

Cerebral blood flow measurements of the extracranial carotid and vertebral arteries with Doppler ultrasonography in healthy adults

Burhan Yazıcı, Beşir Erdoğmuş, Ali Tugay

PURPOSE

To establish normal cerebral blood flow volume by measuring flow volume of the extracranial carotid and vertebral arteries using Doppler ultrasonography in healthy adults.

MATERIALS AND METHODS

A prospective study was performed with a group of 96 healthy adults aged 20 to 80 years (48 women, 48 men; mean age of all patients, 49.8 ± 17.1). The common, external, and internal carotid arteries and the vertebral arteries (CCA, ECA, ICA, and VA, respectively) were examined using Doppler ultrasonography. Peak systolic velocity (PSV), end diastolic velocity (EDV), resistive index (RI), and luminal diameters of the vessels were measured, and flow volumes were calculated in all the arteries. The influence of age on these parameters was also investigated.

RESULTS

In the CCA, ICA, and VA, all flow velocities and flow volumes decreased significantly with an increase in age. The luminal diameters of the carotid and vertebral arteries increased significantly with aging, while there was no significant alteration in the RI. The luminal diameters of the CCA, ICA, and ECA were significantly smaller in women than in men. PSV and EDV in the ICA, and EDV in the VA were significantly higher in men. There was no gender-linked difference in flow volumes of the brain-feeding arteries, however, in the ECA flow volumes were significantly higher in women.

CONCLUSION

Normal cerebral blood flow volume was established by measuring the flow volume of the ECA and VA with Doppler ultrasonography in healthy adults. We believe that these data can be useful in evaluating cases with cerebrovascular disease, which are related to altered cerebral blood flow volume.

Key words: • ultrasonography, Doppler • regional blood flow • carotid arteries

Measurement of cerebral blood flow is an important parameter in the diagnosis and follow-up of ischemic cerebrovascular disease. In previous studies, various results have been reported regarding blood flow in the extracranial carotid and vertebral arteries (VA) of healthy individuals and a debate about the amount of change in the blood flow that is related to age ensued (1-4). Therefore, in this study, we used Doppler ultrasonography, which is a practical, non-invasive, economical, and repeatable exam that can be performed bedside, to quantify the amount of cerebral blood flow in healthy individuals and to define the effect of aging on blood flow.

Materials and methods

A group of 96 individuals between the ages of 20 and 80 years (mean, 49.8 ± 17.1 years), consisting of 48 females and 48 males volunteered for the study. In order to form a homogeneous stratification regarding age and sex, 12 groups were formed, each with 5-year age differences. Each group included 4 women and 4 men. None of the participants had a history of smoking, alcohol use, diabetes, or hypertension. The systolic blood pressures were not above 135 mmHg in any of the individuals and there was no evidence of tachycardia. To avoid interobserver variance, all measurements were done by the same radiologist using the same Doppler ultrasonography device (Hitachi EUB 6500, Japan) with a standard 7 MHz linear transducer. Examination of each individual began after 15 minutes of rest in the supine position. Blood flow measurements in the common carotid arteries (CCA) were done at the segment located 2 cm proximal to the bifurcation and in the internal carotid (ICA) and the external carotid arteries (ECA) 1-2 cm distal to the bifurcation. For the VA, measurements were done bilaterally at the center of the arterial segment between the 4th and 5th cervical vertebral transverse processes in the sagittal plane. The head was turned 10° to the contralateral side for the carotid arteries measurements and $25-40^\circ$ to the contralateral side for the VA measurements. To obtain error-free measurements, arterial diameters were calculated on magnified B-mode images at the end of the diastole as a vertical line through the lumen between the echogenic intimal layers. Later, blood flow velocities were obtained keeping the Doppler insonation angle at a standard 60° . Sample volume was kept sufficiently large to contain the whole lumen. Three consecutive blood velocity waveforms of similar pattern were considered as the correct spectral samples. Peak systolic velocity (PSV), end-diastolic velocity (EDV), resistivity index (RI), blood flow volume (ml/min), and vessel diameter were automatically calculated (Figure). Bilateral ICA and VA blood flows were summed up to calculate the total cerebral blood flow. Parameters such as hematocrite and arterial blood gases were not measured to maintain the study's non-invasive manner and to avoid participant stress.

