Is transcranial Doppler a worthwhile addition to screening tests for cerebrovascular disease?

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Purpose: Carotid duplex imaging has become the standard diagnostic evaluation for patients with suspected cerebrovascular disease. Transcranial Doppler ultrasonography expands the noninvasive diagnostic capabilities to the intracranial circulation. The purpose of this study was to evaluate the results of routine transcranial Doppler studies on patients referred for noninvasive cerebrovascular evaluation.

Methods: A total of 670 patients had routine transcranial Doppler examinations as part of their noninvasive cerebrovascular evaluation. Patients were categorized clinically and according to their severity of extracranial internal carotid artery stenosis (< 50%, 50% to 79%, 80% to 99%, occlusion). Transcranial Doppler examinations were classified as normal or abnormal (intracranial stenosis, collateral pathway, > 30% velocity difference between sides, flow reversal, and velocities ± 2 SD from normal).

Results: Forty-eight percent of the patients were women, and 52% were men. The average age was 65.5 years. Fifty-four percent of the patients were white, 42% were black, 3% were Hispanic, and 1% were other. Forty-eight percent presented with hemispheric symptoms, 34% had no symptoms, and 18% had nonhemispheric symptoms. Forty-five percent (304 of 670) had an interpretable transcranial Doppler examination. The ability to insonate the basal cerebral arteries through the temporal bone was significantly reduced in women ($p < 0.0001$), black patients ($p < 0.0001$), and older patients ($p < 0.0001$). The results of forty-four percent of interpretable examinations were normal, 19% demonstrated side-to-side velocity differences, 13% showed collateral pathways, 11% showed velocities ± 2 SD, 10% showed an intracranial stenosis, and 4% showed reversed flow pattern. Although 56% of the patients had notable findings, no patient had their diagnostic or therapeutic plan altered by the transcranial Doppler results.

Conclusion: Less than 50% of the patients referred for first-time cerebrovascular examination had access for an interpretable transcranial Doppler examination. Though the number of positive findings is reasonably high, no material impact on diagnostic or treatment plans was seen in the patients in this series. These results indicate that selection criteria for examination of the intracranial arteries should be refined and that transcranial Doppler scanning should not be incorporated as part of the "routine" noninvasive cerebrovascular examination. (J VASC SURG 1995;21:90-7.)

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Duplex imaging of the extracranial carotid system and the vertebral arteries has become the standard diagnostic evaluation of patients with suspected cerebrovascular disease. Technology has advanced to the point where the reliability of the noninvasive examination permits carotid endarterectomy to be performed without routine preoperative arteriography.[1,2] Transcranial Doppler (TCD) ultrasonography expands the noninvasive diagnostic capabilities for patients with cerebrovascular disease, permitting investigation of the intracranial arteries that previ-

ously could be examined only by arteriography. TCD applications have rapidly expanded and are useful for a number of clinical applications.[3] Based on the premise that knowledge of the intracranial circulation would assist clinicians in their assessment and treatment of patients with suspected occlusive cerebrovascular disease and to ensure that significant intracranial disease would not be overlooked, TCD scanning was added to our routine noninvasive cerebrovascular evaluation.

The purpose of this study was to evaluate the technical success of the TCD examinations, the frequency of intracranial disease, and pertinent perfusion alterations found with routine TCD examination, and whether this new information contributed to patient care.

MATERIAL AND METHODS

Study period and patients. Nine hundred seventy-six patients were evaluated noninvasively for cerebrovascular disease from July 1991 through December 1993. Only patients presenting for first-time examinations were included. Of the 976 patients 306 did not have a TCD study, either because the examination was performed at bedside or because of poor patient cooperation, equipment malfunction, or inadequate examination time (preoperative coronary artery bypass). Six hundred seventy patients had a TCD examination performed as part of their routine noninvasive cerebrovascular examination.

Equipment. Most patients were evaluated with the Trans-scan (Nicolet Instrument Corporation, Madison, Wis.), which produces a multiprojectional, computer-generated display of the pulsed doppler signal obtained at the various sample volume locations. A 2 MHz, pulsed, focused, bidirectional transducer is used, and interpretation of the data is made from the spectral waveforms. Recently 44 patients were evaluated by transcranial color Doppler imaging (ULTRAMARK 9, HDI; ATL, Bellevue, Wash.). Duplex imaging (2 MHz Doppler) uses anatomic information as landmarks and the color Doppler pattern as a guide to obtain the Doppler spectral waveforms. Both techniques were performed with the assumption of a 0-degree angle.

