Use of transcranial Doppler sonography to predict development of a delayed ischemic deficit after subarachnoid hemorrhage

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Blood flow velocity was recorded from the middle or anterior cerebral and extracranial internal carotid arteries using transcranial Doppler sonography (TCD) in 121 unselected consecutive patients with acute aneurysmal subarachnoid hemorrhage (SAH). Recordings were made daily or every 2nd day after SAH for a 14-day period. The highest recorded velocity was greater in the 47 patients who developed a delayed ischemic neurological deficit (186 ± 6 cm sec⁻¹; mean ± standard error of the mean) than in the 74 patients who did not develop a neurological deficit (149 ± 5 cm sec⁻¹) (p < 0.001, Mann-Whitney test). Peak velocity recordings can thus assist in the diagnosis of delayed ischemic neurological deficit; however, peak velocity was often recorded only after the onset of neurological deficit. When only those readings made before the onset of neurological deficit were considered, there was no significant difference in peak velocity between the groups (157 ± 8 cm sec⁻¹ vs. 149 ± 5 cm sec⁻¹, respectively). Alternative TCD parameters for predicting delayed neurological deficit were therefore sought. The rate of increase in TCD velocity, recorded during the first few days after SAH, was significantly higher in the patients who later developed a neurological deficit. A maximum velocity increase of 65 ± 5 cm sec⁻¹ per 24-hour period was recorded in patients who later developed a neurological deficit, compared to 47 ± 3 cm sec⁻¹ 24 hrs⁻¹ in patients who did not develop a delayed neurological deficit (p = 0.003). A rise of more than 50 cm sec⁻¹ 24 hrs⁻¹ identifies those patients who are most likely to develop a delayed ischemic neurological deficit after SAH. This can be applied prospectively to individual cases. Serial TCD studies in the early period after SAH are thus of value to identify patients who can be selected for prophylactic therapy, which may prevent or ameliorate development of delayed ischemic neurological deficits.

**Key Words**: subarachnoid hemorrhage· vasospasm· delayed ischemic deficit · transcranial Doppler ultrasound

Transcranial Doppler ultrasound (TCD) is now widely used to monitor patients after subarachnoid hemorrhage (SAH). Cerebral artery flow velocities are increased in patients with a delayed ischemic neurological deficit, in vessels shown on angiography to be narrowed, in patients with larger amounts of subarachnoid blood on computerized tomography (CT) scans, and in association with regional cerebral perfusion deficits. However, high TCD velocities often develop after the onset of delayed neurological deficit, and some patients with high flow velocity do not develop deficits. The TCD criteria for significant vasospasm in the “presymptomatic phase” have thus not been clearly defined. In spite of this, the technique has been used to guide prophylactic therapy and timing of aneurysm surgery. In the study reported here, we evaluated TCD as a method to predict delayed ischemic neurological deficits.

**Clinical Material and Methods**

**Patient Population**

One-hundred thirty-five consecutively treated patients with an SAH caused by rupture of an angiographically diagnosed aneurysm were assessed during a 13-month period. Doppler ultrasound examination proved impossible in 10 patients. A further four patients who were judged to be preterminal on admission were excluded, leaving 121 patients in the study group. All patients were treated with oral or intravenous nimodipine. Details of the clinical features, the consciousness level based on the World Federation of Neurological Surgeons (WFNS) grading system, the aneurysm site,
the clinical course, and the TCD and CT findings were prospectively recorded and analyzed by computer. A policy of early aneurysm clipping was followed for the majority of patients in WFNS Grades I to III in this study. Timing of surgery was not based upon the TCD findings. Delayed ischemic neurological deficit was diagnosed clinically after other causes of deterioration such as rebleeding, hydrocephalus, electrolyte imbalance, and cardiac and respiratory complications were excluded by CT and laboratory tests (blood gas and electrolyte levels).

A delayed neurological deficit was recorded if the patient’s level of consciousness deteriorated by more than one point on the Glasgow Coma Scale or if there was deterioration in speech or motor power. Patients who developed a neurological deficit were readmitted to the intensive care unit and managed by volume expansion to achieve a central venous pressure of 8 to 10 cm H2O. Hypertensive therapy using inotropic agents was employed when volume expansion failed to correct the deficit, and in some patients ventilatory support and desmopressin administration were added.

**Transcranial Doppler Ultrasound Recording**

Transcranial Doppler ultrasound recordings* were made using standard transtemporal and transorbital approaches. Readings were made at two sites on the anterior cerebral artery (ACA) and middle cerebral artery (MCA), and extracranially from the internal carotid artery (ICA) in the neck. The TCD study was performed by one of three examiners every 2 days or more frequently if velocities were rising rapidly or the clinical picture was unstable. Time-averaged mean velocities were used in all cases. The ratio of the MCA or ACA velocity to the ipsilateral ICA velocity was also calculated.\(^{17}\)

**Statistical Analysis**

Minitab software was used for statistical analysis. The TCD recordings in the different groups were compared by Mann-Whitney test because the results were not normally distributed. A chi-squared analysis was used to test the significance of the rate of rise in TCD velocity.

