Diagnostic Reliability of the Percutaneous Ultrasonic Doppler Technique for Vertebral Arterial Occlusive Diseases

Hirao Kaneda, M.D., Tadayoshi Irino, M.D., Takao Minami, M.D., and Mamoru Taneda, M.D.

SUMMARY There is little data on the diagnostic reliability of the ultrasonic Doppler technique for vertebral arterial occlusive lesions. Percutaneous vertebral Doppler examination and the vertebral angiograms were compared to determine the diagnostic reliability of this technique in 64 vertebral arteries of 53 patients with cerebrovascular disease. The percutaneous vertebral Doppler findings were quantitatively analyzed using a sound spectrograph and were classified into three types: no flow signal type, poor flow type and normal flow type. In nine patients with the no flow signal type, the diagnostic reliability was 92% (59/64). Percutaneous vertebral Doppler examination has clinical usefulness as a screening test for occlusive vertebral arterial diseases.

Numerous reports show that extracranial arterial occlusive or stenotic lesions play an important role in the development of various kinds of ischemic cerebrovascular diseases. The clinical aspects of cerebrovascular disorders of vertebral arterial disease are less well clarified when compared with internal carotid arterial disease. One reason is that the clinical symptoms caused by vertebral arterial occlusions are quite varied; another reason is that the usual diagnostic procedure for disease in this area is vertebral angiography which may have serious complications.

Increasing interest has been focused on the use of the ultrasonic Doppler technique as a noninvasive means for evaluating extracranial arterial occlusive diseases. Recent reports suggest the clinical usefulness of the ultrasonic Doppler technique for the diagnosis of internal carotid artery occlusive lesions. Detection of vertebral blood flow with this technique was successfully reported earlier and was studied from various points of view, but little has been done to test its diagnostic reliability with vertebral arterial occlusive lesions as seen on angiograms. Keller et al. reported that errors occurred in studying the arteries using the ultrasonic Doppler technique with a peroral probe. We have found this probe very troublesome and difficult to use because of pharyngeal reflexes.

In the present study we estimated the diagnostic reliability of the percutaneous vertebral Doppler technique in patients with vertebral arterial occlusive lesions by making a comparison between the semi-quantitative analysis of the ultrasonic Doppler findings using the percutaneous probe application technique and the angiographic findings in the vertebral arteries.

Subjects
Fifty-three patients and 64 vertebral arteries were studied. All patients had symptoms of chronic or subacute stages of cerebrovascular disease. Patients with intracerebral hemorrhage or brain edema were eliminated. Thirty-six patients had occlusive cerebrovascular disease with various degrees of cerebral blood flow deficit related to the use of the instrument, atraumatic examination of the artery, and no postoperative infections. Although the instrumentation currently available was not designed to meet the specific needs of the vascular surgeon, it did provide an opportunity to establish the feasibility of the technique.

Vascular endoscopy is an alternative to operative arteriography for intraoperative evaluation of vascular repairs. It provides a three dimensional view of the reconstructed segment. It takes less time than arteriography and allows correction of defects prior to the restoration of blood flow. The delicate carotid artery suture line does not have to be reopened to correct residual defects. Endoscopy adds a new dimension to vascular surgery permitting more precise repair which should reduce the morbidity of carotid artery surgery.

Acknowledgment
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References

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of neurological impairment. Nine had vertebro-basilar transient ischemic attacks, five had vertigo, and three had subarachnoid hemorrhage. The ages of the patients ranged from 34 to 83 years and the mean age was 64.4 years.

Methods

All vertebral arteries were examined by a percutaneous vertebral Doppler unit and either retrograde brachial angiography or aortic angiography.

(1) Doppler Ultrasonic Flowmeter

Vertebral blood flow was measured using a bi-directional ultrasonic flowmeter (model EUD-3B, Hitachi Medico, Tokyo) which was connected to an ultrasound probe with

FIGURE 1. The block diagram of the bidirectional ultrasonic Doppler flowmeter (dual filter method). Either the away-from-probe or the toward-probe flow signal was selected and registered on a magnetic tape recorder monitored with a loud speaker.

transmitting ultrasound frequency of 5 MHz. A block diagram of this device is shown in figure 1. This flowmeter has two filters to separate the signal into signals corresponding to toward-probe flow and away-from-probe flow. Either of these directional flows can be selected with a switch. The selected blood flow is then recorded on a magnetic tape recorder while being monitored with a loudspeaker. The recorded blood flow signal was analyzed with a sound spectrograph (Type SG-07, Rion, Tokyo) to produce a pulsatile sound spectrogram (sonogram). The sonogram and the vertebral angiograms of a normal vertebral artery are shown in figure 2.

