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Original Research

Cerebral Oxygenation and Acceleration in Pediatric and Neonatal Interfacility Transport

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A B S T R A C T

Objective: The purpose of this study is to measure peak acceleration forces during interfacility transport; examine whether drops in cerebral oxygenation occurred; and test the associations between cerebral oxygenation, acceleration, and patient positioning.
Methods: A cerebral oximeter (INVOS-5100C; Somanetics, Minneapolis, MN) monitored regional saturation of oxygen (rSO_2 [cerebral oxygenation]) in pediatric and neonatal patients (N = 24) transported between facilities by ground ambulance, helicopter, or fixed wing aircraft. An accelerometer (GP1; SENSR, Georgetown, TX) bolted to the isolette or gurney recorded z-axis (aligned with the spine) accelerations.
Results: The z-axis peak accelerations (absolute values of g) by transport type were as follows: ground ambulance takeoff mean = 0.16 and landing mean = 0.08, helicopter takeoff mean = 0.16 and landing mean = 0.05, fixed wing aircraft takeoff mean = 0.14 and landing mean = 0.20. During takeoff, 2 of 7 patients in the head−to−front of vehicle position experienced rSO_2 drop. During landing, 4 of 13 patients in the head−to−back of vehicle position experienced rSO_2 drop. There were no significant associations of rSO_2 drop during takeoff and landing with patient positioning or with z-axis peak acceleration.
Conclusion: Acceleration forces of pediatric and neonatal interfacility transport are small and comparable in magnitude. The relationship between rSO_2 drop and patient positioning was not significant in this pilot study.

The current model of centralized pediatric and neonatal critical care relies on the interfacility transport of critically ill neonates and pediatric patients via ground ambulance, helicopter, and fixed wing aircraft. However, these transports are not without risks. In a prospective study of 141 interhospital critical pediatric transports, 12% of patients were documented as having physiologic deterioration during transport.[1] In a larger prospective cohort study of 1,085 transported critically ill pediatric patients, unanticipated adverse events occurred in 5% of transports as well as an outcome of death in 10% of the cohort.[2] In order for the centralized model of caring for critically ill children to be successful, the risks of transporting these patients need to be understood and minimized.

Little research has been conducted on the potential physiologic effects of the movement generated by medical transport. Research using acceleration data from adult volunteers during simulated ground and helicopter transports found that supine patients transported by helicopter were subjected to greater lateral and vertical forces and lesser head-to-toe forces than patients transported by ground ambulance.[3] The clinical significance of these acceleration forces on patients has not been investigated. There is growing concern in the transport community about vehicle acceleration on clinical outcomes. For example, when a patient's head is placed toward the rear of a fixed wing aircraft, there is greater intracranial blood pooling and subsequent increased intracranial pressure because of acceleration in the caudal direction during aircraft takeoff.[4] Furthermore, if a patient's head is positioned to the front of the aircraft, the ventral acceleration during takeoff is expected to lead to decreased cerebral oxygenation pressure

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because of blood pooling in the lower extremities as well as decreases in venous return and mean arterial pressure.[5] This risk of decreased cerebral oxygenation has led to the practice of avoiding this positioning for patients who may have poor cardiac output. In current practice, patients with a high risk of morbidity from increased intracranial pressure (eg, patients with head trauma) are positioned such that their heads are aligned toward the front of a fixed wing aircraft during takeoff.[4] However, empirical validation of this practice has yet to be obtained.

Although acceleration effects on cerebral oxygenation have not been studied in patients during transport, near-infrared range spectroscopy (NIRS), which measures regional saturation of oxygen (rSO_2) of the brain, has been used to investigate acceleration effects on cerebral oxygenation in healthy adult aircraft pilots.[6] To our knowledge, 1 study has used NIRS to similarly investigate cerebral oxygenation in the interfacility transport of pediatric patients by helicopter.[7] The NIRS cerebral oximeter is a noninvasive technology that uses the relative absorption of near-infrared light by oxyhemoglobin and deoxyhemoglobin to continuously monitor the oxygen saturation of a small region of cerebral tissue. Compared with pulse oximeters, which measure the oxygen saturation of pulsatile blood (ie, systemic arterial hemoglobin saturation), NIRS measures rSO_2 in nonpulsatile blood (ie, local tissue saturation). NIRS is a venous weighted measure composed of an approximate 5 to 1 ratio of local venous to arterial blood, but it should be noted that this proportion may vary from patient to patient.[8] Because of this variability along with technological limitations, standard cerebral rSO_2 values applicable to all patients have not been established.[9] In the absence of standard values, 1 study has defined abnormal cerebral rSO_2 as a 20% or higher reduction from baseline or as a baseline absolute value below 40%.[10]

