Transcranial Doppler Grading Criteria for Basilar Artery Vasospasm

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OBJECTIVE: Transcranial Doppler (TCD) criteria for basilar artery (BA) vasospasm are poorly defined, and grading criteria for vertebrobasilar vasospasm are unavailable. The purpose of the present study was to define TCD grading criteria for BA vasospasm on the basis of the absolute flow velocities and the intracranial to extracranial flow velocity ratios for the posterior circulation, and to improve the sensitivity and specificity of TCD for diagnosis of BA vasospasm.

METHODS: One hundred twenty-three patients with aneurysmal subarachnoid hemorrhage underwent 144 cerebral arteriograms with views of the BA during the acute phase of vasospasm (Days 3–14 after hemorrhage). BA diameters were measured and compared with diameters obtained from baseline arteriograms. Both BA and extracranial vertebral artery flow velocities were measured by TCD within 4 hours before the arteriogram.

RESULTS: The velocity ratio between the BA and the extracranial vertebral arteries (VA) strongly correlated with the degree of BA narrowing ($r^2 = 0.648$; $P < 0.0001$). A ratio higher than 2.0 was associated with 73% sensitivity and 80% specificity for BA vasospasm. A ratio higher than 2.5 with BA velocity greater than 85 cm/s was associated with 86% sensitivity and 97% specificity for BA narrowing of more than 25%. A BA/VA ratio higher than 3.0 with BA velocities higher than 85 cm/s was associated with 92% sensitivity and 97% specificity for BA narrowing of more than 50%.

CONCLUSION: The BA/VA ratio improves the sensitivity and specificity of TCD detection of BA vasospasm. On the basis of the BA/VA ratio and BA mean velocities, we suggest new TCD grading criteria for BA vasospasm.

KEY WORDS: Aneurysm, Angiography, Basilar artery, Subarachnoid hemorrhage, Transcranial doppler, Vasospasm

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Transcranial Doppler (TCD) is widely used for the diagnosis and monitoring of cerebral vasospasm after subarachnoid hemorrhage (SAH) (1, 2, 4, 5, 7, 10, 11, 13, 17, 20, 21). However, many authors have stressed the low sensitivity of using TCD flow velocities (FVs) alone to detect vasospasm and to differentiate between hyperemic flow and narrowing (8, 9, 12, 14–16, 19).

Lindegaard et al. (14) suggested TCD criteria for the diagnosis of vasospasm in the anterior circulation based on intracranial (IC) to extracranial (EC) velocity ratios, which improved the sensitivity of TCD to detect arterial narrowing. Sloan et al. (23) suggested criteria for the diagnosis of vasospasm in the posterior circulation using TCD based on FV measurements alone. Unlike the anterior circulation, an IC/EC ratio is not routinely used for the diagnosis of vertebrobasilar vasospasm (6, 12, 26, 27). Soustiel et al. (28) presented an IC/EC ratio method based on measurements of the extracranial vertebral arteries (ECVAs) that significantly improved the specificity and sensitivity of TCD for the diagnosis of basilar artery (BA) vasospasm. According to these authors, a ratio between the vertebral artery (VA) and the BA (BA/VA) higher than 2.0 was associated with 100% sensitivity and 95% specificity for the diagnosis of BA vasospasm, as diagnosed on computed tomographic angiography (CTA). Furthermore, this ratio showed a close correlation with BA diameter, and a ratio higher than 3.0 was found in all patients with severe BA vasospasm. However, they studied a heterogeneous group of patients with spontaneous SAH of various etiologies, as well as traumatic brain injury patients, and compared TCD measurements with degree of BA narrowing in only 14 patients. Other authors (22) have raised some methodology concerns regarding the accuracy of ECVA velocity measurements and the use of CTA rather than conventional angiography for the measurement of BA diameters in this small group of patients.

Recently, in a large cohort study, we reported that patients experiencing BA vasospasm after aneurysmal SAH had an increased incidence of posterior circulation ischemia, particularly in the brainstem (29). Furthermore, the severity of brainstem ischemia correlated with BA velocities and patients with BA vasospasm or brainstem ischemia experienced worse outcomes. These findings indicate that BA vasospasm probably has a significant role in cerebral vasospasm after aneurysmal SAH and further emphasizes the need for better TCD grading criteria for vasospasm in the vertebrobasilar system.

