NEAR-INFRARED SPECTROSCOPY IN THE NEONTAL INTENSIVE CARE UNIT - A LITERATURE REVIEW

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Abstract

Introduction: The brain of newborns and infants is extremely vulnerable due to circulation and oxygen changes. In this concern, brain lesions occur relatively often in preterm infants. As prevention of preterm has been largely unsuccessful, it would be desirable to assess the oxygenation, haemoglobin concentration, and function of the preterm brain, in order to detect and prevent conditions, which may lead to brain lesions. Therefore one method of choice is near-infrared spectroscopy (NIRS). In 1977, Jobsis described NIRS for the first time for medical use. Several different NIRS devices are currently available: FORE-SIGHT, INVOS, NIRO, InSpectra, O2C, OM-220, OxiplexTS, TOx, and TRS-20. These devices use different near-infrared light sources (laser/LED), wavelengths, optode distances, and algorithms to calculate cerebral oxygen saturation. The INVOS and NIRO devices use spatially resolved spectroscopy.

Material and methods: The aim of this paper is to determine the clinical value of near-infrared spectroscopy in monitoring cerebral oxygenation in the NICU. A literature research on the subject was done from 1977 till date using manual library search and journal publications on Pubmed/Medline and Google scholar. Full texts including those of relevant references were collected and studied. The most relevant reported case series, case reports, and literature review were used for this study.

Results: Near-infrared spectroscopy is an optical technique based on the principle that light in the near-infrared range (700-1000 nm) is able to pass through skin, soft tissue and bone with relative ease, and can penetrate brain tissue to a depth of up to 8 cm. The light is mainly absorbed by two chromophores: hemoglobin and cytochrome aa3. NIRS measures the relative change in the tissue concentration of intravascular HbO2 and HbH. Using NIRS, we are able to infer changes in cerebral blood flow by measuring changes in the hemoglobin difference, which is obtained by calculating the difference between the changes in HbO2 and HbH concentrations.

Conclusion: In the neonatal intensive care unit (NICU) there is an acute need for a non-invasive clinical tool in order to evaluate the cerebral perfusion and possibly prevent a series of cerebral pathologies. NIRS is a safe, noninvasive, bedside technique for exploring pathophysiological mechanisms underlying brain injury in NICU patients. The most important issue regarding clinical application of NIRS monitored cerebral oxygenation and saturation is the ability to perform reliable and non-invasive long-term monitoring of cerebral oxygenation in the most immature and unstable neonates without the necessity to frequently disturb the infant.

Keywords: Near-Infrared Spectroscopy (NIRS), INVOS, Neonatal Intensive Care Unit (NICU), cerebral pulsoxymetry

Introduction

The brain remains the most poorly monitored organ in the human body, thus negative events may occur unnoticed and treatment delayed. Moreover, the brain of newborns and infants is extremely vulnerable due to circulation and oxygen changes [1]. In this concern, brain lesions occur relatively often in preterm infants. Even though, brain injury has a poor etiological background, a few postnatal factors have been associated: respiratory distress syndrome (RDS), hypocapnia due to inadvertent hyperventilation, low blood pressure (BP), perturbations in arterial and venous pressure, and low cerebral blood flow (CBF) [2].

As prevention of preterm has been largely unsuccessful, it would be desirable to assess the oxygenation, haemoglobin concentration, and function of the preterm brain, in order to detect and prevent conditions, which may lead to brain lesions. Therefore one method of choice is near-infrared spectroscopy (NIRS). NIRS has been used extensively over the past decade during cardiac and vascular surgeries to monitor oxygen delivery to the brain and spine in adults, children, and infants [7-9]. NIRS is the basis of pulse oximetry for the estimation of arterial hemoglobin saturation and in cerebral oximetry to measure regional hemoglobin saturation in the capillary beds, reflecting venous saturation.

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In 1977, Jobsis described NIRS for the first time for medical use [3], but the use in neonates to measure cerebral oxygenation was first reported by Brazy et al [4] and Delpy [5] and since then NIRS started to become more popular in neonates. Currently, NIRS is generally believed to be a valuable trend monitor in the individual patient and it is useful for comparing different groups of infants exposed to a variety of risk factors. [18-20] Several different NIRS devices are currently available: FORE-SIGHT, INVOS [Fig.1], NIRO, InSpectra, O2C, OM-220, OxiplexTS, TOx, and TRS-20 [10,11]. These devices use different near-infrared light sources (laser/LED), wavelengths, optode distances, and algorithms to calculate cerebral oxygen saturation. The INVOS and NIRO devices use spatially resolved spectroscopy.

The INVOS device measures regional cerebral tissue oxygen saturation (rSO2). These measures are thought to reflect the oxygen saturation in a mixed vascular bed dominated by venules and serve as indicators of cerebral hypoxic hypoxia.