Examination protocol. The examination protocol included evaluation of the basal cerebral arteries with the transtemporal, transorbital, and suboccipital approaches. The transtemporal window allowed evaluation of the middle cerebral artery (MCA), anterior cerebral artery (ACA), posterior cerebral artery, and anterior and posterior communicating arteries (PCoA). The transorbital approach permitted evaluation of the carotid siphon and the ophthalmic artery, whereas the intracranial vertebral arteries and the basilar artery were evaluated through the foramen magnum via the suboccipital approach.

Interpretation criteria. TCD results were read according to previously published interpretation criteria.[4] Intracranial arteries were identified by depth of the sample volume, direction of blood flow, angle of the transducer, spatial relation of one Doppler signal to another, and traceability of the artery. Doppler signal response to compression or vibration maneuvers was not performed.

Spectral waveforms from the intracranial arteries were evaluated for flow direction and mean velocity. The ACA/MCA ratio was also used as an interpretation guideline. An ACA/MCA ratio of greater than 1.2 is indicative of underlying disease of the ACA (such as a hypoplastic artery), an ACA stenosis, a collateral channel, or perhaps an infarction in the distribution of the middle cerebral artery.

The TCD results were grouped into one of six categories. If the arterial velocity fell within the normal range, it was considered a normal examination result. An intracranial stenosis was indicated by a focal increase in mean velocity ($>30\%$), turbulence, and distal dampening of the Doppler waveform. Collateral pathways were defined by cross-filling via the anterior communicating artery, (opposite internal carotid artery), increased velocity in the PCoA (vertebral), or reverse-flow direction in the ophthalmic artery (external carotid). Velocity differences from one side to the other in healthy adults usually do not exceed 25%. Small differences generally do not indicate underlying disease; rather they indicate technical variation with the examination. For the purpose of this study, side-to-side differences were considered abnormal if they exceeded 30%. An examination result was also considered abnormal if an artery demonstrated flow reversal or if its velocity exceeded normally defined velocity limits by ± 2 SD.

Disease and symptoms. All patients were categorized according to their symptoms, the amount of extracranial carotid disease, the three TCD approaches, and the ability to penetrate the temporal bone and obtain a temporal window. Patients were classified as having no symptoms, hemispheric symptoms, or nonhemispheric symptoms. The amount of extracranial disease present was defined by diameter reduction of the internal carotid artery as determined by duplex imaging. Each patient was categorized according to the carotid artery with the most severe disease. Categories were (1) less than 50% stenosis,

(2) 50% to 79% stenosis, (3) 80% to 99% stenosis, and (4) occlusion.

Statistical analysis. The statistical significance of associations with interpretable TCD examinations was assessed by chi square statistic.

RESULTS

Of the six hundred seventy patients examined, 48% (319 of 670) were women, and 52% (351 of 670) were men. Fifty-four percent (360 of 670) were white, 42% (280 of 670) were black, and 3% (21 of 670) were Hispanic. Asians and other nationalities represented the remaining 1%. The average age was 65.5 years. When classified according to symptoms, 48% (325 of 670) had hemispheric symptoms (amaurosis fugax or hemispheric transient ischemic attacks), 34% (226 of 670) had no symptoms, and 18% (119 of 670) presented with nonhemispheric symptoms.

The transtemporal window is the main access to the basal cerebral arteries and is considered the most important window of the transcranial Doppler examination. In this series 38% (252 of 670) of the patients had no temporal window, and 17% (114 of 670) had an inadequate transtemporal examination (one to three arteries insonated). Only 45% (304 of 670) had an interpretable examination, which was defined by insonation of four or more arteries. In patients with an incomplete but interpretable examination (four or five arteries), the posterior cerebral artery was the most difficult to insonate and represented 64% of the missing arteries, followed by the ACA (32%) and the MCA (4%). Ability to insonate basal cerebral arteries through the temporal bone was significantly reduced in women ($p < 0.0001$), black patients ($p < 0.0001$), and older patients ($p < 0.0001$) (Table I). Specifically, in patients aged 60 years or older, successful transtemporal insonation was 62% for white men, 32% for white women, 33% for black men, and only 8% for black women.

Symptoms. The results of the TCD examination stratified by symptoms are summarized in Table II. The findings were similar in patients without symptoms and those with nonhemispheric symptoms. Patients presenting with hemispheric symptoms more commonly had an intracranial stenosis and collateral pathways; however, these differences were not significant ($p = 0.10$ and $p = 0.19$, respectively).