(2) Vertebral Blood Flow Detection
For the detection of a vertebral blood flow signal, the patient was placed in the supine position with his head slightly extended and rotated about 45 degrees to the opposite side. The examiner applied the ultrasound probe coated with impedance adaptation jelly (Echojelly) on the skin just under the mastoid process and pointed the transmitting ultrasound beam toward the eyeball of the opposite side. In this region the vertebral blood flow was detectable in both directions, away-from-probe flow at the upper point and toward-probe flow at the lower point. The away-from-probe flow was measured first because of easier
detection than the toward-probe flow. Then the probe was slowly moved to find the place and angle where the blood flow signal became maximal and the probe was manually fixed at this point.

The identification of the vertebral artery from the internal carotid artery or branches of an external carotid artery was possible by the manual compression of the homolateral common carotid artery. Carotid compression diminished and then caused the blood flow signals from arteries other than the vertebral artery to disappear. The blood flow signal of the vertebral artery increased or did not change.

(3) Analysis of Vertebral Flow with Sonogram

The most stable and maximal part of the blood flow signal recorded was analyzed with a sound spectrograph at a time section of 2.4 sec. Figure 3 shows the schematic diagram of the sonogram obtained from a normal vertebral artery. In this illustration the abscissa indicates the time scale and the ordinate represents the sound frequency resulting from the Doppler effect between the transmitting ultrasound and the ultrasound reflected from flowing red blood cells. In the sonogram, the time scale is represented as 270 mm = 2.4 sec and the scale of sound frequency is 12 mm = 1 Kcycle/sec. The enveloped curve of the sonogram indicated maximum blood flow velocity "S" during systole and "d" during diastole.

(4) Vertebral Angiography

Retrograde brachial angiography was done using a No. 18 gauge Teflon catheter 200 mm long placed in the brachial artery in the region of the antecubital fossa. Contrast medium (30 ml, 60% Amidotrizoate — Urografin) was injected at a speed of 23 ml/sec. To avoid angiospasm and reduce pain on injection, about 10 ml of saline solution was injected.

Figure 5. Sixty-seven-year-old male, the left vertebral artery. A) (Above) Vertebral Doppler: poor flow type. B) (Left) Angiography: occlusion. The collateral flow was observed via the ascending cervical artery (lateral position, see arrow).
layered on the contrast medium within an autoinjecting syringe so the saline solution could be injected just after the contrast medium.

For the visualization of the neck vessels as well as those in the posterior fossa, the X-ray tube was focused on the cricoid cartilage using a 24 by 30 cm X-ray film. Two or three projections were obtained; the first, in the lateral position and the second, in the antero-posterior position of the neck and/or in the Towne position. Using an automatic injector and an automatic cassette changer, serial angiography was performed. Aortic or carotid angiography was added if needed.

Results

(1) Angiographic Findings

Angiographic findings of the vertebral arteries were classified as follows:

(a) Occlusion of Vertebral Artery: Seven Patients

The angiographic diagnosis of vertebral occlusion was restricted to the finding of no filling at the vertebral origin with the demonstration of collateral flow to this vessel. The collateral flow was demonstrated through the contralateral vertebral artery in two cases, through the external carotid artery via the occipital artery in two cases (fig. 4), and through the brachial artery via the ascending cervical artery in one case (fig. 5). A definite stump of the vertebral artery in two cases (fig. 6) also indicated vertebral occlusion.

(b) Missing Vertebral Artery: Four Patients

If the aortic and retrograde brachial angiograms did not reveal the vertebral artery without visualized collateral flow (fig. 7) this vertebral artery was designated as "missing," because the differentiation of aplasia or occlusion was impossible.

