Evaluation of Occlusive Cerebrovascular Disease Using Ultrasonic Quantitative Flow Measurement

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SUMMARY Eighty-four patients with cerebrovascular disease were studied by cerebral angiography and a prototype Doppler device, ultrasonic quantitative flow measurement (UQFM), that provides data from which absolute common carotid flow can be determined. The UQFM showed significantly lower flows in 23 patients who had complete occlusion of the internal carotid artery on the affected side (p < 0.001). In 11 patients with occlusion of the middle cerebral artery at its origin and in 5 with branch occlusions, the blood flow in the ipsilateral common carotid artery was also significantly lower (p < 0.01). There was no significant difference between blood flow on the 2 sides in 9 patients with stenosis of middle cerebral artery and in 7 with stenosis of internal carotid artery. Due to the small number of patients no definite conclusion can be drawn. The UQFM is thought to be useful not only in screening for occlusive cerebrovascular disease but also to help understand better the mechanisms of ischemia in the presence of carotid lesions.

Methods

An ultrasonic quantitative flow measurement system (Hayashi Electric Co.) was used in this study. The principle of this system has been described in detail by Furuhata et al.

STUDIES have been made using ultrasound as a non-invasive means of diagnosing arterial lesions in the neck, but current techniques in general use for evaluation of hemodynamics at the carotid bifurcation do not provide quantitative blood flow data.

An ultrasonic quantitative flow measurement (UQFM), a newly developed device in Japan, does provide an index of flow velocity, which is useful in identifying circulatory disturbances due to obstructive carotid lesions. Determining absolute flow in the common carotid artery might provide more clinically meaningful data on the hemodynamic effects of such lesions in the carotid artery and its branches. Using the UQFM, Ohara et al. investigated and observed changes with age in the volume flow rate, blood velocity and vessel diameter in the carotid artery, but there was no cerebral angiographic correlation.

This paper compares the results of cerebral angiography with those obtained by UQFM that provides data from which absolute carotid flow can be determined. This device determines velocity of flow, using the Doppler principle, and the cross-sectional area of the carotid. The product of velocity and cross-sectional area gives a quantitative blood flow measurement.

An ultrasonic quantitative flow measurement system (Hayashi Electric Co.) was used in this study. The principle of this system has been described in detail by Furuhata et al. It is designed to use ultrasonic Doppler flowmetry with an ultrasonic pulse echo tracking method to trace and display simultaneously the pulse patterns of absolute volume flow rate and wall displacement. These are independent of beam incidence angle. Absolute volume flow rate and its values are calculated as the product of blood velocity and the cross-sectional area of the blood vessels. The probe, whose structure is illustrated in figure 1, has a 3 mm circular, barium titanate transducer for the measurement of wall displacement with 3 ceramic transducers for blood flow measurement. The former is fixed perpendicular to the surface of the probe and the latter at an angle of 65° to the transmitting transducer which is interposed between 2 receiving transducers placed at angles differing by 10° from another. These 4 transducers are so arranged that their sound fields cross each other at a depth of 15 mm. The components of the system include, as shown in figure 2, a probe, a wall displacement measuring unit, a blood velocity measuring unit, ADC, an operation control unit, a monitoring and a display and recording unit. Wall displacement was measured at an ultrasonic frequency of 6 MHz [pulse wave] by the echo tracking method using a phase locking loop. The ultrasonic Doppler method was employed with a directional zero cross-counter for the measurement of blood flow, which was done at an ultrasonic frequency of 5 MHz [continuous wave]. Mean blood volume flow rate (ml/sec), mean blood velocity (cm/sec) and mean vessel diameter (mm) were displayed; mean, maximum and minimum values were printed out together with the range of vessel displacement and the heart rate. Pulse patterns are printed out along with ECG patterns and those of blood volume flow rate, blood velocity and vessel displacement.

By using the system, 7 measurements were made on each common carotid artery to calculate the average value from 5 measurements excluding the maximum and minimum values.

Eighty-four patients with occlusive cerebrovascular disease (58 males and 26 females; mean age 60.2 years) who had been admitted to the Institute of Brain and Blood Vessels, Mihara Memorial Hospital, over the period January, 1979, to March, 1980, were studied. Cerebral angiography was performed along with CT and UQFM examination in all patients.

The patients for the "control group" were selected on the basis of normal cervical and cerebral angiograms.

