Cerebral vasospasm evaluated by transcranial ultrasound correlated with clinical grade and CT-visualized subarachnoid hemorrhage

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In 39 patients with a proven subarachnoid hemorrhage (SAH), the clinical status, the amount of subarachnoid blood on a computerized tomography scan obtained within 5 days after SAH, and the flow velocities (FV's) in both middle cerebral arteries (MCA's) measured by transcranial Doppler sonography were recorded daily and correlated. All patients had pathological FV's over 80 cm/sec between Day 4 and Day 10 after SAH. The side of the ruptured aneurysm showed higher FV's than did the unaffected side in cases of laterally localized aneurysms. Increase in FV preceded clinical manifestation of ischemia. A steep early increase of FV's portended severe ischemia and impending infarction. Maximum FV's in the range of 120 to 140 cm/sec were not critical and in no case led to brain infarction. Maximum FV's over 200 cm/sec were associated with a tendency for ischemia, but the patients may remain clinically asymptomatic. In cases of no or only a little blood in the basal cisterns, mean FV's in both MCA's increased only moderately whereas, with thick clots of subarachnoid blood, there was a steeper and higher increase of mean FV's.

KEY WORDS - ultrasound - cerebral blood flow velocity - subarachnoid hemorrhage - cerebral vasospasm - computerized tomography

The controversy concerning the clinical significance of cerebral vasospasm stems partly from the fact that there is no acceptable objective measure to follow the course of vasospasm. Angiography is an invasive procedure that cannot be repeated at frequent intervals. Arterial narrowing causes an increase in the velocity of flow through the affected segment, and this change is inversely proportional to the diameter squared.4 Therefore, recording of flow velocities (FV's) should be a sensitive monitor of the development and resolution of arterial narrowing.

With the transcranial Doppler ultrasound technique described in 1982 by Aaslid, et al.,2 it is possible to record the FV's in the basal cerebral arteries through an intact cranium. Because this method is noninvasive, it can be repeated as often as necessary and represents an ideal method to monitor cerebrovascular spasm after subarachnoid hemorrhage (SAH). Aaslid, et al.,1 found a clear correlation between the velocity of flow and the diameter of the middle cerebral artery (MCA) in 38 patients. The relationship in the proximal anterior cerebral artery (ACA) was more complicated to assess, due to the collateral channels in the anterior part of the circle of Willis.1 In multisegmental or global vasospasm, however, the proximal part of the MCA is almost always involved, so FV recordings in this arterial segment should be useful in monitoring vasospasm. If the correlation between the change in FV and the course of clinical symptoms is known, FV's can be used as a prognostic factor for the management of these patients because an increase in FV should precede the appearance of clinical symptoms.

A significant correlation between the amount and distribution of subarachnoid blood detected by computerized tomography (CT) early after aneurysmal rupture and the later development of cerebral vasospasm visualized angiographically was found by Fisher, et al.3 When there was no subarachnoid blood or it was distributed diffusely, severe vasospasm was almost never encountered, whereas when there were blood clots and thick layers of blood, severe vasospasm almost invariably followed. These observations have been confirmed by several other authors.7-13 The aim of the present study was to correlate the FV's in the proximal MCA's with the clinical course of patients after aneurysmal SAH, and to investigate if cerebral vasospasm evaluated...
by transcranial Doppler ultrasound has the same positive correlation to CT-visualized subarachnoid blood as is found angiographically.

**Clinical Material and Methods**

**Patient Population**

Thirty-nine consecutive patients who were admitted within 10 days after their last SAH were selected for the study. Their clinical grade according to the classification of Hunt and Hess and day of admission are given in Table 1. All had a spontaneous SAH proven by bloody and/or xanthochromic cerebrospinal fluid and/or by CT. An aneurysm was verified as the source of bleeding by angiography or autopsy in all cases. The location of the 39 aneurysms is summarized in Table 2. Patients in Grade IV with massive intracerebral or intraventricular hematomas or in Grade V were not included in the present series. Medical treatment consisted of analgesic, sedative, and steroid agents. No antifibrinolytic drugs or calcium antagonists were used. Eleven patients in Grade I and with no or little subarachnoid blood visualized by CT were operated on within the first 10 days after the SAH; all others underwent surgery later, if they survived in a satisfactory condition. The clinical grade and day of operation are given in Table 3. Preoperatively, three patients died from cerebral infarction and three from rebleeding. No patient died postoperatively. Three patients were in poor clinical condition due to cerebral infarction and did not undergo surgery.