(c) Narrowing of the Terminal Portion of the Vertebral Artery: Ten Patients

This group consisted of those patients whose basilar arteries did not appear but whose vertebral arteries were...
TABLE 1  Percutaneous Vertebreal Doppler Compared with Angiographic Findings

<table>
<thead>
<tr>
<th>Angiographic findings</th>
<th>Percutaneous vertebral Doppler</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>No flow signal type</td>
</tr>
<tr>
<td>Occlusion</td>
<td>4</td>
</tr>
<tr>
<td>Missing</td>
<td>2</td>
</tr>
<tr>
<td>Terminal narrowing</td>
<td>0</td>
</tr>
<tr>
<td>Hypoplasia</td>
<td>0</td>
</tr>
<tr>
<td>Normal</td>
<td>3</td>
</tr>
<tr>
<td>Total: 64</td>
<td>9</td>
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</table>

For the quantitative evaluation of vertebral blood flow, we measured the degrees of “S” and “d” in the sonograms of 55 vertebral arteries in which blood flow was detected with ultrasonic Doppler technique and then plotted them on the coordinates (fig. 9). The abscissa was the degree of “S” and the ordinate was the degree of “d” (12 mm = 1 Kcycle/sec). In figure 9 the open circles indicate angiographically normal vertebral arteries and the closed circles indicate angiographically abnormal vertebral arteries, e.g. occlusion, missing, terminal narrowing and hypoplasia.

From this figure it is possible to determine criteria which differentiate abnormal vertebral arteries from normal vertebral arteries. All abnormal vertebral arteries except one satisfy the criteria of “S” ≤ 12 mm or “d” ≤ 4 mm and all normal vertebral arteries except one satisfy the criteria of “S” > 12 mm and “d” > 4 mm. The sonograms of vertebral blood flow which satisfy the criteria of “S” ≤ 12 mm or “d” ≤ 4 mm are “poor flow type” and the sonograms which satisfy the criteria of “S” > 12 mm and “d” > 4 mm are “normal flow type.”

Vertebral blood flow can be divided into three types: “normal flow type,” “poor flow type,” and “no flow signal type.”

(3) Percutaneous Vertebral Doppler Versus Angiography (Table 1)

In nine patients with a no flow signal type, there were four whose vertebral arteries were occluded, and in these collateral flow was observed via the contralateral vertebral artery in two and collateral flow via occipital artery in two (fig. 4). A missing vertebral artery was verified in two cases (fig. 7). However, three other patients had normal vertebral arteries on angiograms.

In 17 patients with a poor flow type, there was one whose angiogram revealed occlusion of the vertebral artery at its origin with collateral filling via the ascending cervical artery (fig. 5). In two a definite stump at the terminal portion of the vertebral artery was observed (fig. 6). Two instances of missing vertebral artery, nine of terminal narrowing (fig. 8) and two of hypoplasia were verified angiographically.

There was one normal vertebral artery on angiograms with the poor flow type of change on percutaneous vertebral Doppler. Among 38 vertebral arteries of normal flow type, 37 vessels were normal on angiograms, but one was narrowed terminally.

The diagnostic reliability of the percutaneous vertebral Doppler was 67% (6/9) for the no flow signal type, 94% (16/17) for the poor flow type, 97% (37/38) for the normal flow type and 92% (59/64) for all the vertebral arteries examined.

(2) Percutaneous Vertebral Doppler Findings

In 64 vertebral arteries of 53 patients, the vertebral flow signal was detected in 55 but in nine patients the flow signal could not be detected using the percutaneous vertebral Doppler technique. These nine instances of undetected flow signal were grouped as “no flow signal type.”

(2) Percutaneous Vertebral Doppler Findings

In 64 vertebral arteries of 53 patients, the vertebral flow signal was detected in 55 but in nine patients the flow signal could not be detected using the percutaneous vertebral Doppler technique. These nine instances of undetected flow signal were grouped as “no flow signal type.”

(4) Hypoplasia of the Vertebral Artery: Two Patients

The vessel was narrow from its origin and terminated at the posterior inferior cerebellar artery or at the fourth cervical segment of the vertebral artery with a nonvisualized basilar artery.

(e) Normal Vertebral Artery: 41 Cases

The vertebral and basilar arteries were filled from their origin to their termination on retrograde brachial angiograms (fig. 2). If minor areas of atherosclerosis coiling or hypoplasia existed in the vertebral artery they were classified as “normal.”

(2) Percutaneous Vertebral Doppler Findings

In 64 vertebral arteries of 53 patients, the vertebral flow signal was detected in 55 but in nine patients the flow signal could not be detected using the percutaneous vertebral Doppler technique. These nine instances of undetected flow signal were grouped as “no flow signal type.”
Discussion
Since the first application of the ultrasonic Doppler technique for the detection of blood flow by Satomura et al., this technique has been widely used for the evaluation of blood flow in various arteries. The clinical application of this technique to the vertebral artery has been delayed. Müller et al. and Mol et al. questioned the constant detection of vertebral blood flow signal in any normal subject. Successful vertebral blood flow detection was reported earlier by Miyazaki. Recently, Freund, Matsunaga et al., and Tada et al. studied vertebral blood flow using the ultrasonic Doppler technique. All of these reports lacked significant angiographic comparison. Angiographic comparison with the vertebral Doppler results was reported by Keller et al. They described five patients among 42 cases who were diagnosed correctly with the peroral vertebral artery Doppler probe with one false negative and two false positive cases. They concluded that the diagnosis of vertebral

