Noninvasive Evaluation of Dynamic Cerebrovascular Autoregulation Using Finapres Plethysmograph and Transcranial Doppler

Andrea Lavinio, MD; Eric Albert Schmidt, MD, PhD; Christina Haubrich, MD; Piotr Smielewski, PhD; John D. Pickard, F Med Sci; Marek Czosnyka, PhD

Background and Purpose—Mx is an index of cerebrovascular autoregulation. It is calculated as the correlation coefficient between slow spontaneous fluctuations of cerebral perfusion pressure (cerebral perfusion pressure−intracranial pressure) and cerebral blood flow velocity. Mx can be estimated noninvasively (nMxa) with the use of a finger plethysmograph arterial blood pressure measurement instead of an invasive cerebral perfusion pressure measurement. We investigated the agreement between nMxa and the previously validated index Mx.

Methods—The study included 10 head-injured adults. Intracranial pressure was monitored with a parenchymal probe. Arterial blood pressure was monitored simultaneously with an arterial catheter and with the Finapres plethysmograph. Flow velocity in the middle cerebral artery was measured bilaterally with transcranial Doppler. Mx and nMxa were computed in both hemispheres, and asymmetry of autoregulation was calculated.

Results—Ninety-six measures of Mx and nMxa were obtained (48 for each side) in 10 patients. Mx correlated with nMxa (R=0.755, P<0.001; 95% agreement = ±0.36; bias = 0.01). Asymmetry in autoregulation assessed with Mx correlated significantly with asymmetry estimated with nMxa (R=0.857, P<0.0001; 95% agreement = ±0.26; bias = −0.03).

Conclusions—The noninvasive index of autoregulation nMxa correlates with Mx and is sensitive enough to detect autoregulation asymmetry. nMxa is proposed as a practical tool to assess cerebral autoregulation in patients who do not require invasive monitoring. (Stroke. 2007;38:402-404.)

Key Words: head injury ■ neuromonitoring ■ transcranial Doppler ■ autoregulation ■ cerebral blood flow

Cerebrovascular autoregulation (CA) can be investigated by calculating the correlation coefficient between spontaneous slow changes in cerebral perfusion pressure (CPP), which is the difference between arterial blood pressure (ABP) and intracranial pressure (ICP), and cerebral blood flow velocity (FV) measured with transcranial Doppler. This correlation coefficient, termed Mx, has been validated in traumatic brain injury and subarachnoid hemorrhage.1,2 Mx is used for continuous CA assessment in intensive care, where ABP and ICP are routinely monitored. However, there are several other clinical conditions in which assessment of Mx would be valuable, such as stroke, autonomic disorders, recurrent syncope, migraine, liver failure, and eclampsia. These conditions require a completely noninvasive approach to the study of CA.

CA can also be estimated noninvasively by calculating the correlation coefficient between slow changes of ABP, evaluated with the use of a finger plethysmograph (noninvasive ABP [nABP]), and slow changes of FV measured with transcranial Doppler. This index, termed nMxa, was used for evaluation of CA in patients suffering from carotid artery disease.3

To our knowledge, no study has compared nMxa in respect to the invasive index of autoregulation Mx. Therefore, we investigated the degree of agreement between those 2 indices describing CA.

Methods

The study included severely head-injured adults admitted to the Neuro Critical Care Unit of Addenbrooke’s Hospital, Cambridge, UK. Patients were sedated and ventilated and treated following international standards for advanced trauma life support and head injury guidelines.4 ICP was monitored with Codman parenchymal probes (Johnson&Johnson Medical, Raynham, Mass). ABP was monitored invasively (ABP) through an arterial line positioned in the radial artery and connected to a pressure transducer (Baxter, Healthcare Cardiovascular Group) zeroed at heart level. ABP was monitored noninvasively (nABP) with a servo-controlled finger plethysmograph (Finapres2300, Ohmeda). The hand was kept steady at heart level.
CPP was calculated as the difference between ABP and ICP.

FV in both middle cerebral arteries was measured with transcranial Doppler (DWL-MultiDop, DWL). Two-megahertz probes were held in position by means of a purpose-built apparatus (LAM-Rack, DWL).

ICP, ABP, nABP, CPP, and FV were monitored simultaneously for a duration of 30 minutes daily. Monitoring of blood pressure and ICP and daily assessment of CA by transcranial Doppler are part of the clinical routine after severe head injury. The ethical committee was informed, and consents to publish recorded data were obtained.

