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

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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 = arterial blood 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.5

**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 nMxain−nMxairt, correlated positively with asymmetry in CA as-

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**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.
Discussion

This study explored the feasibility and accuracy of a completely noninvasive approach to dynamic CA.

The use of noninvasive nMxa implies 2 assumptions: (1) negligibility of ICP changes on CA calculation and (2) accuracy of Finapres ABP slow-wave estimation.

The assumption of considering the magnitude of ICP changes negligible in respect to CA assessment was verified in a previous report and confirmed by our results. We must, however, emphasize that CA evaluation does not substitute for ICP monitoring, the latter allowing recognition of intracranial hypertension and CPP management. Invasive Mx should be considered the reference method for CA assessment in head-injured patients.

The assumption that Finapres nABP accurately replicates the slow waves of ABP was proven with transfer function analysis. Coherence and transfer function gain close to unity indicate that (1) the transmission from ABP to nABP is linear and (2) there is no significant dampening or amplification of the signal, respectively. The correct use of the Finapres device (adequate finger cuff size, hand kept steady at heart level) accurately replicates ABP slow waves, supporting the strong correlation between nMxa and Mx.

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 Mx_{left-right} against nMxa_{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.

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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

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