From the Department of Radiology (B.Y. ✉ dryazici@yahoo.com), Abant İzzet Baysal University Faculty of Medicine, Düzce, Turkey.

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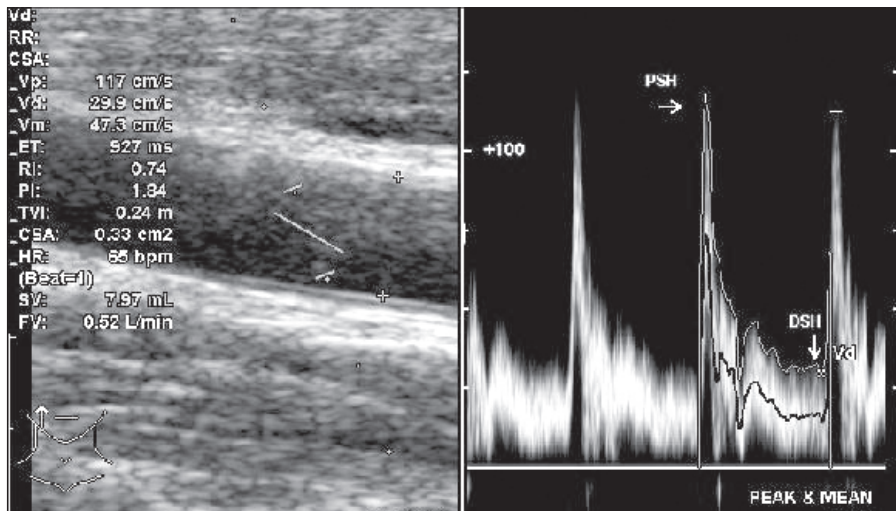


Figure. Doppler ultrasonography measurement of the vessel diameter, PSV, EDV, and flow volume in the CCA. Measurements were done in a horizontal segment in sagittal plane with the Doppler insonation angle at a standard 60 degrees. Sampling volume was maximum, containing most of the vessel lumen. The figure demonstrates automatic measurement of blood flow volume after the vessel diameter was measured. (CCA: common carotid artery, PSV: peak-systolic velocity, EDV: end-diastolic velocity).

For the statistical analysis, Statistical Package for Social Sciences Version 10.0 (SPSS Inc., Chicago, IL, USA) software was used. All parameters were shown as mean±SD. Student's t-test was used to determine if there was a difference between the right and left extracranial vessels and genders. P values less than or equal to 0.05 were considered as statistically significant.

Results

Volume measurements and B-mode imaging was technically successful in all participants. Two individuals were excluded from the study because their carotid bifurcations were located too high and three other individuals were excluded because vertebral artery blood flows were too low, unilaterally. Average examination time ranged from 15 to 20 minutes.

Lumen diameters of CCA, ICA, and ECA were significantly larger in men as compared to women. Mean CCA diameter was 6.7±0.8 mm in men and 6.3±0.7 mm in women (p=0.012); ICA diameter was 4.7±0.6 mm in men and 4.4±0.5 mm in women (p=0.03); ECA diameter was 4.4±0.6 mm in men and 3.8±0.6 mm in women (p=0.000). No significant differences were found between the genders regarding VA diameters. Vertebral artery diameter in men was 3.6±0.4 mm and 3.5±0.4 in women (p=0.060).

In women, PSV and EDV in ICA and EDV in VA were higher as compared

to men. PSV in ICA was 75.8±15.6 cm/sec in women and 64.3±12.3 cm/sec in men (p=0.000); EDV in ICA was 30.6±6.9 cm/sec in women and 24.2±6.3 cm/sec in men (p=0.000). In VA, EDV was 21.1±17.5 cm/sec in women and 16.0±3.6 cm/sec in men (p=0.045).

CCA, ICA, and VA blood flow volumes were 417.8±100 ml/min, 213.4±59 ml/min, and 85.8±37.3 ml/min, respectively; total cerebral blood flow was 640±105 ml/min. No significant differences were noted between the genders regarding CCA, ICA, and VA blood flow volumes. ECA blood flow volume was significantly higher in men compared to women (144±52.5 ml/min in men and 122.2±49.1 ml/min in women, p=0.035). A significant decrease was detected in the CCA, ICA, and VA blood velocities and blood flow volumes with respect to aging. Carotid and vertebral artery diameters significantly increased with increasing age. No significant changes were noted in RI.