The aim of the present study was to define TCD grading criteria for BA vasospasm, as well as to improve the sensitivity and specificity of TCD for the diagnosis of vasospasm in the posterior circulation.

MATERIALS AND METHODS

Patients

The study was approved by the Institutional Review Board of Harborview Medical Center, Seattle, Washington. We conducted a retrospective chart review of 381 patients with SAH treated at Harborview Medical Center between September 2002 and March 2004. One hundred twenty-three patients (*Table 1*) were identified as meeting the following inclusion criteria: 1) aneurysmal SAH; 2) four-vessel diagnostic angiography performed within 48 hours of initial bleeding, which did not show narrowing, stenosis, or occlusion of the VA or BA; 3) a second arteriogram with views of the BA performed within the period of risk for vasospasm (Days 3–12 after initial hemorrhage); and 4) daily TCD measurements of the posterior circulation arteries, including measurements of the ECVAs.

TABLE 1. Clinical and demographic data[a]

No. of patients	123
Age (yr)	51.2 ± 11.2
Sex (M/F)	42/81
H&H grade	
I–III	81
IV–V	42
Fisher's Score	
I–II	25
III	61
IV	37
Aneurysmal location	
Anterior circulation	98
Posterior circulation	25

[a] H&H, Hunt and Hess grades.

For correlation between the presence of BA vasospasm according to TCD measurements and symptomatic vasospasm, delayed ischemic deterioration was defined as a worsening of the neurological condition (a drop of two points in Glasgow Coma Scale in patients with altered consciousness and a new hemiplegia or hemiparesis or a drop of two points in the muscle scale [on a scale of 0–5] in a previously hemiparetic patient) that could not be attributed to rebleeding, postoperative complications, hydrocephalus, or systemic complications.

Angiographic Study

Quantification of vasospasm using angiographic images from multiple studies is not straightforward because of differences in patient positioning and image magnification. We used the distance between the medial margins of the two posterior cerebral arteries at their widest point as an internal standard to correct for these effects. We measured vasospasm on the anterior and posterior views of the posterior circulation, which were generally obtained in a Caldwell projection, by computing the ratio of the BA diameter to the inter-posterior cerebral artery distance on each study. Because the inter-posterior cerebral artery distance does not change significantly between studies, this makes it possible to compare the diameter of the BA on later studies to the initial diameter, which was assumed to represent the no-vasospasm diameter. On the lateral projection, the BA diameter was measured and compared with the sella turcica.

All angiography was performed on a biplane system (Integris 5000; Philips Medical Systems, Eindhoven, The Netherlands), using selective catheterization of either the left or right VA (if both arteries were injected, care was taken to use the same side of injection for both sets of images). Measurements were performed with image magnification and digital calipers on an electronic image viewing system (Centricity; General Electric Medical Systems, Milwaukee, WI).

All measurements were performed by two observers whose interobserver agreement was approximately 10%. For descriptive purposes, and to better follow clinical practices, as well as to follow other authors' grading for BA vasospasm, BA vasospasm was graded as mild (0–24% narrowing), moderate (25–49% narrowing), and severe (50% narrowing and above).

TCD Recording

Initial TCD evaluation was performed in all patients within the first 48 hours after onset of SAH. The intracranial VA and BA mean FVs (MFVs) were measured though the foramen magnum according to the technique described by Fujioka and Douville (3), and the ECVA FVs according to the technique described by Soustiel et al. (28). All patients included in the study had a baseline BA MFV of less than 60 cm/s. The initial BA/VA ratios were 1.66 ± 0.053.

TCD of the ECVA was performed by placing a 2.0-MHz pulsed wave Doppler transducer below the tip of the mastoid process at a depth of 40 to 50 mm, depending on body habitus and amount of soft tissue at this location. FVs were obtained both away from and toward the transducer by changing the angulations of the probe obliquely. Care was taken to exclude insonation of the occipital artery by using firm transducer pressure, which will normally obliterate flow in this more superficially located vessel. Confusion of the distal internal carotid artery with the VA was avoided by maintaining a probe position that was more posterior and/or moving forward to identify the internal carotid artery as separate from the VA.

