Comparison of Doppler Ultrasonography with Arteriography of the Carotid Artery Bifurcation

R. G. Weaver, Jr., M.D., George Howard, M.S., William M. McKinney, M.D., Marshall R. Ball, M.D., Anne M. Jones, R.N., and James F. Toole, M.D.

SUMMARY Continuous-wave (CW) Doppler ultrasound imaging for prediction of arteriographic abnormality at the carotid bifurcation was carried out in 195 arteries of 105 patients. The Doppler method had no predictive value when compared to angiographic findings in arteries classified as 0-50% stenosis by Doppler. In 50-75% stenosis by arteriography Doppler accuracy was 52%. With stenosis of 76-99% Doppler imaging correlated with 71% reliability. When an arteriogram was compared with Doppler imaging the latter gave a "false negative" reading in 56% and "false positive" readings in 19%. We conclude that Doppler ultrasound evaluation provides important information regarding the state of the carotid bifurcation, which supplements the bedside evaluation, but it does not substitute for arteriography.

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CONTINUOUS WAVE DOPPLER imaging and audio frequency analysis were first reported by Reid and Spencer for detection of atherosclerosis at the carotid bifurcation. The purpose of the present study was to determine the correlation between this procedure and arteriography.

The advantage of the Doppler evaluation is that arteriography carries a low but definite risk so that it cannot be used for screening asymptomatic patients or for longitudinal studies (table 1). Therefore, it was hoped that the Doppler examination could be substituted for or help screen suspected individuals for the necessity of arteriography.

Materials and Methods

Sixty men and 45 women, aged 37 to 80, scheduled to have arteriography for carotid distribution transient ischemic attacks or bruits, were evaluated prior to arteriography with a continuous wave Doppler Dopscan® imaging system. Recording and interpretation have been described by Spencer et al. and by Blackwell et al. and were classified by category as follows:

Cat. 1. Normal No abnormality heard or seen Arterial segment which would not image and/or attenuation with minor turbulence
Cat. 2. Plaque Barely audible increases in pitch
Cat. 3. 0-25% stenosis Increase in pitch and turbulence
Cat. 4. 26-50% stenosis Higher pitch followed by short diastolic flow and turbulence
Cat. 5. 51-75% stenosis Very high-pitched sounds during systole and short diastolic flow sounds followed by severe turbulence
Cat. 6. 76-95% stenosis No flow identified
Cat. 7. Occlusion

This study was designed to evaluate Doppler findings and compare them with arteriography; therefore, ophthalmic artery flow direction, compression tests, and orbital plethysmography were not used as ad-
of additional aids for diagnostic accuracy.

Resolution of carotid arteriography was tested with a test grid placed 5 cm deep in a 15 cm plastic phantom. Separate sequences to anteroposterior and lateral films were obtained with a tube-to-film distance of 40 inches. The test object-to-film distance in the lateral sequence was 14 inches, with a resolution of 0.34 mm with 1.51× magnification.

Arteriographic findings were categorized as follows:
1. Normal
2. Non-stenotic plaque, smooth or ulcerated
3. Stenotic plaque, smooth or ulcerated graded for degree of stenosis ranging from 8 to 99%
4. Occlusion

The arteriographic lumen was measured with calipers at the point of maximum stenosis (B and D in fig.) in both the anteroposterior and lateral projections and across the parallel wall segment of the internal carotid artery distal to the carotid sinus (A and C in fig.). The figure also shows the formula used for calculating stenosis as suggested by Spencer.

Both arteriographic and the Doppler classifications were made independently by 2 different observers (WMM and MRB) in a blind protocol.

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Doppler</th>
<th>Arteriogram</th>
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<tbody>
<tr>
<td></td>
<td>atraumatic</td>
<td>traumatic, carries risk of complication</td>
</tr>
<tr>
<td></td>
<td>outpatient procedure</td>
<td>inpatient procedure</td>
</tr>
<tr>
<td></td>
<td>easily repeatable</td>
<td>not readily repeated</td>
</tr>
<tr>
<td></td>
<td>no radiation</td>
<td>radiation</td>
</tr>
<tr>
<td></td>
<td>low cost</td>
<td>high cost</td>
</tr>
<tr>
<td></td>
<td>measures flow dynamics and vessel wall characteristics</td>
<td>depicts anatomy of vessel wall</td>
</tr>
<tr>
<td></td>
<td>auditory interpretation and visual interpretation</td>
<td>visual interpretation</td>
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Results

