in patients undergoing VA ECMO, oxygenator parameters were set to maintain the same target values in the arterial (ie, outflow) line. Blood pressure was monitored invasively from the radial or femoral artery in all patients.

2.2. Study population

Most patients with cardiogenic shock experienced acute myocardial infarction or decompensated chronic heart failure. All were treated with inotropes and vasopressors, and the majority (80%) with an intra-aortic balloon pump. All patients who experienced acute myocardial infarction underwent primary percutaneous coronary intervention. For the analysis, 10 consecutive individuals who recently underwent simultaneous monitoring of NIRS oximetry and hemodynamics were identified.

Up to May 2013, 69 nonsurgical patients who experienced cardiogenic shock with persisting or progressing tissue hypoperfusion despite standard therapeutic approaches or refractory cardiac arrest underwent successful VA ECMO (Levitronix Centrimag pump (Thoratec Corporation, Pleasanton, California) using the Quadrox oxygenator (Maquet Cardiopulmonary AG, Hirrlingen, Germany) or Cardiohelp system (Maquet Cardiopulmonary AG, Hirrlingen, Germany) at the Na Homolce Hospital. In 2010, the hospital began using cerebral and peripheral oximetry in these patients, and to date, 44 patients on VA ECMO have been monitored using this noninvasive method. From this group, 12 individuals who underwent simultaneous monitoring of NIRS oximetry and hemodynamics using PAC were identified. In all of these individuals, PAC was placed already before ECMO introduction. In patients with limb ischemia caused by arterial outflow cannula (oximetry <40% with absolute difference >10% with contralateral limb), distal perfusion bypass was introduced using 5F or 6F arterial sheath.

2.3. Statistical analysis

A mean value was calculated for each pair of NIRS oximetry data (left and right brain hemisphere or left and right lower limb); this value was used for further analysis. Spearman correlation and linear regression were performed to analyze the relationship between oximetry and hemodynamic values using GraphPad Prism 6 software (GraphPad Software, Inc, San Diego, California). Stepwise multiple regression analyses of $PrSO_2$ and $CrSO_2$ against the set of hemodynamic parameters were conducted using the MedCalc 12 software (MedCalc Software bvba, Ostend, Belgium). $P < .05$ was considered statistically significant.

3. Results

The baseline characteristics of individual patients are shown in Table 1. In patients experiencing cardiogenic shock, a strong, highly significant correlation was observed between $PrSO_2$ and CI ($r = 0.81$; 95% confidence interval [95% CI], 0.71-0.87; $P < .0001$; Fig. 1A), and a weaker yet still highly significant correlation was found between

Table 1
Baseline characteristics of individual patients

	Patient	Cause of circulatory failure	Age (y)	Sex	Alive
Cardiogenic shock	1	AMI	53	M	No
	2	AMI, MR	52	M	Yes
	3	DCMP	68	F	Yes
	4	DCMP	60	M	Yes
	5	AMI	72	M	No
	6	ICMP	66	M	Yes
	7	AMI	67	F	No
	8	AMI, MR	58	M	Yes
	9	DCMP	69	F	Yes
	10	AMI	71	M	Yes
VA ECMO	1	CA, AMI, MR	65	M	Yes
	2	Myocarditis	66	F	No
	3	AMI	66	M	Yes
	4	AMI	67	F	No
	5	DCMP	70	M	Yes
	6	DCMP	67	M	Yes
	7	DCMP	61	M	Yes
	8	AMI	63	M	Yes
	9	AMI	65	M	No
	10	CA, AMI	24	M	No
	11	AMI	58	M	Yes
	12	CA, AMI	54	M	Yes

AMI indicates acute myocardial infarction; CA, cardiac arrest; DCMP, dilated cardiomyopathy; F, female; ICMP, ischemic cardiomyopathy; M, male; MR, severe mitral regurgitation. Patients marked "Alive: Yes" were either discharged from hospital or alive at 30 days.

Please cite this article as: Ostadal P, et al, Noninvasive assessment of hemodynamic variables using near-infrared spectroscopy in patients experiencing cardiogenic shock and in..., J Crit Care (2014), http://dx.doi.org/10.1016/j.jcrc.2014.02.003