Carotid artery disease. Most of the patients did not have significant carotid artery occlusive disease. Seventy-two percent (479 of 670) had less than 50% diameter reduction stenosis, 13% (91 of 670) had 50% to 79%, 9% (60 of 670) had 80% to 99%, and 6% (40 of 670) had an occluded internal carotid artery.

Interpretable TCD examinations. Although 56% of patients who could be evaluated had notable findings on the TCD examination, we could not identify any patient in whom the attending physician chose to use the TCD results to modify patient care either diagnostically or therapeutically. Forty-four percent (134 of 304) of the results were normal, 19% (59 of 304) demonstrated side-to-side velocity differences, 13% (41 of 304) showed evidence of intracranial collateral pathways, 11% (32 of 304) had velocity measurements ±2 SD normal, 10% (29 of 304) showed an intracranial stenosis, and 4% (11 of 304) showed an unexplained reversed-flow direction (Table III).

Of the 29 patients with intracranial stenoses, 20 had stenoses in a single middle cerebral artery, five had bilateral MCA stenoses, and four had an isolated internal carotid artery siphon stenosis. Three patients had a stenosis documented by both the temporal and orbital approaches. Table IV lists the TCD approaches that identified intracranial stenoses, which are stratified by presentation and severity of cervical carotid disease. Interestingly no intracranial stenosis was identified in the posterior circulation.

In patients with adequate temporal windows 57 collateral pathways were identified in 41 patients. The most common collateral channel was through the anterior communicating artery, which represented 67% (38 of 57) of the collateral pathways. The ophthalmic artery provided 21% (12 of 57) of the collateral channels, and the PCoA provided only 12% (7 of 57). Although seven PCoA collateral pathways existed, only two patients had the PCoA as their only collateral pathway. Interestingly both of these patients had severe bilateral carotid disease with occlusion of one internal carotid artery and an 80% to 99% stenosis of the other. Fifty-nine patients had side-to-side velocity differences that were greater than 30%. Seventeen (29%) of these cases could be explained by extracranial carotid occlusive disease. The remaining 42 (71%) were likely due to technical limitations of the TCD examination. The 11 patients with reversed-flow direction can be explained by anatomic variation, tortuosity, or insonation of the P2 segment of the posterior cerebral artery mistaken for the P1 segment.

Velocities ±2 SD can be caused by extracranial carotid disease (low velocity) or low hematocrit (high velocity), and in some patients no definite explanation could be offered.

Table I. Access to transtemporal examination by sex, race, and age

	No.	*Transtemporal window*	
		Yes	*No*
Sex			
Male	351	59% (208/351)	41% (143/351)
Female	319	30% ((96/319)	70% (223/319)
		$p < 0.0001$	
Race			
White	360	56% ((201/360)	44% ((159/360)
Black	280	29% (81/280)	71% (199/280)
		$p < 0.0001$	
Age			
<60	182	63% (114/182)	37% (68/182)
60-69	205	46% (95/205)	54% (110/205)
70-79	211	38% (80/211)	62% (131/211)
80+	72	21% (15/72)	79% (57/72)
		$p < 0.0001$	

Table II. Results of TCD in 304 interpretable examinations by symptoms

Symptom	*No.*	*Normal*	*Intracranial stenosis*	*Collateral pathway*	*Side-side vel. diff.*	*Flow reversal*	*Velocity (±2SD)*
Asymptomatic	110	51% (56/110)	6% (7/110)	11% (12/110)	17% (19/110)	4% (4/110)	11% (12/110)
Hemispheric	144	36% (52/144)	13% (18/144)	17% (24/144)	21% (30/144)	5% (7/144)	10% (15/144)
Nonhemispheric	50	52% (26/50)	8% (4/50)	10% (5/50)	20% (10/50)	0%	10% (5/50)
Overall	304	44% (134/304)	10% (29/304)	13% (41/304)	19% (59/304)	4% (11/304)	11% (32/304)

Table III. Results of TCD in 304 interpretable examinations by severity of carotid artery disease

Carotid artery stenosis	*No.*	*Normal*	*Intracranial stenosis*	*Collateral pathway*	*Side-side vel. diff.*	*Flow reversal*	*Velocity (±2SD)*
<50%	201	55% (110/201)	9% (18/201)	0.5% (1/201)	21% (42/201)	3% (7/201)	11% (23/201)
50%-79%	49	41% (20/49)	12% (6/49)	8% (4/49)	18% (9/49)	6% (3/49)	16% (8/49)
80%-99%	32	13% (4/32)	13% (4/32)	50% (16/32)	22% (7/32)	3% (1/32)	3% (1/32)
Occluded	22	0%	5% (1/22)	91% (20/22)	5% (1/22)	0%	0%
Overall	304	44% (134/304)	10% (29/304)	13% (41/304)	19% (59/304)	4% (11/304)	11% (32/304)