Hypoxic-ischemic encephalopathy is a common pathophysiological condition of the newborn brain and results from disturbed oxygenation in which CBF seems to play a major role.

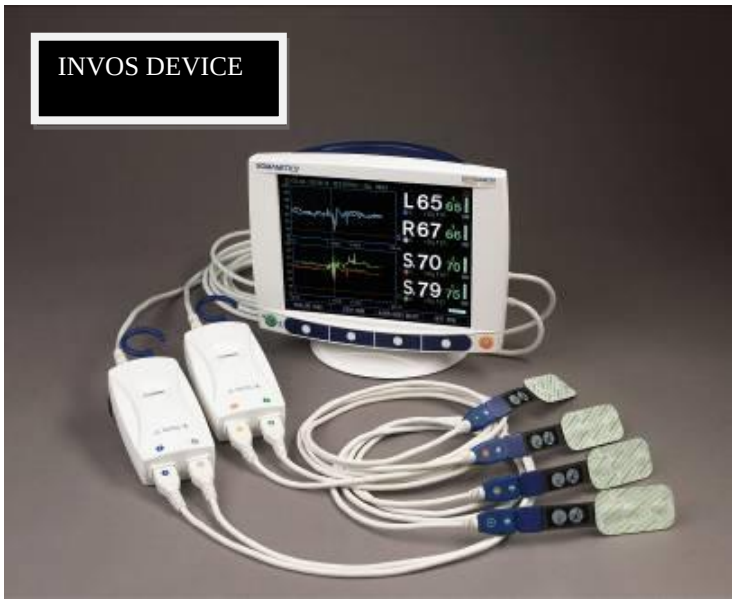

Fig.1 INVOS Device.

Purpose

In the neonatal intensive care unit (NICU) there is an acute need for a non-invasive clinical tool in order to evaluate the cerebral perfusion and possibly prevent a series of cerebral pathologies. Thus, the aim of this paper is to determine the clinical value of near-infrared spectroscopy in monitoring cerebral oxygenation in the NICU.

Material and methods

A literature research on the subject was done from 1977 till date using manual library search and journal publications on Pubmed/Medline and Google scholar. We used the following keywords: Near-Infrared Spectroscopy (NIRS), INVOS, Neonatal Intensive Care Unit (NICU), cerebral pulsoxymetry, newborn, preterm infant. Full texts including those of relevant references were collected and studied. Information relating to the NIRS technique, neonatal cerebral pulsoxymetry and NIRS utility in the NICU was extracted from the materials. The most relevant reported case series, case reports, and literature review were used for this study.

Results and discussions

General information

Near-infrared spectroscopy is an optical technique based on the principle that light in the near-infrared range (700-1000 nm) is able to pass through skin, soft tissue and bone with relative ease, and can penetrate brain tissue to a depth of up to 8 cm [12 17]. However, when illuminating the somatosensory cortex area of the premature infant, the light may enter much deeper, with signals penetrating the primary somatosensory cortex and parts of the secondary somatosensory cortex, insula, cingulate cortex, thalamus and amygdale [12].

The light is mainly absorbed by two chromophores: hemoglobin and cytochrome aa3. Their concentration and absorbance of near-infrared light in the tissue is made possible by a modified Beer-Lambert law, [6] that permits the calculation of the attenuation of a light source that passes through a given substance. When light penetrates the living tissue, part of its propagation is scattered and lost. Thus, the distance from the light source to the receiving end is affected by a differential pathlength factor (DPF). The DPF has been calculated for various biological tissues, but has also been shown to vary between participants, which may partly explain the complexity in standardizing NIRS variables across participants [17]. The hemodynamic signal obtained with the NIRS technique is based on the absorption of NIR light by hemoglobin, which in turn, depends on the oxygenation state of hemoglobin circulating through the tissues. Thus, NIRS measures the relative change in the

tissue concentration of intravascular HbO2 and HbH [12, 17].

Cerebral oxygenation and hemodynamics of human neonates through NIRS was first described by Brazy et al in 1985 and even though there have been significant advances in this field, the understanding of how blood flow, metabolism and neuronal activity interact to affect the NIRS signals remains incomplete [12]. Using NIRS, we are able to infer changes in cerebral blood flow by measuring changes in the hemoglobin difference, which is obtained by calculating the difference between the changes in HbO2 and HbH concentrations. NIRS studies can be divided into two categories: measurement of brain activity through assessment of dynamic relative changes in regional cerebral blood flow in real time; and imaging of brain activity as a function of time.

