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Original Contribution

Cerebral oximetry with cerebral blood volume index in detecting pediatric stroke in a pediatric ED☆,☆☆

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ABSTRACT

Background: Despite pediatric stroke awareness and pediatric stroke activation systems, recognition and imaging delays along with activation inconsistency still occur. Reliable objective pediatric stroke detection tools are needed to improve detection and activations. Regional cerebral oxygen saturation (r_cSO_2) with cerebral blood volume index (CBVI) can detect abnormal cerebral physiology.
Objective: To determine cerebral oximetry in detecting strokes in stroke alert and overall stroke patients.
Method: Left r_cSO_2, right r_cSO_2, and r_cSO_2 side differences for stroke, location, and types were analyzed.
Results: Compared with stroke alert (n = 25) and overall strokes (n = 52), r_cSO_2 and CBVI were less than those in nonstrokes (n = 133; $P < .0001$). R_cSO_2 side differences in stroke alert and overall strokes were greater than in nonstrokes ($P < .0001$). Lower r_cSO_2 and CBVI correlated with both groups' stroke location, left ($P < .0001$) and right r_cSO_2 ($P = .004$). R_cSO_2 differences greater than 10 had a 100% positive predictive value for stroke. Both groups' r_cSO_2 and CBVI side differences were consistent for stroke location and type ($P < .0001$). For both groups, left r_cSO_2 and CBVI were greater than those of the right ($P < .0001$). Hemorrhagic strokes had lower bilateral r_cSO_2 and CBVI than did ischemic strokes ($P < .001$).
Conclusions: Cerebral oximetry and CBVI detected abnormal cerebral physiology, stroke location, and type (hemorrhagic or ischemic). R_cSO_2 side differences greater than 10 or r_cSO_2 readings less than 50% had a 100% positive predictive value for stroke. Cerebral oximetry has shown potential as a detection tool for stroke location and type in a pediatric stroke alert and nonalert stroke patients. Using cerebral oximetry by the nonneurologist, we found that the patient's r_cSO_2 side difference greater than 10 or one or both sides having less than 50% r_cSO_2 readings suggests abnormal hemispheric pathology and expedites the patient's diagnosis, neuroresuscitation, and radiologic imaging.

1. Introduction

Health care providers often misinterpret the signs and symptoms of acute pediatric strokes resulting in significant diagnosis and imaging delays [1–5] with a median time to diagnosis of 9.6 hours [3–7]. One-third of acute pediatric focal neurologic deficits have nonischemic pathologies that mimic stroke, thus impacting the health care provider's awareness of pediatric stroke [2–7]. Significantly reducing the time between suspicion of a neurologic insult from a stroke and initiation of neuroimaging is crucial in childhood stroke as stressed by the Pediatric Stroke consensus management guidelines [2–6]. A rapid, objective, noninvasive neurologic tool that reliably detects abnormal cerebral physiology, pathology, and laterality would be ideal and would significantly increase stroke recognition, decrease stroke recognition time, shorten imaging time, and potentially improve outcomes through earlier initiation of the supportive care and neurointervention treatments.

Cerebral oximetry monitoring provides trends on tissue hemoglobin oxygen saturation (r_cSO_2), blood flow, and oxygen extraction, among other cerebral physiological variables [8–17]. The normal pediatric

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cerebral r_cSO_2 (%O_2HB) range is 60% to 70%, whereas an r_cSO_2 less than 50 or decreasing r_cSO_2 readings indicate hypoxia, decreased perfusion, or increased oxygen extraction [8–16]. The INVOS (INVOS, Somanetics, Troy, MI) cerebral oximetry can also detect cerebral blood volume index (CBVI). Cerebral blood volume index values correspond to regional cerebral blood flow facilitating recognition of ischemia-related cerebral injury [12–16].

Pediatric cerebral oximetry studies have demonstrated that r_cSO_2 variations correlate with abnormal cerebral physiology in various neurologic scenarios [8–16]. In adult and pediatric neurologic emergencies, r_cSO_2 side differences or r_cSO_2 readings less than 50% correlate with the laterality of abnormal cerebral physiology and radiologic pathology [12–16].

A fast objective, noninvasive neurologic tool, indicating abnormal cerebral physiology and pathology and with the potential to indicate a unilateral stroke physiology, would significantly increase stroke recognition, decrease stroke recognition time, shorten imaging time, and potentially improve outcomes through earlier initiation of the supportive care and neurointervention treatments.

The aim of this study is to analyze the diagnostic value of cerebral oximetry with or without CBVI monitoring in PED pediatric stroke and nonstroke patients for stroke location, type (hemorrhagic or ischemic), and its value in a pediatric stroke alert system and in nonalert stroke patients with altered mental status (AMS).

2. Materials and methods

2.1. Study design and participants

We conducted a prospective convenience observational trial at an urban, academic, children hospital's pediatric level 1 trauma ED (PED) with 56 000 annual visits from 2006 to 2013. Cerebral oximetry with CBVI (INVOS) with age-appropriate cerebral oximetry probes (neonate probes and pediatric probes for patients weighing < 40 kg and probes for adults weighing > 40 kg) has been an integral part of the PED cerebral assessment tool in suspected pediatric neurologic emergencies since 2006. The Vanderbilt institutional review board approved waived consent for review of the PED cerebral oximetry in neurologic emergency database and the patient's electronic medical record (EMR).

