Accuracy of Transcutaneous Doppler Ultrasound in Evaluating Extracranial Vascular Disease*

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The ultrasonic transcutaneous Doppler technique has been suggested as a safe method for determining extracranial carotid blood flow. Application of this technique to occlusive extracranial carotid disease has been reported. Arteriography has been the most helpful method used so far to verify the Doppler's effectiveness in diagnosing carotid artery disease. Since the Doppler primarily measures blood velocity, more direct determinations of blood flow would be valuable to check the Doppler's performance. The present study uses intraoperative electromagnetic flow determinations, direct carotid pressure recordings, occlusive carotid clamps (Selverstone), and arch arteriography in an effort to evaluate the effectiveness of the transcutaneous Doppler technique in determining carotid blood flow.

Clinical Material and Methods

This study is based on observations made on 21 patients. Seventeen had arch arteriography for investigation of symptoms suggesting occlusive extracranial vascular disease. Four patients who had subarachnoid hemorrhages were studied with bilateral common carotid arteriography. Dopplergrams were performed on each common carotid artery (42 arteries in 21 patients) usually prior to arteriography. An operation was performed on 14 of the internal carotid arteries in 10 patients. Pre- and postoperative Dopplergrams were obtained in all except one case where only a postoperative study could be done. In seven of the operations an endarterectomy was performed for arteriosclerotic occlusive disease. Another patient was explored for a kinked internal carotid artery. Two patients with intracranial aneurysms had a complete occlusion of the common carotid artery effected by a Selverstone clamp. It was assumed that the common carotid artery was completely occluded at the time of the transcutaneous Dopplergram. Electromagnetic flowmeter determinations were performed intraoperatively before and after endarterectomy on nine carotid arteries and on a tenth, kinked internal carotid artery in head positions of flexion, extension, and lateral rotation. Direct pressure recordings were obtained of the common and internal carotid arteries in five cases. At the conclusion of the entire study, all Dopplergrams were reviewed by two independent observers who had no knowledge of the specific arteriographic flow or pressure measurements.

The transcutaneous ultrasound blood velocity meter used was the "Doptone." Two signals are displayed on a dual trace oscilloscope and are photographed with a Polaroid camera (Fig. 1 left). One trace (amplitude) is related to the total amount of erythrocytes moving, and the other trace (frequency) relates to the velocity of the fastest moving red blood cells. The instrumentation fits on a small mobile cart to facilitate bedside testing.

The transducer probe is placed as low as possible in the neck over the common carotid artery. The position of the probe tip and the angulation are adjusted to give the highest frequency and amplitude readings. Dopplergraphic criteria for reduced carotid blood flow have been described. They consist of absent flow during mid and late diastole as seen on the amplitude curve, and plateauing on the frequency curve during at least 50% of the cardiac cycle (Figs. 1 right and 2 right).

An electromagnetic flowmeter was used (Medicon K-2000), with a Statham flow...
probe (Q-2080). The flow probe was placed around the common carotid artery a few centimeters proximal to the bifurcation. Zero flow was calibrated by occluding the common carotid distal to the flow probe. Care was taken to control the superior thyroid artery. Internal carotid flow was determined by occluding the external carotid (and superior thyroid artery) and measuring flow through the common carotid. When it was feasible, blood pressure readings were taken with a 25-gauge needle in the common and internal carotid arteries.

**Results**

Twenty-seven internal carotid arteries were studied exclusively by arteriography. Eight of these demonstrated stenosis of more than 50% of the vessel diameter. The Doppler predicted a decreased flow in six of these eight stenotic vessels, but had predicted normal flow in two cases. In the other 19 vessels, stenosis was less than 50% in lumen diameter, and the Doppler predicted normal flow in each case (Table 1).