Advantages and precautions

NIRS is a safe, noninvasive, bedside technique for exploring pathophysiological mechanisms underlying brain injury in NICU patients. It has enormous potential as a tool for measuring cerebral hemodynamic responses to changes in blood pressure, oxygenation, carbon dioxide and neuronal activation. It can be adapted to many experimental and clinical situations, and combined with other electrophysiological and neuroimaging techniques [12]

However, certain treatments provided to critically ill neonates may have significant effects on cerebral circulation such as: surfactant administration, mechanical ventilation, blood transfusion, surgery, hypothermia, analgesics/sedatives, caffeine and indomethacin therapies [12, 14,15, 17].

Instrumentation – INVOS oximeter

The INVOS Oximeter system measures regional hemoglobin oxygen saturation (rSO2) of the brain in the area underlying the sensor and uses two wavelengths, 730 and 810 nm. The sensor, is applied to the forehead with an integrated medical-grade adhesive. The spatially resolved spectroscopy (SRS) method is applied by using in the sensor two source-detector distances: a 3 cm from the source and a 4 cm from the source [Fig.2]. Both sample almost equally the shallow layers in the tissue volumes directly under the light sources and detectors in the sensor, but the distant penetrates deeper into the brain. The measurement takes place in real time, providing an immediate indication of a change in the critical balance of oxygen delivery and oxygen consumption [13].

Clinical application - NICU

The most important issue regarding clinical application of NIRS monitored cerebral oxygenation and saturation is the ability to perform reliable and non-invasive long-term monitoring of cerebral oxygenation in the most immature and unstable neonates without the necessity to frequently disturb the infant [Fig.3].

Clinical conditions in NICU patients that can be investigated by NIRS technology: hypoxic hypoxia; anemic hypoxia; ischemic hypoxia; cardiovascular malformation (i.e. PDA); blood pressure passive oxygenation of the brain; artificial ventilation and effects of medication [16].

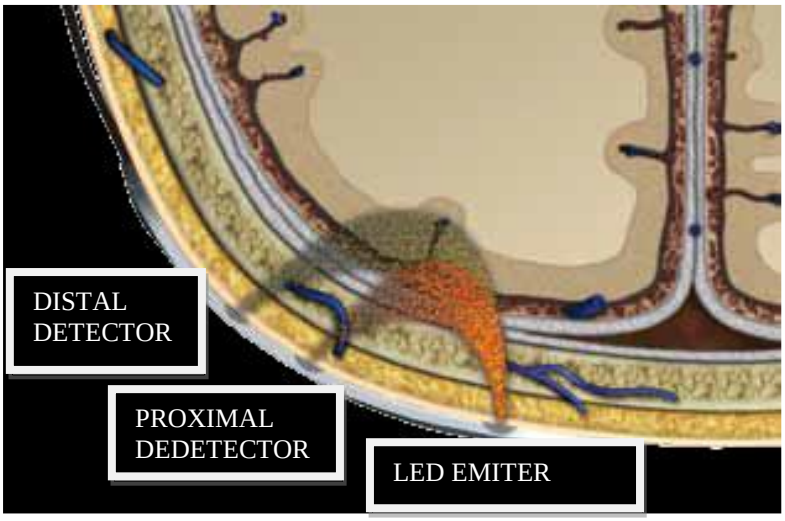

Fig. 2. Localized area of measurement.

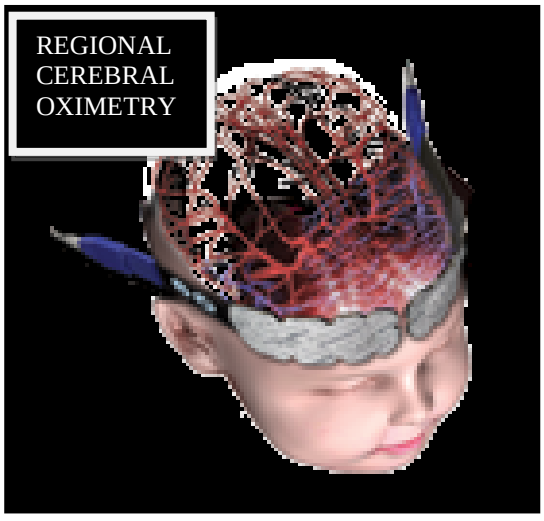

Fig. 3. Cerebral oximetry.

Conclusion

Even though great advances have been made in understanding the human brain-pathology over the past century, there are several aspects that need special attention. Some of these aspects involve the vulnerable population, the non-communicative patients, namely the neonates. NIRS has potential as a non-invasive technique for assessing cerebral structures in critically ill infants. Given the complexity of NIRS technology, the paucity of research supporting its use in critically ill infants, and the need for tight control of many confounding factors as well as artefacts, more studies are clearly needed.

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