Short-term Prognosis of Stroke Due to Occlusion of Internal Carotid Artery Based on Transcranial Doppler Ultrasonography

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Background and Purpose: **The clinical course of stroke due to occlusion of the internal carotid artery is influenced by amount of collateral flow. We measured mean frequency shifts in the middle cerebral artery by transcranial Doppler ultrasonography to determine its prognostic value.**

Methods: **Patients with proven extracranial occlusion of the internal carotid artery and ipsilateral hemispheral stroke were enrolled in our study. We performed transcranial Doppler ultrasonography on 31 patients within 48 hours after the stroke onset and followed up 25 patients in 28 days. At the same time, neurological examination with quantification of neurological deficit was done. We correlated values of flow frequency shifts on the side of stroke with degree of neurological deficit at the onset and at 28 days as well as the degree of clinical improvement and the value of frequency shifts.**

Results: **We found a negative correlation between blood flow frequency shifts in the middle cerebral artery and degree of neurological deficit at the onset (Spearman rank correlation coefficient, −0.567; $p<0.001$). We also found a positive correlation between the change of the neurological deficit during follow-up and frequency shifts at the onset (Spearman rank coefficient, 0.548; $p<0.05$).**

Conclusions: **Diminished blood flow velocity (mean frequency shift) in the area of stroke is a negative prognostic factor for the degree of neurological deficit at the onset and a negative prognostic factor for possible improvement. Knowledge of hemodynamic conditions in the stroke area may help to improve therapeutic decisions. (*Stroke* 1992;23:1069–1072)**

KEY WORDS • carotid artery diseases • prognosis • ultrasonics

The prognosis of stroke is of prominent interest to many authors because of its social and medical relevance. The degree of neurological deficit, reflecting extent and duration of brain ischemia, must be taken into consideration in predicting long-term prognosis.[1–4] Differences of opinion exist concerning the relations between flow velocities measured by Doppler ultrasonography and regional cerebral blood flow. Estimation of the hemodynamic changes caused by occlusion of an artery can be obtained by the evaluation of flow velocities in the vessels distal to the occlusion.[5–7] In our study we compared flow velocities on the side of the occlusion with the grade of neurological deficit, and we determined the value of transcranial Doppler ultrasonography for short-term prognosis of stroke outcome.

Subjects and Methods

Our study included patients hospitalized at the First Neurological Clinic, University Hospital, Bratislava, Czechoslovakia, from October 1988 to November 1990 who met the following criteria. All patients had unilateral hemispheric stroke, angiographically or ultrasonographically proven complete occlusion of the extracranial portion of the ipsilateral internal carotid artery (ICA), and were examined within 48 hours after the onset of neurological deficit. Patients with bilateral carotid occlusion were excluded.

These criteria were met by 37 patients. Another condition was bilateral detectability of middle cerebral artery (MCA) by ultrasonographic examinations. Six patients did not have bilateral MCA flow signal and will be discussed as a separate group. Of the 31 patients, 20 were men and 11 women. Average (mean±SD) age was 63.1±13.2 (range, 29–73) years. During the study period, six patients died (4 men and 2 women, average age 62.4±8.1 years). Four died of pulmonary artery embolization and two of brain stem compression due to swelling of the cerebral infarction. Therefore, follow-up examination was done in 25 patients.

Diagnosis of occlusion of ICA was verified by catheterization angiography of the ipsilateral common carotid artery. Four patients were studied by ultrasonography alone. Ten patients had occlusion of the right ICA and 21 occlusion of the left ICA. Ultrasonographic examination was performed on the day of admission and 28 days after the stroke onset. On the same days, neurological examination was performed with quantification of neurological deficit. Every patient was examined neurologically and ultrasonographically during follow-up by one examiner. Clinical examination was always done before ultrasonography.