A control group (A) of 29 patients with no cerebral angiographic abnormalities but with neurological symptoms (19 males and 10 females; mean age 59.8 years) was investigated. Of these patients, group A-1 (5 patients) had transient ischemic attacks (TIA) but
Figure 1. Transducer array in probe and the relationship between velocity and outputs of ultrasonic Doppler flowmeter.

\[ V = \frac{a}{h'} \sqrt{1 + \left( \cot 10^\circ - \frac{b/a}{\sin 10^\circ} \right)^2} \]

- a: output of UDF-2
- b: output of UDF-1
- h: + 2fs/c
- fs: carrier freq.
- c: sound velocity
- D: Diameter
- R: Receiver
- T: Transmitter
- BF: Blood Flow
- V: Velocity

The patients with angiographically demonstrable lesions are characterized as follows: (B) 23 patients with occlusion of the internal carotid artery, including 2 with bilateral involvement (21 males and 2 females; mean age 60.7 years), (C) 11 with occlusion of the trunk of the middle cerebral artery (10 males and 1 female; mean age 61.5 years), (D) 5 with occlusion of a branch of the middle cerebral artery (1 male and 4 females; mean age 63.6 years), (E) 7 with stenosis of the internal carotid artery (2 males and 5 females; mean age 60.3 years) and (F) 9 with stenosis of the middle cerebral artery (5 males and 4 females; mean age 59.1 years).

Results

1. In a control group (group A, 29 subjects) a mean blood volume flow rate of \(8.17 \pm 2.38\) ml/sec was registered for the symptomatic side (where the lesion responsible for neurological manifestations was present) and \(8.12 \pm 1.63\) ml/sec for the opposite side; there was no statistically significant difference between the 2 (\(p < 0.5\)). Figure 3 shows that there is no appreciable difference between right and left common carotid artery blood flow in patients where cerebral angiography had ruled out occlusion or stenosis.

2. Common carotid artery blood flow on the affected and the normal side was compared in 23 patients with occlusion of the internal carotid artery (group B).

Figure 4 shows the blood volume flow rate in the right and the left common carotid arteries in 23 patients with internal carotid artery occlusion in the neck. The blood volume flow rate on the diseased side

![Graph showing blood flow rates](image-url)
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Figure 4. Comparison of blood flow in 23 cases of internal carotid artery occlusion. (*) Bilateral internal carotid artery occlusion. #: Extra and intracranial arterial bypass.

was reduced to approximately half that on the normal side, the mean value being 4.54 ± 1.85 ml/sec and 8.64 ± 3.14 ml/sec, respectively, with a statistically significant difference between the two (p < 0.001). In 2 patients with bilateral internal carotid artery occlusion the blood volume flow rate was reduced on both sides, but to a greater extent on the symptomatic side of the brain.

The following patient is illustrative.

K.K. is a 55 year old man with left hemiparesis. He reported 3 to 4 episodes of TIAs with left hemiparesis, each lasting 5 to 10 min, over the last 4 to 5 years. His findings on admission were systemic blood pressure 140/80 mm Hg, clear consciousness and left hemiparesis without hemianopsia. There were increased deep tendon reflexes with pathological reflexes on the left side. No bruit was audible in the neck.

UQFM findings: The blood volume flow rate was 3.82 ± 0.44 ml/sec on the right side and 8.30 ± 0.46 ml/sec on the left. The blood velocity was 14.43 ± 1.86 cm/sec and 22.95 ± 1.85 cm/sec, respectively, and the vessel diameter was 5.81 ± 0.21 mm and 6.82 ± 0.29 mm, respectively. These findings led to the diagnosis of occlusion of the internal carotid artery.

Cerebral angiography revealed, as suspected by UQFM examination, occlusion of the internal carotid artery on the right side of the neck with the stump detected approximately 1 cm from the bifurcation (fig. 5). Collateral circulation was through the anterior communicating artery. No abnormalities were observed in the left internal carotid artery system.

CT findings showed a low density area in the right basal ganglia and the right centrum semiovale.

In this patient a diagnosis of internal carotid artery occlusion in the neck was made in a noninvasive manner by means of UQFM and confirmed by cerebral angiography.

3. Common carotid artery blood volume flow rate on the affected side was compared with the normal side in group C — 11 patients with occlusion of the trunk of the middle cerebral artery (fig. 6).