The BA/VA ratio was calculated by averaging the time-averaged maximum MFVs from both VAs and dividing this value into the highest BA MFVs. Time-averaged maximum MFVs were used for all measurements in all vessels. The BA was always followed as far distally as possible, and signals were sampled in 2 to 5 mm steps, via a sample volume size ranging from 7 to 10 mm^3. Establishment of the measurement technique for insonation of the ECVAs requires some training, and one can expect a learning curve (18). Furthermore, a very precise and accurate technique is required. We trained by identifying the ECVAs at the atlas loop using a broadband 4.0- to 7.0-MHz linear transducer and visualizing the atlas loop segment using color and spectral Doppler.

Statistical Analysis

Spearman's correlation was used for correlation analysis between TCD BA velocities and BA/VA ratios and the degree of BA narrowing. Fisher's exact test was used for proportion comparison. Correlations were considered significant when they reached a *P* value of less than 0.05.

RESULTS

Angiographic Findings

One hundred twenty-three patients who met the study criteria had 144 angiography studies including views of the BA, which were compared with the baseline angiogram. The median time of the follow-up arteriograms was Day 4 after the initial hemorrhage. Indications for a second arteriogram were participation in the prophylactic balloon angioplasty study in 74 cases, as a diagnostic workup for vasospasm in 37 cases (of 44 angiographies performed for diagnosis of vasospasm during the study period), and as a preoperative or postoperative diagnostic procedure in 33 cases. Of the 144 arteriograms examined, 68 (47.2%) had angiographically determined BA vasospasm. Of these, 40 had mild vasospasm (<25% narrowing relative to the initial study), 16 had moderate vasospasm (25–49% narrowing), and 12 had severe vasospasm (>49% narrowing).

BA MFVs and Vasospasm

Maximum BA MFVs ranged between 44 and 154 cm/s. BA MFVs correlated with the degree of BA narrowing ($r^2 = 0.405$; $P < 0.0001$; *Fig. 1*). BA velocities greater than 60 cm/s were associated with 92% sensitivity and 47% specificity for BA vasospasm. The specificity improved if higher MFVs were chosen; however, the sensitivity significantly decreased (*Table 2*).

IC/EC MFV Ratio and Vasospasm

The BA/VA ratio significantly correlated with the degree of BA narrowing ($r^2 = 0.648$; $P < 0.0001$; *Fig. 1*). A BA/VA ratio higher than 2.0 was found in 13 of 76 cases without BA vasospasm and in 54 of 68 cases with vasospasm. This ratio (2.0) was associated with 73% sensitivity and 80% specificity for BA vasospasm. If the chosen ratio was higher, the specificity increased; however, the sensitivity decreased dramatically (*Table 2*). A ratio higher than 2.5 was found in 25 of 28 cases with moderate and severe BA vasospasm. This ratio was associated with 89% sensitivity and 90% specificity for moderate and severe BA vasospasm. A ratio higher than 3.0 was found in all 12 cases with severe BA vasospasm. This ratio was associated with 100% sensitivity and 90% specificity for severe BA vasospasm.

TCD Grading Criteria for BA Vasospasm

Combining the BA/VA ratio greater than 3.0 and BA mean velocity of greater than 85 cm/s as diagnostic criteria for severe BA vasospasm, specificity increased to 97%, whereas

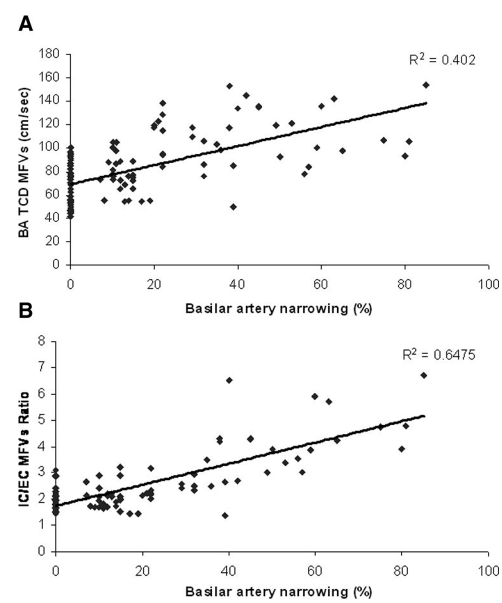

FIGURE 1. A, *graph showing the correlation between maximal TCD BA MFVs and the degree of BA narrowing as measured by angiographic studies ($r^2 = 0.405$; $P < 0.0001$).* B, *graph showing the correlation between TCD BA/VA MFV ratio and the degree of BA narrowing as measured by angiographic studies ($r^2 = 0.648$; $P < 0.0001$).*

