Use of Diastolic Velocity Ratios to Predict Significant Carotid Artery Stenosis

Steven G. Friedman, MD, Brian Hainline, MD, Arthur W. Feinberg, MD, Martin L. Lesser, PhD, and Barbara A. Napolitano, MA

Duplex scanning of the carotid bifurcation has emerged as an accurate noninvasive means of predicting and quantifying carotid arterial stenoses. Compared with the more widely reported measurements of spectral broadening and peak frequency ratios, measurements of diastolic velocity ratios have theoretical advantages in predicting carotid artery stenosis. The use of diastolic velocity ratios between the internal and common carotid arteries was prospectively studied in 30 consecutive patients to determine its accuracy in predicting significant stenosis of the internal carotid artery when compared with angiography. A total of 55 carotid bifurcations were studied, and the use of diastolic velocity ratios correctly predicted high-grade stenosis (≥75% diameter reduction) in 53 cases (95%). We conclude that diastolic velocity ratios may be used to accurately detect significant internal carotid artery stenosis.

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Duplex scanning has become widely accepted as a safe and accurate noninvasive tool for the detection of carotid bifurcation blood flow abnormalities. By combining the ultrasound image with a spectrum analyzer, information regarding carotid arterial topography as well as the frequency content of sample volumes is obtained. These may be used to diagnose anatomic and hemodynamic aberrations. Most reports of duplex scanning rely on the use of peak frequency ratios and indexes of spectral broadening to predict carotid stenosis. These measurements reflect blood flow velocity, which is directly proportional to the arterial cross-sectional area at the point of examination. As this area decreases with the growth of an atherosclerotic plaque, blood flow velocity must increase to maintain constant flow volume. The frequency obtained from red blood cells in motion is subject to variation with the type of transducer used and the angle of interrogation. Theoretically, therefore, direct measurements of blood flow velocity may be more precise. Blackshear et al demonstrated a linear increase in the ratio of mean peak systolic internal carotid artery velocity to common carotid artery velocity as the degree of stenosis increased. This measurement was also quite accurate in predicting high-grade stenoses of ≥60% diameter reduction. One disadvantage of measuring velocity directly is the phenomenon of aliasing, which occurs when the pulse repetition frequency is less than one-half the Doppler shift frequency. This is easily overcome by the use of diastolic velocity curves. In this mode, flow velocities are lower and amputation of these peak signals rarely occurs. Our study was undertaken to assess the accuracy of diastolic velocity ratios between the internal and common carotid arteries in predicting significant internal carotid artery stenosis.

Subjects and Methods

Sample size calculations were performed that would allow detection of a correlation coefficient $r \geq 0.50$ with $\alpha = 0.01$ (one-sided) and power = 0.90. This yielded a requisite sample size of 45 vessels. Information from duplex scans and intra-arterial digital subtraction angiograms was subsequently collected from 55 arteries in 30 consecutive patients, 21 men and 9 women. Their age range was 38–84 with a mean of 66 years. Three ultrasound studies were excluded due to inadequate visualization of the carotid bifurcation, and in two angiograms the degree of stenosis of one internal carotid artery could not be determined due to motion artifact. All vessels were considered statistically independent of one another, even if from the same patient.

Duplex scans were performed by two technicians using an Ultrasonix 750 SD (Yonkers, New York) with a 7.5-MHz linear array transducer. The inter-
nal carotid artery diastolic velocity to common carotid artery diastolic velocity (ICA:CCA) ratio was calculated. The absence of a detectable signal over the internal carotid artery was recorded as complete occlusion.

Intra-arterial digital subtraction angiograms were performed using a Technicare DR-960 digital scanner (Somerville, New Jersey) and injections of a 30% solution of diatrizoate meglumine. Following angiography, a percentage stenosis was assigned to each internal carotid artery by the radiologist performing the study. This was estimated by comparing the stenotic area with the normal lumen at a more distal site. In each case the radiologist was unaware of the duplex scan results.

An ICA:CCA ratio of $\geq 3.0$ has been previously described as indicative of high-grade stenosis. Using an independent sample, we evaluated the correlation of an ICA:CCA ratio of $\geq 3$ to internal carotid artery diameter reduction of $\geq 75\%$ as determined by angiography. The evaluation was, therefore, unbiased. The $75\%$ value was chosen based on data that indicate that asymptomatic patients with this approximate degree of stenosis have an increased risk of developing a total internal carotid artery occlusion or new symptoms compared with individuals with less severe stenosis.

