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An Innovative Approach in Emergency Medicine: Monitoring Brain Oxygenation with Cerebral Oximetry

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Abstract: The monitoring of cerebral oxygenation is a method that is not commonly integrated into the majority of existing emergency departments (ED), but it has attracted increasing attention, particularly in recent years. As the severity of ischemia escalates during cardiopulmonary resuscitation (CPR), the probability of both survival and favorable neurological outcomes diminishes. Therefore, the imperative development of methods to quantify the magnitude of ischemia, particularly cerebral ischemia, during resuscitation is critical for enhancing overall outcomes. Cerebral oximetry (CO), using near-infrared spectroscopy, represents a noninvasive method for measuring brain oxygenation. The objective of this manuscript is to present an overview of the application of cerebral oximetry in the ED. ©2024 NTMS.

Keywords: Oximetry; Spectroscopy; Near- infrared; Emergencies.

1. Introduction

Cerebral oximetry is a medical technique that measures the oxygen saturation of the blood in the brain. This monitoring method provides real-time information about the levels of oxygen in the brain tissue, helping healthcare professionals assess and manage the oxygen supply to the brain. By monitoring cerebral oxygenation levels, healthcare providers can make informed decisions to optimize oxygen delivery and prevent potential complications related to inadequate brain oxygenation [1].

1.1 Historical Background

Cerebral oximeters, like pulse oximeters, are non-invasive devices capable of continuous monitoring, operating on similar pyhsical principles. This technology was first described by Jobsis in 1977 [2]. According to his study, the relatively high levels of brain tissue transparency in the near-infrared range (650-1000 nm) facilitated real time, non-invasive detection of hemoglobin oxygenation using transillumination spectroscopy. Two decades later, the first commercial devices were developed and are now utilized in various medical settings, including cardiovascular surgery, neurosurgery, anesthesia management, and intensive care units (Figure 1).

1.2 Physics

Cerebral oximeter typically consists of sensors or probes that are attached to the patient's forehead (Figure 2). These sensors use near-infrared spectroscopy (NIRS) to measure the amount of oxygenated hemoglobin (HbO2) and deoxygenated hemoglobin (Hb) in the blood of the brain. The cerebral oximeter emits near-infrared light into the tissues of the forehead. The near-infrared light penetrates the skin and underlying tissues and is partially absorbed by Hb in the blood. Detectors in the cerebral oximeter measure the amount of near-infrared light that is absorbed by

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HbO2 and deoxygenated Hb. HbO2 and Hb absorb light differently at specific wavelengths (Figure 3) [3]. By comparing the amount of light absorbed at these specific wavelengths, the cerebral oximeter calculates the ratio of HbO2 to total hemoglobin, providing an estimate of the oxygen saturation level in the blood [4].

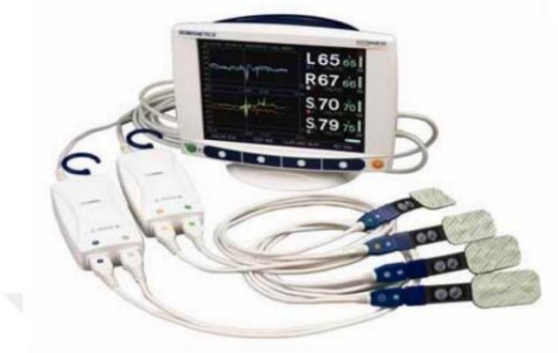

Figure 1: General view of the cerebral oximeter device.

The estimation of cerebral hemoglobin oxygen saturation is achieved through the application of the Beer-Lambert law [5]. Additionally, the presence of extracranial blood poses a potential challenge to accurate CO measurements. To address this issue, cerebral oximeters utilize multiple probes and employ spatial resolution techniques [6]. Spatial resolution relies on the principle that the depth of tissue examined is determined by the distance between the light emitter and the light detector [7]. The system calculates the ratio of oxyhemoglobin to total hemoglobin within the monitored region as a percentage, presenting it to the user as Regional Oxygen Saturation (rSO2). Typically, cerebral arterial blood oxygen saturation ranges from 98% to 100%, while venous blood tends to have an oxygen saturation of nearly 60%. Consequently, normal rSO2 values are expected to fall between 60% and 80%.

