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A Prospective Comparison of Duplex Sonography vs Angiography of the Vertebral Arteries

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A prospective blind comparison was completed between duplex sonography and angiography of the vertebral arteries. Thirty-two vertebral arteries were studied for direction of flow, degree of origin plaque or stenosis, Doppler characteristics, and vessel size. The vertebral arteries were reliably identified by imaging their course from the subclavian artery into the transverse foramina and by identifying a Doppler signal similar in waveform to the internal carotid artery. With Doppler, a 90% accuracy was obtained for direction of blood flow. Nonvisualization of origins was primarily due to vessel depth and/or tortuosity. In 12 vessel origins that were well seen with both techniques, angiography and sonography agreed in two-thirds of the cases. In four cases, origin plaque was underestimated with duplex imaging. Interestingly, no Doppler frequency or velocity elevation was identified distal to significant stenoses. One false-positive diagnosis of occlusion occurred with sonography, in which a 99% origin stenosis resulted in no detectable Doppler signal. By comparing sonography with angiography, sonography was shown to be 80% accurate in determining vertebral artery size.

Our preliminary results indicate that duplex scanning is a reasonably accurate screening technique for size, patency, and direction of blood flow in the vertebral arteries. Duplex evaluation of the vertebral artery origin was limited by vessel depth, tortuosity, and calcifications.

Duplex sonography of the carotid arteries is a well-established screening technique for noninvasive diagnosis of carotid stenosis. The role of duplex imaging of the vertebral arteries is not well established. Reasonably accurate determination of vertebral artery patency and flow direction have been described using Doppler alone or duplex imaging [1–10]; however, few series are available with angiographic correlation. Since atherosclerotic vertebral artery stenoses tend to occur at the vertebral artery origins, it would be useful to quantitate origin stenoses noninvasively. This has not been convincingly achieved with sonography. In this study, the vertebral arteries were evaluated prospectively with duplex sonography to evaluate the role of this noninvasive technique in vertebral artery disease.

Materials and Methods

Between September and December, 1984, sixteen patients who were scheduled for angiography were evaluated for cerebrovascular disease. All patients were suspected of having carotid distribution disease of atherosclerotic origin. The patient population consisted of 12 men and four women, with an average age of 63 years (range, 33–77 years).

Bilateral duplex imaging of the vertebral arteries was performed using a 7.5-MHz imaging system and a 4.5-MHz Doppler system (Technicare Autosector). In patients with particularly deep vertebral artery origins, imaging was also completed with a 5-MHz transducer. Duplex imaging was performed with meticulous attention to technique in order to correctly identify the vertebral artery. The vertebral artery could be identified by initially identifying the common carotid artery in the supraclavicular region and then rotating the transducer posterolaterally (Fig. 1). The identity of the vertebral artery was confirmed by its flow pattern, which was similar in waveform to the internal carotid artery, and by its course from its subclavian origin

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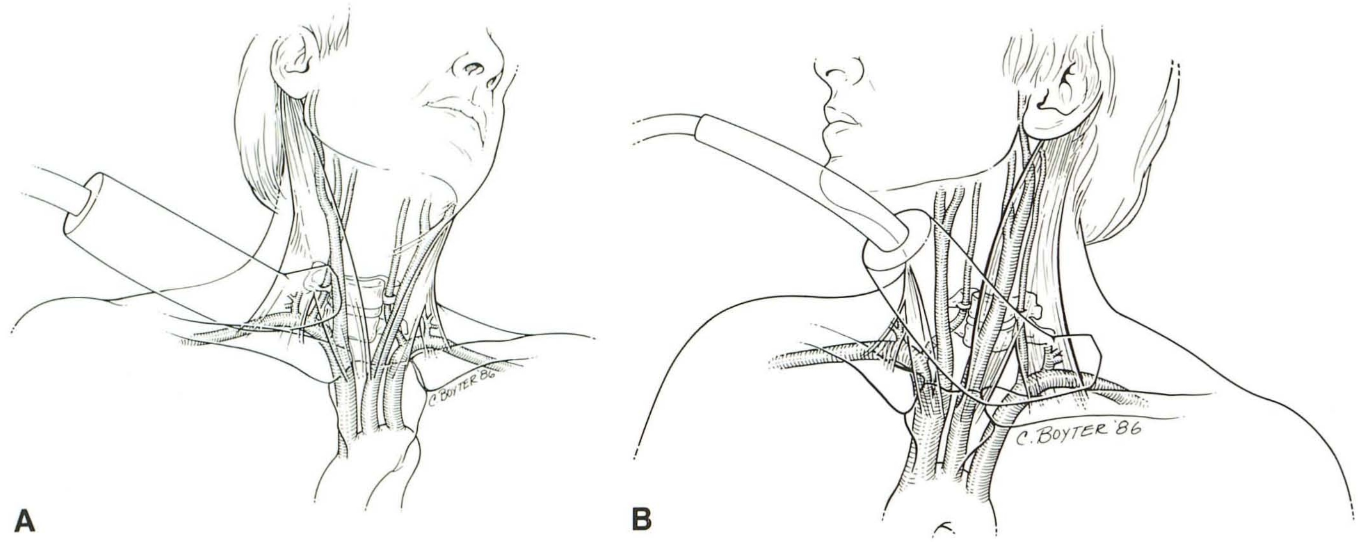


