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Diagnosis of Middle Cerebral Artery Stenosis by Transcranial Color-Coded Real-Time Sonography

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BACKGROUND & PURPOSE: **This study was performed to determine the usefulness of transcranial color-coded real-time sonography (TCCS) in detecting stenosis in the horizontal portion of the middle cerebral artery (MCA).**

METHODS: **Using TCCS and the incident angle correction technique, we measured the peak-systolic flow velocity in bilateral MCAs in 45 consecutive patients in whom cerebral angiography was carried out within 1 week before or after TCCS. Three patients had a stenosis of 75% or greater and four had a unilateral occlusion of the extracranial internal carotid artery (ICA) (the ICS and ICO groups, respectively). Eight patients had a stenosis of 50% or greater (one bilateral and seven unilateral) (the M_1S group). Four patients had unilateral distal occlusion of the horizontal portion of the MCA (the M_1O group). Twenty-six patients had no significant extra- or intracranial stenosis on the ipsilateral or contralateral side (the control group).**

RESULTS: **Mean peak-systolic flow velocity on the affected side was 83.0 ± 20.8 cm/s in the ICS group, 59.8 ± 23.2 cm/s in the ICO group, and 62.3 ± 33.7 cm/s in the M_1O group. In the control group, the mean peak-systolic flow velocity was 116.0 ± 31.5 cm/s. In the M_1S group, however, the mean peak-systolic flow velocity (334.2 ± 35.7 cm/s) on the affected side always exceeded 180 cm/s (mean value ± 2 SD in the control group), and was significantly higher than that in the other groups. The mean peak-systolic flow velocity in the M_1S group increased with the grade of stenosis.**

CONCLUSION: **The M_1S group members could easily be distinguished from the other group members by their peak-systolic flow velocity in excess of 180 cm/s. Measurement of the peak-systolic flow velocity of the MCA by TCCS may help to identify a significant stenosis in the horizontal portion of the MCA.**

Since 1982, when Aaslid et al (1) demonstrated Doppler signals from the arteries at the skull base through the temporal window, transcranial Doppler (TCD) sonography has been widely used to evaluate intracranial hemodynamic alterations, vasospasm after subarachnoid hemorrhage, intracranial arterial stenosis, and arteriovenous malformations (2–4).

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In the early 1990s, a new method, transcranial color-coded real-time sonography (TCCS) was introduced, and added real-time B-mode imaging and color coding of the Doppler signal to conventional TCD sonography (5–7). As a result of the B-mode and color-coded Doppler facilities, one can more readily and confidently identify a particular vascular structure with TCCS than is the case with TCD. Additionally, TCCS allows the investigator to measure the angle of insonation and to obtain flow velocities that are closer to true value than is possible with TCD.

The peak-systolic flow velocity is considered to be useful for grading arterial stenosis because it increases with the progression of an arterial stenosis (8). Therefore, we set out to investigate whether it was possible to detect a significant stenosis in the horizontal portion of the middle cerebral artery (MCA) with TCCS by measuring peak-systolic flow velocity.

Methods

Between April 1, 1997, and August 30, 1997, 47 patients had TCCS examinations within 1 week before or after cerebral angiography. Two patients with MCA occlusion at its origin were excluded because flow images of the MCA could not be obtained. Thus, 45 patients (37 men and eight women; mean age, 59 ± 12 years) were included in the study.

On the basis of angiographic findings, we divided the 45 patients into the following five groups: the internal carotid artery (ICA) stenosis (ICS) group, consisting of three patients with unilateral extracranial ICA stenosis (≥75%); the ICA occlusion (ICO) group, containing four patients with a unilateral extracranial ICA occlusion; the MCA stenosis (M_1S) group, including seven patients with unilateral and one with bilateral stenosis (≥50%) of the horizontal portion of the MCA; the MCA occlusion (M_1O) group, made up of four patients with a unilateral distal occlusion of the horizontal portion of the MCA; and the control group, which included 52 vessels in 26 patients with no stenotic lesions (<50%) in the bilateral carotid systems.

In the ICS, ICO, M_1S, and M_1O groups, 19 patients had atherothrombotic infarction in the carotid system, one had a lacunar infarction, and one had had a transient ischemic attack. In the control group, 11 patients had lacunar infarction, eight had cardioembolic infarction, four had had transient ischemic attacks, two had brain hemorrhage, and one had epilepsy.

The equipment used included a commercially available TCCS system and a transducer that operated at 2 to 3 MHz for B-mode imaging and Doppler functions. The pulse repetition frequency was mainly 3700 Hz (range, 3700 to 10,000 Hz), and the low-pass filter was 50 Hz.

The cerebral angiogram was imported into a computer system and an image of the MCA on the angiogram was magnified about three times to enable accurate measurement. Then, the percentage of stenosis was calculated by measuring the diameter at the stenotic lesion and at an adjacent intact portion.