![Figure 8](image_url)

**Figure 8.** Sixty-year-old female, the right vertebral artery. A) (Above) Vertebral Doppler: poor flow type. B) (Left) Angiography: terminal narrowing. The basilar artery was not visualized and the terminal narrowing of vertebral artery was demonstrated. The irregularity and coiling were observed at the terminal portion.

![Figure 9](image_url)

**Figure 9.** Abscissa: degree of "S" by millimeter. Ordinate: degree of "d" by millimeter. ○: an angiographically normal vertebral artery. ●: an angiographically abnormal vertebral artery. Dotted line: $S = 12$ mm, $d = 4$ mm.
stenosis or hypoplasia was less reliable. In this study, hypoplasia, stenosis, occlusion peripheral to the measuring point and occlusion with collateral flow were diagnosed with a high reliability (94%).

The high diagnostic reliability of our percutaneous probe application technique may be due to the fact that Japanese in the stroke prone age group are thinner than those in Europe or the United States, and the sound spectrograph may thereby be more sensitive. 16

It is reasonable that a no flow signal type can be obtained from a vertebral artery with occlusion or aplasia where there is no blood flow at the measuring point (fig. 7). This point might be at the point of medial flexion in the third segment near the atlantooccipital joint. Even the existence of collateral flow via homolateral carotid territory can be diagnosed as a no flow signal type because carotid compression blocks this collateral flow (fig. 4).

There were five cases with vertebral occlusion or missing vertebral artery whose vertebral blood flow was detected as poor flow type with the ultrasonic Doppler technique. In three of these five cases, the collateral flow or vertebral flow was verified on angiograms (figs. 5, 6). But in the other two cases, the collateral flow could not be verified angiographically. It is quite possible that there can be collateral flow through the angiographically nonexamined or nonvisible arteries.

There were three false positive cases whose ultrasonic Doppler diagnosis was a no flow signal type and whose angiographic diagnosis was a normal vertebral artery. Several possible reasons can be taken into consideration to explain this: 1) narrowing of the atlantooccipital joint may disturb the detection of the flow signal, 2) there may be an error of the vertebral artery course in the transverse vertebral canal at a level higher than C6 and we were unable to identify vertebral flow from internal carotid flow because carotid compression also compressed the vertebral artery, 3) change of the neck position, such as Power's syndrome, might alter vertebral blood flow, and 4) there may be technical errors using percutaneous vertebral Doppler.

We believe the other two false positive and negative cases reflected the difference character of these two diagnostic procedures; i.e. the ultrasonic Doppler reflects the existence of blood flow. It should also be taken into account that the degrees of “S” and “d” in a sonogram are changed according to a change of the angle made by the vertebral artery and the ultrasound probe. 16 This angle may be inappropriate due to the variation of the vertebral artery course in the neck.

Angiographic diagnosis and classification were reported by Thomas et al. 14 and Faris et al. 18 and were slightly modified by us. The direct branching of the vertebral artery from the aorta was verified with retrograde brachial angiograms in three patients and with aortic angiograms in two. These five patients were not included because of the difficulties of angiographic diagnosis, especially in determining terminal narrowing or terminal occlusion.

In ten cases classified as terminal narrowing, four had thrombosis or irregularity at the 3rd or 4th segment of the vertebral artery but the other six cases did not. In these cases the differentiation of terminal occlusion, stenosis, hypoplasia or laminar flow was practically impossible. Based on the pathological study Castaigne et al. 16 reported that terminal occlusions existed more frequently than proximal or intermediate vertebral artery occlusions.

We believe that some cases classified as terminal narrowing might have occlusion of the terminal portion of the vertebral artery. We believe that the percutaneous application of the Doppler technique is a better technique for the evaluation of vertebral blood flow. In 250 patients who were examined with the percutaneous vertebral Doppler in our laboratory, we were able to evaluate vertebral artery blood flow in almost all patients except in four fat patients and in a few uncooperative patients.

There were a few false positive effects in the patients examined with this technique when carotid compression was done. Two patients with acute internal carotid occlusion and one with minor stroke had a transient decrease in their level of consciousness and a disturbance of respiration during carotid compression. Therefore, carotid compression must be done carefully, especially in patients with acute stroke.