Despite its limitations, the nature of rSO_2 as a venous weighted measure makes it useful as a continuous measure of the balance of oxygen delivery and consumption (ie, metabolism). This has led to its clinical use as a continuous measure of cerebral oxygenation in numerous settings in which patients are at risk of decreases in cerebral oxygenation, including monitoring during pediatric cardiac and neurosurgical procedures.[9] In centrifuge and high-performance aircraft studies, decreasing cerebral rSO_2 has been associated with increasing acceleration forces in the head-to-toe direction.[6,11,12] In the context of patient transport, there may also be an inverse association between rSO_2 and acceleration. Therefore, the objectives of this pilot study were to measure peak acceleration forces during interfacility transport; examine whether drops in cerebral rSO_2 occurred; and test the associations between rSO_2 drop, acceleration, and patient positioning, specifically the head–to–back of vehicle (HTB) and head–to–front of vehicle (HTF) positions.

Methods

Study Design and Sample

This was a prospective pilot study of pediatric and neonatal patients (convenience sampling) who were transported to an urban tertiary care children's hospital by a dedicated pediatric/neonatal transport team. This specialized team is assembled from a transport staff of dedicated transport physicians, nurses, and respiratory therapists. The transport staff serves an urban, metropolitan area that spans 4,850 square miles (12,562 km^2) and transports approximately 2,000 patients annually. Modes of transport include ground ambulance (80%), helicopter (20%), and fixed wing aircraft (5%). Patient enrollment into the study was based on the size of the transport vehicle and the availability of study personnel. Study personnel consisted of off-duty transport staff members. Because of space limitations of the transport vehicles, only 1 study personnel member at a time could accompany the on-duty transport team.

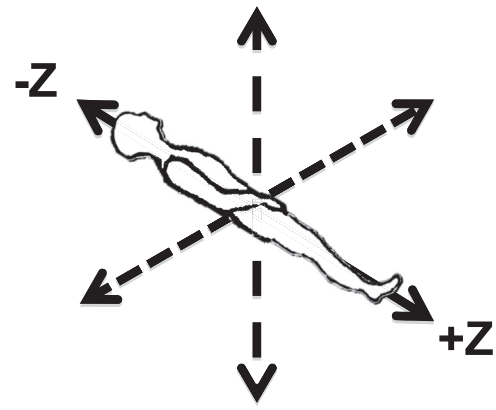

Figure 1. Acceleration in the z-axis.

The institutional review board approved this study with waiver of consent based on the minimal risks of the study and the possible delay of transport if written consent was mandatory. An information sheet was given to the parents in lieu of the written consent process. After the transport, Health Insurance Portability and Accountability Act authorization was obtained. The data collection period began in February 2011 and ended in January 2012.

Equipment and Procedures

Study participants received standard of care transport services, including mode of transport, monitoring, and medical care, which were determined by the transport team. In addition to the standard monitoring, each study participant received (at the beginning and end of transport) continuous monitoring of cerebral rSO_2 by NIRS technology, cerebral oximeter, and in vivo optical spectroscopy (INVOS-5100C; Somanetics, Minneapolis, MN). Two NIRS probes were used, and both had the following dimensions: 17.25 cm^2 for neonates and infants and 26.8 cm^2 for pediatric patients. Both probes had an emitter/diode spacing of 20 to 40 mm and 2 light paths, each with a light penetrating depth of 20 mm. The monitoring of cerebral rSO_2 began at the initial preparation and stabilization before patient transport, and data were used to determine pretransport baseline cerebral saturation. The cerebral rSO_2 data were electronically stored by the INVOS cerebral oximeter during the course of transport. Study personnel logged baseline rSO_2 values onto a written data collection form, and their real-time observations during takeoff and landing of “drop in rSO_2” (20% drop or greater) and “no drop in rSO_2” from baseline were documented categorically as yes or no. The clinical diagnoses of the study patients and whether they required medical intervention during their transport were also documented.

Transport vehicle accelerations were electronically recorded using a programmable accelerometer, specifically the GP1 (SENSR, Georgetown, TX). This accelerometer uses a 3-axis microelectromechanical system with a measurement range of $\pm$ 10 g, a resolution of 0.001 g, and an output rate of 100 samples per second. The accelerometer was mounted on the study participant's gurney or isolette for the duration of the transport. Specifically, the mounting position was consistently oriented to accurately record z-axis accelerations (aligned with the axis of the spine from head to toe) in the supine position (Fig. 1); z-axis peak accelerations were recorded during takeoff and landing. Takeoff was defined as the initial moment of forward movement in ground transport and as the span from taxiing to the attainment of cruise altitude for air transport. Landing was defined as the moment during final braking in ground transport and as the descent completion to final braking for air transport.