We routinely obtained color Doppler flow images and measured flow velocity at MCAs on both sides by pulsed Doppler. The subjects were examined first in the left and then in the right lateral decubitus position. Blood flow velocity and direction were displayed in real time as color signals within a subsector of the black-and-white image through a temporal bone window. Particular care was taken to obtain a long-axis view of the aimed vessel, especially of the horizontal portion of the MCA, by means of tilting, rotating, or shifting the transducer.

Range-gated pulsed Doppler imaging, with a sample volume of 2 mm, was used to measure the blood flow velocity in the MCA. The sample volume was moved slowly from proximal to distal of the horizontal segment of the MCA, displayed as color flow on B-mode images, and the highest flow velocities during five consecutive cardiac cycles were obtained. We calculated the mean value of measured peak-systolic flow velocities corrected with an incident angle. Particular care was taken to keep the incident angle between the MCA and the beam at 60° or less.

The patients' age and flow velocity data were expressed as mean ± SD. For the analysis of velocity data among the five groups, we used the one-way factorial ANOVA. The regression analysis was performed using Cricket Graph software (version 1.3.2) between a peak-systolic flow velocity and percentage of stenosis by angiographic measurements in the M_1S group. A value of $P < .05$ was accepted as a significant difference.

Results

The peak-systolic flow velocity on the affected side was 83.0 ± 20.8 cm/s in the ICS group, 59.8 ± 23.2 cm/s in the ICO group, 62.3 ± 33.3 cm/s in the M_1O group, and 116.0 ± 31.5 cm/s in the control group. All values were less than 180 cm/s (mean value + 2 SD in the control group). There was no difference among the four groups.

In the M_1S group, however, the peak systolic flow velocity (334.2 ± 35.7 cm/s) on the affected side was significantly higher than that in the other four groups ($P < .0001$) (Figs 1 and 2). The values always exceeded 180 cm/s. Therefore, patients in the M_1S group could accurately be distinguished from those in the other groups by their peak-systolic flow velocities above 180 cm/s.

The peak-systolic flow velocities in the M_1S group increased with the grade of stenosis ($r = .87$, $P = .001$).

Discussion

In this study, patients in the M_1S group had a significantly higher peak-systolic flow velocity than did those in the other groups. A stenosis of the horizontal portion of the MCA greater than 50% could be distinguished perfectly from stenoses in any of the other groups by a cutoff point of peak-systolic flow velocity of 180 cm/s.

TCD recordings of flow velocity were reported to be useful for evaluating intracranial occlusive arterial lesions (4, 9–15). The TCD technique, however, has several problems. Precise placement of the sample volume as well as angle correction are not possible in the conventional TCD technique, and therefore it cannot be used for measuring absolute flow velocities. On the other hand, TCCS can be used to image the horizontal portion of the MCA and to measure absolute flow velocity (7), making this a more useful technique than TCD for assessing hemodynamics of the MCA.

In previous studies, application of TCD to the diagnosis of a stenosis of the horizontal portion of the MCA was based on increased peak systolic and mean flow velocities, spectral broadening, low-frequency bidirectional signals during systole, and arterial wall covibrations (9–11). It has been reported that the sensitivity of TCD in detecting MCA stenosis (≥50%) ranged from 75% to 86%, and its specificity exceeded 93% (9, 10). The elevation of peak-systolic flow velocities ranged from 150 to 250 cm/s in stenotic lesions of the horizontal portion of the MCA (9–11). In TCD examinations, the angle between the Doppler beam and the horizontal portion of the MCA is assumed to range from 0° to 30°, so its cosine would vary between 1.00 and 0.86 (12). When a velocity of 150 cm/s measured by TCD is corrected with a cosine of 30°, it would become 173 cm/s. This value, 150 cm/s, for a stenosis of the horizontal portion of the MCA as measured with TCD perhaps coincides with our cutoff value of 180 cm/s, measured with TCCS.

Our study indicates an excellent correlation between flow velocity and grade of stenosis on cerebral angiography. In previous TCD studies, an increased flow velocity corresponding to the grade of stenosis in the MCA has been described (13). However, Bray et al (9) reported that it was not uncommon to find similar flow velocities among patients with different degrees of MCA stenosis. These discrepant TCD