Fig. 1.—**A**, Transducer is positioned in supraclavicular fossa and angled posterolateral to common carotid artery in order to image right vertebral artery origin. Vertebral artery is traced from its origin at subclavian superomedially until it enters transverse foramina of C6. Thyrocervical trunk is distinguished from vertebral by its location, course, branches, and waveform similar to external carotid system. **B**, Transducer positioning for left vertebral origin is demonstrated. As for right vertebral, the left vertebral artery is traced from its subclavian artery origin into transverse foramina of C6.

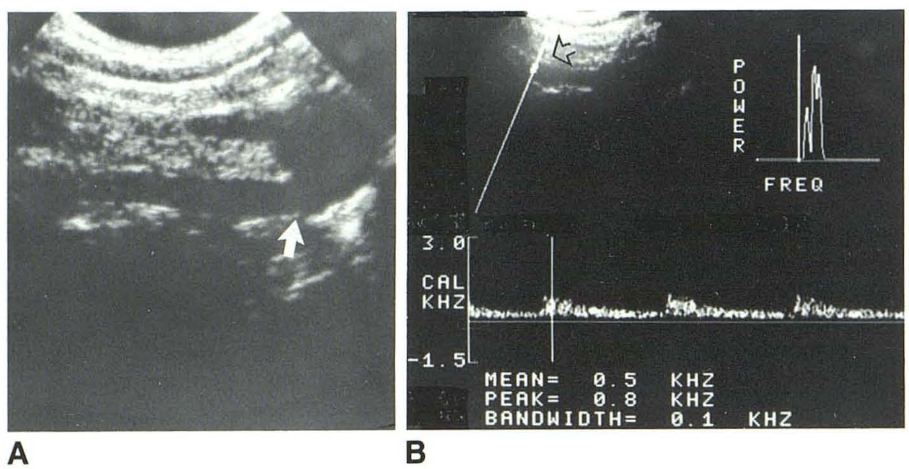


Fig. 2.—**A**, The normal vertebral real-time image is demonstrated in an angiographically normal vessel. Vertebral origin (*arrow*) is well seen. **B**, Normal Doppler waveform of vertebral artery has flow in systole and in diastole, and is similar in waveform to that of internal carotid artery. The angle of incidence between Doppler beam and direction of blood flow should be 30–60° (*open arrow*).

into the transverse foramina (Fig. 2). Other arteries occasionally mimic the appearance of the vertebral artery origin (4, 10, 11); however, owing to their different anatomic course and waveform similar to the external carotid artery, these were excluded from evaluation. The internal carotid artery and the vertebral artery supply a low-resistance vascular bed, and thus have continuous flow through systole and diastole and a ratio of peak systolic to diastolic frequency of about 2 or 3 to 1. Vessels that supply high-resistance vascular areas, such as the external carotid and ascending cervical arteries, result in a waveform with little flow in diastole and a peak systolic to diastolic frequency ratio of about 5 to 1. Doppler waveforms with spectral analysis were recorded for each vertebral artery, as were multiple images of the vertebral artery both at the origin from the subclavian and between the transverse foramina in the neck. Imaging criteria included a qualitative assessment of the visualization of the vertebral artery origin (good, equivocal, or nonvisualization), the presence of plaque formation at the origin, and a percentage stenosis by diameter. The vertebral arteries were visualized between the lower and mid-cervical transverse foramina; however, because of this incomplete visualization, no attempt was made to assess disease in this area. Doppler criteria included waveform, turbulence, direction of flow, peak systolic frequency, ratio of peak systolic frequency to peak diastolic frequency, and flow (cm/sec).

