Ultrasound in Med. & Biol., Vol. ■, No. ■, pp. 1–7, 2017

0301-5629/$ - see front matter

http://dx.doi.org/10.1016/j.ultrasmedbio.2017.02.003

● *Original Contribution*

DYNAMIC CEREBRAL AUTOREGULATION ASSESSMENT USING EXTRACRANIAL INTERNAL CAROTID ARTERY DOPPLER ULTRASONOGRAPHY

NAI-FANG CHI,*† HSIAO-LUN KU,‡ CHEN-YEN WANG,§ YANHUI LIU,¶ LUNG CHAN,*† YING-CHIN LIN,‖ CHUNG-KANG PENG,# VERA NOVAK,** HAN-HWA HU,*† and CHAUR-JONG HU*†

*Department of Neurology, School of Medicine, College of Medicine, Taipei Medical University, Taipei, Taiwan; †Department of Neurology, Shuang Ho Hospital, Taipei Medical University, Taipei, Taiwan; ‡Department of Psychiatry, Shuang Ho Hospital, Taipei Medical University, Taipei, Taiwan; §Research Center for Adaptive Data Analysis, National Central University, Taoyuan, Taiwan; ¶Fengsheng Yongkang Software Technology Corporation, Nanjing, China; ‖Health Management Center, Shuang Ho Hospital, Taipei Medical University, Taipei, Taiwan; #Division of Interdisciplinary Medicine and Biotechnology, Beth Israel Deaconess Medical Center, Boston, Massachusetts, USA; and **Departments of Neurology, Beth Israel Deaconess Medical Center, Boston, Massachusetts, USA

(*Received* 15 *September* 2016; *revised* 7 *January* 2017; *in final form* 2 *February* 2017)

Abstract—Transcranial Doppler ultrasonography of the middle cerebral artery (MCA) is frequently used to assess dynamic cerebral autoregulation (dCA); however, this is difficult in patients with poor temporal bone windows. In the study described here, we investigated the agreement and sensitivity of dCA indices determined from the extracranial internal carotid artery (ICA) and those determined from the MCA. Measurements for 32 stroke patients and 59 controls were analyzed. Measurement of the mean flow correlation index (Mx) and transfer function analysis based on spontaneous blood pressure fluctuation were simultaneously performed for the extracranial ICA and MCA. The mean values of Mx and phase shift did not significantly differ between the ICA and MCA (mean difference: Mx = 0.01; phase shift of very low frequency [VLF] = 0.7°, low frequency [LF] = 3.3° and high frequency = 4.5°), but the gains in VLF and LF in the ICA were significantly lower than those in the MCA (mean difference: gain of VLF = −0.13, gain of LF = −0.10). The intra-class correlation coefficient between the dCA indices of the ICA and MCA was favorable in Mx (0.76) and the phase shift of VLF (0.72). The area under the receiver operating characteristic curve for stroke diagnosis did not differ among the dCA indices. We conclude that dCA assessed from the ICA is as effective as that from the MCA, but the results are not interchangeable. (E-mail: naifangchi@tmu.edu.tw) © 2017 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Cerebral hemodynamics, Cerebrovascular diseases, Dynamic cerebral autoregulation, Transcranial Doppler ultrasonography.**

INTRODUCTION

Cerebral autoregulation is a mechanism for maintaining adequate cerebral blood flow (CBF) in response to changes in cerebral metabolic needs or systemic hemodynamics (Powers et al. 1985). Dynamic cerebral autoregulation (dCA) in humans is measured by analyzing the correlation between changes in CBF and peripheral arterial blood pressure (ABP). Impaired dCA has been correlated with the severity and poor outcome of cerebrovascular diseases (Aries et al. 2010).

Studies have proven that transcranial Doppler ultrasonography (TCD) monitoring of blood flow velocity (BFV) in the middle cerebral artery (MCA) is an effective method for assessing dynamic changes in CBF, under the assumption of constant MCA diameter during the test (Lindegaard et al. 1987; Newell et al. 1994). The use of TCD to assess dCA on the basis of either spontaneous or induced CBF changes is valid and reliable (Brodie et al. 2009; Minhas et al. 2016). The success rate of trans-temporal insonation is affected by ethnicity, age, and thickness and density of temporal bone (Brunser et al. 2012; Kollar et al. 2004; Kwon et al. 2006; Wijnhoud et al. 2008). In studies in Western countries, the success rate of TCD is often

Address correspondence to: Nai-Fang Chi, Department of Neurology, School of Medicine, College of Medicine, Taipei Medical University, 250 Wuxing Street, Xinyi District, Taipei City, 110, Taiwan. E-mail: naifangchi@tmu.edu.tw

Conflict of interest disclosure: All authors report no conflicts of interest.

