

Vertebral Artery Doppler Reference Values in Healthy Turkish Adults: Influence of Age, Sex, and BMI

 Ahmet Tuğrul Akkuş¹,  Muhammed Furkan Barutçigil²,  Said Ali Atalay³

¹Clinic of Radiology, Kağızman State Hospital, Kars, Türkiye

²Clinic of Radiology, Tekirdağ İsmail Fehmi Cumaloğlu City Hospital, Tekirdağ, Türkiye

³Clinic of Radiology, Bayburt State Hospital, Bayburt, Türkiye

Cite this article as: Akkuş AT, Barutçigil MF, Atalay SA. Vertebral artery Doppler reference values in healthy Turkish adults: influence of age, sex, and BMI. *Arch Basic Clin Res*. 2026;8(3):245-255.

ORCID IDs of the authors: A.T.A. 0000-0001-5269-2502, M.F.B. 0000-0003-4345-0442, S.A.A. 0000-0001-8225-3463.

ABSTRACT

Objective: To establish population-specific bilateral reference values for vertebral artery (VA) diameter, peak systolic velocity (PSV), end-diastolic velocity (EDV), resistive index (RI), pulsatility index (PI), and flow volume in healthy Turkish adults, and to assess the effects of age, sex, laterality, and body mass index (BMI) on these parameters.

Methods: This prospective, multicenter study enrolled 223 healthy Turkish adults from three centers. VA Doppler ultrasonography was performed using a standardized protocol. The measured parameters included VA diameter, PSV, EDV, RI, PI, and flow volume.

Results: Left vertebral arteries exhibited significantly larger diameter (3.73 ± 0.57 mm vs. 3.52 ± 0.61 mm), PSV, EDV, and flow volume compared to the right side ($P < 0.05$). Males had a larger right VA diameter and higher RI and PI bilaterally, whereas females had higher right VA EDV ($P < 0.05$). Age was negatively correlated with PSV, RI, and PI, but positively correlated with left VA diameter. BMI was negatively correlated with PSV, RI, and PI, but did not significantly affect flow volume. Reference percentiles were established based on sex and age.

Conclusion: This study investigated normal reference values for six VA Doppler parameters in 223 healthy Turkish adults, stratified by sex and age, with BMI evaluated as a covariate. It is the first study to include BMI as a covariate and to derive percentile-based norms from a multicenter Turkish cohort. The normal range (5th-95th percentile) for total VA flow volume was 124.7-391.8 mL/min. Because this lower limit lies well below the widely quoted 200 mL/min threshold for vertebrobasilar insufficiency, applying that threshold would misclassify a considerable proportion of healthy adults as abnormal. These findings support improved clinical interpretation of VA Doppler ultrasonography.

Keywords: Vertebral artery, ultrasonography, doppler, body mass index

INTRODUCTION

The vertebral arteries (VAs) arise from the subclavian arteries, course through the transverse foramina of the cervical vertebrae, and form the basilar artery at the pontomedullary junction. The VAs supply the brainstem, cerebellum, thalamus, occipital lobes, and medial temporal lobes.¹ vertebral artery (VA) occlusion, stenosis, or hemodynamic alterations may result in significant neurological conditions ranging from transient ischemic attacks to posterior circulation infarcts.

Digital subtraction angiography remains the gold standard imaging modality for vascular pathologies above the aortic arch. However, it is not a suitable screening tool because it is invasive. Thus, color Doppler ultrasonography (CDU) and computed tomography angiography (CTA) are used for screening imaging modalities for vascular pathologies.² CDU is cost-effective, radiation-free, and repeatable, and has therefore been widely used in the diagnosis of atherosclerotic obstructive diseases of the carotid system; however, data on VA are scarce compared with carotid arteries.



Corresponding author: Ahmet Tuğrul Akkuş, **E-mail:** akkustugrul@gmail.com

Received: July 23, 2026

Revision Requested: October 9, 2026

Accepted: October 13, 2026

Publication Date: October 28, 2026



Copyright© 2026 The Author(s). Published by Galenos Publishing House on behalf of Erzincan Binali Yıldırım University. This is an open access article under the Creative Commons AttributionNonCommercial 4.0 International (CC BY-NC 4.0) License.