**Clinical Grading**

The clinical grade according to the classification of Hunt and Hess was recorded daily and computerized. For analytical reasons, patients who were in Grade Ia (fully alert, with no meningeal signs but with a fixed neurological deficit) after 2 to 3 weeks were plotted as 2.5 or 3.5 depending on the severity of the deficit. In cases of clinical deterioration, CT was repeated to exclude rebleeding or hydrocephalus and to evaluate the degree of cerebral ischemia. Patients with rebleeding or hydrocephalus were omitted from the series. Patients were divided into three groups based on their clinical course, as follows: Clinical Group 1 (no neurological symptoms); Clinical Group 2 (delayed neurological symptoms, but fully reversible); Clinical Group 3a (delayed neurological symptoms not fully reversible within 6 months because of cerebral infarction); and Clinical Group 3b (delayed neurological symptoms leading to death because of massive cerebral infarction).

**Grading of CT-Visualized Blood**

Flow velocities were correlated with the CT-visualized subarachnoid blood only in the 35 patients who had a CT scan within 5 days after the SAH, because Scotti, et al., found that subarachnoid blood may be isodense after 6 days. The CT scans were obtained in a horizontal plane using an EMI 1010 scanner with a 160 × 160 matrix and 10-mm slices or a GE 9800 scanner with a 256 × 256 or 512 × 512 matrix and slices of 1.5 to 10 mm thickness. The CT's after admission were classified according to the criteria of Fisher, et al., as follows: CT Group 1 (no blood detected); CT Group 2 (diffuse deposition or thin layers of blood); and CT Group 3 (localized cisternal clots or diffuse thick layers of blood).

**Transcranial Ultrasound Recording**

The technique for transcranial Doppler ultrasound recording, using a 2-MHz focused transducer, has been described in detail previously. The depth of the sample can be selected by the operator through range-gating. First, the terminal segment of the internal carotid artery (ICA) was identified at a depth of between 5 and 6.5 cm. By successive reduction of the sampling depth, the signal from the MCA was extended outward to approximately 3 cm from the probe. The time-velocity spectrum was evaluated on the still-frame display. The segment with the highest velocity was recorded on both

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**TABLE 1**

<table>
<thead>
<tr>
<th>Clinical Grade</th>
<th>Days after SAH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>I</td>
<td>7</td>
</tr>
<tr>
<td>II</td>
<td>1</td>
</tr>
<tr>
<td>III</td>
<td>2</td>
</tr>
<tr>
<td>IV</td>
<td>6</td>
</tr>
<tr>
<td>Total cases</td>
<td>16</td>
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*Clinical grading according to the classification of Hunt and Hess. SAH = subarachnoid hemorrhage.

**TABLE 2**

<table>
<thead>
<tr>
<th>Artery Affected</th>
<th>No. of Cases</th>
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<tbody>
<tr>
<td>internal carotid</td>
<td>13</td>
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<tr>
<td>middle cerebral</td>
<td>5</td>
</tr>
<tr>
<td>anterior communicating</td>
<td>17</td>
</tr>
<tr>
<td>pericallosal</td>
<td>1</td>
</tr>
<tr>
<td>basilar</td>
<td>3</td>
</tr>
<tr>
<td>Total cases</td>
<td>39</td>
</tr>
</tbody>
</table>

**TABLE 3**

<table>
<thead>
<tr>
<th>Clinical Grade</th>
<th>Days After SAH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>I</td>
<td>3</td>
</tr>
<tr>
<td>II</td>
<td>0</td>
</tr>
<tr>
<td>III</td>
<td>0</td>
</tr>
<tr>
<td>Total cases</td>
<td>3</td>
</tr>
</tbody>
</table>

*Clinical grading according to the classification of Hunt and Hess. SAH = subarachnoid hemorrhage.
sides and reported in the present study. The measurements were taken daily, whenever possible, and computerized and correlated with the clinical status on the same day. For final analysis, a mean FV curve for both sides and a mean clinical status curve were calculated by computer analysis for each group.

