Monitoring of Increased Intracranial Pressure Resulting From Cerebral Edema With Transcranial Doppler Sonography in Patients With Middle Cerebral Artery Infarction

Talip Asil, MD, Ilkay Uzunca, MD, Ufuk Utku, MD, Ufuk Berberoglu, MD

Objective. Cerebral herniation resulting from postischemic brain edema is the most common cause of death in patients with large cerebral infarctions. Early monitoring of intracranial pressure and application of necessary treatment procedures may have life-saving value. In this study, the data obtained by transcranial Doppler sonography were compared with clinical examination and the neuroradiologic findings. Methods. Eighteen patients with first-ever strokes and large middle cerebral artery infarction who were admitted within the first 12 hours after stroke onset were included. Clinical findings were evaluated according to the daily Glasgow Coma Scale and Rankin disability scores on the 10th day. Initial cerebral computed tomography was performed at admission to the hospital. Midline shift and ventricular displacement were evaluated on the third day. Follow-up tomographic scans of some patients were performed on subsequent days if necessary. Systolic, diastolic, and mean blood flow velocities and pulsatility indices of all patients were measured by transcranial Doppler sonography daily for 10 days. Results. The pulsatility indices were higher on the third hospital day than on the first day. The increases in the pulsatility indices were correlated with the midline shift measured on the third day. The prognoses of the patients whose maximal pulsatility indices during the first 10 days were higher than 1.5 were poorer than those of the patients whose maximal pulsatility indices were lower than 1.5. Conclusions. Transcranial Doppler sonography enables noninvasive monitoring of raised intracranial pressure in patients with large infarctions. It also provides information for detecting cerebral herniation and deciding on the medical or surgical therapy. Key words: raised intracranial pressure; stroke; transcranial Doppler sonography.

Important life-threatening neurologic deterioration may occur within a few days or weeks after an ischemic stroke. Many types of impairment are deadly, including symptomatic hemorrhagic transformation, respiration insufficiency due to destruction of the respiration center in the brain stem, and transtentorial herniation resulting from cerebral edema in supratentorial hemispheric strokes, especially in proximal middle cerebral artery (MCA) infarctions. Transtentorial herniation and brain death often occur between 3 and 5 days after ischemic stroke. In recent studies, malign cerebral edema was reported in 10% of patients with large supra-
tentorial hemispheric infarctions. In these infarctions, destruction of brain tissue, increased intracranial pressure, a midline shift resulting from raised intracranial pressure, and destruction of brain stem structures result in neurologic deterioration. Displacement of the third ventricle and pineal gland due to a mass-occupying lesion in the supratentorial region has been shown to be a cause of deterioration of consciousness in supratentorial large hemispheric infarctions. It is known that monitoring of intracranial pressure is useful for determining the clinical follow-up and the value of treatment in the patients with severe head trauma and intracerebral hemorrhage. Some studies have also reported that clinical follow-up with monitoring of intracranial pressure is possible in patients who have had supratentorial acute ischemic strokes. Monitoring of intracranial pressure helps in identifying patients who need medical or surgical treatment.

Transcranial Doppler (TCD) sonography allows true and rapid imaging of blood flow velocities of intracranial vessels (arteries and veins). Transcranial Doppler sonography provides non-invasive evaluation of intracranial pressure by its characteristic wave patterns. In patients with raised intracranial pressure, mean and diastolic blood flow velocities decrease, and pulsatility index (PI) values increase. In this study, monitoring of intracranial pressure with TCD sonography was performed daily for 10 days from stroke onset in patients with large MCA infarctions. The results were correlated with the findings of cerebral computed tomographic (CCT) scans and clinical examination.

Materials and Methods

Twenty patients with acute large MCA territory infarctions were enrolled in this study between October 2001 and July 2002. Patients were included within 12 hours after first-ever stroke onset. Patients with infarctions of the total anterior circulation according to the criteria of the Oxfordshire Community Stroke Project were included in the study by a neurologist. Patients with histories of stroke and with primary intracerebral hemorrhage and patients not admitted within 12 hours after onset of stroke were excluded from the study. Two patients whose blood flow velocities could not be obtained from transtemporal acoustic bone windows also were excluded.

