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Brief Report

Cerebral oxygen saturation monitoring in pediatric altered mental status patients☆

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ABSTRACT

Objectives: A pilot study assessing the potential utility of cerebral oximetry (local cerebral oxygen saturation [$rcSO_2$]) in children presenting to the emergency department (ED) with altered mental status (AMS) and no history of trauma.

Methods: Patients who presented to a tertiary pediatric ED with AMS were monitored with left and right cerebral near-infrared spectroscopy probes and the first 30 minutes of $rcSO_2$ data was analyzed. Patients with a history of trauma were excluded. Patients with an abnormal head computed tomography (CT) (n = 146) were compared with those with a negative head CT (n = 45).

Results: Mean $rcSO_2$ values were consistent during each time period studied (5, 10, 20, and 30 minutes). In this study population, $rcSO_2$ less than 50% or greater than 80% and increased absolute difference between the left and right $rcSO_2$ measurements were associated with an abnormal CT scan. A difference of 12.2% between the left and right $rcSO_2$ values had a 100% positive predictive value for an abnormal head CT among our patients. Cumulative graphical plots of $rcSO_2$ trends showed that values <50% were associated with subdural hematomas (SDH) and values >80% were associated with epidural hematomas (EDH).

Conclusions: This study demonstrated that cerebral oximetry can noninvasively detect altered cerebral physiology among a selected patient population. The difference between the left and right $rcSO_2$ readings most reliably identified those subjects with altered cerebral physiology. In the future, $rcSO_2$ monitoring has the potential to be used as a screening tool to identify, localize, and characterize intracranial injuries among children with AMS without a history of trauma.

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1. Introduction

Emergency department (ED) evaluation of children presenting with altered mental status (AMS) is challenging due to subtle signs of external trauma, unclear histories, and a lack of focal neurologic signs [1]. Rapid assessment of children with AMS is vital because delays in recognition of traumatic brain injuries (including subdural and epidural hematoma) are associated with significant morbidity and mortality. Studies have demonstrated with aggressive neurovascular resuscitation therapies such as hypertonic saline and mannitol to lower intracranial pressure. In the ED setting, computed tomography (CT) of the brain is the mainstay of diagnosis in these patients, but new evidence regarding the long-term risks of radiation has forced clinicians to become more judicious with their use of this imaging modality [2]. Emerging studies using near-infrared spectroscopy (NIRS) suggest that it may be a useful tool for the evaluation of these children, and we report our experience with a pilot study of its use among a cohort of children in the pediatric ED.

Cerebral oximetry, which relies on the differential absorption spectrum of oxygenated and deoxygenated hemoglobin, has emerged as a noninvasive method of monitoring changes in local cerebral oxygen saturation ($rcSO_2$), oxygen delivery, oxygen extraction, and metabolism [3-6]. The $rcSO_2$ value, expressed as a percentage, is an indirect measure of the relative oxygen supply and demand within the small area of tissue beneath the probe. $rcSO_2$ readings, like pulse oximetry and end-tidal capnography, do not portray an absolute value but rather represent the aggregate of the local (direct) and global (indirect) physiological factors affecting that particular monitoring area. Low $rcSO_2$ readings are thought to reflect increased oxygen extraction, increased metabolism, and/or decreased perfusion, whereas increased $rcSO_2$ readings indicate decreased oxygen extraction and/or increased perfusion. Studies of cerebral oximetry during CPR have established that an $rcSO_2$ value of 15% equates to the 25% of oxygen that is irreversibly bound to hemoglobin [7-12]. These $rcSO_2$ readings like the pulse oximetry and capnography sampling can never portray an absolute sampling site value but represents more the

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Table 1
Demographics and $rcSO_2$ of patients and controls

	Abnormal head CT (n = 146)	Negative head CT (n = 45)	*P*
Age, y (SD)	4.1 (3.7)	3.2 (3.3)	.10
GCS	9.4 (2.7)	11.3 (1.8)	<.0001
SDH	28.0%	–	–
EDH	32.9%	–	–
SDH and EDH	39.7%	–	–
Unilateral $rcSO_2$ <50%	45.2%	0%	<.0001
Bilateral $rcSO_2$ <50%	24.0%	0%	<.0001
Unilateral $rcSO_2$ >80%	41.8%	4.4%	<.0001
Bilateral $rcSO_2$ >80%	17.8%	13.3%	.65
Left mean $rcSO_2$ (SD)	57.3 (28.7)	70.5 (9.4)	.11
Right mean $rcSO_2$ (SD)	58.1 (28.3)	69.6 (7.8)	.25
Difference between left and right mean $rcSO_2$ (SD)	27.2 (21.8)	4.2 (3)	<.0001

Abbreviation: GCS, Glasgow Coma Scale.

aggregate of the local (direct) and global (indirect) physiological factors affecting that particular monitoring area [5-8]. A majority of healthcare provider still misinterpreted or perceive pulse oximetry or capnography readings as absolute sampling values not as a composite value of local and global physiological parameters which has been an issue with cerebral oximetry's acceptance. A recent study among children with congenital heart disease suggests that $rcSO_2$ measurements correlate with jugular venous saturations across a wide spectrum of oxygenation values [7].