**Results**

Of the 55 carotid bifurcations studied, 38 (69\%) had internal carotid artery stenoses of $<75\%$, 13 (24\%) had stenoses of 75–99\%, and 4 (7\%) were totally occluded. A total of 52 cases (95\%) were accurately classified based on ICA:CCA ratios. These results are displayed in Figure 1. A summary of the measures of diagnostic accuracy using this ICA:CCA ratio to predict absence or presence of significant disease appears in Table 1. A Spearman correlation coefficient of 0.90 was obtained (95\% confidence interval 0.78–1.00), which demonstrated the strong relation between angiography and ICA:CCA ratios.

**Discussion**

Cerebrovascular accidents resulting from embolization of atheromatous material originating at the carotid bifurcation or due to flow-limiting stenotic lesions represent a significant cause of morbidity and mortality throughout the world. Much energy has been focused, therefore, on safe means of detecting these lesions. While angiography has been traditionally considered the most accurate test, it is not free of risk. Duplex scanning has emerged as a noninvasive tool possessing an accuracy that in some centers is comparable to angiography. This has encouraged some surgeons to perform carotid endarterectomy based on ultrasound results alone.

Most evaluations of the accuracy of duplex scanning rely on measurements of frequency and spectral broadening to predict carotid stenosis. The theoretical disadvantages of these methods have been cited as well as the rationale for using velocity measurements. In an assessment of peak frequency ratio to detect internal carotid artery stenosis, Keagy et al noted a success rate of only 81\% in identifying vessels with 50–99\% stenosis and an overall accuracy of 85\%. Psyhojos and colleagues, using a pulsatile flow model, demonstrated that the accuracy of spectral broadening may largely depend on the point of insonation used by the examiner. If the point of insonation is farther than one diameter of the stenosis from the stenosis, they concluded that spectral broadening is no longer diagnostically useful. On the other hand, Neumyer et al documented the accuracy of peak systolic frequency and spectral broadening to predict various degrees of carotid stenosis.

As more reliance is placed on the results obtained from duplex scanning, it is essential to determine the specific data that most precisely depict carotid bifurcation morphology. The results of our study indicate that diastolic velocity (ICA:CCA) ratios may be the most accurate predictors of internal carotid artery stenosis. A prospective randomized comparison of the accuracy of systolic frequency ratios, diastolic frequency ratios, and spectral broadening is necessary to further clarify our results.

**FIGURE 1. Agreement between angiography and internal carotid artery to common carotid artery diastolic velocity ratio in predicting $>75\%$ stenosis. Spearman correlation coefficient, 0.90; 95\% confidence interval, 0.78–1.00.**

<table>
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<th>ANGIOGRAPHY</th>
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<tr>
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<td>3</td>
<td>38</td>
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<td>-</td>
<td>17</td>
<td>38</td>
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<table>
<thead>
<tr>
<th>ICA:CCA value</th>
<th>52/55</th>
<th>95%</th>
<th>89% to 100%</th>
</tr>
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<tbody>
<tr>
<td>TP, true positive; TN, true negative; FP, false positive; FN, false negative.</td>
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**TABLE 1. Internal Carotid Artery to Common Carotid Artery Diastolic Velocity Ratios in Predicting Carotid Stenosis**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Calculation</th>
<th>Value</th>
<th>95% confidence intervals</th>
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<tbody>
<tr>
<td>Sensitivity</td>
<td>TP/(TP + FN)</td>
<td>14/17</td>
<td>82%</td>
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<tr>
<td>Specificity</td>
<td>TN/(TN + FP)</td>
<td>38/38</td>
<td>100%</td>
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<tr>
<td>Positive predictive value</td>
<td>TP/(TP + FP)</td>
<td>14/14</td>
<td>100%</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>TN/(TN + FN)</td>
<td>38/41</td>
<td>93%</td>
</tr>
<tr>
<td>Accuracy (Correct predictions/Total predictions)</td>
<td>52/55</td>
<td>95%</td>
<td>89% to 100%</td>
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</table>
References


**KEY WORDS**  • carotid artery diseases • ultrasonics
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