Cerebral computed tomographic scans of all patients were performed at admission and on the third day; when necessary, third CCT scans of some patients were also performed. Midline shift at the septum pellucidum and ventricular displacement were evaluated on these CCT scans. A daily Glasgow Coma Scale (GCS) score and Rankin disability score were applied for clinical evaluation on the 10th day. An RDS of less than 3 was accepted as an indicator of a good prognosis.

Transcranial Color Doppler Studies

Transcranial Doppler sonography with the criteria described earlier was performed with the patients in the supine position (Multidop X4/TCD8; DWL Electronische Systeme GmbH, Sipplingen, Germany). Transcranial Doppler probes of 2 MHz were placed on the bilateral temporal bone with elastic bandages. Bilateral MCAs were found at a depth of 50-60 mm from the temporal windows (power, 100; sample volume, 13; and gain, 8), and then the probes were stabilized at this level. Flow patterns of the occluded MCAs, however, could not be measured by TCD sonography in the early stages of the stroke. Therefore, in these patients we evaluated only the flow patterns of the healthy MCAs.

Blood flow velocities and flow patterns of the MCAs in a patient with normal and raised intracranial pressure are shown in Figure 1. Transcranial Doppler sonography was performed daily in each patient for 10 days. Three patients died on the fourth, fifth, and seventh days, respectively. Systolic, diastolic, and mean blood flow velocities of contralateral MCAs were measured daily for 10 days. The PI of each patient was calculated according to the formula of Gosling.

The PI values at admission and on the third day were compared. On the third day, the intracranial pressure was expected to be raised. The correlation between the midline shift on CCT scans on the third day and the increase of PI values was evaluated, and the relationship between the PI values at admission and the midline shift on CCT scans on the third day was also evaluated. Studied patients were divided into 2 groups according to CCT findings during the first 10 days. The first group included the patients whose midline shifts were 9 mm or greater, and the second group included those whose midline shifts were less than 9 mm. These 2 groups were com-
pared according to their PI values on TCD sonography, which were obtained at the same time as the CCT examinations. Patients were divided into 2 groups (group I, maximal PI <1.5; and group II, maximal PI >1.5) according to their maximal PI values during the first 10 days. The correlation between the group whose maximal PI values were greater than 1.5 and the group with poor prognoses according to the RDS was also evaluated.

Statistics
The PI values on the first and third days were compared by the Wilcoxon signed ranks test. The PI values of the groups designated according to their midline shifts (<9 or ≥9 mm) were also compared by the Wilcoxon signed ranks test. Maximal PI and RDS values on the 10th day were compared by the $\chi^2$ test. Spearman rank correlation analysis was used to evaluate the correlation between the PI on the third day and the midline shift on CCT scans at the same time, and the same analysis was also used to evaluate the relationship between the PI at admission and the midline shift on the third day.

Results
Eighteen patients participated in the study: 11 female (mean age ± SD, 67.4 ± 7.8 years) and 7 male (mean age, 64.2 ± 11.2 years). Values of PI and GCS on the first and third days, maximal values of PI and GCS measured for 10 days, midline shifts at admission and on the third day, and the RDS on the 10th day are shown in Table 1.

