Prediction of Hemispheric Blood Flow
From Carotid Velocity Measurements

A Study with the Doppler and $^{183}$Xe Inhalation Techniques

JARL RISBERG, PH.D., AND PATRICK SMITH, M.D.

SUMMARY Doppler carotid velocity determinations were related to hemispheric blood flow measurements by the $^{183}$Xe inhalation method in 28 patients with psychiatric disorders without arterial pathology and in 2 normal subjects. Results from 39 double determinations showed a product-moment correlation of 0.88 ($p < 0.001$) between right hemispheric blood flow and right internal carotid end-diastolic velocity. The correlation for the left side was slightly lower ($r = 0.83$), while the common carotid end-diastolic velocity showed a considerably lower correlation of 0.71 (rt) and 0.69 (lt) respectively. The peak-systolic velocity values (internal carotids) showed a less close relationship to hemispheric flow ($r = 0.71$ (rt) and $r = 0.61$ (lt)). It is concluded that a fairly accurate (15–20% maximum error) prediction of hemispheric blood flow from Doppler Internal carotid end-diastolic velocity values is possible in patients without abnormalities in these arterial systems. The high correlations found, in spite of the fact that arterial diameters were not taken into account, are further proof of the accuracy and validity of both methods.

Stroke, Vol 11, No 4, 1980

Material and Methods

Thirty-nine comparisons were made in 28 patients and in 2 normal male volunteers. The mean age in the group was 56 years with a SD of ± 17 and a span of 21 to 87 years. The diagnoses of the patients were: depression (11), Alzheimer’s disease (7), psychic-organic syndrome (5), chronic alcoholism (3) and temporal lobe epilepsy (2). None of the patients had abnormal flow conditions in the carotid and vertebral arterial systems as evaluated by a clinical Doppler control determination (no occlusions, no accelerations, no turbulences and no reversal flow in ophthalmic arteries).

rCBF Determinations by $^{183}$Xe Inhalation

The regional cerebral blood flow was measured by the $^{183}$Xe inhalation technique introduced by Mallett and Veall and modified by Obrist et al. and by Risberg et al. The patient inhaled $^{183}$Xe mixed with air (3–4 mCi/l) for one minute by means of a face mask and a rebreathing system. The one minute inhalation period was followed by 10 minutes during which the patient breathed normal air. The gamma radiation was recorded by 32 lead-shielded scintillation detectors ($\frac{3}{4}$ × $\frac{3}{4}$ NaI (Tl) crystals; Meditronic-Novodiagnostic Systems, Denmark) placed in parallel at right angles to the lateral surfaces of the patient’s head. The detectors covered both hemispheres and had lead collimators 20 mm long and an ID of 22.5 mm. The radiation from a continuous sample of the expired air was recorded by a separate detector for determination of end-tidal concentrations of $^{183}$Xe (the “air curve”) and was used to correct the “head curves” for recirculation of the tracer. The pulses from the 33 detectors were integrated in binary registers (Meditronic-Novodiagnostic Systems, Denmark) during 5 second epochs for the head curve and during 0.3125 second epochs for the air curve. The counts were punched on paper tape (Facit, Sweden) for off-line computer analysis. The results presented...
here are based on the Initial Slope Index (ISI), a cerebral blood flow parameter which is preferable in clinical applications due to its high reliability even in instances of very low cerebral flow rates. The calculations included routines for correction of the head curves for scattered radiation from $^{133}$Xe in air passages according to principles developed by Risberg. The arterial $P_{CO_2}$ was estimated from recordings of end-tidal $CO_2$-concentrations (Beckman, LB2-analyzer).

**Doppler Velocity Determinations**

The Doppler examinations were made immediately after the $^{133}$Xe clearance registrations. A one-channel directional C. W. Doppler device (A.H.S.-Delalande, 4 MegaHz) was used. First, common carotid velocity was measured with the probe facing the flow at the inferior part of the artery. The internal carotid velocity was then determined by placing the probe immediately over the level of the bifurcation with the ultrasound beam in the direction of the flow. Using these routines an optimal stability of the angle between the vessel and the beam was obtained. The velocity registrations were recorded on a potentiometer writer and the average end-diastolic and peak-systolic velocity values of the common and internal carotid arteries were measured manually. No planimetric method was used. The diameters of the arteries were not determined since a non-traumatic method was unavailable.

**Results**

The intercorrelations between the different velocity and mean hemispheric rCBF (ISI) variables are shown in the table. The highest correlation between ISI values and velocity is seen for internal carotid end-diastolic values on the right side ($r = 0.88$). This correlation is also illustrated in figure 1. The corresponding common carotid velocity parameter showed a somewhat lower correlation ($r = 0.71$; fig. 2). The correlations for the left side were slightly lower than the ones for the right side. Peak-systolic velocity values showed a less close relationship with rCBF. The correlation between right and left hemispheric values was very high for ISI ($r = 0.99$), high also for common

<table>
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<tr>
<th>TABLE</th>
<th>PRODUCT-MOMENT CORRELATIONS BETWEEN MEAN HEMISPHERIC CBF (ISI) AND CAROTID VELOCITY (CM/SEC.). $N = 39$ $P &lt; .001$ FOR ALL CORRELATIONS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEFT</td>
<td>COMMON CAROTID VELOCITY</td>
</tr>
<tr>
<td>ISI</td>
<td>DIASTOLIC</td>
</tr>
<tr>
<td>.69</td>
<td>.66</td>
</tr>
<tr>
<td>.71</td>
<td>.71</td>
</tr>
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</table>

**FIGURE 1.** The correlation between velocity in right internal carotid artery measured by Doppler technique and in mean hemispheric CBF (in units of ISI) measured by the $^{133}$Xe-inhalation method. Thirty-nine determinations in 30 subjects. The regression line for estimation of flow from velocity is indicated by the solid line.