No significant differences in blood velocity and other flow parameters were observed between the right and left extracranial vessels in either sex.

When the groups that were formed with 5-year age increments were compared regarding flow parameters, no significant differences were found, however when two groups were formed including 20-50 year-olds and

51-80 year-olds, a significant decrease in blood velocities and blood flow volumes in the CCA, ICA, and VA, and an increase in vessel diameters were noted with increasing age (Table 1).

Discussion

Ultrasonography is an important imaging method in the diagnosis of carotid and vertebral artery diseases. Examination of the carotid and vertebral arteries by Doppler ultrasonography is a non-invasive and easily available method, which provides vital diagnostic data to clinicians dealing with carotid and vertebral arterial diseases. Although there have been reports stating that other imaging methods such as magnetic resonance angiography, computed tomography angiography, digital subtraction angiography, and positron emission tomography may be used to measure cerebral blood flow, use of these methods have disadvantages because some are invasive, some have radiation risks, and some are not suitable for bedside evaluation and follow-up (5-7). Doppler ultrasonography is practical, non-invasive, economical, repeatable, and suitable for bedside imaging, and is therefore preferable to other imaging methods. Its main disadvantage is that the accuracy of the method is dependent upon the experience and dexterity of the performer. Ultrasonographic measurement of cerebral blood flow in the ICA may be difficult due to high carotid bifurcation, plaques, kinks, tortuosity, or stenosis (8).

Cerebral blood flow measurement is an important parameter in the diagnosis of ischemic cerebrovascular diseases. Despite this, there is no standard for normal blood flow. Moreover, there has been an ongoing debate about age-related changes in cerebral blood flow (1-4).

Although in healthy individuals the presence of vertebrobasilar insufficiency is inferred when the total blood flow of both vertebral arteries are below 200 ml/min (9), there are other studies, which claim that vertebral blood flow above 100 ml/min is normal (10, 11).

Despite reports stating that total cerebral blood flow in healthy individuals does not change throughout life (12-14), there were significant decreases in total cerebral blood flow, blood flow velocity, and flow in the CCA, ICA, and VA in our study related to increased

age. Most investigators studying cerebral blood flow on healthy individuals have reported similar results (4, 15-17). In studies where a decrease in cerebral blood flow was detected related to aging, the decrease was related to a decrease in the perfusion demand of the brain, secondary to atrophy from progressive neuronal loss (15-17).

The measured total cerebral blood flow of 640 ± 105 ml/min in our study was similar to the results from many other studies. The total cerebral blood flow was reported as 630 ± 97 ml/min by Dorfler et al. (3), 701 ± 104 ml/min by Schoning et al. (4), and 644 ± 123 ml/min by Scheel et al. Although there were reports stating that vertebral (7) and carotid (18, 19) artery blood flow was less in women than in men, there was no significant difference between the genders in total cerebral blood flow or in ICA and VA blood flow, ac-

ording to our results. These results were in concordance with the data reported previously for healthy individuals (10, 16, 20).

Our study revealed that PSV and ESV of ICA in women were higher than in men, and lumen diameter in men was larger than in women. But no significant difference was found between the genders regarding blood flow volume. Because volume is equal to vessel diameter times blood flow velocity, blood flow velocity should be high when the vessel diameter is narrow in order to keep the equilibrium of flow volume, which explains the high PSV and EDV observed in the ICA in women. Although no significant difference regarding vessel diameter was present between the genders, the slightly larger VA diameters in men provides an explanation for the higher EDV of VA in women by the same mechanism.

We believe that the observed increase in vessel diameter associated with increasing age in this study is secondary to atherosclerotic changes that cause a decrease in the vessel wall elasticity.

