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The Use of Near Infrared Spectroscopy to Assess Infant Pain

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Pain is a complex disorder and described as an unpleasant emotional-sensory experience due to actual or potential tissue damage or injury which requires urgent attention (Benoit, Martin- Misenenir, Newman, Latimer, & Campbell-Yeo, 2017). Because of their continuous developing nervous system, infants are particularly susceptible to the consequences of pain and stress (Holsti, Grunau, & Shany, 2011) and their reactions to nociceptive stimuli differ from the adults (Hartley & Slater, 2014).

Studies have indicated that poor management of infant pain can be associated with enduring neurological-behavioral changes, and developmental learning disabilities (Vinall et al., 2012). Examples of learning disabilities documented in the research include attention deficit disorder, poor executive function, and impaired visual –motor integration (Hall & Anand, 2014 p. 896). Additionally, repeated untreated pain in infants puts them at risk of augmented pain sensitivity and long-term changes in the programming of the pituitary-adrenal axis (cortisol levels) which also has an impact on health and neurodevelopmental outcomes (Holsti et al., 2011). In contrast, other research reveals unnecessary analgesic treatment prolongs the need for intubation, mechanical ventilation, difficulties with advancing enteral nutritional therapy, compromised brain growth, poor short-term memory, and impaired socialization skills (Hall & Anand, 2014). Theoretically favorable pain assessment and management is an essential nursing priority for infants to improve neurodevelopmental outcomes. Due to poor outcomes associated with inadequate pain management in infants, researchers are exploring multidimensional pain assessment tools. Researchers are finding promise in examining infant's cerebral reactions to painful stimuli and are hopeful that this will provide a more precise measurement of pain perception (Ranger, Johnston, Limperopoulos, Rennick, & duPlessis, 2011).

Current Pain Assessment in Infants

Symptoms of pain can be absent or elusive in a critically ill infant and a challenge to manage (Ranger et al., 2011). Because of an infant's nonverbal capacity, many healthcare providers rely on pain assessment scales that incorporate observation of changes in an infant's physiological and behavioral mannerism induced by external stimuli (Ranger et al., 2013). Many pain scales such as CRIES, NIPPS, and FLACC assess specific items which include facial expressions (brow bulge, naso-labial furrow), infant's cry (pitch and onset) body movements (rigidity, relaxation and flexion) (Benoit et al., 2017) and vital signs with oxygen saturation. While the above observations can be advantageous in assessing, and treating an infant's pain in clinical practice, their utility is questionable since physiological and behavioral changes are not unique to an evoked pain response (Hartley et al. 2017). Nurses may be unable to differentiate signs of infant pain from other signs of infant distress such as agitation, hunger, or sleeplessness (Ranger et al., 2013). The subjectivity and inter-rater consistency of infant pain assessments are limiting factors to consider as well (Hall & Anand, 2014). Also, despite the numerous pain scales developed to assess an infant's pain, there is no accepted gold standard for measuring an infant's response to painful stimuli (Benoit et al., 2017) and distinguishing it from other causes. In addition, the capacity to accurately obtain the suitable pain signals from observational data can be compromised using heavy sedation and muscular blocking agents (Ranger et al., 2013). Consequently, pain assessment within this vulnerable population is not fully understood and requires further research (Benoit et al., 2017).

Implementing an objective pain assessment tool like Near Infrared Technology (NIRS) with critically ill infants could significantly improve the quality of pain assessment and management and evade untreated pain or unwarranted analgesia.

Near Infrared Spectroscopy

Measuring infant pain with NIRS is a common subject of infant pain research; subsequently, it is essential for nurses to acquire a basic understanding of this specialized technology. Studies reveal that painful stimuli cause circulatory and metabolic alterations in various cortical

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regions of the infant's brain (Ranger et al., 2011). Infant pain and its effects on brain reactivity has been studied using multiple brain imaging apparatuses which include magnetic resonance imaging (MRI), positron-emission tomography, and NIRS (Ranger & Gelinas, 2014). MRI and position–emission tomography both measure sensory input processing and frontal cortex activation associated with pain (Ranger et al., 2011) however, both are impractical to use in the critical care setting. NIRS not only measures cortical response to noxious stimuli but has the advantage of being portable, economical and noninvasive (Kussman et al., 2016).

The Theory of NIRS Technology

NIRS operates with the use of low absorption of near infrared light and the ability of the light to transcend readily through skin, soft tissue, bone, and brain tissue to a depth of eight centimeters (Ranger et al., 2011). The amount of penetration of the NIRS light is dependent on the thickness and density of the tissue (Ranger & Gelinas, 2014). For instance, NIRS illumination within a premature infant's somatosensory cortex area will enter at a greater depth than an adult, "with signals probing to the primary somatosensory cortex and parts of the secondary somatosensory cortex, insula, cingulate cortex, thalamus, and amygdala".

(Ranger & Gelinas, 2014, p. 523). The NIRS sensor is attached to the infant's forehead. NIRS optical technology penetrates biological tissues and allows functional imaging of the brain activity by monitoring blood oxygenation and blood volume in the pre-frontal cortex (Kussman et al., 2016). The infant's cortical activity can be assessed and recorded with a portable computing device while the infant interacts with different stimuli (Grohl, 2016) (Fig. 1).