Although all patients were scheduled for intraarterial studies (IA-DSA), in two patients IV-DSA was substituted due to contraindications to angiography (one patient was on anticoagulant therapy for cardiac valve disease; the other had significant iliac and subclavian stenoses). Thus, IA-DSA studies were performed in 14 patients, and IV-DSA alone was done in two patients. IA-DSA studies of the aortic arch were completed in 14 patients. Subsequently, selective catheterization of 21 subclavian arteries was done with careful profiling using oblique and angled filming of the vertebral origins, since it was realized that the arch injection often failed to profile the vertebral artery origin. Angiographic criteria included vertebral artery size, patency, direction of flow, and degree of origin stenosis by diameter.

Correlation of the two techniques was then completed. Equivocal visualization and nonvisualization of the vertebral artery origin were grouped together as unsuccessful imaging. In those arteries whose origins were well seen with both techniques, a positive correlation was one falling within the same quartile percentage of stenosis by diameter (i.e., 0–24%, 25–49%, 50–74%, 75–99%, and complete occlusion).

Results

A comparative prospective study was performed between duplex imaging and either IA-DSA (14 patients) or IV-DSA (two patients). Of the 32 vertebral arteries studied with duplex imaging, the origins were well seen in 20 vessels (Table 1). Of these, nine vessels with diseased origins were identified (Fig. 3). Of the 32 vertebral arteries studied, the distal vessel above the origin was identified and a Doppler signal obtained in 31. In one patient, no right vertebral artery was identified by imaging, Doppler, or angiography. Comparison of vertebral artery size revealed seven patients with a left dominant vertebral, three with a right dominant vertebral, five with approximately equal-sized vertebral arteries, and one unrecorded.

TABLE 1: **Correlation Between Duplex Imaging and IA-DSA**

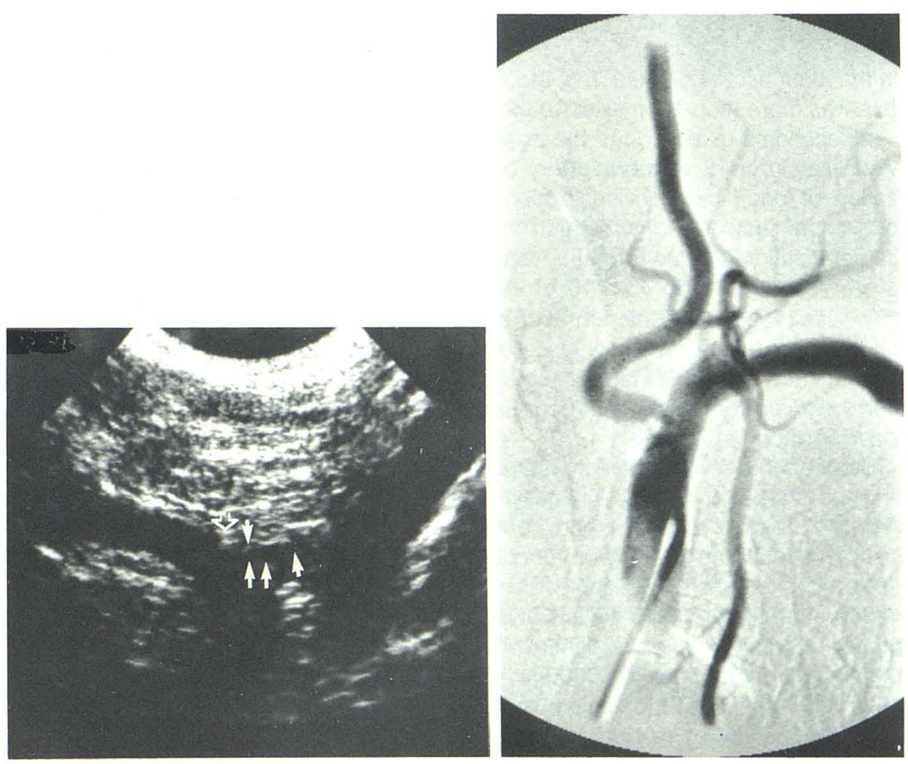
Origin visualization with both techniques (n = 32 vessels)	Adequate Equivocal/no	12 20*
	Agree	Disagree
% stenosis (n = 12 vessels)	8	4
Flow direction (n = 32 vessels)	30	2**
Vessel occlusion (n = 32 vessels)	30	2**
Size (n = 15 patients)	12	3

* 8 nonvisualizations with IA-DSA; 7 nonvisualizations with duplex imaging, 5 nonvisualizations with both.

