Journal of Radiology Nursing 36 (2017) 3–9

Contents lists available at ScienceDirect

Journal of Radiology Nursing

journal homepage: www.radiologynursing.org

Transcranial Doppler Ultrasound Use in Pediatric Traumatic Brain Injury

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Keywords:
Cerebral flow velocity
Children
Head injury

ABSTRACT

Transcranial Doppler (TCD) ultrasound is an inexpensive portable diagnostic tool commonly available within most health care systems. A team of trained individuals perform and interpret the test to inform patient care management. The benefit of TCD is well established in adult patients with traumatic brain injury (TBI). However, in children with TBI, it is still considered exploratory, and its use is not a part of the standard of care. This article describes what TCD is, its use in children, and how TCD measurements apply to children and adolescents in an effort to establish criteria for the use of TCD for children with TBI. The benefit of TCD in pediatric TBI is illustrated by two cases of children who participated in a TBI research study. Early indications are that the use of TCD in pediatric cases of TBI may produce unexpected real-time data about the cerebral vasculature and circulation characteristics in children with TBI. TCD ultrasound has the potential for playing an informative diagnostic role in future pediatric TBI management. Ultimately, the goal to promote best outcomes after a TBI requires insights into the multidynamic nature of the injury, and TCD has the ability to support these efforts.

Introduction

Transcranial Doppler (TCD) ultrasound is an inexpensive, noninvasive, portable, and low-frequency ultrasound that can measure cerebral blood flow velocities (FVs). The use of a Doppler ultrasound was first reported in the early 1960s, but it was not until 1982 when Rune Aaslid and his team described how to insonate the middle cerebral artery (MCA) that TCD became a diagnostic measure for blood FV (Aaslid, Markwalder, & Nornes, 1982; Coman & Popescu, 2015). Since that time, TCD has become standard practice in the evaluation of adult patients experiencing intracranial stenosis, such as acute stroke, sickle cell disease, and subarachnoid hemorrhage. It has also been used to determine the presence or the absence of collateral vascular flow and embolisms. It has the capability to assess cerebrovascular dynamics and function while also providing intraoperative monitoring in interventional neurodiagnostic procedures, cardiopulmonary bypass, and carotid endarterectomy (Markus, 2000; Newell, 1995). However, in children, TCD has been used most often in evaluations of sickle cell disease and cerebrovascular anomalies and only recently in traumatic brain injury (TBI) (LaRovere & O'Brien, 2015; Verlhac, 2011). As the indications for its clinical use expand, it behooves clinicians and researchers to familiarize themselves with TCD practice standards and guidelines, diagnostic interpretation, and common data reporting. TCD ultrasound plays a unique role in providing real-time information for patients at risk of cerebrovascular compromise.

TCD ultrasound

TCD ultrasound has been recognized as a diagnostic device that allows the clinician to better understand the pathologic changes that affect cerebral circulation after injury. In adults with TBI, most arteries within the Circle of Willis are measured (Table 1). However, in children, the anterior (MCA) and posterior (basilar artery [BA]) cerebral vessels are most commonly assessed and reported. Although the use of TCD in pediatric TBI is still considered experimental and it is not part of the standard of care, there is a growing body of literature. Most recent studies conducted using TCD in pediatric TBI have primarily focused on its use in the diagnosis of increased intracranial pressure (ICP), cerebral vasospasm, or hyperemia, and trending of cerebral FVs (LaRovere & O'Brien, 2015;

Funding/grant: This work was supported by the National Institutes of Health (National Institute of Nursing Research: 1P30 NR014139-01) Adaptive Leadership for Cognitive Affective Symptom Science ADAPT Institute of Nursing Research Center of Excellence; 2012 to 2015 and by the Robert Wood Johnson Foundation as a Nurse Faculty Scholar Project (no. 71244; 2013 to 2016).

This manuscript has not been previously presented.

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http://dx.doi.org/10.1016/j.jradnu.2016.11.003
1546-0843/$36.00/

Table 1
Cerebral arteries measured by transcranial Doppler

Vessel	Abbreviation
Middle cerebral artery	MCA
Anterior cerebral artery	ACA
Posterior cerebral artery	PCA
Terminal internal carotid artery	TICA
Internal carotid artery (siphon)	ICA
Ophthalmic artery	OA
Vertebral artery	VA
Basilar artery	BA

LaRovere, O'Brien, & Tasker, 2016; O'Brien, Maa, & Reuter-Rice, 2015a; O'Brien, Maa, & Yeates, 2015b; O'Brien, Reuter-Rice, Khanna, Peterson, & Quinto, 2010).

The most common TCD devices are color Doppler ultrasounds, and they are located in radiology departments, neurodiagnostic laboratories, and some intensive care units. Doppler color flow systems assign a given color to the direction of flow; red is the flow toward the transducer, and blue is the flow away. The measurement of the cerebral arteries is determined by the systolic peak flow, mean flow (mean FV = time − mean of the maximal velocity envelope curve), and end diastolic peak flow. The derived calculated measures allow the determination of high-, normal-, and low FV states. Cerebral vasospasm is the state of higher-than-expected FV and has been associated with poor outcomes after TBI (Edelman, 2007; Lee et al., 1997). To determine true cerebral vasospasm, a Lindegaard ratio must be calculated. This ratio is based on the highest mean FV in the MCA divided by the extracranial internal carotid artery (ECICA) (LR = VmMCA / VmECICA) Lindegaard, Nornes, Bakke, Sorteberg, & Nakstad (1989). This ratio must be three or greater to be considered true cerebral vasospasm; however, because normal cerebral FVs are different in adults and children, so are the definitions of cerebral vasospasm (Table 2) (O'Brien, 2015).

