Radiologic Importance of a High-Resistive Vertebral Artery Doppler Waveform on Carotid Duplex Ultrasonography

Esther S. H. Kim, MD, MPH, Megan Thompson, Kristine M. Nacion, BA, Carmel Celestin, MD, Alejandro Perez, MD, Heather L. Gornik, MD, MHS

Objective. The appearance of the vertebral artery (VA) waveform on a pulsed Doppler examination performed during standard carotid duplex ultrasonography (CDU) may suggest vertebrobasilar disease. We sought to determine the radiographic importance of high-resistive (HR) pulsed Doppler VA waveforms seen on CDU. Methods. The Noninvasive Vascular Laboratory database was queried for CDU studies noting the HR VA Doppler signal. Studies with unilateral or bilateral HR and antegrade VA waveforms with correlative neuroimaging studies within 60 days were included. Imaging reports were reviewed to determine the following: (1) a normal VA; (2) at least moderate distal VA or basilar artery (BA) stenosis, occlusion, or dissection; (3) a congenitally diminutive VA; or (4) other abnormalities. Results. Of 1338 studies with 1 or more HR VA waveforms, 79 studies met all inclusion criteria (n = 157 arteries) and had adequate correlative neuroimaging. There were 90 HR VAs, and HR waveforms were equally distributed between right and left sides. The mean peak systolic velocity of HR versus low-resistive (LR) VAs was 51.7 versus 63.6 cm/s (P = .04); the mean end-diastolic velocity of HR versus LR VAs was 4.6 versus 17.3 cm/s (P < .001); and the resistive index of HR versus LR VAs was 0.92 versus 0.73 (P < .001). Of all HR VAs, 18.9% were normal; 38.9% had distal vertebrobasilar stenosis or occlusion; 35.6% were congenitally diminutive; and 6.7% had other abnormalities (proximal stenosis, excessive tortuosity, fibromuscular dysplasia, and BA hypoplasia). Conclusions. The finding of an HR spectral Doppler signal in the VA was associated with major vertebrobasilar disease (46% of cases) and should prompt additional neuroimaging in the appropriate clinical situation. Key words: angiography; duplex ultrasonography; vertebral artery.

Although standard duplex ultrasonography is not a comprehensive modality for assessment of the vertebral arteries (VAs), useful information can be obtained with limited interrogation of the VAs during carotid duplex ultrasonography (CDU). Determination of the direction of blood flow (ie, antegrade or retrograde) in the VAs using color and pulsed Doppler waveforms can be especially helpful in assessment of severe subclavian stenosis with the vertebral steal phenomenon. In addition to directional information, CDU of the VAs can provide blood flow velocities and allow for qualitative analysis of Doppler waveform characteristics. The normal VA has substantial pandiastolic flow as it feeds the low-resistance vascular bed of the circle of Willis and the cerebral vasculature. A high-resistive (HR) vertebral signal from the cervical VA with loss of diastolic flow may indicate more cephalad vertebrobasilar disease (Figure 1).1
Limited pulsed Doppler interrogation of the VAs is a standard component of the CDU examination. Complete evaluation of the VAs with CDU is limited by its intraforaminal course with considerable acoustic shadowing and dropout of the Doppler signal. Based on the Intersocietal Commission for the Accreditation of Vascular Laboratories standards for extracranial cerebrovascular testing, in addition to the evaluation of the common, internal, and external carotid arteries, bilateral VAs are identified and, at minimum, a single midartery Doppler signal is obtained for each cervical VA. Although an HR Doppler signal in the cervical VA may indicate disease located cephalad to the ultrasound probe, ultrasonographic-angiographic correlation studies have been limited by small numbers of angiographic correlations or by preselection of patients with neurologic symptoms. Thus, the clinical importance of an HR pulsed Doppler VA waveform in an unselected patient population presenting for routine carotid ultrasonography remains uncertain.

Materials and Methods

Our institutional Noninvasive Vascular Laboratory database was queried for sequential CDU studies performed between January 1, 2002, and December 31, 2007, regardless of the indication for ordering the study. Study reports that noted antegrade HR (decreased or absent end-diastolic velocity) pulsed wave Doppler VA waveforms in one or both VAs were identified. The HR appearance of the VA waveform was entered into the study report and database at the time of the ultrasonographic examination and was based on qualitative interpretation by the vascular technologist and interpreting physician. Those studies that had correlative neuroimaging performed within 60 days of ultrasonography were included in the analysis. Acceptable neuroimaging studies were catheter-based angiography, computed tomographic angiography (CTA), and magnetic resonance angiography (MRA). Studies were excluded if there was a documented neurologic event between the dates of the CDU and correlative neuroimaging studies.