**Clinical Findings**

Complete TCD and clinical data were available for study in 121 patients aged 12 to 72 years (mean 47 years). Forty-seven patients (38.8%) developed a delayed neurological deficit, at a median of 7 days (range 0 to 17 days) after SAH. The duration of neurological deficit was less than 24 hours in six patients, between 24 hours and 7 days in 20 patients, and more than 7 days in 21 patients. Only 21 patients (16%) thus demonstrated a fixed ischemic neurological deficit that was present at discharge from the neurosurgical unit.

The date of SAH was clearly established in 117 cases. The initial TCD examination was within 48 hours of the first bleed in 79 (68%) of these patients and within 72 hours in 91 (78%). On admission, the WFNS clinical evaluation was Grade I in 74 patients, Grade II in 16, Grade III in 14, Grade IV in 14, and Grade V in three cases. The severity of SAH on CT scans was rated according to the Fisher grading system\(^7\) as follows: Group 1 in seven cases, Group 2 in 31, Group 3 in 81, and Group 4 in 27. The ruptured aneurysm arose from the ACA in 37 patients, the MCA in 33, the ICA or posterior communicating artery in 38, the vertebral-basilar circulation in six, and other sites (pericallosal or ophthalmic) in seven.

**Transcranial Doppler Ultrasound Recordings**

Peak Velocity. The highest recorded TCD velocity was obtained from the MCA in 75 patients and from the ACA in 46 patients. The daily velocity profile in these vessels showed an increase from normal values early after SAH to a plateau phase lasting from Day 7 to Day 11 or 12 (Fig. 1). Velocities were significantly higher on Days 8 and 9 (p < 0.01) and on Day 10 (p < 0.05) in patients with a neurological deficit than in patients without (Fig. 1). The post-SAH day on which the highest recorded velocities were obtained ranged from Day 3 to Day 28 (mean Day 11) so that the values shown in Fig. 1 in the plateau phase represent an average of the peaks together with increasing and decreasing velocities in different patients.

To facilitate further analysis, the time sequence of the TCD velocities for each individual patient was plotted in relation to the day on which peak velocity was achieved (Fig. 2). The mean peak velocity in patients who developed a neurological deficit was 186 ± 6 cm sec\(^{-1}\) (± standard error of the mean), which was significantly (p < 0.001) greater than the mean peak velocity in patients who did not develop a neurological deficit (149 ± 5 cm sec\(^{-1}\), Figs. 2 and 3). When the TCD velocity readings (which were made only during the period before the onset of deficit) were considered,
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Fig. 2. Transcranial Doppler ultrasound velocity recordings from the same patients as depicted in Fig. 1: closed circles denote 47 patients with a delayed neurological deficit, open circles denote 74 patients with no deficit. Data are plotted for 4 days before and after peak velocity. Mean peak velocity was 186 ± 6 cm sec\(^{-1}\) in patients with a delayed neurological deficit and was significantly higher than in patients without a deficit (149 ± 3 cm sec\(^{-1}\), p < 0.001).

however, the highest mean velocity recorded in patients who later developed a neurological deficit was 157 ± 8 cm sec\(^{-1}\), a value not significantly greater than that seen in patients who did not later develop a neurological deficit (Fig. 3).

A peak TCD velocity of more than 190 cm sec\(^{-1}\) was recorded in 27 of the 47 patients who developed a delayed neurological deficit and in nine of 74 patients without deficit, giving a sensitivity for diagnosis of delayed ischemic deficit of 57%, a specificity of 88%, and a positive predictive value of 75%. When peak TCD velocity cutoff was set at 180 cm sec\(^{-1}\), sensitivity increased to 64% but specificity was reduced to 84%. A peak velocity of more than 190 cm sec\(^{-1}\) was recorded before the onset of a deficit in only 16 (36%) of the 44 patients in whom TCD readings were available from the period before the onset of deficit (Fig. 3).

Rate of Velocity Increase. The mean maximum rise in MCA or ACA velocity over a 24-hour period was 67 ± 6 cm sec\(^{-1}\) for all patients who developed a delayed neurological deficit. This was significantly (p = 0.003) greater than that measured in patients with no deficit (47 ± 3 cm sec\(^{-1}\), Fig. 4). When only the TCD readings obtained before the onset of the delayed neurological deficit were considered, the mean maximum rise recorded in patients who later developed a deficit was 65 ± 5 cm sec\(^{-1}\). This was significantly (p = 0.005) greater than that observed in patients who did not develop a deficit (Fig. 4).

A maximum rise in TCD velocity of more than 50 cm sec\(^{-1}\) 24 hrs\(^{-1}\) was found in 33 of 47 patients with a delayed neurological deficit and in 23 of 74 patients with no deficit. In six of the 47 patients with a delayed deficit, it was not possible to calculate a rate of velocity rise before the onset of neurological deficit because the deficit developed very soon after admission and before two TCD studies had been obtained. A rise of more than 50 cm sec\(^{-1}\) was recorded in 26 of the 41 remaining patients (Table 1). The sensitivity of this rapid rise in

![Graph](image-url)
TCD velocity for the diagnosis of delayed ischemic neurological deficit was therefore 63% and the specificity was 67%.

