Transcranial Doppler Measurement of Middle Cerebral Artery Blood Flow Velocity: A Validation Study


SUMMARY Measurement of intracranial arterial blood flow velocity is a new technique with potentially a number of very useful applications. This study validates the technique by comparing it to cerebral blood flow (CBF) measured using intravenous Xenon133 and extracranial clearance recording. We have measured the middle cerebral artery (MCA) blood flow velocity in 17 symptomatic patients with the EME TC 264 transcranial Doppler velocimeter and compared these measurements to the ipsilateral hemispheric cerebral blood flow measured with an intravenous Xenon133 technique (Novo Cerebrograph 10A). Measurements were made at rest and during hypercapnia.

The absolute measurement of MCA velocity and hemispheric CBF showed a poor correlation (r = 0.424, p < 0.01) due to wide between-patient variations at rest but the blood flow response to hypercapnia, expressed as a reactivity index, showed a good correlation (r = 0.849, p < 0.001).

Thus changes in MCA velocity reliably correlate with changes in cerebral blood flow but the absolute velocity cannot be used as an indicator of CBF.

The use of Doppler to measure blood flow velocity in intracranial arteries is a new technique, which has a number of potentially useful applications. It has been advocated as a method of peroperative monitoring during carotid endarterectomy when it can provide continuous on-line information about middle cerebral artery velocity, information of particular importance when the common carotid artery is clamped in deciding which patients need shunting. It may also be used to predict preoperatively whether or not the use of an indwelling shunt is necessary. Another use for the technique has been in the assessment of cerebrovascular spasm following subarachnoid hemorrhage and furthermore measurement of blood flow velocity in the middle cerebral artery, anterior cerebral artery and posterior cerebral artery combined with common carotid compression can provide information on the integrity of the Circle of Willis.

In an attempt to show that Doppler measured middle cerebral artery velocity corresponds to cerebral blood flow, a number of workers have performed hypercapnia stress tests and measured the resulting increase in middle cerebral artery velocity. However, this only provides indirect proof of the validity of these measurements. Therefore, we have measured the response to hypercapnia of both the middle cerebral artery velocity and the cerebral blood flow measured with an intravenous Xenon133 technique. A good correlation between the two methods would provide direct evidence that middle cerebral artery velocity changes actually reflect changes in cerebral blood flow.

Methods

Patients

In order to get a wide spread of response to hypercapnia, we have studied 17 symptomatic patients with cerebrovascular disease aged between 41 and 70 years (mean 61); providing 34 middle cerebral arteries for study. In 11 instances, the ipsilateral internal carotid artery was totally occluded and in the remaining 23 was patent.

Measurement of MCA Velocity

The probe of the EME TC 264 2MHz pulsed transcranial Doppler velocimeter was placed against the side of the skull just above the zygomatic arch and the sample depth volume altered until the trunk of the MCA was being insonated. The mean of 15 measurements of MCA peak velocity was taken to represent the mean MCA peak velocity in cm/sec.

Measurement of CBF

Cerebral blood flow was measured using the Novo Cerebrograph 10a. Approximately 10mCi of Xenon133 dissolved in normal saline was injected into an arm vein as a bolus and flushed through with normal saline. Clearance was monitored by five scintillation detectors positioned over the MCA territory of each hemisphere and the hemispheric blood flow calculated from the means of a one minute initial slope analysis of the five clearance curves. End expiratory Xenon133 concentration was continuously monitored to allow for the effect of arterial recirculation.

Response to Hypercapnia

Hypercapnia was induced by giving a mixture of 5% CO2 and 95% air through a non-return valve connected to an anaesthetic mask. End expiratory CO2 was continuously monitored by drawing off a sample from the mask by a line connected to a PK Morgan 901.2 infrared CO2 analyser.