Because of the preponderance of arteriographically normal common carotid and external carotid arteries (62.4 and 70.5%), statistical comparisons of results pertaining to these arteries were not feasible. However, the arteriographic data for the internal carotid artery were well distributed as follows: 53 (27.2%) of the arteries normal, 51 (26.2%) non-stenotic plaque, 81 (41.5%) stenosed, and 10 (5.1%) occluded. For calculation of measures of accuracy the findings were collapsed to 2 categories, "normal" and "diseased," for both the Doppler and the arteriogram (table 2). The Doppler "false positive" rate was 25 of 132 or 19%. In this group of 25 arteriographically normal arteries, the Doppler results were 12% category 2 (plaque), 20% category 3 (0–25% stenosis), 48% category 4 (26–50% stenosis), 8% category 5 (51–75% stenosis), 8% category 6 (76–95% stenosis) and 4% classified in Doppler category 7 (occlusion). The "false negative" rate was 35 of 63 or 56%. Of the 35 arteries found to be abnormal on angiogram but normal by Doppler, the angiogram results were 43% plaqued, 46% stenosed, and 11% occluded. Sensitivity was 75% and specificity was 53%.

Chi-square analysis showed overall significance to be (p ≤ 0.01). In order to determine specific categories, the proportion of "correct" Doppler interpretations in each arteriographic category was calculated and category 5 (51–75% stenosis) was significantly higher (p ≤ 0.05). Doppler category 6 (76–95% stenosis) also demonstrated a significantly

<table>
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<th>Normal</th>
<th>Diseased</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>Doppler</td>
<td>28</td>
<td>35</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>107</td>
<td>132</td>
</tr>
<tr>
<td></td>
<td>53</td>
<td>142</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Diseased</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative Accuracy = 44%</td>
<td>False Neg. = 56%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive Accuracy = 81%</td>
<td>False Pos. = 19%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity = 75%</td>
<td>Accuracy = 69%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specificity = 53%</td>
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et al. 8 and Barnes et al. 9 of stenosis less than 50%, as also reported by Spencer
differences demonstrated at arteriography. We found
These categories comprised only 24% of our patient
doppler to be of very little value for predicting degrees
changes demonstrated at arteriography. We found
new improvement requires validation for sensitivity
four such studies. The development of ultrasound technology for the
Doppler categories normal, plaqued, 0–25% stenosed,
level of the carotid bifurcation on the Doppler image.
small variations in arteriographic measurement of
Doppler categories did not account for Doppler misclassification.
for example, when (category 6), highly stenotic
In an attempt to explain this variation, a sample of
Doppler recordings was reviewed independently by
two observers (RGW and WMM). It was ascertained
that 1) the presence of loud venous interference, 2) variations in the location and orientation of the
(bifurcation), 3) kinks, coil and other anatomical variants in the
carotid arteries, and 4) changes in the flow
characteristics caused by hypertension, short diastolic
flow, cardiac irregularities and differences in vascular
resistance in the cerebral circulation, all cause
difficulty in interpretation. Moreover, different
technicians varied widely in their ability to identify the
level of the carotid bifurcation on the Doppler image.

Discussion

The development of ultrasound technology for the
study of extracranial arteries has progressed steadily
since this method was introduced 12 years ago. Each
new improvement requires validation for sensitivity
and specificity. For the Doppler continuous wave
audiovisual technique we find that only in Doppler
categories 5 and 6 (50–95% stenosis) was there a
significant positive correlation with arteriography.
These categories comprised only 24% of our patient
population which was heavily biased for athero-
sclerotic disease with 73% having atherosclerotic
turbulence which is not visible on arteriography; alterations in
pitch resulting from a long symmetrical reduction in the
lumen of the artery which does not appear as a focal
stenosis. Dynamic information is obtainable
with the Doppler technique, but easily overlooked on
arteriography, including flow pattern characteristics in the external and internal carotid
circulations which are audible but not visible.
The relative ease and safety of continuous wave
Doppler ultrasound, as well as its low cost in com-
parison to arteriography, offers so many advantages
that it is hoped that its further development will make it possible to obtain improved CW Doppler studies.
On the basis of our findings, we have improved our
techniques and sharpened our criteria for interpreta-
ion both of the audio and visual aspects of Doppler
studies.

References

1. Reid JM, Spencer MP: Ultrasonic Doppler technique for imaging blood vessels. Science 176: 1234-1236, 1972
5. Spencer MP: Personal communication, Sept. 1978
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