Twenty-six patients underwent x-ray computed tomographic examination, which in all cases showed ischemic

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TABLE 1. Mean Shift Frequencies, Mean Flow Velocities, and Pulsatility Index in Middle Cerebral Artery During Follow-up of 25 Patients

Parameter	Occlusion side		Contralateral side	
	First exam	Day 28	First exam	Day 28
Mean shift frequency in MCA (Hz)	893.3±417.7*	1148.6±433.3	1526.0±532.9*	1477.1±576.8
Mean velocity in MCA (cm/sec)	34.8±16.3*	44.8±17.9	59.5±20.8*	57.6±22.5
Pulsatility index	0.84±0.37	0.93±0.41	1.08±0.22	1.13±0.24

Values are mean±SD. Comparison of mean shift frequencies from first examination on the side of occlusion and contralateral side were significant; other values were not significant. MCA, middle cerebral artery.
*$p<0.01$ by Student's t test.

brain infarction ipsilateral to the side of the occlusion of ICA. All patients underwent echocardiography, which did not reveal cardiac sources of embolization. All patients were treated with standard therapeutic procedures used at our clinic, and all received standard rehabilitation procedures as indicated.

Intracranial vessel examination was performed using a pulsed-wave instrument with a 2-MHz probe (TC 2–64, EME, Uberlingen, FRG). The signal was processed by fast-Fourier transformation spectral analysis. We evaluated systolic, diastolic, and mean velocities. We used frequency velocity (in Hertz) in our laboratory, which is equivalent to Doppler frequency shift. Velocity in centimeters per second can be calculated by the formula $v=0.039\times f$. Pulsatility index was calculated according to the formula PI=(systolic shift−diastolic shift)/mean shift.[8]

We used the transtemporal approach described by Aaslid et al[9] in 1982. The MCA was evaluated at a depth of 45–60 mm; MCA shift frequency was calculated from the mean of four values. The signal from the anterior cerebral artery (ACA) was obtained at a depth of 65–75 mm. Collateral flow in the anterior communicating artery was evaluated as the response to compression of extracranial carotids.[10]

Ultrasonographic examination of the extracranial segment of carotid vessels was performed using a Phase II duplex instrument (Biosound, Indianapolis, Ind.) The patients for whom angiography was not accomplished were diagnosed as having complete occlusion of the ICA at its origin by duplex ultrasonography.

We adopted the scoring system designed by Bartko and Danisova[11] in 1977. The scale evaluates 16 subsystems, including pyramidal tract impairment, sensory deficit, cerebellum and cranial nerves involvement, alteration in consciousness, and neuropsychological and language impairments. Every subsystem is scored from 1 point (normal) to 6 or 8 points (most abnormal). The grade of neurological deficit is calculated according to the formula $K+N/K-n\times100$, where K is equal to 16 (basic value of a normal, healthy individual), N is the sum of points from every impaired subsystem, and n is the number of involved subsystems.

A normal finding is equal to 100 points. Scores up to 140 points indicate a mild neurological deficit; up to 180 points, a moderate deficit; and over 180 points, a severe neurological deficit.

The MCA Doppler mean frequency shifts and the pulsatility indexes on the initial and follow-up exams on the healthy and occluded sites were compared with Student's t test. The frequency shifts and pulsatility indexes were correlated with the stroke severity scale by Spearman rank-order correlation analysis. Sensitivity and specificity of clinical outcome prognosis was calculated for different values of mean frequency shifts.

Results

The average time of the first examination (clinical and ultrasonographic) after stroke onset was 35 hours; 12 patients were examined before 24 hours and 19 between 24 and 48 hours.

We excluded six patients because of undetectable signals from the MCA (in four cases the echo-free area was on the occluded side, and in two the echo-free area was on both sides of the temporal window). Of the patients with the undetectable signal on the side of the stroke, one patient died, and occlusion of the MCA was not found on autopsy. The other three were examined on day 28; in two patients, signals from the ischemic side were detected on repeated examination. Both patients with bilateral undetectable signals on the first examination remained echo-free during the follow-up.

Baseline ultrasonography of extracranial and intracranial ICAs on the contralateral side of the stroke showed no stenosis over 30% in any patient.

The mean neurological deficit at the first examination was 184.6 points (range, 133–262). The mean neurological deficit on day 28 was 156.3 points (range, 100–220). Average improvement during the follow-up was 38.2±25.4 (mean±SD) points.

Values of mean frequency shifts (also calculated velocities) in the MCA and pulsatility indexes are shown in Table 1. Mean frequency shifts in the MCA during the first examination were depressed on the side of the occlusion compared with the contralateral side ($p<0.01$). However, changes of frequency shifts on day 28 were not significant. Pulsatility indexes were lowest on the side of occlusion at the first examination. Neither comparison to values on day 28 on the same side nor to those on the contralateral side on day 1 was statistically significant.

