CONTINUOUS WAVE DOPPLER imaging and audio frequency analysis were first reported by Reid and Spencer\(^1\) 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\(^2\) 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.\(^1\) and by Blackwell et al.\(^4\) and were classified by category as follows:

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

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-
TABLE 1  Comparison of Doppler and Arteriographic Techniques

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

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.

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, 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

Cross Sectional Area

\[ \frac{B \times D}{A \times C} = \frac{100 (1-X)}{X} = \% \text{ stenosis} \]

Minimal Luminal Diameter

\[ \frac{B}{A} = \frac{100 (1-X)}{X} = \% \text{ stenosis} \]

Figure. Arterial lumen measured with calipers at point of maximum stenosis with Spencer's formula for calculating stenosis.

"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 \( p \leq 0.05 \). Doppler category 6 (76-95% stenosis) also demonstrated a significantly

TABLE 2  Findings Collapsed to Normal and Diseased Categories for Doppler and Arteriogram

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

*Data available upon request.*
greater proportion of arteriographically stenosed arteries compared with the proportion that were either normal, plaqued, or occluded. No significant differences in the proportion classified by arteriogram as normal or stenosed were found in the Doppler categories normal, plaqued, 0–25% stenosed, 26–50% stenosed, or occluded.

Analysis of variance showed a significant difference ($p < 0.01$) in the percentage of stenosis between Doppler categories using either cross sectional area or minimal luminal diameter. Keul's test showed that Doppler category 6 (76–99% stenosed) is significant ($p < 0.05$) and that there were no significant differences in mean stenosis among any of the first 5 Doppler categories ($p > 0.05$).

Small variations in arteriographic measurement of stenosis did not account for Doppler misclassification. For example, when (category 6), highly stenotic vessels, were misclassified, they were as likely to be called normal by Doppler as category 4.

In an attempt to explain this variation, a sample of the 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 atherosclerotic disease with 73% having atherosclerotic changes demonstrated at arteriography. We found Doppler to be of very little value for predicting degrees of stenosis less than 50%, as also reported by Spencer et al. and Barnes et al.

Doppler flow characteristics and radiographic display of arterial lumen anatomy are 2 different indirect measures of atherosclerotic disease and are not necessarily comparable parameters. We believe longitudinal studies of our patients may reveal as yet unrecognized conditions such as turbulence, which are not visible on the arteriogram, which may prove to have predictive value as an early sign of cerebrovascular disease. Some of these might include: increased thickness of the arterial wall resulting in attenuation of the auditory signal before any arteriographic abnormality is visible; 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 comparison 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 interpretation both of the audio and visual aspects of Doppler studies.

**References**

5. Spencer MP: Personal communication, Sept. 1978
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