** 1 vessel with 99% stenosis angiographically; 1 interpreter error.

Using directional Doppler, 27 vessels had normal antegrade flow while two patients had reversal of flow by Doppler (Figs. 4 and 5). Three patients had no flow identified in what appeared to be the vertebral artery. One of these, after retrospective comparison with angiography, reflected an error in interpretation due to a 90° angle of incidence of the Doppler with the direction of flow in the blood vessel (Fig. 5).

Peak systolic frequency on the left averaged 1.39 kHz (range, 0.7–2.7), and on the right, 1.14 kHz (range, 0.5–1.9 kHz). The Doppler waveform revealed flow in systole and in diastole in all patent vessels without turbulence. The peak systolic to end-diastolic frequency ratio on the left averaged 2.96 (range, 1.9–5.5), and on the right, 3.32 (range, 1.9–5.3). Velocities were determined in five patients; on the left the average was 75.4 cm/sec (range, 47–155 cm/sec), and on the right the average was 58.8 (range, 22–90 cm/sec). In four patients with stenoses greater than 50% by diameter (three on the left, one on the right), none resulted in an elevated frequency or velocity compared with the insignificantly stenosed and normal vessels. (The peak frequency average was 1.15 kHz; the maximum velocity average was 59 cm/sec.) Of these, one patient with no Doppler flow and a 99% stenosis was excluded. Doppler frequency and velocity were measured



A B

Fig. 3.—**A**, Proximal vertebral artery plaque with calcification (*open arrow*) resulted in shadowing of portions of this vessel. Echogenic material reduces lumen diameter of vessel origin (*arrows*) by approximately 80%; however, detection of a waveform characteristic of vertebral artery confirmed vessel patency. **B**, Angiography of same vessel confirmed stenosis and calcified plaque formation seen with sonography.