DISCUSSION

The indications for TCD examinations have grown, and we believe that many are now of proven value (Table V). This study specifically addresses the use of TCD as a part of the routine noninvasive cerebrovascular examination. For this indication the TCD examination was of little objective value. A large proportion of the patient population did not have an adequate examination, which is likely due to an inherent bias of an older population with a high percentage of women and black patients. Previous authors also reported high failure rates in insonation of vessels through one or both temporal windows.[5-7] In a survey reviewing results from 60 laboratories in the United States, percentages for failure to access the transtemporal window ranged between 0% and 65% (mean 16%).[6] This range may be explained by variable thickness of the temporal bone. In an anatomic study examining the thinnest portion of the temporal bone, Halsey[8] reported mean values of 1.83 mm for white men, 2.24 mm for white women, 2.35 mm for black men, and 3.52 mm for black women. The trend in these anatomic measurements parallel our failure rate in each of these groups. Furthermore Halsey's clinical experience is similar, with a transtemporal failure rate of 73% in black women older than 70 years.[7]

In patients whose examinations could be interpreted, intracranial stenoses were documented in 10% and collateral pathways in 13%. Unfortunately this information proved to be of limited if any clinical value, if such "value" was defined as a change in

Table IV. The window by which intracranial stenoses were diagnosed: according to clinical presentation and severity of extracranial carotid artery disease

		Window		
	No.	*Temporal*	*Orbital*	*Suboccipital*
Presentation				
Hemispheric symptoms	144	11% (16/144)	2% (3/144)	0%
Nonhemispheric symptoms	50	6% ((3/50)	2% (1/50)	0%
Asymptomatic	110	5% (6/110)	3% (3/110)	0%
Carotid artery disease				
<50%	201	8% (15/201)	3% (6/201)	0%
50-79%	49	12% (6/49)	0%	0%
80-99%	32	13% (4/32)	0%	0%
Occluded	22	0%	5% (1/22)	0%

Table V. Indications for transcranial Doppler ultrasonography

Proven
Monitoring vasospasm
Evaluation of brain death
Diagnosis of arteriovenous malformations
Evaluating stroke risk with sickle cell disease
Evaluating suspected intracranial stenoses
Document subclavian steal
Evaluate vertebrobasilar insufficiency
Potential
Evaluate effects of extracranial disease
Assess intracranial collateral pathways
Intraoperative monitoring during carotid endarterectomy
Evaluate migraine headaches
Epidemiologic studies

planned patient care. Whereas some authors have demonstrated the usefulness of the TCD examination,[3] others have corroborated its limited utility in this patient cohort even in patients who have symptoms and intracranial stenoses and occlusions.[9] It is known that blood flow velocity in the arteries of the circle of Willis does not correlate with cerebral perfusion,[10] which is likely to be responsible for these findings.

These data raise a dilemma in terms of the practical function of the noninvasive vascular laboratory. The TCD examination is by far the most operator-dependent technique of all the noninvasive studies. Repetition improves skill and maintains acceptable sensitivity, specificity, and predictive values. If the TCD examination is limited to a select few, the number of available studies may be inadequate to maintain appropriate levels of skill in all operators.

Perhaps the most pertinent question is which patients should have TCD examinations performed as part of their noninvasive cerebrovascular evaluation?

Though the answer is not entirely clear, data are available that can help guide more appropriate patient selection. Those patients being considered for carotid endarterectomy may benefit from transcranial doppler evaluation to refine their risk of subsequent neurologic events and to properly evaluate outcome of carotid endarterectomy. Carotid siphon stenosis has been shown to be associated with ipsilateral ischemic events subsequent to its diagnosis.[11-13] The reports by Wechsler et al.,[11] Craig et al.,[12] and Marzewski et al.[13] indicated the potential morbidity of intracranial stenoses, whereas Schuler et al.[14] and Borozan et al.[15] suggested a benign course for carotid siphon stenoses. Though this issue is still unresolved, understanding the definition of "stenosis" in these reports is helpful. In the former reports most stenoses were greater than 60% diameter reduction, whereas in the latter reports patients who had a 20% or more diameter reduction lesion were included. A severe extracranial carotid stenosis may well warrant correction even in association with intracranial disease. However, the prognosis for additional neurologic events after successful carotid endarterectomy may be linked to the intracranial lesion, particularly if the lesion is a high-grade stenosis. As more patients are being offered carotid endarterectomy without preoperative arteriography, the opportunity to evaluate the intracranial circulation becomes limited. Therefore to properly evaluate the etiology of neurologic events remote from carotid endarterectomy, TCD may be useful.