Statistical Methods

The mean FV curves were compared between Days 7 and 10 using the Mann-Whitney method, and the maximal FV by chi-square analysis.

Results

Pathological Flow Velocities After SAH

Doppler ultrasound recordings were made in 24 patients during the first 3 days after SAH. Ten patients had normal values during this time, whereas 14 (58%) already had FV’s over 80 cm/sec on the 2nd and 3rd day after SAH. All three patients who died from cerebral infarction had FV’s over 120 cm/sec before the 3rd day (see Fig. 2 lower right).

Between Days 4 and 10 after SAH, all patients had pathological FV’s over 80 cm/sec. In laterally localized aneurysms (arising from the ICA and MCA) the side of the aneurysm showed higher FV’s than the unaffected side in 16 of 18 patients (Fig. 1), but the difference of the mean FV curves was not statistically significant (p = 0.739). In the 21 midline aneurysms (arising from the anterior cerebral, basilar, and pericallosal arteries), the FV’s of the MCA’s were increased equally on both sides in 16 cases, corresponding to a bilateral distribution of the subarachnoid blood. In the one patient with a pericallosal aneurysm and a thick clot only in the interhemispheric fissure, the FV’s of the MCA’s were symmetrically increased, but only up to 110 cm/sec.

Correlation With Clinical Course

Twenty patients had no neurological symptoms (Clinical Group 1), 11 had transient neurological symptoms (Clinical Group 2), and five patients had permanent neurological symptoms from a cerebral infarction (Clinical Group 3a). Three patients died from a massive brain infarction (Clinical Group 3b). The mean FV curves of these groups correlated with the mean clinical condition are represented in Fig. 2. The mean FV’s between Days 7 and 10 increased consistently between Clinical Groups 1 and 3b, and the differences were statistically significant (p = 0.008).

Each group was subdivided, according to the maximal FV on the afflicted side, into patients with a maximum FV under 140 cm/sec, those with a maximum FV between 140 and 200 cm/sec, and those with a maximum FV over 200 cm/sec. These subgroups are represented in Fig. 3. There was a statistically significant difference between Clinical Groups 1 and 3 (p = 0.003).

FV Correlated With CT-Visualized Blood

Nine patients had a normal CT scan (CT Group 1). Figure 4 upper left shows the mean FV curve of the side with the higher and lower FV’s for these patients. There was a gradual increase to about 140 cm/sec on Day 7. The peaks on Days 11 and 15 were due to the increased postoperative FV’s of the six patients who were operated on before the 10th day. The maximum FV’s recorded in each of these patients are given in Fig. 5. None showed a peak FV over 200 cm/sec.

Diffuse deposition or thin layers of blood were seen in 11 patients (CT Group 2). The mean FV curves of the side with the higher and lower FV for these patients are represented in Fig. 4 upper right. The curve reached a peak value of about 150 cm/sec during the 2nd week. The maximum FV’s recorded in this group are illustrated in Fig. 5. Five of these 11 patients had a peak FV over 200 cm/sec.

Localized cisternal clots or diffuse thick layers of blood were seen in 15 patients (CT Group 3). The mean FV curve of these patients derived from the side with the higher and lower FV is shown in Fig. 4 lower. There was a steep increase on the afflicted side to about 190 cm/sec on Day 7. No patient was operated on before Day 10 after the SAH, so there was no influence of early operation. The maximum FV’s recorded in these patients are given in Fig. 5. Nine of the 15 patients had critical FV’s over 200 cm/sec. The two patients with FV’s under 140 cm/sec had aneurysms of the anterior communicating and pericallosal artery, respectively, with the main clot in the interhemispheric fissure. Both manifested delayed symptoms of cerebral ischemia. Cerebral vasospasm probably developed mainly in the region of the distal ACA and pericallosal artery which cannot be evaluated by transcranial Doppler ultrasound.

