Carotid blood flow measured by an ultrasonic volume flowmeter in carotid stenosis and patients with dementia

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SUMMARY The volume flowmeter is a simple, noninvasive Doppler ultrasound technique that provides accurate measurement of carotid artery diameter and flow. The device provides a useful laboratory test that can aid significantly in diagnosis of carotid stenosis and dementia.

Ultrasonic Doppler flowmeters have been used extensively in recent years in the evaluation of haemodynamics. However, none of the devices routinely used is able to measure the actual rate of blood flow. In previous papers, we reported on the accuracy of a new device, the transcutaneous Doppler Volume Flowmeter, in measuring actual blood flow in an experimental model¹ and in determining carotid blood flow in carotid disease.² In this paper, we report the use of this device in assessing common carotid blood flow in dementia patients.

Subjects

A total of 330 persons were studied. Of these, 27 were normal subjects age 5 to 60 years. The others were taken from a patient population whose ages ranged from 40 to over 80 years. The patients were divided into two groups, the first being 54 patients with dementia (ages 50 to over 80 years). The second group of 249 patients had the following diagnoses: neuropathy (12 cases, ages 40 to 60), carotid bruits (210 cases, ages 50 to over 80), and angiographically confirmed carotid stenosis (27 cases, ages 50 to 70 years). A more detailed breakdown of the population studied is given in table 1.

Criteria for selection of patient controls and dementia patients

Dementia patients selected for study all exhibited deterioration of intellectual function and a Minimal Status Exam (MMS) score of less than 24.³ All were referred

from the Johns Hopkins dementia research clinic after diagnosis. They were diagnosed as suffering from either Alzheimer's disease or multiinfarct dementia, and no evidence of other neurological disorders could be discovered on neurological examination, CT examination, or electroencephalography.

The 12 patient controls exhibiting neuropathy without dementia were classified through use of neurological examination and electrodiagnostic study. They showed no clinical signs or symptoms of cerebrovascular disease or dementia. The patients with carotid bruit ranged from those suffering dizziness and black-outs to those discovered to have asymptomatic bruits. These patients were referred for carotid flow study because of suspected carotid stenosis, but none has any fixed or transient sensory or motor neurological deficit.

Among patients with carotid stenosis, only those who exhibited reduction of the diameter of the carotid artery in excess of 40%, confirmed by angiography, were included in the study. The diameter measurements were made in either of two planes at the level of the most severe stenosis. For angiographic determination of the percent reduction, the diameter of the stenotic portion was compared to the diameter measurement of the nearest normal portion of the artery.

Technique of carotid blood flow measurement

The transcutaneous Doppler Volume Flowmeter (VFM) provides quantitative estimation of cerebral blood flow through the carotid artery. The VFM has a built-in computer and a cathode ray tube that provides digital and analog display of the data, and it will provide a hard copy of the data. The VFM simultaneously measures both the diameter of a cross-section of the pulsating artery and the velocity of the blood at that point. The two values obtained are processed by the computer, and the calculated volume of blood flow is expressed in ml/s. The new mathematical formula developed by Furuhashi *et al*⁴ and the principle of the procedure are shown in fig 1. Details of the procedure are described elsewhere.^{1,2,5}

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Table 1 Flow values for control and patient groups

Group/diagnosis	Age (years)	Number	Flow (ml/s)
Normal controls	5-60	27	8.1 ± 1.3
Neuropathy	40-60	12	8.2 ± 0.6
Carotid bruit	50-59	52	7.9 ± 1.5
	60-69	58	7.2 ± 1.4
	70-79	81	7.0 ± 1.8
	80+	19	6.9 ± 1.4
Carotid stenosis			
41-70%	50-70	5	5.7 ± 1.9
71-90%	50-70	8	5.5 ± 1.8
91-100%	50-70	14	3.5 ± 1.8
Dementia	50-59	5	7.2 ± 0.5
	60-69	22	6.6 ± 1.9
	70-79	21	6.0 ± 1.9
	80+	6	4.7 ± 0.8
		Total 330	

Results

Normal controls

Variation with age. Thirty-two newborns, with an average age of $2.9 \pm 2/3$ days, were also examined in our facility. Their volume flow was initially 1.6 ± 0.46 ml/s. Flow then increased to an average of $3.9 \pm$ ml/s at one month, and to 7.4 ± 0.3 ml/s at 3 years. In our normal group of controls, blood flow

reached its highest level between 5 and 20 years of age, with a mean of 8.1 ± 1.3 ml/s, and it declined thereafter. In controls age 21 to 40, the flow was 7.99 ± 1.5 ml/s. In the 40 to 60-year age group it decreased to 6.7 ± 0.49 ml/s. The overall range of acceptable normal values for flow was 6 to 11 ml/s over the age range of 5 to 60 years.