The blood volume flow rate in the common carotid artery was reduced on the affected side in 9 of these 11 patients and in the other 2 it was higher on the diseased than on the normal side. The mean volume flow rate was 6.86 ± 1.37 ml/sec on the diseased side and 8.56 ± 1.06 ml/sec on the normal side with a statistically significant difference between the two (p < 0.01).

4. The common carotid artery blood volume flow rate on the affected side was compared with the normal side in group D — 5 patients with occlusion of a
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These requirements are met, to some extent, by the system used in the present study. The characteristic feature of the system is the use of Doppler ultrasound with an ultrasonic pulse echo tracking method, which enables simultaneous tracing of pulse patterns, independent of the incident angle, of absolute blood velocity and wall displacement and hence calculation of absolute volume flow rate as the product of blood velocity and the cross-sectional area of the vessel. This device provides a higher estimated flow measurement compared to cerebral blood flow determined by means of N₂O or isotope method based on the Fick principle as well as electromagnetic flowmetry. But an UQFM gives information on flow which is related not only to bifurcation lesions, but to more distal obstructions as well.

In the present study a comparison was made of common carotid artery blood volume flow rate on the affected side (where the lesion responsible for neurological symptoms was found) and the contralateral normal side in 29 patients with transient ischemic attacks (TIA) or minor stroke who had no cerebral angiographic abnormalities. Our results show no significant difference \((p < 0.5)\) between the 2 sides. Measurements obtained with the system appear to correspond well to cerebral angiographic findings.

The common carotid artery blood volume flow rate on the diseased side (mean 4.54 ml/sec) gave an average ratio of 0.52 to that on the normal side (mean 8.64 ml/sec) in 23 patients with internal carotid artery occlusion. In one subject, however, the ratio was as high as 0.95, probably because of anastomosis between the superficial temporal artery and the middle cerebral artery, performed about a half a year previously, which might result in increased blood flow in the external carotid artery.

The blood volume flow rate on the diseased side was higher than that on the normal side in 2 patients with occlusion of the trunk of the middle cerebral artery. A cerebral angiographic feature common to these patients was a large posterior communicating artery of fetal type. A statistically significant difference was present \((p < 0.01)\) between the volume flow rate on the diseased side (mean 8.56 ml/sec) in this group of 11 patients, the ratio between the 2 being 0.80.

The volume flow rate on the diseased side was much lower than the normal side in 4 of 5 subjects with occlusion of a branch of the middle cerebral artery, although the subjects studied were too limited to warrant any definite conclusion.

No significant difference between the diseased and the normal side were observed in subjects with stenosis of the internal carotid artery or of the middle cerebral artery.

The UQFM used in the present study is of value not only as a screening test for occlusive cerebrovascular disease, but also may have the potential to assess the
Quantitative Carotid Phonoangiography


SUMMARY One hundred and sixteen carotid artery bruits were assessed using quantitative phonoangiography (spectral bruit analysis — SBA). This technique uses the averaged break frequency of the bruit to calculate the diameter of the residual lumen at the site of stenosis. Biplanar contrast arteriography was performed on 43 (37%) of the sides. All 116 sides were also evaluated with an ultrasonic Duplex scanner. Ten (8.6%) bruits could not be analyzed by the SBA, leaving 106 sides in which the residual lumen diameter could be estimated. The diameter of the vessel at the site of stenosis estimated by SBA and arteriography were compared and found to agree within 1 mm of each other in 85% of patients. A linear relationship was demonstrated between absolute lumen diameter and percent stenosis as measured from the arteriograms, but we were unable to correlate the absolute diameter of the residual lumen as assessed by arteriography or SBA with the assessment of the degree of the stenosis derived from spectral analysis of the pulsed Doppler signal. The significance of these findings is discussed with relevance to the clinical application of spectral bruit analysis.

Methods

The patients in this study were all consecutive referrals to the non-invasive laboratory for ultrasonic Duplex scanning of their extracranial arterial system. They all had neck examination with a stethoscope and if a bruit was present, a quantitative phonoangiogram was performed. All patients also had a pulsed Doppler assessment of both carotid systems, but the decision to obtain an arteriogram was made at the discretion of the referring physician.

Those who had arteriography had bilinear views of both carotid bifurcations. The films were read by a radiologist who was unaware of the test results. The diameter of the lumen at the site of the stenosis was measured directly from the arteriogram using calipers and corrected for the effect of magnification. The degree of stenosis of the internal carotid artery was

References


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