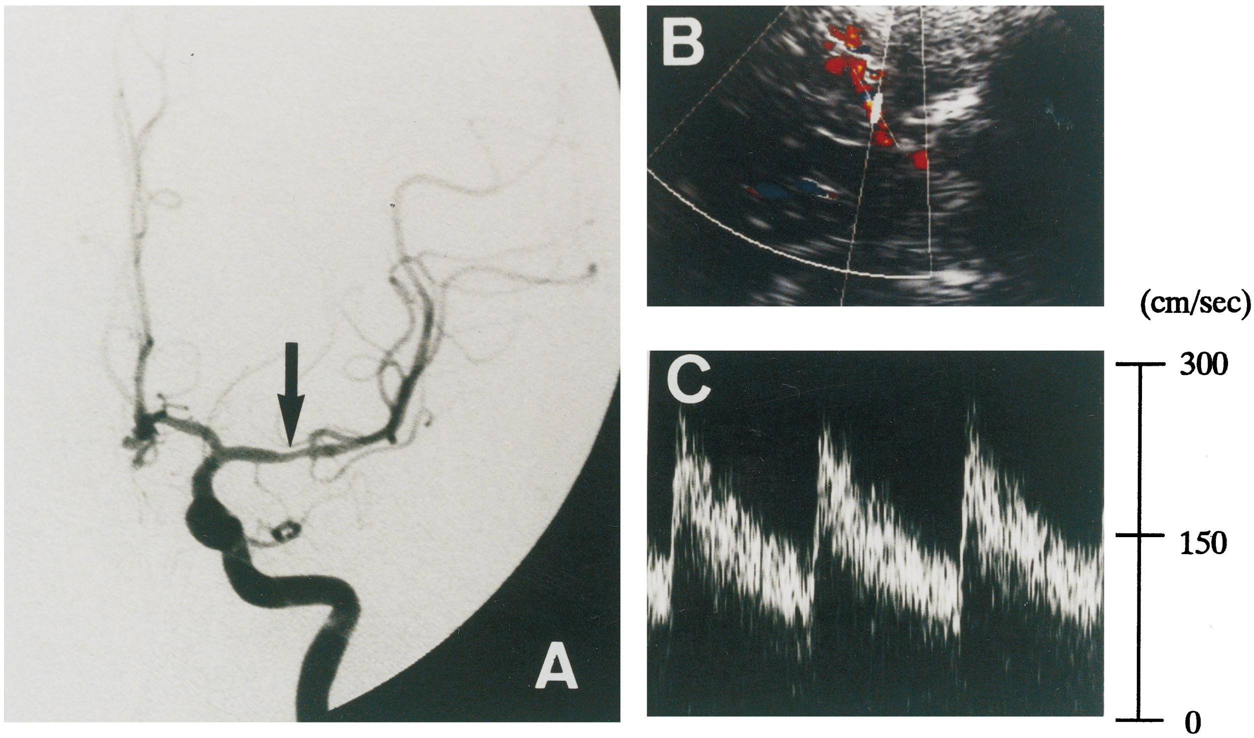

FIG 1. A representative case of MCA stenosis evaluated with cerebral angiography and transcranial color-coded real-time sonography.
A, Left carotid angiogram, anteroposterior view, shows a 50% stenosis in the left MCA (*arrow*).
B. Transcranial color-coded real-time sonogram shows the MCA (in *red*), indicating flow toward the transducer. The sample volume is situated in the MCA. The angle between the Doppler beam and the vessel is adjusted (48°).
C, Doppler waveforms of the left MCA show the peak-systolic flow velocity is 281 cm/s.

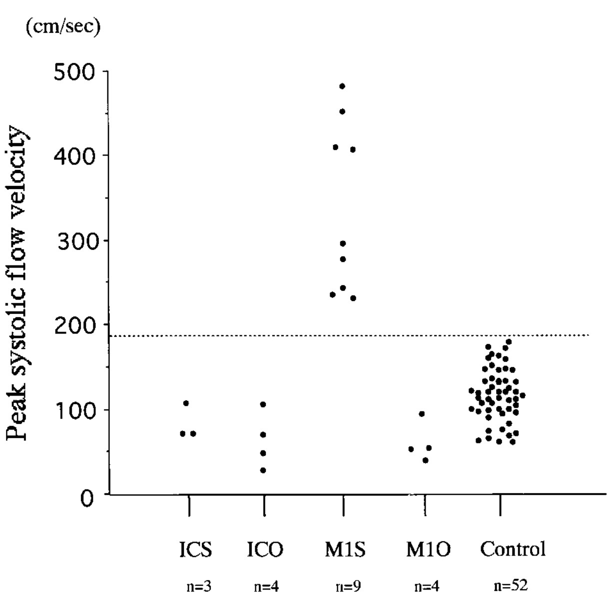

FIG 2. Comparison of peak-systolic flow velocity among the groups. In the M_1S group, the peak-systolic flow velocity was significantly higher than that in the ICS, ICO, M_1O, and control groups ($P < .0001$). *Dotted line* indicates the mean + 2 SD value of the peak-systolic flow velocity (180 cm/s) in the control group. ICS, stenosis (>75%) of the extracranial ICA; ICO, occlusion of the extracranial ICA; M_1S, stenosis (≥50%) of the horizontal portion of the MCA artery; M_1O, occlusion of the horizontal portion of the MCA artery; and Control, no significant arterial lesions in the carotid system.

findings are probably attributable to inaccurate measurements of MCA flow velocity by TCD.

Conclusion

Recently, we reported that end-diastolic flow velocity as measured with TCCS might help to identify the site of occlusion in the horizontal portion of the MCA (16). In this study, we demonstrated that peak-systolic flow velocity may be useful to quantitate the degree of stenosis in the horizontal portion of the MCA. We conclude that in any evaluation of occlusive lesions in the MCA with TCCS, it is important to measure both the peak-systolic and end-diastolic flow velocities.

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