Patients with clear-cut vertebrobasilar symptoms are appropriately studied with TCD. Kinsella et al.[16] demonstrated that in patients with vertebrobasilar insufficiency, the results of the TCD examination changed patient treatment in 42%, increased aspirin treatment by 128%, and reduced the use of arteriography by 58%. Though we did not demonstrate such a clinical impact, our patients did not have clear-cut vertebrobasilar insufficiency and therefore likely represent a different patient cohort. The

observation that the intracranial stenoses in our patients were detected through an anterior approach may reflect the facts that in the absence of clear-cut vertebrobasilar insufficiency, intracranial stenoses are much more common in the anterior circulation and that unique difficulties exist in insonation of the posterior circulation.[3] Furthermore other authors have concluded that TCD results of the vertebrobasilar system provide unambiguous information, only if TCD scanning is used in combination with cerebral angiography.[17]

We initially believed that the MCA velocity profile would correlate with the severity of cervical carotid disease. This was not the case in our study, and Lindegaard et al.[18] also found that the hemodynamic effect of the cervical internal carotid stenosis cannot be satisfactorily assessed by MCA flow velocity alone.

Currently most of the TCD examinations are performed with nonimaging techniques. Imaging techniques improve vessel identification and improve visualization of the M2 branches of the MCA and the vertebrobasilar system. Additionally in patients with a single temporal window, the contralateral arteries often can be evaluated. Whether the introduction of transcranial color Doppler imaging or the development of contrast media and software will alter the clinical utility of TCD in patients remains to be evaluated.

It is apparent that patient selection for TCD examinations should be refined and that TCD should not be included as part of the routine noninvasive cerebrovascular evaluation.

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DISCUSSION

Dr. David S. Sumner (Springfield, Ill.). Several years ago we reviewed the literature on transcranial Doppler scanning and decided that it would not contribute enough information in terms of time and effort expended to adopt the test as part of our evaluation protocol for extracranial cerebrovascular disease. Nothing we have read since then has altered this opinion.

Transcranial Doppler has been around for more than a decade, and its investigation has enlisted some of the best minds in the cerebrovascular field and the skills of some of the most talented vascular technologists. On the positive

side it is the only test available (invasive or noninvasive) that permits direct assessment of blood flow in individual arteries composing the circle of Willis. It has proved useful to neurosurgeons in the evaluation of vasospasm, arteriovenous fistulas, and brain death.

Dr. Comerota and his associates have identified some of the problems. Only 45% of the patients in their series had an interpretable examination. In women, black patients, and patients older than 70 years, this figure dropped to 30%. Although abnormalities were demonstrated in 56% of the patients with interpretable examinations, in no case did the transcranial Doppler findings alter the diagnosis or change treatment plans. Identification of intracranial stenoses and collateral pathways may have some prognostic significance, but this information seldom changes the approach to extracranial disease in patients with symptoms or in patients without symptoms who have critical stenoses.

That intraoperative TCD contributes little to patient management has been amply demonstrated by Dr. Eugene Bernstein and his colleagues. Some recent reports, however, indicate that TCD might be useful for identifying emboli arising from the carotid bifurcation immediately after endarterectomy in patients who are at risk of postoperative stroke.

I have a few questions. How did the authors establish the validity of their examination? What was their gold standard? Can symptoms be correlated with transcranial Doppler findings? What specific findings might conceivably alter their approach to extracranial carotid artery disease? What do they see as the future for transcranial Doppler? Does it have a role in the immediate postoperative period? And finally, what recommendations can be made to those of us who do not use the method? Should we start now or just wait and see?

Dr. Anthony J. Comerota. In terms of the question of validity, our data were not precisely validated but were preceded by 4 to 5 years of experience and correlation with all available arteriograms. All examinations were performed by registered vascular technologists. It has been shown that collateral pathways demonstrated by TCD do not always correlate with arteriographic findings, and unfortunately intracranial velocity profiles do not correlate with cerebral perfusion; therefore we have also faced the dilemma of assessing the severity of angiographic findings and correlating them with intracranial velocities. It is a very difficult validation to perform, and I think anyone who has been faced with it can appreciate the problem.