Most pediatric studies of NIRS technology have addressed its utility as a marker of adequate cerebral perfusion among children undergoing cardiac surgery for congenital heart disease [3,8,9]. Numerous Cerebral Oximetry NIRS studies suggest it may be a useful noninvasive tool for cerebral physiology and pathology for adults and children [7-14]. Cerebral Oximetry NIRS technology studies have addressed its utility as a noninvasive neurological monitor in clinical setting outside the emergency department for cerebral physiology and pathology among adults and children in numerous clinical studies especially in neurological emergencies [5-7,12-16]. In military and civilian studies utilizing cerebral NIR technology in assessing trauma patients they have shown the ability for cerebral oximetry to identify cases of intracranial hemorrhage among adults and children [17-20].

In our pediatric ED, $rcSO_2$ monitoring has been used as part of the evaluation of children with suspected neurologic emergencies. We present a pilot study of the utility of $rcSO_2$ monitoring among children presenting with AMS without historical or physical examination findings indicative of trauma. This pilot study's primary objective is to investigate the potential for cerebral oximetry $rcSO_2$ as a screening tool for altered children with no history of trauma and correlate it to their CT scan in the emergency department setting and not to correlate their $rcSO_2$ readings to the degree, size, age or depth of their cerebral pathology. The ability to promptly recognize altered cerebral physiology among this vulnerable population could decrease the time to head CT and definitive treatment, thereby improving overall neurologic outcomes.

2. Methods

We conducted a PED retrospective chart analysis from January 2008 to October 2012, of patients who presented with chief complaints, signs or symptoms for 1) altered mental status, 2) no history of trauma, 3) had cerebral oximetry $rcSO_2$ monitoring and 4) had head CT scan as a part of their initial workup. Patients who were seizing, those with a history of trauma or obvious traumatic injuries, and those undergoing active cardiopulmonary resuscitation or with a history of cardiopulmonary resuscitation were excluded. Children who did not have head CT imaging performed as part of their AMS workup were also excluded. Children were also excluded if they had neurosurgical interventions performed as a part of their initial resuscitation. A total of 191 patients fulfilled inclusion criteria, and $rcSO_2$ data was collected using an INVOS 5100C Cerebral Oximeter (Somanetics, Troy, MI) using either adult (>40 kg) or pediatric (<40 kg) probes placed on the patient's left and right forehead.

The $rcSO_2$ data were collected from the left and right cerebrum every 30 seconds for a total of 30 minutes (60 total measurements) for each individual in the abnormal head CT (n = 146) and negative head CT (n = 45) group. This time interval was chosen so as to minimize the effects of any ED interventions on the cerebral physiology. The electronic medical record was reviewed for each patient, and demographic, clinical, and radiographic data were collected. Mean $rcSO_2$ values among patients with a negative head CT were compared with those with an abnormal head CT at 5, 15, 20, and 30 minutes. The absolute difference between the left and right mean $rcSO_2$ was the summary statistic with the greatest area under the curve as the most useful characteristic to identify patients with an abnormal head CT. Performance characteristics including sensitivity, specificity, positive predictive value, and negative predictive value were computed for the mean absolute difference between left and right $rcSO_2$. Subgroup analysis was performed to determine if $rcSO_2$ predicted injury type (subdural or epidural hematoma) and/or location (left or right cerebrum). Cumulative graphical spaghetti plots demonstrating the

Table 2
Performance characteristics using left and right mean $rcSO_2$ difference to predict an abnormal head CT

Left and right mean $rcSO_2$ difference (%)	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
3.8	0.83 (0.76-0.88)	0.62 (0.48-0.75)	0.88 (0.81-0.92)	0.53 (0.40-0.66)
5.1	0.77 (0.70-0.83)	0.71 (0.57-0.82)	0.90 (0.83-0.94)	0.49 (0.38-0.61)
8.0	0.71 (0.63-0.78)	0.84 (0.71-0.92)	0.94 (0.88-0.97)	0.48 (0.37-0.58)
10.0	0.69 (0.61-0.76)	0.96 (0.85-0.99)	0.98 (0.93-1.0)	0.49 (0.39-0.59)
12.2	0.67 (0.59-0.74)	1 (0.92-1.0)	1 (0.96-1.0)	0.48 (0.39-0.58)

Abbreviations: CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

Table 3
Local cerebral oxygen saturation among patients with an abnormal head CT (n = 146)

	Only left CT lesion (n = 42)	Only right CT lesion (n = 33)	Bilateral CT lesion (n = 72)	Bilateral SDH (n = 27)	Bilateral EDH (n = 9)
Left mean $rcSO_2$ (SD)	47.6 (28.4)	77.4 (13.6)	49.3 (30)	24 (6.9)	89.2 (4.2)
Right mean $rcSO_2$ (SD)	73.8 (15.2)	50.9 (26.9)	51 (32.1)	22.5 (9.5)	89.9 (3.5)