TABLE 2. Sensitivity and specificity of different basilar artery velocities and velocity ratio between the basilar and vertebral arteries for detection of basilar artery vasospasm in 123 patients (144 arteriograms) with aneurysmal subarachnoid hemorrhage[a]

	Sensitivity	Specificity
BA FVs		
>60 cm/s	91%	47%
>70 cm/s	87%	55%
>80 cm/s	65%	75%
>85 cm/s	57%	86%
>90 cm/s	50%	88%
>95 cm/s	44%	93%
>100 cm/s	35%	100%
BA/ECVA ratio		
1.8	85%	64%
2	73%	80%
2.2	54%	87%
2.5	46%	95%
3	31%	99%

[a] BA, basilar artery; FV, flow velocity; BA/ECVA, extracranial vertebral arteries.

the sensitivity decreased to 91.7%. Combining a BA/VA ratio greater than 2.5 with a BA mean velocity of greater than 85 cm/s as diagnostic criteria for moderate and severe BA vasospasm, the specificity improved to 97% and the sensitivity decreased to 86%. Only four out of 116 cases with mild BA vasospasm or no vasospasm had a ratio higher than 2.0 with BA velocities higher than 85 cm/s. Using both absolute BA-MFV and BA/VA ratios above 2.0, the sensitivity and specificity for the diagnosis of BA vasospasm did not improve significantly. TCD grading criteria for BA vasospasm is presented in *Table 3*.

BA TCD Grading Criteria and Correlation with Delayed Ischemic Deficit

Of 123 patients included in the study, 41 experienced delayed ischemic deficit on the same day as the TCD measurements (49 angiography studies). Of these, 27 experienced focal neurological deterioration, and altered consciousness was found in 31. In patients (n = 26) with severe and moderate BA vasospasm according to the proposed TCD criteria, 10 (38%) experienced focal DID, and altered consciousness was found in 13 (50%), whereas, in cases without BA vasospasm (n = 82) according to TCD measurements, only 10 (12%) experienced focal DID and, in 9 cases (11%), altered consciousness was found ($P = 0.0069$ and $P = 0.0001$, respectively; *Table 4*).

DISCUSSION

BA vasospasm has been reported to be associated with poor outcome in patients with head injury. In a large cohort study, we recently reported that patients with BA vasospasm after aneurysmal SAH experienced a higher incidence of posterior circulation ischemia and had a worse outcome (29). In this study, elevated BA MFVs were found in correlation with the severity of brainstem ischemia, and patients experiencing brainstem ischemia had a very poor prognosis. The reported incidence of BA vasospasm in that study as measured by TCD was 37.8%, similar to the incidence reported by Soustiel et al. (27). However, elevated MFVs in the acute phase of SAH do not necessarily mean vasospasm, and many studies have shown low accuracy of TCD in differentiating between hyperemia and arterial narrowing (8, 9, 12, 14–16, 19).

By using the IC/EC index (hemispheric index) in the anterior circulation, Lindegaard et al. (14) showed that the ability of TCD to differentiate between hyperemia and narrowing after SAH is increased significantly, and that, when the index was higher than 6.0, vasospasm was almost always present.

Current diagnostic criteria for posterior circulation vasospasm suggested by Sloan et al. (23) are based on MFV measurements alone, and grading criteria are unavailable. According to Sloan et al. (23), BA mean velocities higher than 60 cm/s were associated with 60% specificity and 100% sensitivity for vasospasm. However, when the MFV threshold was increased, the sensitivity was reduced significantly. To improve the accuracy of TCD measurements in the diagnosis of BA vasospasm, Sloan et al. (23, 24) suggested an index for BA vasospasm based on a ratio between the BA MFV and the proximal intracranial VA mean velocity. A ratio higher than 2.5 was associated with a higher risk for BA vasospasm. However, this index did not measure the extracranial VA and has not been routinely accepted as a criterion for BA vasospasm (6, 12, 26, 27). Soustiel et al. (28) suggested a new BA/VA index for the diagnosis of BA vasospasm based on velocity measurements of the ECVAs. This new index improved the ability of TCD to differentiate between arterial narrowing and hyperemia. However, their study raised many methodological concerns (8, 22, 25). Among these concerns were 1) CTA, rather than conventional angiogra-