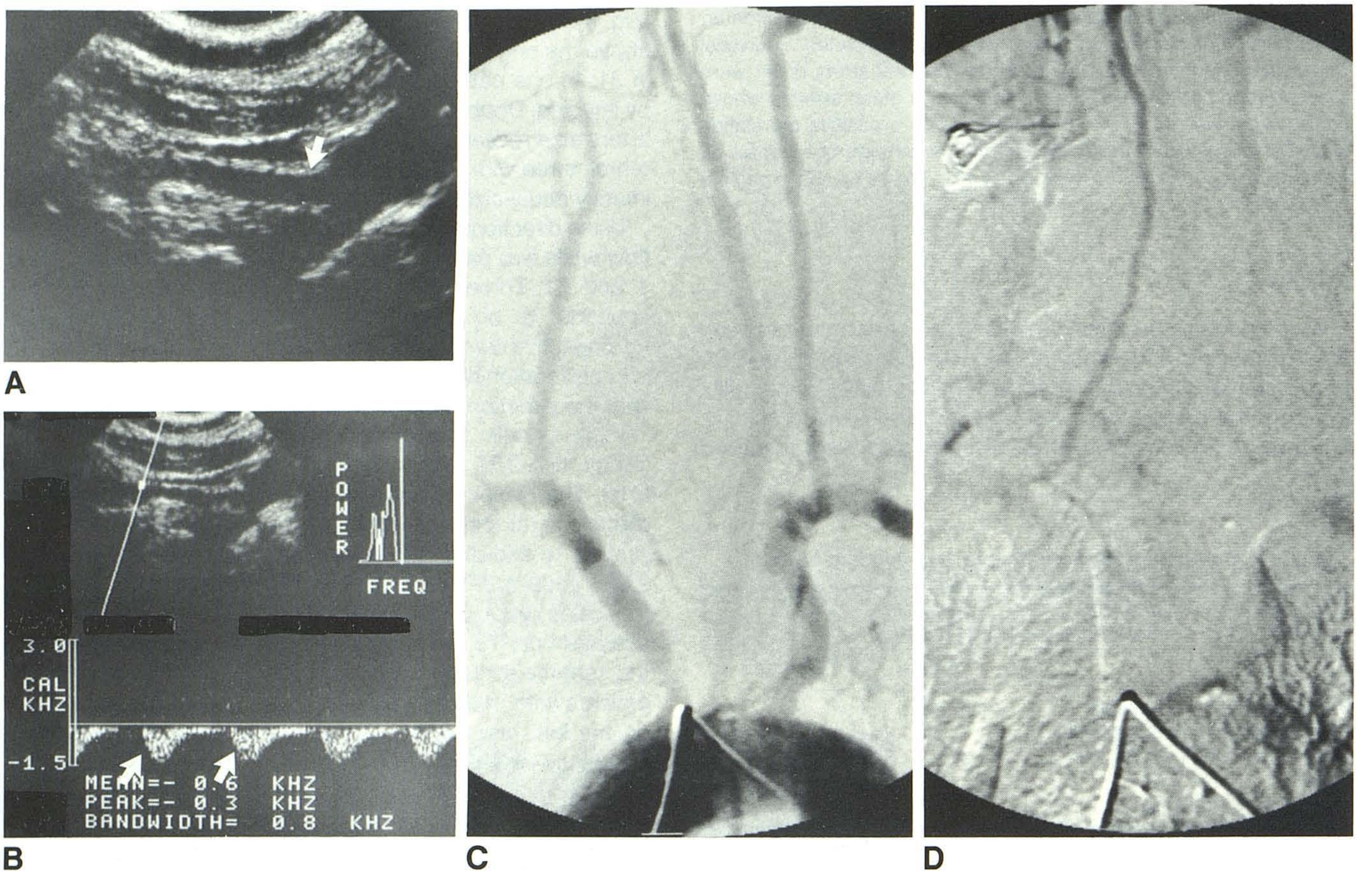


Fig. 4.—**A**, In this example, vertebral origin was unremarkable by imaging (*arrow*). **B**, Doppler waveform was reversed in direction and thus appeared below baseline (*arrows*). Early (**C**) and late (**D**) images angiographically confirmed reversal of flow in right vertebral artery.

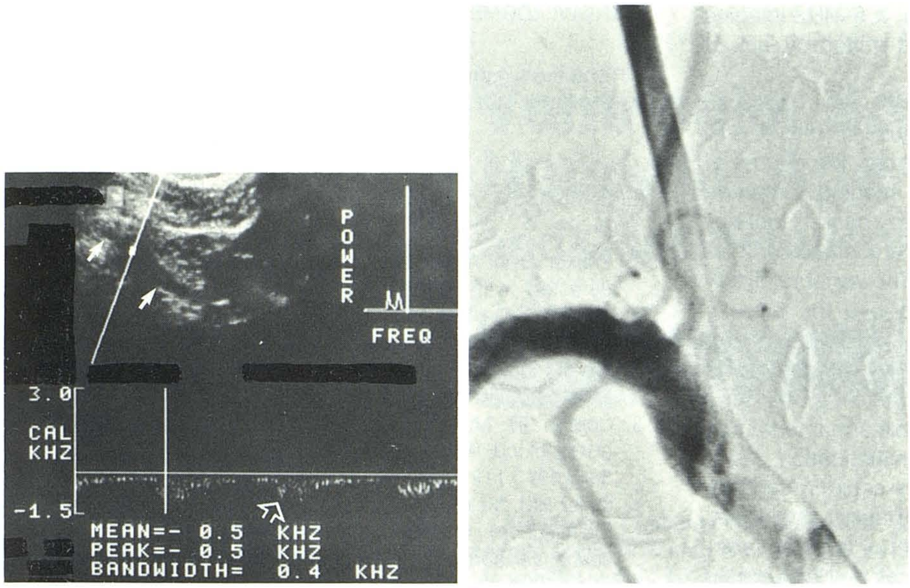
in the most accessible region of the vertebral artery; typically this was more than 1 cm distal to the vessel origin.

Independent evaluation of the arteriograms revealed good visualization of 19 vertebral artery origins, equivocal visualization of one, and nonvisualization of 12 vertebral artery origins primarily due to aortic arch injection without selective catheterization. Plaque formation was identified at the origin of 10 vessels ranging from 10 to 99% stenosis. Antegrade flow was present in 30 vertebral arteries, one right vertebral had reversal of flow, and one vessel was not visualized. Eight patients had a left dominant vertebral artery, four had a right dominant vertebral artery, and four had approximately equal-sized vertebral arteries.