The mean PI value of MCAs was 1.18 ± 0.24 at admission and 1.5 ± 0.42 on the third day. The PI values on the third day were significantly higher than the values on first day ($P<.001$). Maximal PI values were found on the third day in 7 patients, on the fourth day in 8 patients, and on the fifth day in 3 patients with daily monitoring of MCAs by TCD sonography. Daily changes of mean PI values are shown in Figure 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Age, y</td>
<td>66.22 ± 9.16</td>
</tr>
<tr>
<td>Sex, male/female</td>
<td>7/11</td>
</tr>
<tr>
<td>PI, 1 d*</td>
<td>1.18 ± 0.24</td>
</tr>
<tr>
<td>PI, 3 d*</td>
<td>1.5 ± 0.42</td>
</tr>
<tr>
<td>Maximal PI</td>
<td>1.56 ± 0.4</td>
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<tr>
<td>Midline shift on CCT, 1 d, mm</td>
<td>None</td>
</tr>
<tr>
<td>Midline shift on CCT, 3 d, mm</td>
<td>0.44 ± 0.59</td>
</tr>
<tr>
<td>GCS, 1 d</td>
<td>11.8 ± 2.5</td>
</tr>
<tr>
<td>GCS, 3 d</td>
<td>10 ± 3.5</td>
</tr>
<tr>
<td>RDS, 10 d</td>
<td>3.6 ± 0.9</td>
</tr>
</tbody>
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All values except sex are mean ± SD.
*Pulsatility index values obtained from healthy MCAs.
The increases in the PI values were found to be correlated with the midline shift on CCT scans on the third day by Spearman rank correlation analysis (r = 0.656; P = .01; Fig. 3). A significant relationship between PI values measured by TCD sonography at admission and a midline shift due to raised intracranial pressure on the third day was also found (r = 0.532; P = .023).

Thirty-eight CCT scans were obtained from the 18 patients during the first 10 days. Midline shifts of 9 mm or greater were found in 6 of these CCT evaluations, and shifts of less than 9 mm were found in 32. The PI values obtained from MCAs by TCD sonography were found to be significantly higher in the patients whose midline shifts were 9 mm or greater than in the patients whose midline shifts were less than 9 mm (PI, 1.90 ± 0.53 and 1.25 ± 0.25, respectively; P < .01). Three of the 4 patients whose midline shifts on the CCT scans were 9 mm or greater died during the first 10 days, and the fourth patient survived but was severely disabled after the 10th day (RDS, 4). The patients whose maximal PI values were greater than 1.5 had poorer prognoses for the RDS on the 10th day than the patients whose maximal PI values were less than 1.5 (P = .043).

Discussion

Global cerebral hypoperfusion and ischemic encephalopathy resulting from raised intracranial pressure cause deterioration of consciousness. Frank noted that raised intracranial pressure resulting from decreased cerebral perfusion pressure was the most common cause of neurologic deterioration in patients with large supratentorial infarctions. Ropper and Shafran reported that intracranial pressure higher than 18 mm Hg within the first 12 hours in patients with large supratentorial infarctions caused neurologic deterioration and poor prognosis. Monitoring of intracranial pressure, however, is an invasive procedure and requires special equipment. Krieger et al reported that intracranial pressure could be evaluated by monitoring pupillary abnormalities and brain stem auditory evoked potentials in acute lesions with supratentorial mass effects but also noted that the data at admission did not have predictive value. In recent studies, TCD sonography was reported as a useful method for monitoring intracranial pressure in patients with intracerebral hemorrhage and especially in patients with brain trauma. Mayer et al noted that mean and diastolic blood flow velocities were decreased and PI values were increased when intracranial pressure was raised in patients with intracerebral hematoma volumes in excess of 25 mL. Similarly, reports about sonographic monitoring of intracranial pressure and the midline shift in large supratentorial infarctions have been published in the last few years. Our study included patients with large MCA infarctions admitted within 12 hours after stroke symptoms. We performed noninvasive monitoring of intracranial pressure with TCD sonography. We found that the intracranial pressure was higher on the third day than at admission in these patients. The findings obtained by TCD sonography were correlated with midline shifts on CCT scans.

Evaluation of the severity of the raised intracranial pressure, which will happen because of edema, is possible with TCD sonography at admission in patients with large MCA infarctions, and TCD measurement is predictive of

Figure 2. Daily changes of mean PI values on TCD examinations.

Figure 3. Correlation between PI values measured by TCD sonography and the midline shift on CCT scans on the third day.
future increases in intracranial pressure. Therefore, we suggest that increased PI values in the MCA as measured by TCD sonography may have as great a value for clinical prognosis as the midline shift on CCT scans. Early stage outcomes of the patients who had increased intracranial pressure on TCD sonography were poorer than those of the other patients.

Noninvasive and safe monitoring of raised intracranial pressure resulting from increased cerebral edema in large MCA infarctions is possible with TCD sonography. Thus, this technique may have value in detecting cerebral herniation and deciding on medical or surgical treatments.

References