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● *Original Contribution*

GRADING OF DYNAMIC CEREBRAL AUTOREGULATION WITHOUT BLOOD PRESSURE RECORDINGS: A SIMPLE DOPPLER-BASED METHOD

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Abstract—Transcranial Doppler sonography allows for noninvasive assessment of dynamic cerebral autoregulation. A wider clinical use of this approach has been hampered by the need for continuous arterial blood pressure (ABP) measurements. We describe a new method of a pure Doppler signal based estimation of dynamic autoregulation using heart rate (HR) and cerebral blood flow velocity (CBFV) information. The phase between these two signals was assessed from 0.1 Hz oscillations induced by regular breathing. We compared this new approach with the standard method (phase between ABP and CBFV oscillations) in 93 patients with unilateral severe carotid artery obstruction. On a group level, the phase HR-CBFV differed significantly between ipsi- and contralateral sides ($p = 0.024$) and correlated significantly with the standard phase ABP-CBFV ($r = 0.369$, $p < 0.001$). The proposed method can, thus, detect impaired dynamic autoregulation in occlusive carotid artery disease using a single Doppler probe. (E-mail: matthias.reinhard@uniklinik-freiburg.de) © **2012 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Dynamic cerebral autoregulation, Transcranial Doppler sonography, Blood pressure measurement.**

INTRODUCTION

Cerebral autoregulation is an intrinsic and rapid regulatory mechanism of the cerebral vasculature. Its clinical measurement has long been regarded as difficult because of the need for invasive arterial blood pressure (ABP) manipulation and the low temporal resolution of cerebral blood flow measurements. With the advent of transcranial Doppler sonography (TCD), continuous assessment of short-term changes in cerebral hemodynamics became possible (Bellapart and Fraser 2009; Panerai 2009). Together with the use of rapid ABP transients, an entirely noninvasive assessment of dynamic characteristics of cerebral autoregulation has evolved (Aaslid et al. 1989; Sorond et al. 2009). Besides mechanically induced ABP stimuli also repetitive up- and downward stimuli of oscillating ABP are used (Reinhard et al. 2003). Using cross-spectral analysis from orthostatic, spontaneous or respiratory-induced ABP oscillations, a phase shift between ABP oscillations and the steadily regulating cerebral perfusion has been found (Diehl et al. 1995; Kuo et al. 1998; van Beek et al. 2010). This phase shift is variably impaired (*e.g.*, in severe carotid stenosis and occlusion) and predicts the risk of transient ischemic attack (TIA) and stroke in these patients (Hu et al. 1999; Reinhard et al. 2008).

One of the most important obstacles to a broader application of dynamic autoregulation measurements is the need of a continuous assessment of blood pressure to track the stimulus for the rapid dynamic autoregulatory response. Invasive blood pressure recordings are not justified in outpatients. Noninvasive continuous manometers are costly and, thus, not suitable ftor a widespread application of autoregulation testing in the regular clinical ultrasound lab. A simple ultrasound-based autoregulation test without the need of continuous ABP measurement would be a promising approach for a wide-spread applicability of dynamic autoregulation measurements. Furthermore, since many labs only have the possibility of unilateral transcranial Doppler or Duplex studies at a time, an autoregulation test with a single Doppler or Duplex probe is desirable.

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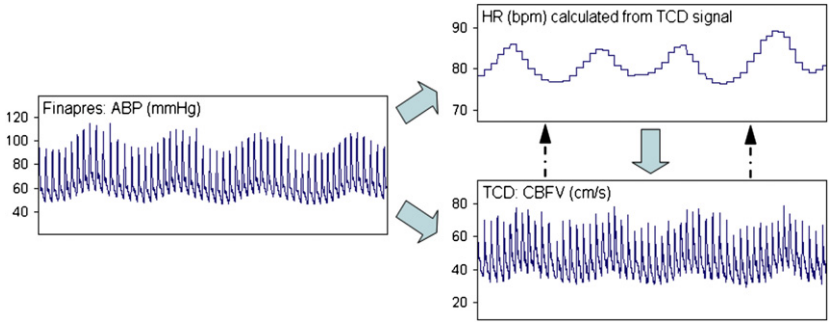