Despite multiple studies, no universally accepted reference values exist for VA Doppler parameters, and inter-study variability [e.g., peak systolic velocity (PSV) ranging from 37 to 53 cm/s across populations] complicates the diagnosis of vertebrobasilar stenosis in clinical practice. This variability likely reflects a combination of population-specific biological differences, inconsistent measurement protocols, and the absence of anthropometric covariates such as body mass index (BMI). Several factors contribute to the variability in VA Doppler parameters. Prior studies were single-center and therefore prone to selection bias. Many studies had limited sample sizes. No prior study has incorporated BMI into VA Doppler evaluation, despite evidence that BMI influences peripheral vascular resistance and carotid artery hemodynamics, suggesting it may also modulate VA flow dynamics. Tarnoki et al.³ demonstrated moderate genetic heritability of VA diameter in a European twin cohort, suggesting that population-specific genetic variation may contribute to inter-study differences in Doppler parameters. Given the distinct genetic and anthropometric profiles of Turkish populations compared with Western European cohorts, population-specific reference values are needed to improve diagnostic accuracy in these populations.

To address the absence of population-specific, BMI-informed, and multicenter-validated reference values for Turkish adults, we designed the present prospective study. By enrolling a large cohort of healthy Turkish adults across geographically diverse centers, using a standardized protocol, we aimed to establish population-specific bilateral reference values for VA diameter, PSV, end-diastolic velocity (EDV), resistive index (RI), pulsatility index (PI), and flow volume and to systematically evaluate the effects of age, sex, laterality, and BMI on these parameters. We aimed to provide normal reference values for the Turkish population to improve the clinical interpretation of VA Doppler examinations. Future validation studies are needed to assess whether population-specific norms reduce diagnostic misclassification compared with existing European reference values.

MAIN POINTS

- Our study is the first in the literature to include body mass index (BMI) in vertebral artery (VA) Doppler evaluation. While BMI was negatively correlated with peak systolic velocity (PSV), resistive index (RI), and pulsatility index (PI), it was not correlated with flow volume.
- The normal range (5th-95th percentile) for total VA flow volume was 124.7-391.8 mL/min; the 5th- percentile value (124.7 mL/min) was well below the commonly used 200 mL/min threshold for vertebrobasilar insufficiency.
- Male participants exhibited a significantly larger right VA diameter (median 3.70 mm vs. 3.50 mm, $P = 0.004$) and higher RI and PI bilaterally, whereas female participants demonstrated a higher right VA end-diastolic velocity ($p = 0.037$).
- No statistically significant differences were observed in the PSV and flow volume between the sexes.

MATERIALS AND METHODS

This prospective, observational, multicenter study was conducted at three centers between March 1, 2026, and June 1, 2026. Ethics committee approval was obtained from Tekirdağ İsmail Fehmi Cumaloğlu City Hospital Clinical Research Ethics Committee (approval no.: AN-262105-45, date: 21.05.2026) and conducted in accordance with the current principles of the Declaration of Helsinki. Written informed consent was obtained from all participants.

A total of 223 volunteers participated in the study. Participants were selected from individuals who applied to outpatient services at the relevant centers or responded to study announcements, and the plan was designed to ensure equal distribution of applications from healthy volunteers across all three centers.

The inclusion criteria for the study are as follows: be older than 18 years of age; have no neurological symptoms or complaints (including dizziness, vertigo, syncope, transient ischemic attack, stroke, ataxia, diplopia, dysphagia, and gait disturbance); agree to participate voluntarily and provide written informed consent; and have sufficient acoustic windows in which VA Doppler ultrasonography can be technically performed.

The exclusion criteria for the study are as follows: history of known neurological disease (stroke, transient ischemic attack, multiple sclerosis, Parkinson's disease, epilepsy, etc.), cervical vertebral pathology (severe osteoarthritis, disc herniation, cervical stenosis, instability, etc.), history of carotid or VA disease (atherosclerosis, dissection, occlusion, stenosis), history of previous surgery or radiation therapy in the head and neck region, uncontrolled hypertension ($\geq 160/100$ mmHg) or inadequate regulation with antihypertensive therapy, atrial fibrillation or other cardiac arrhythmias significantly affecting hemodynamics, congestive heart failure or severe valvular disease, known coagulopathy or active anticoagulant/thrombolytic therapy, active infection, wound, or skin disease affecting the skin in the neck region, morbid obesity (BMI > 40 kg/m²) or abnormal neck anatomy Short neck/thickness that makes examination impossible, inability to measure due to known VA hypoplasia (diameter < 2 mm) or anatomical variant, pregnancy or breastfeeding period, severe difficulty in cooperation that prevents reliable measurement (dementia, psychiatric disorder, etc.).

VA Doppler ultrasonography examinations were performed at all three centers using real-time ultrasonography devices with B-mode, color Doppler, and spectral Doppler (pulsed-wave Doppler) capabilities. The Toshiba Aplio 400 ultrasound system (Toshiba Medical Systems, Otawara, Japan) was used at all three centers. Examinations were performed using a high-frequency linear probe (7-15 MHz). To ensure that device settings and measurement protocols remained consistent throughout the study, examinations at each center were performed by radiology specialists with 5 years' experience in carotid-VA Doppler ultrasound. An inter-center technical standardization meeting was held prior to commencing measurements.