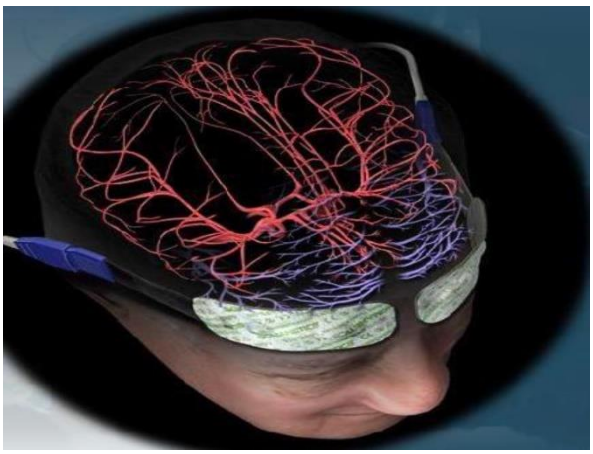

Figure 2: Placement of cerebral oximeter probes.

1.3 Limitations of Cerebral Oximetry Measurements

Currently, several CO devices are available for clinical use, each exhibiting variability in measurements due to differences in emitted light wavelengths, variations in light sources among devices, and the utilization of diverse mathematical algorithms for determining cerebral oxygenation values [8]. Moreover, extracranial contamination, skin pigmentation, and physiological conditions contribute to the variability of rSO2 values [9,10]. Anatomical variations like incomplete Circle of Willis or carotid artery stenosis can further introduce errors in CO values. Therefore, conducting bilateral CO is recommended to minimize potential biases. An overview of various factors that could result in decreased cerebral oxygenation values due to alterations in blood flow or oxygen levels is provided in Table 1. Furthermore, all CO devices exhibit limitations in clinical use, encompassing compromised accuracy in the presence of electrosurgical equipment like diathermy, limited coverage restricted to regional cerebral oxygenation, and the absence of monitoring in significant brain regions [3,11].

1.4 Clinical Applications

As outlined above, continuous monitoring of CO facilitates the early detection of changes in brain oxygenation, enabling timely interventions to enhance oxygen delivery and prevent adverse outcomes [12]. CO is considered as a safeguard and used in various medical procedures characterized by iatrogenic brain ischemia, including carotid endarterectomy in patients with high-grade carotid artery stenosis, temporary clipping during brain aneurysm surgery, hypothermic circulatory arrest for aortic arch procedures, and other pathologies like traumatic brain injury and stroke that inherently lead to brain ischemia [13-15].

Table 1: Factors leading to decreased cerebral oxygenation values.

Oxygen Content	Cerebral Blood Flow
Hemoglobin concentration	Cardiac output
Inspired oxygen concentration	Acid–base status
Pulmonary function	Arterial inflow/venous outflow
Hemoglobin saturation	Major hemorrhage

1.5 Cerebral Oximetry in Emergency Department

CO is not widely used in ED, but has attracted attention, especially in last few years. Despite advances in CPR, survival and neurological recovery after cardiac arrest remain very poor due to the impact of severe ischemia and subsequent reperfusion injury [16]. As the severity of ischemia intensifies during CPR, there is a reduction in the probability of survival and the attainment of favorable neurological outcomes [17]. The consequences of hypoxic-ischemic brain injury following the return of spontaneous circulation (ROSC) post-cardiac arrest are profound, leading to significant mortality and morbidity [18]. Consequently, the imperative to enhance overall outcomes necessitates the creation of methodologies for quantifying the extent of cerebral

ischemia throughout the resuscitation process. Numerous preclinical and clinical studies have demonstrated that rSO2 during CPR is correlated with enhanced survival rates following cardiac arrest and improved neurological outcomes [19,20].