The hemodynamic signal obtained with the NIRS modality is grounded on the absorption of NIRS light by hemoglobin, (Ranger et al., 2011) situated in small vessels, such as arterioles, venules, and capillaries (Ranger & Gelinas, 2014). NIRS optical imaging captures fluctuations in the concentrations of oxygenated (HbO2), deoxygenated (HbR), total hemoglobin (HbT), as well as, variations in the redox state of cytochrome *c*-oxidase "(the terminal enzyme of the respiratory chain of the mitochondria that catalyzes transfer of electrons to oxygen)" (Kussman et al., 2016, p. 5) by their different specific spectra in the near-infrared range between 700 and 1000 nm (Grohl, 2016) (Fig. 2). Simply, NIRS discerns the oxygenation status of the cerebral tissue. In healthy children, the normal cerebral saturation. (ScO2) is 60% to 80% (95% confidence interval, average is 68%) (Bakker, Smith, Ainslie, & Smith, 2012). NIRS is influenced by tissue oxygen transport factors, such as cerebral blood flow, cerebral metabolic rate, hemoglobin concentration, SaO2, and hemoglobin-O2 binding affinity (Bakker et al., 2012). Hence, the data recorded could reflect alterations in the blood flow or the oxygenation levels of the brain, during possible painful procedures or invasive tasks during the infant's care.

Application of NIRS Technology Associated with Pain

Monitoring cortical activity evoked by noxious events is one of the central elements of physiological pain (Hartley & Slater, 2014). The primary somatosensory cortex is situated more superficially and reachable to analyze with NIRS optical techniques (Ranger et al., 2011). Holsti et al. (2011) conducted a study that utilized a NIRS device with premature infants after heel stick or hand venipuncture. Results of the study showed an increase in the cerebral blood flow in the contralateral somatosensory cortex. Holsti et al.'s study demonstrates that preterm infant pain responses are not purely reflexive but are processed at cortical levels.

Ranger et al. (2013) studied behavioral reactions and regional cerebral, systemic hemodynamic changes, in 20 infants (<12 months age) post-cardiac surgery during chest tube removal. The instruments used in the study included NIRS to view cerebral hemodynamics, the FLACC scale with physiological parameters, and video recording (Ranger et al., 2013). Notably, in the study, there was no association with the three outcome measures (Ranger & Gelinas, 2014). The results were significant for a meaningful increase in regional cerebral deoxygenated hemoglobin concentrations in the right hemisphere of the brain (Ranger et al., 2013). This is noteworthy because during brain activation there is an uncertain deployment of energy which is portrayed by an "increase in blood flow, glucose utilization, and oxygen delivery" (Ranger &

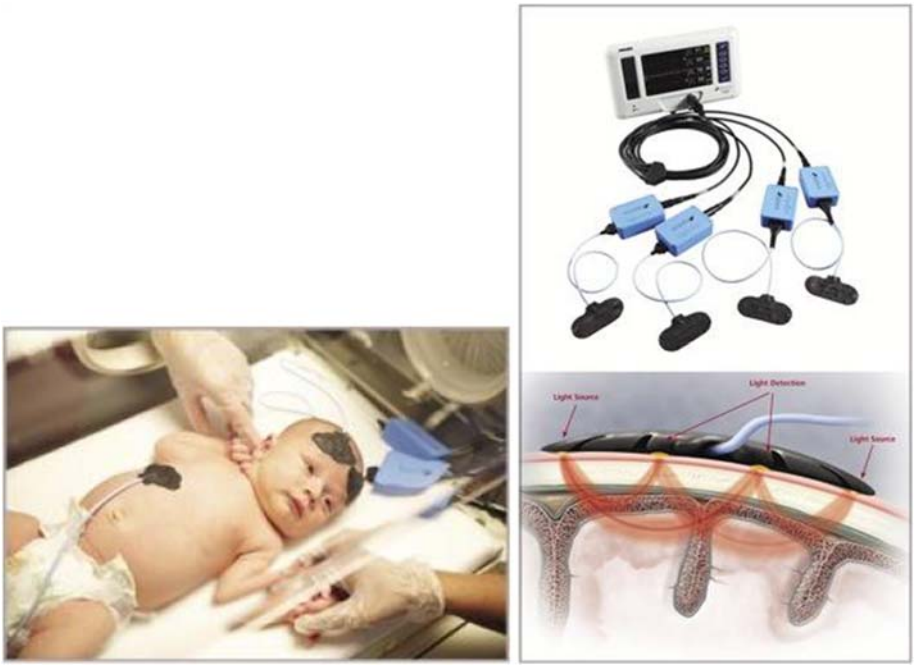

Fig. 1. Nonin Medical, Inc. (n.d.) *Accurate, Portable Cerebral/Somatic Tissue Oximeters* (rSO_2). Retrieved from http://static-96-232-192-10.nycmny.fios.verizon.net/ancp/0812/content/ANCP12_036a.html#. Permission from Nonin Medical, Inc., n.d. The EQUANOX™ Model 7600 Cerebral/Somatic Tissue Oximetry System is a NIRS-based monitoring device that noninvasively and continuously detects oxygen saturation status in brain and other tissues.

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