Based on the Intersocietal Commission for the Accreditation of Vascular Laboratories standards, the complete CDU protocol in our laboratory includes spectral Doppler waveforms taken from the proximal, mid, and distal portions of bilateral common and internal carotid arteries and limited Doppler assessment of bilateral innominate, subclavian, external carotid, and vertebral arteries. The VA is imaged in the mid-cervical segment (V2) with at least 1 pulsed Doppler waveform recorded from each side. A Doppler angle of 60° or less with respect to the direction of blood flow is maintained during the examination.

Figure 1. Left panel, Typical pulsed wave Doppler spectrum of a normal VA showing a systolic peak with continuous flow in diastole. The end-diastolic velocity is 12.7 cm/s. This is a typical Doppler waveform of an arterial vessel supplying a low-resistance bed, such as the brain. Right panel, Abnormal HR VA. There is a rapid rise to a sharp systolic peak followed by a rapid descent in flow velocity back to baseline. There is no antegrade flow at end diastole (end-diastolic velocity is 0). Although this is a more typical Doppler waveform of an artery supplying a high-resistance vascular bed, such as the resting limbs, it is a pathologic finding in the evaluation of the VA and may indicate cephalad vertebrobasilar occlusive disease.
Two investigators independently reviewed the final reports of the correlative neuroimaging studies to categorize the vertebrobasilar system into one of the following: (1) a normal VA; (2) at least moderate distal VA or basilar artery (BA) stenosis, occlusion, or dissection; (3) a congenitally diminutive VA; or (4) other vertebrobasilar abnormalities (proximal stenosis, excessive tortuosity, fibromuscular dysplasia, and BA hypoplasia). In cases of disagreement, a third investigator independently reviewed the neuroimaging reports and acted as a tie breaker.

All statistics were performed using Stata software (StataCorp LP, College Station, TX)\(^5\). Resistive indices (RIs) of HR and low-resistive (LR) VA waveforms were calculated by dividing the difference in peak systolic velocity (PSV) and end-diastolic velocity (EDV) by the PSV \([(\text{PSV} - \text{EDV})/\text{PSV}]\).\(^6\) Mean velocities and RIs between HR and LR VA waveforms were compared using the Student \(t\) test. Analysis of radiographic correlations according to the EDV of the Doppler waveforms (EDV of 0 or EDV >0) was done using \(\chi^2\) testing. All statistical testing was performed with a significance level of \(P = .05\).

### Results

There were 1338 studies with HR VA waveforms noted. Of these, 86 studies met all inclusion criteria. Of the 172 possible VAs to be analyzed in these 86 studies, 4 VAs were not able to be visualized during the ultrasonographic examinations, and 11 VAs were not adequately assessed by neuroimaging, resulting in 79 complete studies (\(n = 157\) VAs). Of the 157 VA waveforms in the 79 studies, 90 VA waveforms were HR; 13.9% of patients (\(n = 11\)) had bilateral HR waveforms. Ultrasonographic findings are shown in Table 1. High-resistive VA waveforms were equally distributed between the right and left sides (53.3% versus 46.7%, respectively; \(P\) not significant). The mean EDV among HR VA waveforms was 4.6 cm/s (range, 0–90.0 cm/s). High-resistive VA waveforms had significantly lower mean PSVs and mean EDVs when compared with LR VA waveforms. As expected, the mean RI of HR VAs was significantly higher than that of those with normal Doppler waveforms (0.92 versus 0.73; \(P < .001\)).

Of all HR VAs with correlative neuroimaging studies, 18.9% were normal (false-positive HR waveforms); 38.9% had at least moderate distal vertebrobasilar disease; 35.6% had congenitally diminutive VAS; and 6.7% had other abnormalities (proximal VA stenosis, excessive tortuosity, fibromuscular dysplasia, or BA hypoplasia). When categorized by EDV of 0 versus greater than 0 (mean EDV 10.8 cm/s), HR VAs with 0 end-diastolic flow were no more likely to be reflective of vertebrobasilar disease on neuroimaging (Table 2); however, the sample size for this determination was low.

### Discussion

Although conventional angiography remains the reference standard for assessing the vertebrobasilar circulation, it is invasive and reserved for patients for whom there is a strong neurologic indication. Although previous studies have shown a correlation between Doppler ultrasonography of the VAs and angiographic findings,\(^1,3,4\) to our knowledge, ours is the largest to investigate the correlation between a single Doppler waveform of the V2 segment of the VA and correlative neuroimaging in an unselected patient population referred for CDU.