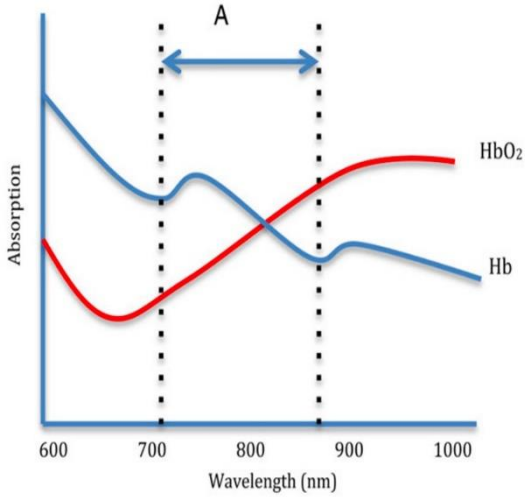

Figure 3: Absorption spectra for oxygenated and deoxygenated hemoglobin. Area A represents light wavelengths used by cerebral oximeters 3. Hb: Deoxygenated hemoglobin, HbO2: Oxygenated Hemoglobin.

2. Discussion

The evaluation of central and cerebral circulation through CO in the prehospital setting has the potential to enhance patient outcomes [21]. In a CPR environment, the ideal rSO2 monitor should be characterized by a compact, lightweight design and a durable battery. Absolute real-time values, accompanied by suitable indicators, ought to be measured without the need for frequent calibration. Additionally, the monitor should exhibit an absence of detection limits, insensitivity to ambient light, and resistance to extracranial contamination. None of the currently available devices, however, encompass all the aforementioned features indicative of an ideal pre-hospital rSO2 monitor. However, in cases of out-of-hospital cardiac arrest (OHCA), CO monitoring can be used both pre-hospital and during transport to measure CPR effectiveness in patients reaching advanced life support [22,23].

The use of CO monitoring was also examined to determine the potential role of baseline and rSO2 in monitoring CPR effectiveness and predicting ROSC. In a meta-analysis reviewing 13 studies conducted by Liu and colleagues, it was demonstrated that, during CO monitoring, male gender and the location of the arrest may exert an influence on the initial or average rSO2 and ROSC [24]. Studies have also indicated that the outcomes may be influenced by geographical variations attributed to country-spesific legislation. For instance, in Japan, unlike in many other countries, termination of resuscitation at the scene of OHCA cases is not permitted, and application of CO may contribute to delays [21].

The integration of noninvasive neuromonitoring in the ED and ICU could serve as a valuable adjunct to clinical diagnosis and radiological imaging, especially in patients without primary brain injury [25]. In one meta-analysis using NIRS monitoring during resuscitation, a strong correlation was observed between ROSC and NIRS saturation [26]. Similarly, NIRS has proven to be valuable in the early detection of changes in cerebrovascular parameters during respiratory distress in patients with acute respiratory distress syndrome and COVID-19 [27]. The presence of systemic inflammation, commonly noted in sepsis patients frequently encountered in the ED, triggers changes in cerebral blood flow, disruption of the brain-blood barrier, and alterations in autoregulation, ultimately contributing to sepsis-related brain dysfunction [28]. In adults, benefits for the continuous assessment of cerebral autoregulation could also be provided by NIRS [29,30].

3. Conclusion

Growing evidence emphasizes the pivotal role of non-invasive cerebral oximetry as a crucial monitoring approach in the care of patients undergoing anesthesia or sedation in the intensive care unit, particularly when the primary injury does not affect the brain directly. This significance extends beyond the perioperative context to include applications in the emergency department and the ICU. NIRS offers distinct advantages as a non-invasive, cost-effective, safe, and readily accessible bedside tool, holding substantial potential for diagnosing and treating patients at risk of neurological complications. Larger-scale studies are necessary to facilitate the widespread integration of NIRS into daily routine practice.

Limitations of the Study

Further research is required to validate cerebral oximetry monitoring in improving patient outcomes in emergency department.

Acknowledgement

None.

Conflict of Interests

The authors have no conflicts of interest to declare.

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Author Contributions

Conception and Design of the study, Collection and/or Processing and Literature review, Writing Original Manuscript, Analysis and/or interpretation and final version and is responsible for final approval of the submitted manuscript; ÖGÇ.

Ethical Approval

None.

Data sharing statement

None.

Consent to participate

None.

Informed Statement

None.

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