Participants were instructed to avoid consuming caffeinated beverages and smoking for at least 2 hours before the

examination. The examination was performed in a quiet environment at room temperature (20-24 °C), after the participant had rested in the supine position for at least 10 min. The participant was placed in the supine position with the head slightly turned to the opposite side and the neck slightly extended.

The common carotid artery was visualized in the sagittal plane 1-2 cm proximal to the bifurcation in B-mode imaging. The probe was tilted slightly laterally without exerting pressure. The V2 segment of the VA was visualized between the transverse foramina; all Doppler, diameter, and cross-sectional area measurements were obtained in the intertransverse segments at the mid-cervical level (C3-C5). This segment was chosen because it is readily accessible with ultrasound, has a relatively straight course that minimizes angle-related measurement error, and is the standard site for detecting hemodynamically significant stenosis in clinical practice. Spectral Doppler sampling was performed with a Doppler angle of 45°-60°, and all measurements used this angle correction (Figure 1).

PSV and EDV were measured three times and the averages were calculated. The VA diameter (intima-to-intima distance) was measured in millimeters (mm) at the end-diastolic stage of the cardiac cycle. The measurement was taken at a point where the vessel walls were clearly visible in a section perpendicular to the insonation angle (Figure 2). Flow volume (mL/min) was calculated using the device's automatic calculation function as the product of time-averaged mean velocity (TAMV, cm/s) × cross-sectional area (cm²) × 60. TAMV was obtained from the angle-corrected spectral Doppler waveform, averaged over three consecutive cardiac cycles. The cross-sectional area was measured directly by manually tracing a circular region of interest along the vessel lumen on the transverse (cross-sectional) image at the same level (Figure 3), and it was not derived from the longitudinally measured diameter.

Statistical Analysis

All statistical analyses were performed using SPSS version 24.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean ± standard deviation and median with interquartile range (IQR). The normality of the distribution was assessed using the Kolmogorov-Smirnov test. The Kruskal-Wallis H test was used to assess inter-center homogeneity prior to data pooling. The Mann-Whitney U test was used to compare parameters between sexes, and the Wilcoxon signed-rank test was used to compare left and right sides within the same subject. Spearman's rank correlation coefficient (ρ) was used to assess associations between age, BMI and Doppler parameters. The sex distribution across the centers was assessed using the chi-square test. Percentiles and stratification by sex and age were provided to support the development of the nomogram. Reference limits (5th and 95th percentiles) were derived nonparametrically as empirical percentiles of the observed data, using linear interpolation between adjacent order statistics and without assuming any underlying distribution. In line with the CLSI EP28-A3c guideline, 90% confidence intervals for the overall and sex-specific 5th and 95th percentiles were estimated with the nonparametric rank-based (binomial order-statistic) method (Supplementary Table S1).¹² IQRs were calculated in

the same way. Two implausible values that were considered data-entry errors (a right VA diameter of 0.38 mm and a right VA RI of 7.00) were treated as missing. To assess the robustness of the pooled estimates, the main analyses were repeated after excluding the center with the oldest participants, as a sensitivity analysis (Supplementary Table S2). Statistical significance was set at p < 0.05.

RESULTS

Of 283 volunteers assessed for eligibility, 60 were excluded: 20 for uncontrolled hypertension, 10 for cardiac arrhythmia, 8 for atherosclerotic changes in the common or internal carotid artery, 6 for severe difficulty cooperating, 5 for previous stroke, 4 for VA hypoplasia, 3 for pregnancy, 3 for previous head and

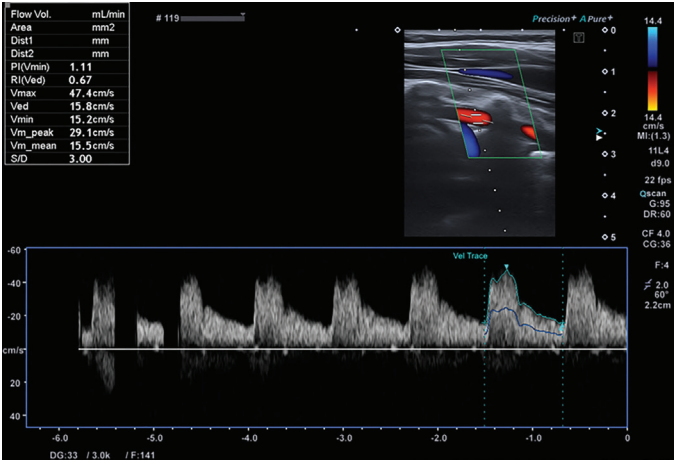


Figure 1. Angle corrected spectral doppler sampling of left vertebral artery with calculation of RI, PI, PSV and EDV.