Correlation between duplex sonography and angiographic findings is charted in Table 1. After prospective evaluation, a retrospective evaluation was completed to identify and correct errors made at angiography or sonography (Fig. 5). As noted above, in one patient no Doppler signal was obtained from a vertebral artery that was patent at angiography due to improper Doppler angle of incidence with the vessel. The optimum angle of incidence is 30–60° with the direction of flow; however, in this case the angle of incidence approached 90° and presumably was responsible for the absent signal in this vessel. In another case, the flow direction was initially interpreted as reversed. In retrospect, marked vessel tortuosity resulted in a negative angle of incidence of the Doppler beam, and thus a spurious reversal of flow. In one case, no Doppler signal was obtained from a vessel that was successfully imaged. In this instance, a 99% origin stenosis with very slow flow was noted at angiography. In this series, significant stenoses (>50% diameter) were not necessarily characterized by an increase in Doppler frequency and/or velocity probably due to sampling too distal to an area of stenoses (>1 cm distal). Certainly with carotid duplex imaging, the Doppler shifts caused by a significant stenosis revert to normal within a few centimeters of a stenosis.

Discussion

In this small preliminary series of patients studied prospectively with duplex imaging and angiography, the relative strengths and weaknesses of the two techniques are apparent. With duplex imaging, an accurate determination of direction of flow was identified with a 96% correlation with angiographic findings. Accurate determination of flow direction requires a directional Doppler and careful attention to the angle of incidence of the Doppler beam with the direction of blood flow in the vessel, not with the skin. The one error in



A B

C D E

Fig. 5.—**A**, Sources of error with duplex imaging: Doppler angle of incidence was caudally directed relative to direction of flow in vertebral artery; thus, a negative signal (*open arrow*) was appropriate for antegrade flow. Note the importance of obtaining a correct angle of incidence to vessel (*arrows*) and not to skin. **B**, Angiography confirmed antegrade flow in this vessel. **C**, In another example, the Doppler angle of incidence to direction of blood flow in vertebral artery (*arrows*) was approximately 90°. This resulted in a spurious absence of signal in a patent vessel (*open arrow*). **D**, In this example, origin plaque (*arrow*) was identified that reduced vessel diameter by approximately 60%; however, in spite of multiple attempts, no Doppler signal was obtained. **E**, Comparison with angiography revealed severe origin stenosis, which was underestimated by sonography. Markedly slow flow angiographically correlated with absence of a detectable Doppler signal, and is a recognized limitation of duplex imaging in differentiating tightly stenosed vessels from occluded vessels.

this series in determination of flow direction was in failing to recognize a negative angle of incidence of the Doppler beam with the direction of blood flow in a tortuous vertebral artery.

As expected, based on data from carotid arterial duplex studies [12], it is more difficult to accurately determine vascular occlusion with duplex imaging than with angiography. In this series of three vessels suggested by duplex to be occluded, two diagnoses were false-positive. One of these resulted from an interpreter error in failing to identify an incorrect angle of incidence of the Doppler signal with the direction of blood flow. The other false-positive diagnosis involved a vessel with a 99% origin stenosis and marked delay in filling at angiography. This is a limitation of duplex sonography, which has been described previously in an evaluation of the internal carotid artery [12]. A markedly dampened velocity of blood flow and a decreased number of red blood cells traversing the area evaluated result in a Doppler signal of such low amplitude as to be undetectable.

A comparison of vertebral size within each patient was completed to increase our confidence in the correct identification of the vertebral artery. In 12 of 15 patients, the vertebral arteries were correctly compared on the basis of size, with very slight differences shown by angiography in three patients.

Confident visualization of the vertebral artery origin and quantitation of the degree of stenosis encountered was problematic with both duplex and IA-DSA. Initially, intraarterial arch injections were performed; however, the vertebral artery origins frequently were not adequately profiled from an arch injection alone. Subsequently, selective subclavian injections with caudal angulation were used to optimally profile the vertebral artery origins. With duplex, the 7.5-MHz imaging transducer did not always penetrate deeply enough to assess the vessel origin. Likewise, the sonographic beam tended to intercept the vertebral arterial wall almost in a parallel fashion rather than tangentially. Owing to limitations imposed by the supraclavicular notch, we were not able to image the vertebral in multiple planes in the manner in which an internal carotid artery is studied. In some patients, use of a 5-MHz imaging transducer improved our imaging but was limited by lack of simultaneous Doppler capability.