Fig. 1. Hypothesis of a single transcranial Doppler sonography (TCD) probe method for assessment of dynamic autoregulation. Short data segment of 0.1 Hz oscillations of arterial blood pressure (ABP), heart rate (HR) and cerebral blood flow velocity (CBFV) induced by slow regular breathing at a rate of 6 breathes per minute. The usual calculation refers to the phase shift between the ABP signal (left) and CBFV (lower right). ABP oscillations are accompanied by HR oscillations (upper right), which can be calculated from the electrocardiogram signal (RR interval) or the systolic ABP peaks (Finapres signal, left). HR values can, however, also be calculated from the systolic peaks of the Doppler signal (lower right) resulting in the upper right curve in this example. Assuming a fixed phase relation between ABP and HR oscillations, ABP oscillations could be substituted as input signal for calculation of dynamic autoregulation. Because the HR signal can be calculated from the CBFV signal of the Doppler probe, calculation of dynamic autoregulation would ideally become possible by using a single Doppler probe ('single Doppler probe method').

For this purpose, the autoregulation test of phase shift calculation between oscillations of ABP and cerebral blood flow velocity (CBFV) could be modified by replacing ABP by another fix oscillating cardiovascular signal. The heart rate (HR) signal also oscillates in a certain phase relation to ABP during spontaneous or respiratory-induced oscillations in ABP (Keyl et al. 2002).

Although additional interindividual variability might be introduced, HR oscillations could potentially serve as an individual temporal surrogate for the ABP signal, allowing the estimation of absolute phase values for determination of dynamic autoregulation. Even more, HR oscillations can be estimated from the intersystolic interval of the Doppler signal, resulting in a single transcranial Doppler probe as a sufficient tool to gain information on dynamic cerebral autoregulation. This hypothesis is illustrated in Figure 1.

In this study, we investigated the feasibility of a single Doppler probe based determination of dynamic autoregulation using the phase shift between heart rate and CBFV in patients with severe unilateral stenosis or occlusion of the ICA.

PATIENTS AND METHODS

Data sets of 93 patients (mean age 67, range 36–85 years, 11 female) with severe unilateral stenosis (≥80% local degree of stenosis) or occlusion of the internal carotid artery (ICA) were analyzed. Moderate stenosis on contralateral ICA sides was allowed. Recordings were obtained in a previous study on dynamic autoregulation (Reinhard et al. 2008), which had been approved by the local ethics committee. All patients gave informed consent to participate. A complete neurosonological workup, including extracranial and intracranial color-coded and transcranial Doppler sonography, was performed in all patients. Grading of stenosis was performed using Doppler velocities pre-, intra- and poststenotically in combination with B-mode imaging. Baseline characteristics of patients are given in Table 1.

Autoregulation measurements were performed with the patients in a supine position with an inclination of 50° of the upper body in quiet room with ambient temperature kept constant at 21°C. CBFV was measured in both middle cerebral arteries (MCA) by standard transcranial Doppler sonography (button-shaped 2 MHz ultrasound probes fixed to a headband, pulsed wave directional insonation, axial width of the sample volume 6–10 mm, mean I_{SPTA} 597.2 mW/cm^2, MCA insonated in depths ranging between 50 and 60 mm; device type and manufacturer: Multidop X4©, DWL Medizinische Systeme, Singen, Germany). ABP at heart level was recorded *via* a servo-controlled finger plethysmograph (Finapres 2300©; Ohmeda, Englewood, CO, USA) and this device was also used for heart rate assessment using intersytolic ABP intervals. After establishing stable baseline signals and careful instruction of the patient, oscillations in ABP and CBFV were elicited by paced breathing at a rate of 6 breathes per minute (*i.e.*, 5 s periods of in- and expiration) for 180 s. Paced breathing was achieved both by visual feedback of a large clock with a red sweep hand and additionally by verbal instruction of the examiner to breathe in and out. Accuracy of paced breathing was checked during the investigation by thoracic excursions and by capnometry (measurement of end tidal carbon dioxide partial pressure). A block diagram of the set-up is shown in Figure 2.