At the first examination, the neurological deficit was negatively correlated with the mean frequency shift in the MCA on the occluded side ($r=-0.567$, $p<0.001$; Figure 1). The change in deficit from onset to day 28 was positively correlated with the initial MCA mean frequency shift ($r=0.548$, $p<0.05$; Figure 2), although there was no significant correlation between change in mean frequency shift and change in disability ($r=0.187$, NS). The relation between pulsatility index and grade of neurological deficit were in same directions as the mean frequency shifts, but none was statistically significant.

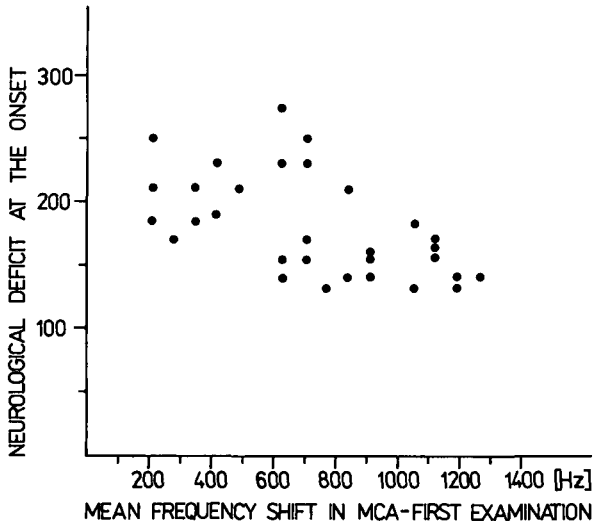

FIGURE 1. *Plot of negative relation between severity of neurological deficit at onset and mean shift frequencies in middle cerebral artery (MCA). Patients with values lower than 600 Hz (approximately 23.4 cm/sec) had highest degree of neurological impairment.*

We calculated the sensitivity and specificity for improvement of neurological deficit of less than 38 points (the average value of change during the follow-up in our patients) in MCA evaluation obtained at the first examination. For a frequency shift of 800 Hz (31.2 cm/sec), sensitivity was 0.87 and specificity 0.60 for less-than-average outcome.

Discussion

Blood flow distal to the site of occlusion is dependent on collateral flow, the amount of which may influence clinical course after stroke. There are instances in which occlusion of the extracranial portion of ICA is asymptomatic, while in others a similar situation can result in death. This is, however, a simplification of the problem because many other factors affect the ischemic area and exact analysis is difficult.[12,13]

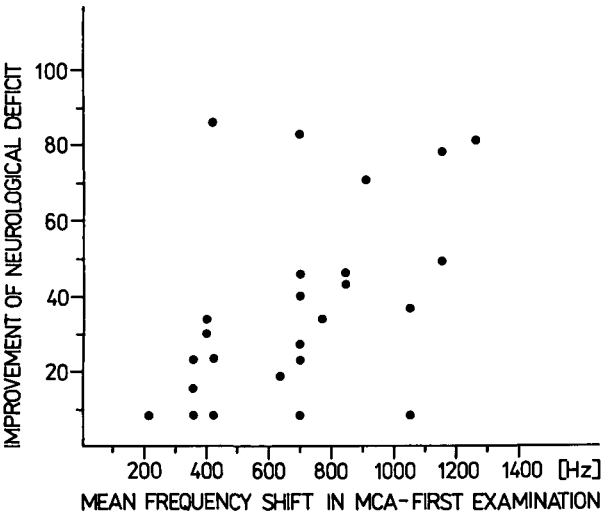

FIGURE 2. *Plot of positive relation between improvement of neurological deficit in 28 days and mean shift frequency in MCA at first examination. Patients with values lower than 800 Hz (approximately 31.2 cm/sec) had lower degree of improvement than average (38 points), with sensitivity of 0.87 and specificity of 0.60.*

We selected a group of patients with similar mechanisms of stroke caused by occlusion of extracranial segment of ICA. It was impossible to deduce the rapidity of arterial obstruction, which influences the development of collateral pathways.[13] We did not include patients with undetectable flow signal in the MCA because a coincidental intracranial occlusion of the horizontal segment of the MCA could not be excluded. Occlusion of this artery changes the pathways of collateral flow, which cannot be measured ultrasonographically. Whether these patients have occlusion of the MCA or whether failure to detect a signal from the vessel is caused by other conditions is impossible to determine by transcranial Doppler ultrasonography. Even detection of an MCA signal after 28 days is not necessarily attributed to recanalization of the lumen. The relation between stroke prognosis and an undetectable signal from the MCA will require further study.