Although we found no significant differences between the genders regarding blood flow velocity and flow parameters in the right and left extracranial vessels, ECA blood flow and velocity were higher in men as compared to women. Similarly there are reports, which state that blood flow in men in the left CCA (14, 21) and right CCA (22) are higher as compared to women. We do not know the exact reason for this mismatch. Table 2 demonstrates previously published blood flow results for CCA, ICA, ECA, and VA in the literature. Different results were also reported about vertebral artery diameters. Some authors suggest that the right VA (10, 16) or the left VA (23)

Table 1. Reference data for blood velocity, resistive index, vessel diameter, and blood flow of different age groups

Vessel (age range, years)	n	PSV (cm/sec)	EDV (cm/sec)	RI	Diameter (mm)	Volume (ml/min)
CCA (21-50)	48	98 ± 20	26 ± 6	0.78 ± 0.06	6.2 ± 0.6	427 ± 106
CCA (51-80)	48	74 ± 15	20 ± 5	0.80 ± 0.05	6.8 ± 0.8	408 ± 95
ECA (21-50)	48	72 ± 15	16 ± 5	0.78 ± 0.06	4.1 ± 0.5	128 ± 45
ECA (51-80)	48	73 ± 19	14 ± 5	0.80 ± 0.05	4.1 ± 0.7	139 ± 57
ICA (21-50)	48	76 ± 14	30 ± 7	0.60 ± 0.06	4.5 ± 0.5	238 ± 57
ICA (51-80)	48	65 ± 14	25 ± 6	0.61 ± 0.05	4.6 ± 0.7	225 ± 60
VA (21-50)	48	53 ± 10	18 ± 5	0.65 ± 0.07	3.5 ± 0.4	86 ± 34
VA (51-80)	48	48 ± 12	15 ± 17	0.68 ± 0.05	3.6 ± 0.5	77 ± 41

CCA: common carotid artery, ECA: external carotid artery, ICA: internal carotid artery, VA: vertebral artery, PSV: peak systolic velocity, EDV: end-diastolic velocity, RI: resistive index.

Table 2. Previously published data concerning blood flows for CCA, ECA, ICA, and VA

Authors (reference no.), year	n	Age	CCA	ICA	N-ICA	VA	N-VA	Total	ARC
Schoning et al. (10), 1994	48	26-78	470 ± 120	265 ± 26	530 ± 98	85 ± 33	175 ± 56	701 ± 104	↔
Seidel et al. (11), 1999	49	31-84	-	-	-	91 ± 37	182 ± 56	-	-
Scheel et al. (8), 2000	78	20-85	-	-	499 ± 108	-	158 ± 43	644 ± 123	↓
Weskott et al. (19), 1997	205	20-87	417 ± 87	-	-	-	-	-	-
Dorfler et al. (3), 2000	85	-	-	238 ± 45	-	82 ± 44	-	630 ± 97	↓
Acar et al. (24), 2005	20	50-75	-	-	-	-	180 ± 64	-	-
Yazıcı et al. 2005	96	20-80	418 ± 100	231 ± 59	476 ± 85	85 ± 37	165 ± 53	640 ± 105	↓

CCA: common carotid artery, ECA: external carotid artery, ICA: internal carotid artery, VA: vertebral artery, Total: total cerebral blood flow, ARC: age related changes in the blood flow, ↓: Decrease in blood flow with aging, ↔: No change in blood flow related to age, - = undetermined or unobserved parameters.

has a narrow caliber, while others state that no significant difference exists (9, 24). In our study, no significant difference in diameter was present between the right and the left VA as well.

Vertebral blood flow less than 30-40 ml/sec on either side may signify vertebral artery hypoplasia (4). Three individuals with VA blood flow less than 40 ml/min (left VA, n=2; right VA, n=1) were excluded from the study. These three cases were asymptomatic although they had vertebral artery blood flow less than 40 ml/min and had 87-95 ml/min blood flow in the contralateral vertebral artery, which suggested that this situation might be a variance.

Basic indications of Doppler studies of the extracranial carotid and vertebral arteries are as follows: vertebrobasilar insufficiency (24), arteriovenous malformation (25), intracranial hemorrhage (26), trauma and intracranial hypertension (27), arteriosclerotic lesions, and endarterectomy and post shunt Doppler evaluation (28). The results obtained in our study were similar with the majority of the literature (10, 15-17). Therefore, we believe that these data could prove to be useful in the evaluation of cerebral hemodynamics and follow-up in patients with pathologies that affect cerebral hemodynamics, such as vertebrobasilar insufficiency, arteriovenous malformation, intracranial hemorrhage, intracranial hypertension, cerebral damage, and endarterectomy.

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