>90% (Brodie et al. 2009; Minhas et al. 2016; Ortega-Gutierrez et al. 2014), whereas in reports from Asian countries, the successful trans-temporal insonation rate is 60%–70% in middle-aged populations (Gao et al. 2002; Itoh et al. 1993; Kwon et al. 2006; Lien et al. 2001; Yagita et al. 1996). A high rate of TCD failure in aged individuals is detrimental to subject recruitment for studies on cerebrovascular or neurodegenerative diseases. Because high-quality Doppler signals can be obtained more easily from the extracranial internal carotid artery (ICA) than from the MCA, this may be an alternative for assessing dCA when trans-temporal insonation fails. Before the widespread use of TCD, the ICA flow volume measured with an electromagnetic flowmeter was used as a surrogate for CBF in assessing dCA (Lindegaard et al. 1987; Newell et al. 1994). The MCA is the main branch of the ICA, accounting for 80% of the flow volume in a hemisphere (Lindegaard et al. 1987). Under a drug-induced change in ABP, the average diameter change in both the ICA and MCA is less than 4% (Giller et al. 1993), and the change in BFV is consistent between the ICA and MCA (Liu et al. 2013). Accordingly, the BFV of the ICA may be used for assessing dCA, and the dCA determined from the BFV of the ICA may be similar to the dCA of the MCA, especially under spontaneous ABP fluctuations in resting states because no significant changes in the diameter of the ICA or MCA occur under this condition. Agreement of the autoregulation index between the ICA and MCA has been studied (Nogueira et al. 2016; Saeed et al. 2013), but only healthy volunteers have been tested. This study used both time- and frequency-domain analyses to compare the agreement, sensitivity, and specificity of ICA- and MCA-based dCA assessments for identifying patients with stroke.

METHODS

Patients and measurements

This study was approved by the Institutional Review Board of Taipei Medical University. Patients with ischemic stroke in the MCA territory were recruited within 1 wk of onset from the neurology ward at Taipei Medical University Shuang Ho Hospital. Controls without a history of stroke were recruited from the health management center at the same hospital. Written informed consent was obtained from all participants.

In each patient, the stroke location was confirmed through magnetic resonance imaging. Electrocardiography, extracranial carotid Doppler ultrasonography and transcranial color-coded Doppler ultrasonography were performed in all patients; those with poor bilateral temporal windows, atrial fibrillation or ICA or MCA diameter stenosis >50% were excluded. A total of 91 patients, comprising 32 patients with stroke (age, 59 ± 10 y; 29 men) and 59 controls (age, 49 ± 14 y; 20 men), were enrolled for the final analysis. In all patients, the National Institutes of Health Stroke Scale (NIHSS) was applied on the day of dCA measurement.

The dCA measurements were recorded in spontaneously breathing patients placed in a supine position with their heads elevated at 30°; signal recording was initiated after 15 min of rest, and a stable end-tidal CO_2 was confirmed through capnography (Nellcor N85, Medtronic, Fridley, MN, USA). The BFVs in the ipsilateral ICA and MCA were simultaneously recorded using a Doppler monitor (MultiDop-T, Compumedics DWL, Singen, Germany) with two 2-MHz probes and a custom-made head frame (Fig. 1a). In stroke patients and controls, affected side (right = 20, left = 12) and right-side measurements were recorded, respectively. In the controls, if insonation failed on the right side, then left-side measurements were recorded (tested side: right = 55, left = 4). The depth

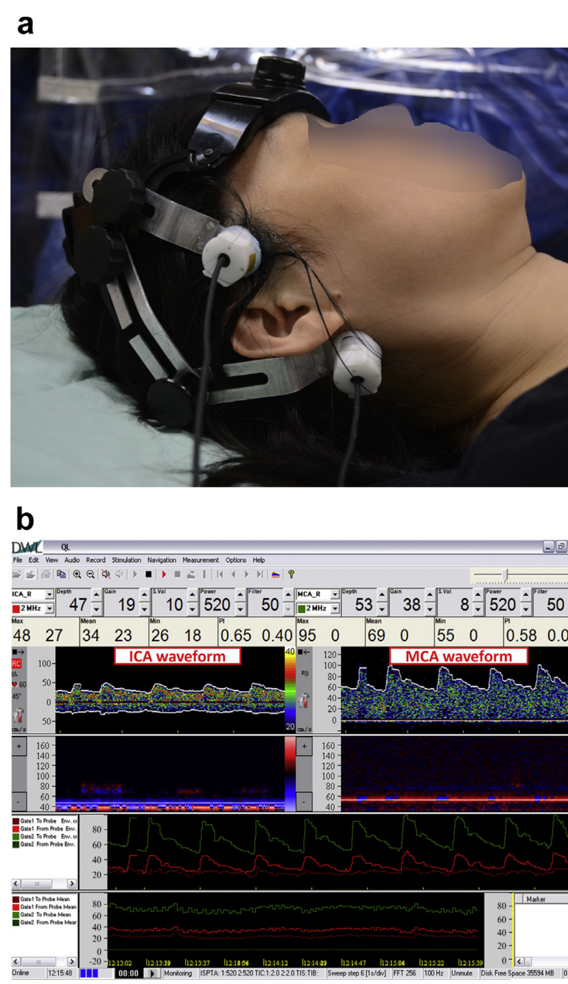

Fig. 1. (a) Probe position for the extracranial ICA and MCA. (b) Test settings of the Doppler monitor and the blood flow velocity waveforms of the extracranial ICA and MCA. ICA = internal carotid artery; MCA = middle cerebral artery.