It is difficult to calculate blood flow volume based on mean FVs because the diameter of the artery is unknown. Therefore the Gosling pulsatility index (PI) is used to describe the TCD waveforms. The PI or Gosling equation is calculated by subtracting the end diastolic peak FV from the systolic peak FV and dividing the remainder by the mean FV ($PI = [FV_{sys} - FV_{dia}] / FV_{mean}$). The calculated value is a ratio of the systolic peak FV to end diastolic FV (De Riva et al., 2012; Figaji, Zwane, Fieggen, Siesjo, & Peter, 2009).

The PI has been described as the distal cerebral vascular resistance and has been most associated with increased ICP when PIs are recorded as higher than normal. However, this has not been established with certainty in the pediatric TBI literature. In adults with TBI, a PI of one was associated with better functional outcomes after 6 months than a PI of 1.56, which was associated with poorer outcomes, such as death, vegetative state, and severe disability (Moreno et al., 2000). Yet when Figaji and his team examined the use of a PI of one to better predict increased ICP in children with severe TBI, they found PIs were unreliable noninvasive indicators. In a recent study, PIs in children with severe TBI who had a PI threshold of >1.31 in the first 24 hr after injury had a higher association of increased ICP; thereafter, PI was not a trusted measure to solely manage ICP (O'Brien et al., 2015a).

Table 2
Definitions of cerebral vasospasm in adults and children

Individual	Anterior cerebral vasospasm	Posterior cerebral vasospasm
Adult	MCA > 120 cm/s *AND* LR ≥ 3	BA > 90 cm/s
Pediatric	MCA ≥ 2 SD above normal for age *AND* LR ≥ 3	BA ≥2 SD above normal for age

MCA = Middle cerebral artery; LR = Lindegaard ratio; BA = basilar artery; SD = standard deviation.

TCD imaging refers to a generated pulse sound wave that moves from the transducer (probe) to the tissues. The sound waves bounce off of, in the case of TCD, moving red blood cells, thereby creating echoes. The echoes are then sent back (reflected) to the ultrasound transducer to provide structural information and the speed and flow of blood (Figure 1). Location of cerebral arteries for TCD requires appropriate transducer placement (Table 3) over an acoustic window. This is an area of the skull where the bones are thinner and allow for better penetration of the ultrasound beam. The supine position is preferred for conducting a TCD (American College of Radiology, 2007; Bathala et al., 2013), but in a child, a 30° head angle is allowed. In children, the depth for cerebral artery insonation is based on age and head circumference (Table 4), different from adults, in whom these depths are stable regardless of age (Table 5). The direction of blood flow is the same for both. In children and adolescents, the mean FV (Table 6) is commonly used for trending.

In 1988, Bode and Wais conducted a cross-sectional study to describe mean and standard deviation of FVs in children 0 days to 18 years of age (for a full description of these values, please refer to Bode & Wais, 1988). In the work, cerebral FVs are defined for systolic peak flow, mean flow, and end diastolic peak flow. FVs have also been normed for sex and ages 4 to 16 (Table 7). FVs are increasingly higher in the children from birth to 8 years of age and to decline to adult values at age 18 (Bode & Eden, 1989; Bode & Wais, 1988; LaRovere & O'Brien, 2015; O'Brien, 2015). Other studies have found that girls have higher MCA and BA FVs than boys (Tontisirin et al., 2007; Vavilala et al., 2005) and in children who are critically ill, ventilated, and sedated have lower BA flow than healthy children (O'Brien, 2015).

Steps to conduct a TCD ultrasound for pediatric TBI

After a request for a TCD has been placed, the individual conducting the TCD enters all relevant patient data into the TCD software. Because the TCD is a portable ultrasound, the examination can be conducted at the bedside. Proper positioning of the patient's head in midline position will promote access of the bilateral anterior circulation. If medically safe, logrolling the patient on his or her side while maintaining the midline head position will allow access to the posterior circulation. In smaller children, the posterior circulation may often be accessed without turning them. If a cervical collar is in place, it may be loosened, with the health care teams' permission to promote access to the bilateral external carotid arteries and the BA. While maintaining c-spine precautions, the

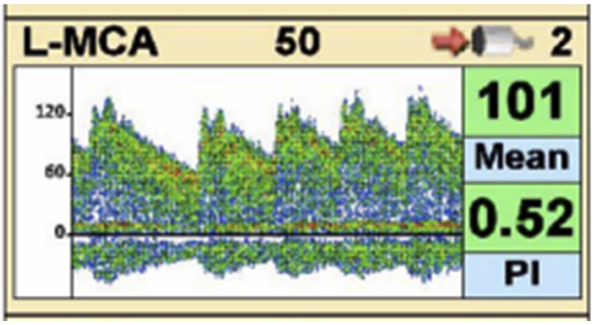

Figure 1. Example of a mean flow velocity of the left middle cerebral artery (L-MCA) at a depth of 50 mm with a flow of 101 cm/s and a pulsatility index (PI) of 0.52 (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.).