Our results suggest that low flow velocities in the area of ischemia are related to the severity of neurological impairment at the time of stroke onset. Depression of flow velocities as measured by transcranial Doppler ultrasonography in the initial stage of infarction is an unfavorable prognostic sign. Decrease of mean frequency shift on the side of ischemia is actually a less favorable prognostic factor than only severe neurological deficit, although both findings are often parallel.

Patients with mean frequency shifts of less than 800 Hz (31.2 cm/sec) in the MCA on the side of occlusion tended to have poorer clinical outcome. Transcranial Doppler ultrasonography had the highest sensitivity and specificity for prediction of less than average improvement in our group at this frequency shift. Identification of patients with possibly worse prognoses with high sensitivity is important for further therapeutic decisions. Other authors who studied the prognostic value of transcranial ultrasonography also considered the value of 30 cm/sec mean MCA velocity as the borderline for indicating better prognosis.[14,15] The subgroup of our patients with mean MCA frequency shifts lower than 600 Hz had an especially unfavorable clinical course with the lowest degree of improvement. The frequency shift 600 Hz corresponds to 23.4 cm/sec (using the coefficient 0.039). It is still questionable whether such low velocities are caused by occlusion of the branches of the MCA or by inadequate collateral pathways. The most likely explanation is that both possibilities may play a role.

The trend toward lower pulsatility indexes in patients with extracranial carotid occlusion has been described previously.[10] It reflects compensatory vasodilatation and lower peripheral resistance behind the occluded vessel. In our study, pulsatility index did not correlate with measures of neurological deficit. However, the tendency toward decreased pulsatility index at the time of onset in patients with more severe clinical impairment may indicate insufficient collateral flow and, thus, more profound hypoperfusion of the ischemic area.

For each patient, baseline and follow-up clinical and ultrasonographic examinations were performed by the same investigator, with the clinical examination always

preceding ultrasonography. Although this may be a source of potential bias, a knowledge of the result of the clinical examination should not influence the results of transcranial ultrasonography because the highest frequency signal of best possible quality was recorded for further analysis.

The interval that passes after the onset of stroke is important for assessment of the depression of flow velocities (and for hypoperfusion as well). We set a time limit of up to 48 hours to avoid reactive hyperemia in the ischemic area. A shorter interval would have been preferable, but most of the patients were not referred to us at the earlier time. Halsey[14] found a relation between the degree of clinical improvement and flow velocities measured by transcranial ultrasonography up to 12 hours after the onset of stroke. Our results suggest that examination done up to 48 hours after the onset might be clinically helpful.

Only the frequency shifts from the first examination had predictive value for prognosis and also correlated with the degree of clinical impairment. On the other hand, frequency shifts from day 28 did not show the same correlation, either in the values on day 28 or in the differences of the velocities during the follow-up. However, the mean frequency shifts in the MCA on the side of occlusion remained lower than those on the contralateral side. These are known findings in patients with the occlusion of the extracranial segment of the ICA without specification of duration of neurological symptomatology.[10,16] Yamauchi et al[17] analyzed a similar group of patients using positron emission tomography. They measured blood flow with $C^{15}O_2$ and blood volume with $C^{15}O$ and found hypoperfusion in the region of MCA on the side of extracranial occlusion of the ICA in all patients with different durations of stroke. We think that lack of correlation between frequency shifts on day 28 and the degree of improvement of the neurological deficit is caused by unequal dynamics of resolution of focal brain ischemia.

Transcranial Doppler ultrasonography has an established place as a diagnostic procedure in patients with stroke for diagnosis of anatomic conditions or determination of hemodynamic situations in the infarcted area. Our data suggest that ultrasonographic examination may have a role in estimation of the prognosis of stroke based on blood flow velocities with satisfactory sensitivity and specificity.

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