**Vasospasm Index.** The highest mean achieved ratio of MCA or ACA velocity to ICA velocity (the "vasospasm index" of Aaslid, et al.,1,2,25) was 6.0 ± 0.3 in patients who developed a neurological deficit, which was significantly (p < 0.001) greater than that found in the patients without a neurological deficit (4.5 ± 0.2). When the ratio was calculated from TCD readings before the onset of a neurological deficit, no difference was found between the vasospasm index in the 44 of 47 patients with neurological deficit in whom this ratio was available, when compared to patients who did not develop a deficit (4.4 ± 0.3 vs. 4.5 ± 0.2, respectively).

**Discussion**

**Significance of Vasospasm**

The outcome for patients who initially survive an SAH has improved markedly over the last two decades, but one-third of cases still suffer avoidable mortality and morbidity.14,15,24,27 This is most commonly due to delayed ischemic neurological events caused by vasospasm.14,15 The consequences of vasospasm have been ameliorated by the use of calcium antagonists, plasma expansion, and hypertensive therapy, but its etiology remains unknown.2,3,25 A diagnosis of vasospasm is usually made after a neurological deficit has developed, and alternative causes have been excluded. However, once a delayed deficit has developed, its response to conventional therapy is often incomplete.2,3,11

**Transcranial Doppler Ultrasound Diagnosis of Vasospasm**

We and other authors have evaluated techniques for predicting vasospasm and neurological deficit when selecting patients for prophylactic therapy, such as induced hypertension, or the use of recombinant tissue plasminogen activator or neuroprotective drugs.4,13 Transcranial Doppler sonography has recently been assessed by many groups,1,5,8,17,21,27,28 and has been determined to be a valuable bedside screening tool to diagnose vasospasm in a patient whose condition has deteriorated. In some centers, the use of TCD has reduced the need for repeat angiography.1,8,27 Our data confirmed this role for TCD. Fifty-seven percent of patients developed a neurological deficit when the peak velocity was 190 cm sec⁻¹ or greater, while 88% developed a neurological deficit when the peak velocity was lower than 190 cm sec⁻¹.

**Transcranial Doppler Ultrasound Prediction of Vasospasm**

Unfortunately, peak TCD velocities often develop after the onset of a neurological deficit,5,8,27,28,30 so they are not useful for detecting patients at risk for neurological deficit. The major question addressed in this study was the predictive role of TCD testing early after SAH. A variety of TCD parameters were serially evaluated, but only the rate of rise in TCD velocity was found to be useful.

A greater rate of rise in TCD velocity has been described previously in patients who develop a neurological deficit.1,2,27 Pasqualin, et al.,23 noted a rapid rise to high levels in one-third of cases. A rapid increase in velocity has been found in the first 6 days after SAH in patients who developed a delayed ischemic deficit.4 An early velocity increase in patients with permanent neurological deficit due to vasospasm was reported in one study.27 However, rapid rises are not always followed by a delayed ischemic deficit: in a study by Compton, et al.,5 three of 12 cases with an acute rise to over 200 cm sec⁻¹ remained asymptomatic.

It has not been possible to identify a critical value for rapidity of rise in TCD velocity from the existing literature, because TCD readings made after the onset of deficit have been included or because group mean values have been given.11,27 In this study, a velocity increase of at least 50 cm sec⁻¹ 24 hrs⁻¹ was identified as the best discriminant for the development of a delayed neurological deficit. Over 60% of patients with this rate of TCD velocity increase went on to develop a neurological deficit. However, about 30% of patients who exceeded this rate of rise failed to develop a neurological deficit. Nevertheless, the difference was statistically significant.

**Limitations of Transcranial Doppler Ultrasound Testing**

These results and those from previous studies show a relatively low sensitivity rating for early TCD testing. There may be several reasons for this. Vasospasm in peripheral cortical vessels may not be detected by TCD.1,2,3,6,26,27,29 Global reductions in cerebral blood flow (CBF)19 and/or loss of cerebral autoregulation20 may induce changes in arterial flow velocity, independent of changes caused by vasospasm. The MCA:ICA index corrects for volume flow,17 but we did not find this index useful in predicting delayed neurological deficit. This may be because a major reduction in CBF develops suddenly, as a late feature, after autoregulatory compensation has been exhausted.

Cerebrovascular collateral reserve capacity may maintain adequate CBF despite severe vasospasm. Older patients may be at greater risk of delayed ischemia for a given level of vasospasm on TCD than younger patients; resting CBF and TCD velocity values fall with age after SAH.11,16,26

Arterial flow velocity on TCD may increase independent of vasospasm, as a consequence of postoperative hyperemia1 or hypertensive therapy.20 In two of our patients, hypertensive therapy was employed prophylactically on the basis of TCD results alone; neither developed a neurological deficit. Additional influences affecting development of a neurological deficit include the duration of spasm, hematocrit, and CO₂ levels.1,28 Autoregulatory tests may help to refine TCD testing.12

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