Twelve vessels were examined by direct measurement of flow during operation, using the electromagnetic flowmeter and/or direct arterial pressure recordings (Table 2). Internal carotid artery flow was significantly decreased in six cases. The preoperative Dopplergram had correctly predicted this decreased flow in two cases, and had suggested it in another two cases, but had incorrectly predicted a normal flow in two other cases. The six vessels with normal flow had been correctly assessed by preoperative Dopplergrams. Endarterectomy, which had been
Transcutaneous Carotid Dopplergrams

done on 12 of the internal carotid arteries, had resulted in an improved flow in three cases as determined by an electromagnetic flowmeter and direct carotid artery pressure measurements. Postoperative Dopplergrams demonstrated this improvement in only one of the cases. In the other two cases the pre- and post-endarterectomy Dopplergrams suggested normal flow. In two patients with a Silverstone clamp on the common carotid artery, postoperative Dopplergrams were made a few days after the clamp was completely closed. In one case, the Doppler confirmed the decrease in flow. In the other cases the Doppler suggested the diminished flow, but was equivocal.

In three cases, preoperative arteriographic stenosis involving 50% or more reduction of the lumen diameter was not associated with diminished flow (Table 2). Preoperative Dopplergrams done in two of these three patients had showed normal flow in both cases.

Discussion

Doppler\(^2\) demonstrated in 1842 that the frequency of a wave form will be altered if there is relative movement between the receiver and sender. If the change in frequency is known, the velocity of the receiver relative to the sender can be determined. Rushmer, et al.,\(^14,15\) have shown that blood flow could be detected through intact human skin by ultrasonic techniques. The application of transcutaneous Doppler flowmeter measurements to occlusive arterial disease in the extremities has been discussed by Strandness, et al.\(^16\)

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**TABLE 1**

<table>
<thead>
<tr>
<th>Doppler Flow</th>
<th>No. of Arteries</th>
<th>Confirmation by</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Direct Flow(\ast)</td>
</tr>
<tr>
<td>Decreased(\ddagger)</td>
<td>6 6</td>
<td>6</td>
</tr>
<tr>
<td>Normal</td>
<td>9 21</td>
<td>7(\S)</td>
</tr>
</tbody>
</table>

* Based on electromagnetic flowmeter, direct carotid pressures, and known complete occlusion of the common carotid artery by a Silverstone clamp in two cases.
\(\dagger\) Based on reduction of lumen diameter by at least 50%.
\(\ddagger\) Based on prediction or suspicion of decreased flow.
\(\S\) Two other cases had decreased flow by direct measurements.
** Two other cases had decreased flow in arteriography.

**TABLE 2**

<table>
<thead>
<tr>
<th>Vessel No.</th>
<th>Age (yrs), Sex</th>
<th>Side</th>
<th>Electromagnetic Flow (cc/min)*</th>
<th>Pressure (Systolic)*</th>
<th>Arteriogram % Diameter Reduction</th>
<th>Doppler Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>1</td>
<td>68 F</td>
<td>Rt</td>
<td>CCA</td>
<td>200</td>
<td>120</td>
<td>375</td>
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<td>Lt</td>
<td>CCA</td>
<td>210</td>
<td>20</td>
<td>65</td>
</tr>
<tr>
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<td>Rt</td>
<td>CCA</td>
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<td>190</td>
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<td>Rt</td>
<td>CCA</td>
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<td>240</td>
<td>380</td>
</tr>
<tr>
<td>5</td>
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<td>Lt</td>
<td>CCA</td>
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<td>32</td>
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<tr>
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<td>Rt</td>
<td>CCA</td>
<td>224</td>
<td>48</td>
<td>380</td>
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<tr>
<td>7</td>
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<td>CCA</td>
<td>480</td>
<td>300</td>
<td>480</td>
</tr>
<tr>
<td>8</td>
<td>65 M</td>
<td>Lt</td>
<td>CCA</td>
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<td>0</td>
</tr>
<tr>
<td>9</td>
<td>52 F</td>
<td>Rt</td>
<td>CCA</td>
<td>---</td>
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</tr>
<tr>
<td>10</td>
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<tr>
<td>12</td>
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<td>Rt</td>
<td>CCA</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>13</td>
<td>16 F</td>
<td>Lt</td>
<td>CCA compl. occl. with Silverstone clamp</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>14</td>
<td>33 M</td>
<td>Rt</td>
<td>CCA compl. occl. with Silverstone clamp</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>15</td>
<td>62 F</td>
<td>Rt</td>
<td>CCA compl. occl. with Silverstone clamp</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

* Electromagnetic flow and pressure measurements were made during operations. Before = before endarterectomy; After = after endarterectomy; CCA = common carotid artery; ICA = internal carotid artery.
\(\ddag\) External carotid artery.
\(\ddag\) Obtained in positions of neck flexion, extension, and lateral rotation.
At present it is impossible to quantitate blood flow using a transcutaneous Doppler technique because change in the angle of the sending crystal as it is held over a vessel will cause frequency alterations unrelated to blood velocity changes. Human blood volume is such that an audible frequency is obtained when a 5 megacycle (Mc) sound wave is used. A more detailed analysis of the sound wave is made electronically by breaking it down into its two major components, actual frequency and amplitude.