TABLE 3. Transcranial Doppler grading criteria for basilar artery vasospasm[a]

	TCD measurements			
	Ratio (BA/ECVA, Soustiel's ratio)	BA velocity	Sensitivity	Specificity
Basilar artery vasospasm	>2	>70 cm/s	77%	82%
Moderate or severe vasospasm	>2.5	>85 cm/s	86%	97%
Severe vasospasm	>3	>85 cm/s	92%	97%

[a] TCD, transcranial Doppler; BA, basilar artery; ECVA, extracranial vertebral arteries.

TABLE 4. Basilar artery vasospasm grading according to the suggested transcranial Doppler criteria and symptomatic vasospasm, as was defined by the appearance of delayed ischemic deterioration in the day of the transcranial Doppler measurements[a]

		TCD findings			
	Total	No BA vasospasm	BA vasospasm	Moderate or severe BA vasospasm	Severe BA vasospasm
No. of patients	144	82 (57%)	62 (43%)	26 (19%)	19 (13%)
Delayed ischemic deficit					
No	103 (72%)	67 (82%)	36 (58%)	10 (38%)	6 (32%)
Focal	27 (20%)	10 (12%)	17 (27%)	10 (38%)	7 (37%)
Altered consciousness	31 (22%)	9 (11%)	22 (35%)	13 (50%)	10 (53%)

[a] TCD, transcranial Doppler; BA, basilar artery.

phy, was used for measurement of BA vasospasm; 2) baseline CTA was performed in only 14 patients; and 3) patients studied had SAH of varying etiologies (of 34 patients included, 15 had aneurysmal SAH, seven had traumatic SAH, four had arteriovenous malformation, and eight had SAH of unknown etiology).

The present findings confirm the accuracy of the ratio method suggested by Soustiel et al. (28) for the diagnosis of BA vasospasm. We prefer to call this ratio method Soustiel's ratio, parallel to Lindegaard's ratio in the anterior circulation. For BA measurements, we used digital subtraction angiography. All patients had a baseline arteriogram before the period of vasospasm, and only patients with aneurysmal SAH were included. We found that the degree of BA narrowing significantly correlated with the BA/VA ratios. All patients with severe BA narrowing (>50%) had a ratio greater than 3.0, which was associated with 100% sensitivity and 90% specificity for severe BA vasospasm.

In the present study, we tried to answer some of the methodology concerns that were raised regarding the use of the BA/VA ratio for vertebrobasilar vasospasm. To improve criteria for the diagnosis of BA vasospasm, especially in patients with more significant narrowing, we suggest TCD grading criteria for BA vasospasm based on a combination of BA absolute velocity and Soustiel's ratio (BA/ECVA ratio) (*Table 3*). These criteria are based on an analysis of 144 arteriograms in 123 patients and, to the best of our knowledge, this is the largest study ever performed to correlate TCD measurements with arterial narrowing. Using both absolute BA-FV greater than 85 cm/s and a BA/VA ratio greater than 3.0, the sensitivity and specificity for severe BA vasospasm are 92 and 97%, respectively. BA FV greater than 85 cm/s and BA/VA ratios greater than 2.5 are associated with 86% sensitivity and 97% specificity for moderate and severe vasospasm.

Using both the ratio and the absolute FVs, the sensitivity and specificity of the TCD in the diagnosis of moderate and severe BA vasospasm improved dramatically (*Table 3*). Therefore, TCD can serve well as a bedside test for estimation of posterior circulation vasospasm after aneurysmal SAH. Although the findings suggest that the accuracy of TCD to diagnose BA vasospasm improves dramatically by using the BA/VA ratio, the insonation of the ECVAs is not trivial and requires some training, and one can expect a learning curve.

The clinical significance of BA vasospasm is still unclear. Previous studies have suggested that BA vasospasm is associated with poorer prognosis after SAH (26, 27, 29). Our findings suggest that BA vasospasm, especially moderate and severe, is associated with a higher incidence of delayed ischemic deficit. However, because of the involvement of the anterior circulation in the vasospasm process, we are currently unable to isolate the BA vasospasm as an independent predictor of ischemic deterioration. This and the role of BA vasospasm in the outcome of patients with SAH should be further evaluated.