ICP, ABP, nABP, CPP, and FV waveforms were captured digitally with a sampling rate of 50 Hz on bedside laptops running house-built software (ICM/H11001). Artifacts were removed offline. Mx was calculated as the correlation coefficient between CPP mean and FV, and nMxa was calculated as the correlation coefficient between nABP mean and FV mean (Figure 1).

To assess whether the nMxa is sensitive enough to identify the left-right asymmetry of CA, we compared the left-right differences of the 2 indices of CA.

Using transfer function analysis, we evaluated whether the Finapres nABP accurately replicates ABP slow waves (0.01 to 0.15 Hz). If Finapres slow waves can be detected as reliably as with the invasive ABP measurement, the simultaneous monitoring should yield a sufficient linearity (coherence >0.4), and slow waves should have similar amplitude ratios (transfer function gains approaching unity).

Correlations between indices were expressed as Pearson R correlation indexes and probability values. Limits of agreement were calculated according to Bland and Altman.

Results

Ninety-Six Recordings Were Obtained (48 for each hemisphere) in 10 Patients

Average ICP was 15.9±5.9 mm Hg. The average magnitude of ICP changes during the recordings was 5.0±7.3 mm Hg, ranging from 0.6 to 32.9 mm Hg.

The signal transmission from ABP to nABP in the low-frequency range was evaluated in terms of average coherence=0.90±0.08 and transfer function gain=1.33±0.93.

nMxa correlated positively with Mx (R=0.755, P<0.001; 95% agreement=±0.36; bias=0.01; Figure 2).

Asymmetry in autoregulation, calculated as nMxaright−nMxaleft, correlated positively with asymmetry in CA as-

Figure 1. nMxa calculation. Time trends of ABP (dashed line) and nABP (solid line), ICP, and FV (middle cerebral artery left), averaged over 8-second epochs. Mx and nMxa are calculated as the Pearson correlation coefficient of the 40-sample scatterplot of FV vs CPP and FV vs nABP, respectively.

Figure 2. Mx−nMxa. A, Scatterplot. B, Bland-Altman plot. Regression lines (solid) and 95% predictor limits (dashed) are shown.
Noninvasive Mxa has been validated previously in healthy volunteers with the Aaslid’s cuff test used as a reference method. However, no previous study verified this noninvasive approach in direct comparison to the Mx.

The limits of agreement between Mx and nMxa are ±0.36. Although nMxa satisfactorily describes CA in comparison to Mx ($R = 0.755$), the 2 indexes should not be used interchangeably.

Asymmetry in autoregulation suggests midline shift and is a predictor of fatal outcome after head injury. Autoregulation asymmetry may prompt brain imaging and allows optimization of CPP. To explore whether the noninvasive index could describe interhemispheric differences in CA, we plotted $M_{x\text{left-right}}$ against $nM_{xa\text{left-right}}$. Good correlation ($R = 0.857$) indicates that nMxa has an acceptable capability of detecting asymmetry in CA.

**Conclusion**

nMxa is proposed as a practical tool to assess CA in patients who do not require invasive monitoring. nMxa is an adequate approximation of Mx, and the application of the completely noninvasive index nMxa may be of importance in many fields of clinical research and practice.

**Acknowledgments**

The authors are indebted to the whole team participating in data collection and all the nursing and research staff on the Neurosciences Critical Care Unit.

**Sources of Funding**

Drs Czosnyka and Smielewski are supported by Medical Research Council grant G9439390, ID 65883. Dr Czosnyka is on unpaid leave from Warsaw University.

**Disclosures**

ICM+ software (www.neurosurg.cam.ac.uk/icmplus) is licensed by University of Cambridge, Cambridge, UK, and Drs Smielewski and Czosnyka have a financial interest in the fraction of licensing fee.

**References**

Noninvasive Evaluation of Dynamic Cerebrovascular Autoregulation Using Finapres Plethysmograph and Transcranial Doppler
Andrea Lavinio, Eric Albert Schmidt, Christina Haubrich, Piotr Smielewski, John D. Pickard and Marek Czosnyka

Stroke. 2007;38:402-404; originally published online January 11, 2007;
doi: 10.1161/01.STR.0000254551.92209.5c
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2007 American Heart Association, Inc. All rights reserved.
Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/38/2/402

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Stroke can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Stroke is online at:
http://stroke.ahajournals.org//subscriptions/