The difference between the mean FV’s of CT Groups 1 and 2 was not statistically significant, but the difference between CT Groups 1 plus 2 and CT Group 3 was statistically significant (p = 0.024). The difference between the maximal FV of CT Groups 1 plus 2 versus CT Group 3 was also statistically significant (p = 0.004) (Fig. 2 lower left).
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**FIG. 2.** Mean flow velocity (FV, in cm/sec) curves of the side with the higher FV's (continuous line) and the side with the lower FV's (dotted line) correlated with the mean clinical status according to the classification of Hunt and Hess (H & H) over a 28-day time course after subarachnoid hemorrhage (SAH). **Upper Left:** Data for 20 patients with no neurological symptoms (Clinical Group 1). Because the 13 patients operated on before Day 10 generally showed an increase in FV postoperatively, the curve has an irregular form. This postoperative increase of the FV was never critical and was clinically asymptomatic. **Upper Right:** Data for 11 patients with transient neurological symptoms (Clinical Group 2). The initial curve shows the natural time course of mild symptomatic vasospasm, because no patient underwent surgery before Day 11. **Lower Left:** Data for five patients with permanent neurological deficits due to cerebral infarction (Clinical Group 3a). The curve shows the time course of severe symptomatic vasospasm. The early increase in FV precedes clinical deterioration. **Lower Right:** Data for three patients who died from cerebral infarction (Clinical Group 3b). There is already a steep increase of FV on the 2nd and 3rd day after SAH.
Pathological Flow Velocities After SAH

Vasospasm is rarely seen angiographically during the first few days after SAH, and it is thought to occur on about Days 3 to 4 after the bleeding. In comparison with 50 healthy adults who had mean FV's of 62 ± 12 cm/sec in the MCA, we found pathological FV's of 80 cm/sec or more in 58% of 24 patients on the 2nd and 3rd day after SAH. This early onset of arterial narrowing is not seen angiographically, because MCA's classified on angiography as spastic demonstrated FV's of 120 cm/sec or more. It is of clinical importance that patients who later developed brain infarction showed an early and steep increase of FV (Fig. 2 lower left and right), so that these Doppler ultrasound findings represent a bad prognostic sign.

Vasospasm is seen angiographically within 2 weeks after SAH in between 33% and 66% of cases. In our series, we found FV's over 80 cm/sec in the MCA's of all 39 patients between the 4th and 10th day after SAH, and also in patients with minor bleeding who had no neurological symptoms. These findings have the following clinical implication: in cases of questionable SAH with no blood on the CT scan and uncertain cerebrospinal fluid analysis because of the presence of iatrogenic blood, Doppler ultrasound findings of increased FV's can be taken as a diagnostic indicator of SAH.

In laterally localized aneurysms (arising from the ICA or MCA), we found higher FV's on the side of the ruptured aneurysm compared with the unaffected side in 16 of 18 patients (Fig. 1). The difference in the mean FV was not statistically significant; however, this tendency suggests that, in bilateral aneurysms where the bleeding side is not identified from clinical or CT findings, the higher FV may be taken as an indicator of the side of the ruptured lesion.

Discussion

Pathological Flow Velocities After SAH

In patients with asymptomatic vasospasm (Clinical Group 1), the mean FV curve is influenced by some early operations, associated with marked increase of the FV postoperatively. In the other patients who were operated on later, the FV reached its maximum level between Days 7 and 12, which corresponds well to the time course of vasospasm evaluated by angiography. The more severe the spasm the steeper the increase of FV (Figs. 2 lower left and lower right and 3). Comparison of the FV with the clinical status curve shows that in symptomatic vasospasm the increase in FV occurs, as expected, before the clinical symptoms appear. Therefore, the Doppler ultrasound findings can be used as a prognostic factor. In cases of an early and steep increase of the FV, angiography and operation should be delayed and therapeutic measures should be undertaken before the vasospasm becomes symptomatic.