The patients lay supine until the end expiratory CO2 was stable. The resting measurement of either MCA velocity or CBF was then performed. The inspired air was then switched to 5% CO2 in air and when the end expiratory CO2 became stable a further measurement of either MCA velocity or CBF performed. In the case
FIGURE 1. CBF (ml/100 g/min) measured using Xenon\textsuperscript{133} compared to ipsilateral MCA peak velocity (cm/sec) measured using Doppler ($r = 0.424$, $p < 0.01$).

of Xenon\textsuperscript{133} CBF measurements, the hypercapnic measurement was done at least one hour after the resting study in order to allow for complete excretion of the first dose of Xenon\textsuperscript{133}.

Results

There was a wide range of resting hemispheric CBF, from 24.2 ml/100g/min to 49.8 ml/100g/min, and resting MCA peak velocity, from 36 cm/sec to 140 cm/sec. When resting CBF was compared to resting MCA velocity, the correlation was poor ($r = 0.424$) although it did reach statistical significance ($p < 0.01$) (fig. 1).

The response to hypercapnia of both CBF and MCA peak velocity was expressed as a reactivity index in order to relate the increase of flow to the increase in end tidal CO\textsubscript{2}.

Reactivity index for MCA velocity: % change in Peak Velocity (cm/sec) per unit change end tidal CO\textsubscript{2}.
Reactivity index for CBF: % change CBF (ml/100 g/min) per unit change end tidal pCO\textsubscript{2}.

MCA velocity reactivity ranged from zero to 21.4 and CBF reactivity ranged from 0.3 to 6.6. When the reactivity measured in these two ways was compared, the correlation was excellent ($r = 0.849$) and highly significant ($p < 0.001$) (fig. 2).

Discussion

Previous attempts at validating the technique of transcranial measurement of arterial blood flow velocity have indicated indirectly that such measurements reflect cerebral blood flow. This has been done by showing a reduction of MCA velocity on carotid cross clamping during carotid endarterectomy\textsuperscript{2,3} or by relying on the known cerebral vasodilator properties of CO\textsubscript{2}\textsuperscript{12} and showing that MCA velocity increases with hypercapnia\textsuperscript{9,10}.

However direct validation of the technique requires correlation with an existing method. The measurement of cerebral blood flow by intravenous Xenon\textsuperscript{133} and extracranial clearance recording is a well proven method of measuring cerebral blood flow\textsuperscript{13,14} and the response to hypercapnia well documented\textsuperscript{15,16}.

We have shown a poor correlation between absolute measurements of cerebral blood flow and MCA velocity (fig. 1). This is because of the wide variation found in the normal range. However when we compared the response to hypercapnia measured using these two methods, the correlation is excellent (fig. 2). Therefore we suggest that MCA velocity measurements give an accurate indication of changes in cerebral blood flow.

FIGURE 2. CBF reactivity to hypercapnia (% change CBF/mm Hg change CO\textsubscript{2}) measured using Xenon\textsuperscript{133} compared to MCA velocity reactivity to hypercapnia (% change velocity/vol % change CO\textsubscript{2}) measured using Doppler ($r = 0.849$, $p < 0.001$).
flow but that the absolute measurement of velocity is an unreliable indicator of cerebral blood flow.

The Xenon technique is invasive and expensive, and so the use of Doppler would be of benefit in situations where changes in CBF are monitored. Such situations might include screening patients with a hypercapnic stress test to discover those patients that are already maximally vasodilated as there is some evidence that they may benefit from revascularization.15,18

In addition to its simplicity and non-invasive technology the Doppler method has another important advantage over the Xenon method in that it can provide continuous on-line information. It can therefore be used to monitor situations where cerebral blood flow may fall to critical levels such as during cardiac or carotid artery operations or in severely ill patients in the ITU.

Acknowledgments

We would like to thank Medelec for the loan of the EME TC 264 transcranial Doppler velocimeter.

This work has been carried out as part of the requirement for the degree of MChir of the University of Cambridge (CCRB).

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Stroke. 1986;17:913-915
doi: 10.1161/01.STR.17.5.913

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