It is difficult to diagnose vertebral artery occlusion from the clinical symptoms alone. In 11 patients with vertebral artery occlusion or a missing vertebral artery in our series, brain stem or cerebellar signs were evident in only three patients and the other patients were not diagnosed as having ischemic disease in the vertebrobasilar territory. In the latter cases, the vertebral artery obstructions were suspected with the percutaneous vertebral Doppler technique and verified correctly with angiography.

We term this ultrasonic Doppler examination "Doppler neck study." It requires about 20 minutes to perform. The Doppler neck study is very useful and valuable as a screening test for occlusive diseases of the cerebral arteries in the neck. 13

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References

Intracranial Aneurysms and Subarachnoid Hemorrhage — Report on a Randomized Treatment Study

IV-B. Regulated Bed Rest — Statistical Evaluation

WILLIAM G. HENDERSON, M.P.H., PH.D., JAMES C. TORNER, M.S.,
AND DONALD W. NIBBELINK, M.D.

SUMMARY Regulated bed rest was one of four treatment modalities evaluated in a randomized clinical trial conducted between 1963 and 1970 for patients with a ruptured intracranial aneurysm. A life table method of statistical analysis was used to determine cumulative mortality and rebleeding rate during a five-year follow-up period for 187 patients in this treatment program and for subgroups of this patient sample. Linear discriminant function analysis was used to develop equations of clinical variables to predict mortality and rebleeding during the 90-day period following the bleed.

The clinical variables found to be most indicative of mortality included a poor initial neurological and medical state and sex (male). Other variables somewhat indicative of high mortality but not reaching statistical significance included a short interval from last bleed to treatment and high mean blood pressure and a large aneurysm.

REGULATED BED REST was one of four treatment modalities studied in a randomized clinical trial conducted between 1963 and 1970 for patients with a ruptured intracranial aneurysm. The other three treatment programs were: (1) drug-induced hypotension with regulated bed rest, (2) ipsilateral common carotid artery occlusion with bed rest, and (3) intracranial surgery. An introduction to the study, the objectives and design of the study, a comparison of the treatment groups, a detailed analysis of intracranial surgery, and a medical analysis of bed rest have been published. The purpose of this report is to provide a statistical analysis of the clinical factors associated with mortality and rebleeding in those treated with bed rest. Although bed rest therapy alone is outmoded as an early treatment category. All patients except eight completed their designated period of bed rest. Among the remaining 194 patients, 35 had an internal carotid artery aneurysm, 22 had a middle cerebral artery aneurysm, and 130 had an anterior cerebral-anterior communicating artery aneurysm, and seven had an aneurysm on the vertebral-basilar arterial system (table 1). On June 19, 1967, collection of protocols from patients with a vertebral-basilar artery aneurysm was interrupted, and this group was eliminated from all statistical analyses because the sample size was too small.

Patients allocated to the bed rest treatment program remained at regulated bed rest for 21 days following formal initiation of this therapeutic program. Details of the treatment were described in a previous report. Characteristics of Aneurysm site, age, number of bleeds, pre-existing hypertension, and evidence of vasospasm were not indicative of higher mortality.

The clinical variables found to be most related to rebleeding included a short interval from the last bleed to treatment and sex (male). Other variables less related to rebleeding but not reaching statistical significance included a high mean blood pressure and the number of bleeds in the medical history. Aneurysm site, initial neurological and medical state, age, aneurysm size, pre-existing hypertension, and evidence of vasospasm did not appear to be related to rebleeding.

The discriminant functions derived were used to reclassify the subjects into dead and alive and rebleeding and no rebleeding 90 days after initial hemorrhage. The misclassification percentages were substantial, making doubtful the prediction of mortality and rebleeding.

results of this analysis are considered to be of importance, because the outcome of patients treated with regulated bed rest most closely approximates the natural history of the disease.

Methods

Between June 15, 1963 and February 15, 1970, 202 patients were assigned randomly to the regulated bed rest treatment category. All patients except eight completed their designated period of bed rest. Among the remaining 194 patients, 35 had an internal carotid artery aneurysm, 22 had a middle cerebral artery aneurysm, 130 had an anterior cerebral-anterior communicating artery aneurysm, and seven had an aneurysm on the vertebral-basilar arterial system (table 1). On June 19, 1967, collection of protocols from patients with a vertebral-basilar artery aneurysm was suspended, and this group was eliminated from all statistical analyses because the sample size was too small.

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