**FIGURE 2.** The correlation between right common carotid velocity and CBF (otherwise same as Fig. 1).
and internal diastolic values ($r = 0.94-0.95$) and somewhat lower for internal systolic values ($r = 0.83$).

A multiple regression analysis was also performed which indicated that only a very slight ($r = 0.89$) improvement of the prediction was obtained when other velocity values were added to the internal carotid end-diastolic values.

**Discussion**

Fairly high correlation coefficients were found between internal carotid velocity in the end-diastolic phase and mean hemispheric rCBF. The coefficients are considerably higher than those published by Yoshida et al.$^{19}$ ($r = 0.41$). The difference might be explained by the fact that there was a 1-7 days time interval between the 2 determinations in the study by Yoshida and also by the presence of arteriosclerotic vascular pathology in many of the patients studied.

The present correlations of 0.83 and 0.88 between internal carotid diastolic velocity and mean hemispheric rCBF seem to permit an estimation of mean hemispheric flow from Doppler determinations with reasonable precision (15-20% maximal error).

Several factors might explain the residual error variance when estimating cerebral blood flow from internal carotid velocity:

1. **Variations in Arterial Size.** In the present study the arterial diameters were not determined and thus no arterial flows could be calculated. In the study of Yoshida et al.$^{19}$ the internal carotid flow values (obtained by angiography) showed a considerably higher correlation to rCBF than the velocity values ($r = 0.77$ and 0.41 respectively). It might be assumed that similar flow calculations based on the present velocity data would have further increased the correlations obtained. However, very precise measurements of arterial diameters are not obtained by present non-traumatic techniques such as ultrasound devices.

2. **Variations in Brain Weight.** The rCBF determinations are expressed as perfusion of a fixed tissue mass (usually 100 g) and is thus independent of absolute brain size. The flow rate of the artery, however, is directly dependent upon the absolute flow of the organ perfused, which, naturally, is partly dependent on its weight.

3. **Variations in Vertebral Flow.** The velocity of the vertebral arteries was not estimated in the present study due to technical difficulties in reliably recording velocity in deeply situated arteries. This error is, however, probably of limited importance since normally only a small proportion of the cortex measured by the $^{133}$Xe inhalation technique is supplied by the vertebral arteries.

4. **Measurement Errors.** The Doppler recordings must be made by a skilled technician in order not to pick up the blood flow velocity in other arteries or veins. Since velocity values are partly dependent upon the angle between the ultrasound beam and the vessel, this angle must be kept as constant as possible. The variations in velocity will, however, be less than 6% if the angle between the blood velocity vector and the beam is less than 20 degrees.$^{18}$ This condition, we believed, was fulfilled in the present study. The results obtained show clearly, however, that the measurement errors for the 2 techniques are small, the most striking illustration being the very high right to left hemisphere correlations.

The finding of a slightly lower correlation on the left side might be due to chance but might also be due to a better position of the technician (always on the left side of the patient) in the right-sided determinations. In view of the limiting factors described above, the correlation coefficients obtained should be considered highly satisfactory. They showed that a fairly precise estimate of mean hemispheric blood flow on the bases of internal carotid velocity values is possible, provided no major arterial pathology is present.

**Acknowledgment**

Supported by grants from the Swedish Medical Research Council (contract 14X-04969), the Swedish Council for Social Science Research and Konsul Thure Carlssons Stiftelse, Stockholm. Special thanks are given to Mrs. Monique Smith for excellent technical assistance and many helpful suggestions. Miss Siv Karlsson, eng., aided in the Xenon inhalation studies and in preparation of the illustrations. The authors are also grateful for aid in the statistical analysis given by Miss E. Laborie, Department of Mathematics, Faculté des Sciences, Pau, France.

**References**

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Comparison of Doppler Ultrasonography with Arteriography of the Carotid Artery Bifurcation

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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 arteriographic 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.

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:

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
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<tbody>
<tr>
<td>Cat. 1. Normal</td>
<td>No abnormality heard or seen</td>
</tr>
<tr>
<td>Cat. 2. Plaque</td>
<td>Arterial segment which would not image and/or attenuation with minor turbulence</td>
</tr>
<tr>
<td>Cat. 3. 0–25% stenosis</td>
<td>Barely audible increases in pitch</td>
</tr>
<tr>
<td>Cat. 4. 26–50% stenosis</td>
<td>Increase in pitch and turbulence</td>
</tr>
<tr>
<td>Cat. 5. 51–75% stenosis</td>
<td>Higher pitch followed by short diastolic flow and turbulence</td>
</tr>
<tr>
<td>Cat. 6. 76–95% stenosis</td>
<td>Very high-pitched sounds during systole and short diastolic flow sounds followed by severe turbulence</td>
</tr>
<tr>
<td>Cat. 7. Occlusion</td>
<td>No flow identified</td>
</tr>
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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-
Prediction of hemispheric blood flow from carotid velocity measurements. A study with the Doppler and 133Xe inhalation techniques.
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Stroke. 1980;11:399-402
doi: 10.1161/01.STR.11.4.399
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0039-2499. Online ISSN: 1524-4628

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