In terms of symptoms we have not been able to correlate symptoms with velocity profiles as demonstrated by the TCD examination.

In terms of the future I think I have listed both at the presentation and in the manuscript where I think the appropriate applications of TCD examinations can play a role. Whether they will help us evaluate patients in the postoperative period remains to be seen, but we have not noted any palpable benefit in that regard.

In terms of our ultimate recommendations and who should be performing these examinations, I think we should be performing these examinations as part of the noninvasive vascular laboratory, because I do not think anyone can perform them better. Now the question arises whether TCD duplex color imaging will improve our reliability, and I think that remains to be seen. A number of advantages exist. I think we will certainly have more accurate intracranial vascular identification, and we will probably be able to insonate more basal arteries, and in those patients who have compromised temporal windows, we can probably insonate the opposite basal arteries from one available transtemporal approach.

Dr. David M. Lolley (Pittsburgh, Pa.). My group and a combination of other groups across the country have had a large experience in transcranial Doppler scanning. It has become an exquisitely useful tool in planning and carrying out operations. We have had experience with several thousand exams, and we are approaching a level of about five to 600 patients treated during the operation with this procedure.

Our technicians can perform insonation and do a complete examination in about 90% to 95% of cases examined, and we do this with a very cheap Carolina Instruments unit. We are a little perplexed at this low yield that you have obtained.

This procedure has also been useful in management of cerebral blood flow problems during cardiopulmonary bypass and has been more useful in the management of combined lesions in the heart and in the carotid and intracranial circulation.

My question is does your lack of enthusiasm for a screening test extend into the operative use of this instrument?

Dr. Comerota. We have used transcranial Doppler scanning sporadically during surgical procedures, and it has been associated with a rather large number of technical problems. We have not been able to obtain useful information from it during surgical procedures. I must say we began using these techniques enthusiastically. It was a very long learning curve, as I think you can appreciate. We have no experience using TCD during cardiopulmonary bypass. I should add that our definition of an "adequate" examination is strict, requiring insonation of at least four intracranial vessels from the transtemporal approach. Simply obtaining MCA velocities was not enough.

Dr. Brian L. Thiele (Hershey, Pa.). I am puzzled as to why you would advocate using it in patients before arteriography and in those undergoing carotid endarterectomy, because you have made the statement that this procedure does not influence what you do, and it is sort of like a test looking for an application and you have not really found it.

Dr. Comerota. The reason for that recommendation, Brian, is that as I mentioned, if the examination is to be

done, we should be doing it because I think our technologists are the most talented. I do not think anyone will ever be able to establish their own baseline validity, unless the test is performed in conjunction with arteriography observing the strengths and the weakness of both examinations.

Dr. Freddy Vermeulen (Nieuwegein, The Netherlands). We have quite a lot of experience in the use of transcranial Doppler in preoperative screening and also in perioperative use, monitoring the systolic peak and mean velocities of the ipsilateral middle cerebral artery in the patients upon whom we operate. In the selected group of patients with or without symptoms, who have high-grade lesions. First of all the success rate of finding the window was 86%, and I believe this rate corresponds to the first discussant's experience. This has certainly been the case since the initial studies, and actually we really would be a little bit unhappy not to have the transcranial Doppler as the immediate intraoperative audible control of the perfusion of the brain while we do the carotid endarterectomies.

I have one specific question concerning the use of transcranial Doppler scanning in evaluating the patient with asymptomatic carotid disease. We found that by using criteria of electroencephalography and transcranial velocity signals analysis during the operation, we could define the patient at higher risk for having either a stroke or needing a shunt during the operation by a cutoff point of the reduction of peak systolic velocity to 70% of the preexisting velocity or of 65% of the mean systolic velocity. By applying these criteria in the preoperative screening, we believe we can discern the patient at higher risk of having a stroke by applying a carotid compression test during the preoperative transcranial Doppler screening of patients with asymptomatic disease.

Dr. Comerota. Yes, we are aware of the elegant studies from The Netherlands that have made important contributions in the use of TCD. Your 86% success rate may reflect your patient population bias, much like our patient bias against successful insonation. It is likely that you have a much larger percentage of white patients, and we have a large percentage of black patients in our patient population. If you have a predominance of males, that will likely increase your success rate on TCD examinations. We did not use carotid compression studies, nor did we use CO_2 reactivity, both of which may be important adjuncts in future uses for TCD.