A multidisciplinary team developed the pediatric stroke activation system in 2009 with the PED as the only site for stroke alert activation. Upon PED stroke activation, the patient had immediate left and right cerebral oximetry monitoring as part of their stroke monitoring order set and before any radiologic studies. High-acuity PED AMS patients assessed in the PED resuscitation room as part of their monitoring assessment had left and right cerebral oximetry monitoring applied by the PED staff prior to computed tomographic scans or magnetic resonance imaging (MRI) studies. The patient's cerebral oximetry monitoring was maintained until discharge from the PED. The normal pediatric cerebral r_cSO_2 (%O_2HB) range is from 60% to 70% [8–17]. The CBVI has a range from −50 to +50 [12–16]. The positive or negative CBVI value equates to the fact that an increase or a decrease in regional cerebral blood flow has occurred [12–16].

Because of the non-MRI compatibility of the cerebral oximetry probes, they were removed from the patient prior to the MRI studies and replace upon return to the PED. The neuroradiologist had no prior knowledge of the patient's cerebral oximetry readings.

2.2. Study population

Investigators analyzed 2 databases for PED stroke patients who had cerebral oximetry monitoring, the PED cerebral oximetry redcap database (nonstroke activation) 2006-2013 and the PED stroke activation redcap database 2009-2013. The control patients were nonstroke alert and nonstroke AMS patients who had left and right r_cSO_2 with or without CBVI monitoring and normal neuroradiologic studies.

The first population comprised 2009-2013 pediatric stroke activation patients, consisting of PED patients who presented (by emergency medicine services or private transportation and no interfacility patient transfer) with signs or symptoms triggering the pediatric stroke alert activation system with cerebral oximetry monitoring (left and right r_cSO_2 readings recorded every 5 seconds for 60 minutes at minimum) before radiologic studies. The second study population comprised the PED overall stroke patients from 2006 to 2013, consisting of patients with high-acuity PED AMS nontrauma, prestroke activation AMS, and nonstroke activation AMS (no trauma history or trauma-related radiologic pathology), and strokes or nonstroke patients who had cerebral oximetry (left and right r_cSO_2 readings recorded every 5 seconds for 60 minutes at minimum) prior to head computed tomographic scans or MRI plus the stroke alert activation patients (nonstroke and stroke patients [2009-2013]; Table 1).

We excluded patients with a cerebrospinal fluid shunt, prior neurosurgical procedures, new or old brain tumors, history of trauma, or any trauma-related radiologic pathology; inpatients; those who had interfacility transfers; and/or patients whose cerebral oximetry monitoring occurred after their radiologic studies. These patients were excluded due to their potential abnormal cerebral physiology and r_cSO_2 readings as defined in prior cerebral oximetry studies [8–16].

The study investigators reviewed the selected patients for inclusion and exclusion criteria, EMR, radiologic reports, and final diagnosis by the pediatric neurology attending.

2.3. Statistical analysis

The primary cerebral oximetry outcome analysis was for the left and right r_cSO_2 and r_cSO_2 side difference values for detecting abnormal unilateral cerebral physiology, stroke location, and types (hemorrhagic or ischemic) compared with the radiologic pathology in both groups. The primary statistical analysis was based on patients enrolled between 2009 and 2013 in the stroke alert activation group. Secondary statistical analysis was based on overall stroke patients enrolled between 2006 and 2013. A 0- to 60-minute mean r_cSO_2 was selected for analysis. Statistical analysis methods for both groups used 2-sample *t* test, receiver operating characteristic (ROC) curves, stroke probability, and Youden Index to determine the optimized cutoff point. A 2-sided statistical significance level of .05 was used for all statistical tests.

3. Results

In the stroke alert and overall stroke groups, there were no issues with cerebral oximetry probes obtaining r_cSO_2 readings of any age and no false-positive correlation for left, right, and side differences of r_cSO_2 readings to radiologic pathology.

3.1. Stroke alert patient populations

From 2009 to 2013, 88 patients triggered and completed the PED stroke alert system: 25 stroke (8 hemorrhagic and 17 ischemic) patients and 63 nonstroke patients in Tables 1 and 2. All stroke alert patients had stroke activation, radiologic studies, and cerebral oximetry.

3.2. Overall stroke patient population

From 2006 to 2013, 210 PED patients who fulfilled AMS inclusion and exclusion criteria had cerebral oximetry before radiologic studies. The overall stroke population was 52 AMS strokes, 25 positive stroke alerts (hemorrhagic [n = 33] or ischemic [n = 44]), 133 AMS nonstrokes, and 63 nonstroke alerts (Tables 1 and 2).

Patients' pertinent medical history examination showed that 36% had no medical history for the stroke alert group and 39% for the overall stroke group. The rest of the both groups' pertinent medical history in decreasing frequency is neurologic (arteriovenous malformation