When the transducer probe is placed low in the neck over the common carotid artery in normal subjects, a characteristic oscillographic tracing is obtained. There is a sharp increase in the quantity of blood (amplitude tracing) and velocity of blood (frequency tracing) during systole with a rapid fall during early diastole (Figs. 1 left and 2 left). Continuous readings above the baseline are observed during mid-diastolic flow. The rise in frequency and amplitude with systole are simultaneous and a fraction of a second behind the QRS complex of the electrocardiogram. When stenosis is significant enough to reduce the total arterial blood flow, there may be diminution in quantity (amplitude) and velocity (frequency) tracings (Figs. 1 right and 2 right, and 3 left).

In a recent clinical study, normal Dopplergrams were verified by arteriography in 10 patients who had no significant stenosis. Dopplergram evidence for stenosis was present in 27 patients, 23 of whom had stenosis seen on arteriography. The other four patients had severe generalized atherosclerosis without significant stenosis.

Decreased blood flow through a vessel depends on a number of factors including degree and length of stenosis, intimal irregularity, blood velocity, and peripheral resistance. Although a 50% stenosis in the internal carotid artery will usually result in a decreased blood flow, the above factors may modify this flow change. This emphasizes the limitations of arteriography in determining blood flow and the importance of direct flow measurements in evaluating a technique, such as the transcutaneous ultrasound Doppler, which is an experimental method for estimating blood flow.

The Doppler is helpful in repeated determinations over a period of time. Pre- and post-endarterectomy Dopplergrams may be useful as well as subsequent ultrasound determinations in an effort to follow the patency of a carotid artery (Fig. 3 left and right).

It is very difficult with present instrumentation for transcutaneous ultrasonics to separate internal from external carotid flow. In our study, Doppler recordings were made over the common carotid artery to avoid confusion from the multiple overlapping blood vessels at the site of bifurcation. In each of seven cases where electromagnetic flow measurements showed a diminished

![Fig. 3. Vessel 6. Left: Preoperative right carotid artery Dopplergram showing moderately abnormal pattern with flattening in the diastole and systole of the amplitude curve and lowering of the frequency curve. Intraoperative electromagnetic flows were markedly decreased in the internal carotid artery and moderately decreased in the common carotid artery. Right: Postoperative right carotid artery Dopplergram showing improved flow with increased systolic and diastolic recording on the amplitude curve and increased systolic recording on frequency curve.](image-url)
flow in the common carotid artery, there was a diminished flow in the internal carotid artery (Table 2).

Another transcutaneous Doppler ultrasound technique for determining carotid stenosis has been reported by Brinker, et al.1 Their work is based on the fact that blood flow is laminar and of multiple frequencies. They used filters to separate out four different frequency components. They measured frequencies below and at the stenosis and found an increase in the high frequency component at the area of stenosis. Two cases were presented in their initial report.

Summary

A transcutaneous Doppler ultrasonic technique for determining carotid artery blood flow has been evaluated using an intraoperative electromagnetic flowmeter, direct pressure recordings, Selverstone carotid artery clamps, and arteriography.

A Dopplergram prediction or suspicion of decreased internal carotid blood flow was correct in six out of six cases as judged by arteriography and six out of six cases as checked by direct flow measurements. A Dopplergram prediction of normal blood flow was correct in 19 out of 21 vessels as verified by arteriography and in seven out of nine cases checked by direct flow determinations.

A Dopplergram reading of decreased carotid flow is a good indicator that flow in the common and internal carotid arteries is diminished. A Dopplergram prediction of normal flow in no way rules out significant stenosis.

The transcutaneous Dopplergram remains an experimental tool that is showing increasing promise in the clinical diagnosis of carotid vascular disease.

References