**Table 1. Velocities in the VAs by HR and LR Waveforms**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HR ((n = 90))</th>
<th>LR ((n = 67))</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean PSV (range), cm/s</td>
<td>51.7 (15–180)</td>
<td>63.6 (19–276)</td>
<td>.04</td>
</tr>
<tr>
<td>Mean EDV (range), cm/s</td>
<td>4.6 (0–89)</td>
<td>17.3 (0–120)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Mean RI (range)</td>
<td>0.92 (0.51–1.0)</td>
<td>0.73 (0.48–1.0)</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Comparison of mean PSV, EDV, and RI by HR- versus LR-appearing Doppler waveforms of the VAs.

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Kim et al
Because of the differing modes of neuroimaging we used as the comparator studies (CTA, MRA, and angiography), calculation of the sensitivity or specificity of a single VA waveform to detect vertebrobasilar disease was not performed. A previously published ultrasonographic-angiographic correlation study of 58 patients (116 VAs) by Nicolau et al found that Doppler ultrasonography of the intertransverse V2 segment of the VA had sensitivity of 90%, specificity of 100%, a positive predictive value of 100%, and a negative predictive value of 95% for the detection of disease at any level of the vertebrobasilar circulation. This study, however, was limited to ultrasonographic investigation of patients with stroke symptoms who were referred by general or stroke neurologists for evaluation of the extracranial circulation. Although our study did not include as detailed an ultrasonographic investigation of the VAs as the study by Nicolau et al (a spectral Doppler waveform obtained at one site in the VA in our study compared with investigation of the course of the VA in the V2 segment by taking Doppler readings in several vertebral interspaces in the study by Nicolau et al), we did find that an HR appearance of a single VA Doppler waveform in an unselected population was associated with documented vascular abnormalities on correlative neuroimaging in a significant proportion of cases (46%). Although it is not a pathologic finding, congenital nondominance accounted for most of the remaining waveforms.

The high false-positive rate of 18.9% may have been due to several factors, including the qualitative assessment of VA Doppler waveforms into HR and LR categories and the lack of a single reference standard neuroimaging comparator (angiography). Additional analyses could be performed using the RI as the discriminator between HR and LR waveforms, but our laboratory does not have validated RI standards for assessing the VA. Future correlation studies may also consider stratifying patients according to the indication for ordering the ultrasonographic examination (neurologic symptoms versus other reasons) and using a quantitative definition of HR and LR waveforms in addition to qualitative assessment in an effort to increase the performance characteristics of VA Doppler waveform analysis to detect vertebrobasilar disease.

Notable weaknesses in our study were the review of the neuroimaging study reports, rather than independent review of the actual images, and assessment of VA Doppler waveforms only by the performing technologist and interpreting physician before being entered into the clinical database without an independent second physician review.

Despite these limitations, we found that a significant proportion of VAs with an HR Doppler waveform on CDU were associated with vertebrobasilar disease, and when accompanied by clinical findings, the appearance of an HR VA Doppler waveform on CDU may warrant additional neuroimaging. These data emphasize the importance of careful review of the VA Doppler waveform for its morphologic characteristics as well as the directionality of blood flow.

### Table 2. Radiographic Correlations of HR VA Doppler Signals

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal, n (%)</th>
<th>Congenitally Diminutive, n (%)</th>
<th>Vertebrobasilar Occlusive Disease, n (%)</th>
<th>Other Abnormalities, n (%)</th>
<th>Overall P</th>
</tr>
</thead>
<tbody>
<tr>
<td>LR (n = 67)</td>
<td>46 (68.7)</td>
<td>3 (4.5)</td>
<td>10 (14.9)</td>
<td>8 (11.9)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>HR (n = 90)</td>
<td>17 (18.9)</td>
<td>32 (35.6)</td>
<td>35 (38.9)</td>
<td>6 (6.7)</td>
<td>.13</td>
</tr>
<tr>
<td>EDV 0 cm/s (n = 51)</td>
<td>9 (17.6)</td>
<td>18 (35.3)</td>
<td>23 (45.1)</td>
<td>1 (1.96)</td>
<td>.13</td>
</tr>
<tr>
<td>EDV &gt;0 cm/s (n = 38)</td>
<td>8 (21.1)</td>
<td>14 (36.8)</td>
<td>11 (29.0)</td>
<td>5 (13.2)</td>
<td>.13</td>
</tr>
</tbody>
</table>

Findings of vertebrobasilar neuroimaging by EDV on CDU. High-resistive VAs with an EDV of 0 (no flow at end diastole) were no more likely to have significant vertebrobasilar disease than those with an EDV of greater than 0 cm/s (mean EDV for HR VAs with an EDV >0 cm/s, 10.8 cm/s; P not significant).

*Includes at least moderate distal VA or BA stenosis, occlusion, or dissection.

*Includes proximal stenosis, excessive tortuosity, fibromuscular dysplasia, and BA hypoplasia.
References


5. StataCorp LP. Intercooled Stata 9.0 for Windows. College Station, TX: StataCorp LP; 2005.