Reproducibility The standard deviation of repeated intrasession measurement was 3.8%. This indi-

Fig 1 Diagram of the VFM probe. Classic mathematical formulae for calculation of the Doppler frequencies and flow velocity use the angle of incidence (θ) between the Doppler transducer and the direction of blood flow. In the method described in this paper, angle θ is not used. Instead, the new formula uses a fixed predetermined angle of 10° between the transmitting (T) and receiving (Ra and Rb) Doppler transducers. The transducers are fixed in a moulded plastic case, about 7 mm wide by 20 mm long and high. Values for the diameter and velocity are fed into the built-in microcomputer for calculation of the volume of flow (ml/s). The mathematical formula used in this technique is shown here (*). Further details of the technique are available elsewhere.¹

cates that if a patient has repeated readings taken on one side, the readings will probably fall within $\pm 7.6\%$ (2 SD) variation. The standard deviation for intersession reproducibility was 10.66%. This indicates that readings taken from the same patient from week to week could fluctuate $\pm 21.2\%$ from the average flow.

Side-to-side flow variation and ratio Comparisons were also made between the flow of the right carotid and the flow in the left carotid. The high to low flow ratio between the two carotids was 1.07 ± 0.052 . Correlation between the left and right sides between sessions was calculated to determine if the variations were due to a symmetrical change in cerebral blood flow or due to a lateralised change. The relatively low correlation, 0.63, suggested that both changes occur. There were no consistent left-to-right differences in flow.

Patient controls (without dementia)

In the patients with peripheral neuropathy, the mean carotid blood flow was 8.2 ± 0.60 ml/s. The high to low flow ratio was 1.04 ± 0.5 . These values were comparable to the values for an age-matched normal control group.

In the patients with carotid bruit, the flow averages were 6.9 to 7.9 ml/s, and the high flow to low flow ratio was 1.01 to 1.03. These values were within normal ranges. However, it must be noted that the patients with carotid bruit were not subjected to angiographic study, which would help rule out other disorders possibly associated with the bruit.

Patients with carotid stenosis documented by carotid angiography were chosen for statistical comparison with the controls. Only those patients with carotid reduction in excess of 40% were interpreted as positive for significant stenosis. Those with stenosis under 40% were interpreted as negative for

stenosis for the purposes of this study (table 2). The mean high to low flow ratios between the two carotid arteries were 2.1 ± 0.5 in 41%–70% stenosis, 2.6 ± 1.5 with 71%–90% stenosis, and 4.2 ± 3.7 ml/s with 91%–100% stenosis. The degree of stenosis and flow volume were inversely correlated, as expected, with a correlated coefficient of -0.73 (table 1).

Patients with dementia

Carotid blood flow in dementia patients rapidly declined with age, from 7.2 ml/s for patients in their 50s to 4.7 ml/s for 80-year-old patients. The high flow to low flow ratio for these patients was within normal values (average 1.025).

Discussion

Over the past 5 years, we have measured carotid blood flow in 3200 patients. The VFM method offers the advantages of being noninvasive and accurate. In the study of selected patients and controls reported here, VFM measurement of common carotid flow differentiated between patients with dementia and controls.

The decline in carotid blood flow with age is statis-

Fig 2 Carotid flows in normal controls, patient controls with carotid bruits, and demented patients.

Table 2 High to low flow ratio between the carotids in patients and controls (age in parentheses)

Group/diagnosis	Flow ratio
Normal controls (5-60)	1.07
Neuropathy (40-60)	1.04
Carotid bruit	
(50-59)	1.01
(60-69)	1.01
(70-79)	1.03
(80+)	1.03
Carotid stenosis (50-70)	
41-70%	2.1
71-90%	2.6
91-100%	4.2
Dementia	
(50-59)	1.0
(60-69)	1.0
(70-79)	1.1
(80+)	1.0

tically significant. Flow decreased with age in all the groups we studied, but flow was comparable between patient controls and normal age-matched controls. The high to low flow ratio remained within normal limits in all patient controls.

In the 27 patients with carotid stenosis, the flow was significantly lower in the stenotic artery and the flow ratio was significantly elevated. The sensitivity of the VFM in these patients was 96%. Our study indicates that a flow ratio of more than 1.2 or unilateral reduced flow of less than 6.0 ml/s (usually with compensatory increased flow on the opposite side) strongly suggests carotid stenosis. In cases of unilateral internal carotid stenosis, the degree of stenosis and the flow are inversely correlated, with a correlation coefficient of -0.73 ($p < 0.01$).

Carotid blood flow in the demented patients at various age levels is shown in fig 2. For comparison, the flow in age-matched carotid bruit patients is also shown, along with the mean flow for normal controls. The flow in the demented patients is significantly lower than that in the age-matched patient controls ($p < 0.01$, $t = 3.9$ df:23; $p = 0.20$ at age 50 yr). Rapid decline in flow in dementia is apparent.

Our results showed that VFM determination of normal flow with an elevated flow ratio can be used to differentiate carotid stenosis patients from nor-

mal controls, and that low flow with normal ratios can be used to differentiate dementia patients from controls.

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