If the maximum FV is compared with the clinical status (Fig. 4), it is evident that FV's in the range of 120 to 140 cm/sec are not critical and have never led to brain infarction. However, FV's over 200 cm/sec seem to be critical, with a tendency for ischemia and brain infarction, but they may also remain asymptomatic, probably depending on the existence of collateral circulation and the state of autoregulation of the afflicted region. This corresponds well with the clinical experience that, in Hunt and Hess Grade I patients, an angiogram made 7 to 10 days after SAH may show severe but asymptomatic vasospasm. In these cases especially, transcranial ultrasound is valuable in detecting and monitoring this severe but asymptomatic vasospasm. The course of arterial narrowing can be followed by daily ultrasonic measurement, and angiography and operation can be avoided during the critical phase of increasing and high FV's.

In patients in Hunt and Hess Grade I or II with FV's not critically increased, surgery during the phase of increasing vasospasm had no significant influence on the clinical course (Fig. 2). With daily monitoring of the clinical status and FV's, it is possible to identify patients at low risk for symptomatic vasospasm. Operations in these patients should be carried out as early as possible after the hemorrhage whereas, in patients with critically increased FV's during the first 10 days after SAH, surgery should be delayed until decreasing FV's indicate the resolution of vasospasm. Since only three patients were operated on during the first 3 days after SAH, the effect of an operation during this acute period must be explored in a further study.

**FV Correlated With CT-Visualized Blood**

In the present series, there was a significant correlation between the amount of subarachnoid blood and the development of vasospasm evaluated by transcranial Doppler ultrasound. In cases of no or only a little blood in the basal cisterns, FV's in both MCA's
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increased only moderately whereas, with thick clots of subarachnoid blood, there was a steeper and higher increase of FV. Small amounts of blood may be visible in CT scans obtained directly after the hemorrhage but may disappear after 1 or 2 days. Therefore, the distinction between CT Group 1 and 2 patients is influenced by the interval between the SAH and CT diagnosis, and may explain the small difference between these two groups. The higher mean FV in patients with thick clots of subarachnoid blood is in agreement with the observations of Fisher, et al., and others that the amount of subarachnoid blood is probably the most important etiological factor for the later development of cerebral vasospasm.

The MCA is favorably located for transcranial Doppler ultrasound recording, while the other basal cerebral arteries are more difficult to identify. In the present series, therefore, the FV data were obtained from the MCA alone. For each different location of ruptured aneurysm and subarachnoid blood, the same correlation was found between the amount of blood visualized on CT scans as by angiography. This confirms our previous assumption that ultrasound recording of the FV's in both proximal MCA's monitors vasospasm occurring after rupture of aneurysms in different locations of the basal arteries. In laterally localized aneurysms (arising from the ICA or MCA), the side of the lesion showed increased FV in almost all cases. A significant SAH caused by rupture of a mediobasal aneurysm (arising from the ACA or the basilar artery) produces an increase of the FV in both MCA's in the majority of the patients. However, the usefulness of the method is limited when the main clot is localized in the interhemispheric fissure, due to rupture of an upwardly directed ACA or pericallosal aneurysm. In such cases, the FV's in the MCA's are not sufficiently representative for evaluation of the vasospasm that usually occurs in the region of the distal ACA and pericallosal artery. This is illustrated by the two CT Group 3 cases with clinically symptomatic vasospasm but only slightly increased FV's in both MCA's.

![Fig. 4](image-url) Mean flow velocity (FV, in cm/sec) curves from the side with the higher FV (continuous line) and the side with the lower FV (dotted line) recorded over 28 days after subarachnoid hemorrhage (SAH). **Upper Left:** Data for nine patients with a normal computerized tomography (CT) scan (CT Group 1). There is only a slow increase to about 140 cm/sec on Day 7. The peaks on Days 11 and 15 are due to increased FV's postoperatively. **Upper Right:** Data for 11 patients with diffuse deposition or thin layers of subarachnoid blood (CT Group 2). There is a slow increase of FV to about 150 cm/sec during the 2nd week. **Lower:** Data for 15 patients with localized cisternal clots or diffuse thick layers of blood (CT Group 3). There is a steep increase of FV's on the afflicted side to about 190 cm/sec on Day 7. No influence of early operation is seen because no patient underwent surgery before Day 10 post-SAH.

![Fig. 5](image-url) Distribution of patients within the three computerized tomography groups with their maximum flow velocities (FV's). There is remarkably positive correlation between the amount of subarachnoid blood and the increase of FV, v = flow velocity.
References


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