In 12 vessels, the vertebral artery origins were visualized using both techniques; in 67%, the techniques correlated well as to the degree of stenosis. In all four errors, the degree of stenosis was underestimated with duplex imaging compared with angiography. Interestingly, the Doppler peak frequency was not helpful in quantitating a significant stenosis. This probably reflects the difficulty in sampling the vertebral artery even with pulsed Doppler immediately above the area of stenosis. Perhaps a smaller transducer would provide greater flexibility, particularly in obtaining a Doppler sampling at or immediately above a stenosis.

The role of vertebral duplex in the available armamentarium of imaging techniques requires further investigation. As a screening test, vertebral duplex imaging could potentially identify those patients with correctable bilateral origin stenoses or those with stenosis of a dominant or solitary vertebral artery. Certainly, detailed evaluation of the intracranial circulation would remain the domain of angiography; however, the exclusion of operable vertebral origin disease may be adequate for instituting medical therapy. Likewise, the demonstration of normal antegrade flow in patients with symptoms suggestive of steal could eliminate the need for a more invasive study, such as angiography.

In summary, this preliminary study suggests that a learning curve is involved in accurately evaluating the vertebral arteries with duplex imaging. Meticulous attention to technique and correlation with angiography are necessary to identify and correct errors in imaging. Duplex imaging is accurate for determining flow direction and vertebral artery size, and it is reasonably accurate for evaluating vessel occlusion. In this series, visualization of the vertebral artery origin was difficult with duplex imaging. The errors in quantitating stenosis with duplex imaging leaned toward underestimation of the stenosis; thus, caution is indicated when any plaque formation is visualized at the vertebral origin with duplex imaging. In this small series, the accuracy of duplex imaging for quantitation of vertebral artery origin stenosis has not been established. However, in view of our encouraging results, we believe further study with high-resolution imaging and Doppler is warranted.

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REFERENCES

1. Walker DW, Acker JD, Cole CA. Subclavian steal syndrome detected with duplex pulsed Doppler sonography. *AJNR* **1982**;3:615–618
2. Kaneda H, Irino T, Minami T, Taneda M. Diagnostic reliability of the percutaneous ultrasonic Doppler technique for vertebral arterial occlusive diseases. *Stroke* **1977**;8:571–579
3. Corson JD, Menzoian JO, LoGerfo FW. Reversal of vertebral artery blood flow demonstrated by Doppler ultrasound. *Arch Surg* **1977**;112:715–719
4. Keller HM, Meier WE, Kumpe DA. Noninvasive angiography for the diagnosis of vertebral artery disease using Doppler ultrasound (vertebral artery Doppler). *Stroke* **1976**;7:364–369
5. Liljeqvist L, Ekestrom S, Nordhus O. Monitoring direction of vertebral artery blood flow by Doppler shift ultrasound in patients with suspected "subclavian steal." *Acta Chir Scand* **1981**; 14:421–424
6. Ekestrom S, Eklund B, Liljeqvist L, Nordhus O. Noninvasive methods in the evaluation of obliterative disease of the subclavian or innominate artery. *Acta Med Scand* **1979**;206:467–471
7. Platz M. Doppler ultrasound studies of subclavian steal hemodynamics in subclavian stenosis. *Thorac Cardiovasc Surg* **1979**;27:404–407
8. Berguer R, Higgins R, Nelson R. Noninvasive diagnosis of reversal of vertebral-artery blood flow. *N Engl J Med* **1980**;302:1349–1351
9. Wood CPL, Meire HB. A technique for imaging the vertebral artery using pulsed Doppler ultrasound. *Ultrasound Med Biol* **1980**;6:329–339
10. White DN, Ketelaars CEJ, Cledgett PR. Noninvasive techniques for the recording of vertebral artery flow and their limitations. *Ultrasound Med Biol* **1980**;6:315–327
11. Diener HC, Dichgans J, Voigt K. Functional anatomy of extracranial arteries in occlusive vascular diseases by direct continuous wave Doppler sonography. *Cardiovasc Intervent Radiol* **1981**;4:193–201
12. Zwiebel WJ, Crummy AB. Sources of error in Doppler diagnosis of carotid occlusive disease. *AJNR* **1981**;2:231–242, *AJR* **1981**;137:1–12