CONCLUSION

Measurement of the BA/VA ratio significantly improves the sensitivity and specificity of TCD to detect moderate to severe BA vasospasm. On the basis of this ratio and BA mean velocities, we suggest new TCD grading criteria for BA vasospasm that enable a more accurate diagnosis of significant BA vasospasm.

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COMMENTS

This is a well-written and interesting article with a large and well-managed series. Basilar vasospasm is a serious condition that necessitates early detection and treatment. Transcranial Doppler (TCD) is a noninvasive and quick method for evaluating blood flow. However, interpretation of the measurements remains challenging and controversial. The article clarifies some of the TCD criteria of basilar vasospasm that has been reported previously. By using the proposed new criteria, it will be interesting to determine whether or not they really can be used in clinical practice to replace more complex digital subtraction angiogram studies. It is possible that computed tomographic angiography combined with computed tomographic perfusion studies could also show basilar vasospasm, but it would necessitate transporting a potentially fragile patient to undergo a computed tomographic scan, whereas the TCD is a bedside examination without radiation.

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Sviri et al. have reported TCD criteria for the evaluation of angiographic basilar artery vasospasm based on a retrospective review of 123 patients with aneurysmal subarachnoid hemorrhage. Patients underwent cerebral angiography at baseline and follow-up angiography at a median of 4 days later. TCD studies performed up to 4 hours before follow-up angiography were used to determine basilar artery mean flow velocity (BA MFV) and Soustiel's ratio, which is the BA MFV divided by the time-averaged mean flow velocity of the extracranial vertebral arteries (BA/VA). TCD data were correlated with angiographic vasospasm, and Sviri et al. derived "best fit" criteria.

A BA/VA ratio greater than 3.0 combined with a BA MFV greater than 85 cm/sec was 92% sensitive and 97% specific for more than 50% angiographic basilar artery narrowing. A BA/VA ratio greater than 2.5 combined with BA MFV greater than 85 cm/sec was 86% sensitive and 97% specific for more than 25% angiographic basilar artery narrowing.

At our institution, we routinely obtain an angiogram on postbleed Day 7 to evaluate for vasospasm. TCDs are obtained three times a week for 2 weeks after admission. When a patient is within the window for vasospasm, TCD data and trends aid in clinical decision-making. However, we do not think that TCD studies are sensitive enough to obviate angiography (1–3). Although catheterization is associated with risks, it also allows additional treatment options for vasospasm including angioplasty and intraarterial delivery of nicardipine.

The BA/VA ratio and BA MFV TCD criteria proposed by Sviri et al. seem to maintain a high level of sensitivity and specificity for the detection of moderate to severe vasospasm of the basilar artery after aneurysmal subarachnoid hemorrhage. We look forward to a prospective validation of these criteria and anticipate that the method of Sviri et al. will prove useful in the clinical setting.

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Sviri et al. have attempted to improve upon TCD grading for basilar artery vasospasm. They examined 123 patients with subarachnoid hemorrhage and evaluated angiographic vasospasm and basilar artery and extracranial vertebral artery flow velocities using TCD.

They found that the velocity ratio between the BA/VA ratio highly correlated with the degree of angiographic basilar artery vasospasm. Using both the BA/VA ratio and the basilar artery mean flow velocity, TCD evaluation of posterior circulation vasospasm demonstrated acceptable sensitivity and specificity for angiographic basilar artery narrowing, particularly for more severe basilar artery narrowing.

The authors have provided a potentially useful contribution for evaluating patients at risk for vasospasm. Posterior circulation vasospasm may be underdiagnosed, and its significance may be underestimated in patients experiencing deterioration in the window of vasospasm after subarachnoid hemorrhage. As always, TCD evaluation of vasospasm is highly operator-dependent, and the excellent results illustrated in this report may not be initially replicable at other centers. Additionally, TCD data are only one component to consider in the multi-factorial evaluation of patients who have sustained subarachnoid hemorrhage.

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Odysseus in the cave of Polyphemus *(1st half of the 17th century), oil on canvas, Jacob Jordaens. (Courtesy of the Pushkin Museum, Moscow, Russia).*