RI, resistive index; PI, pulsatility index; PSV, peak systolic velocity; EDV, end-diastolic velocity.

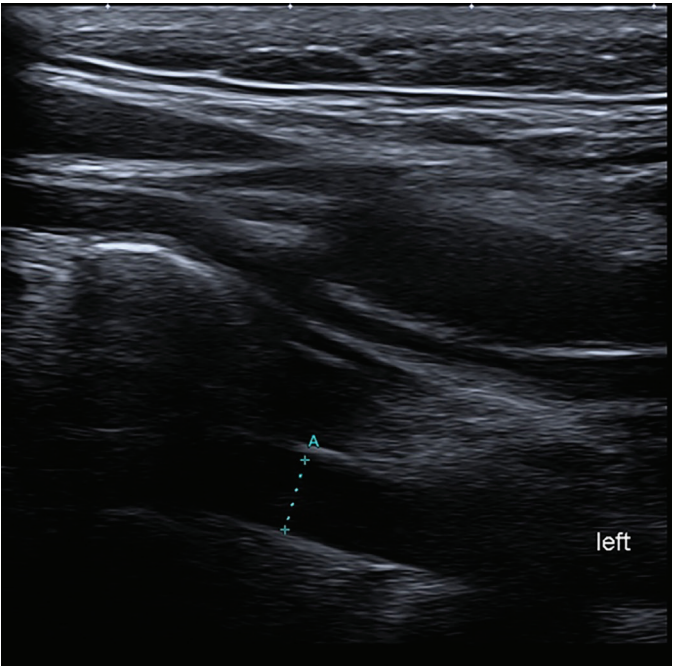


Figure 2. Left vertebral artery diameter measurement.

neck surgery, and 1 for morbid obesity ($\text{BMI} > 40 \text{ kg/m}^2$). A total of 223 healthy adults (140 women, 62.8%; 83 men, 37.2%) from three independent centers were included in the study. The mean ages were 39.4 ± 12.2 years (range 18-72) and mean BMI was $26.9 \pm 4.5 \text{ kg/m}^2$. For one female participant, only age and sex were recorded, and no Doppler or BMI data were available because of a technical problem; therefore, the

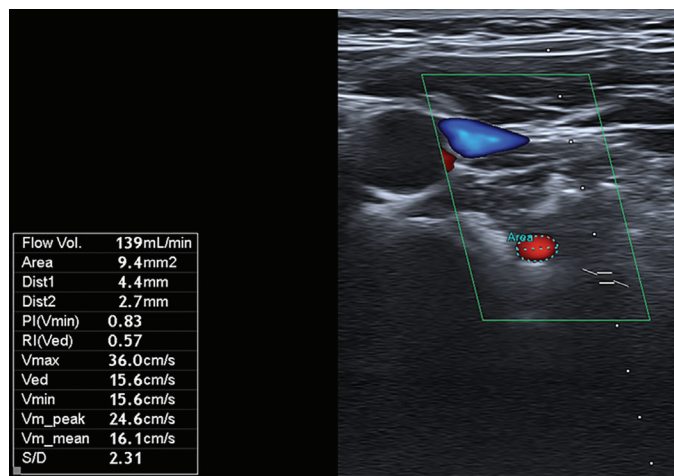


Figure 3. Cross section area (mm^2) measurement of left vertebral artery.

Doppler analyses and reference percentiles were based on 222 participants (139 women, 83 men). In addition, bilateral RI was not recorded in one participant, and right VA diameter was not recorded in another; the two implausible values described in the Methods were set to missing. As a result, left VA RI was available in 221 participants, while right VA diameter and right VA RI were each available in 220 participants. Missing values were not imputed. Participant flow is shown in Figure 4.

There were no statistically significant differences among the three centers in sex distribution ($p = 0.96$) or BMI ($p = 0.78$). A statistically significant difference in age was observed ($p = 0.02$), with an older subgroup at one of the three centers (mean age 42.8 versus 38.0-38.3 years). To assess whether this difference biased the pooled estimates, we performed a sensitivity analysis excluding the older center. The left-sided predominance of all six parameters; the higher right VA diameter and bilateral PI in men; the higher right VA EDV in women; the negative correlations of age with PSV, PI, and left RI; and the negative correlations of BMI with PSV, RI, and left PI remained statistically significant, with direction unchanged. In contrast, the sex difference in RI (left $p = 0.22$, right $p = 0.09$), the correlations of age with right RI ($p = 0.058$) and with EDV (left $p = 0.08$, right $p = 0.15$), and the correlation of BMI with right PI ($p = 0.11$) were no longer significant, although the direction of these associations remained unchanged. The positive correlation between age and left VA diameter was

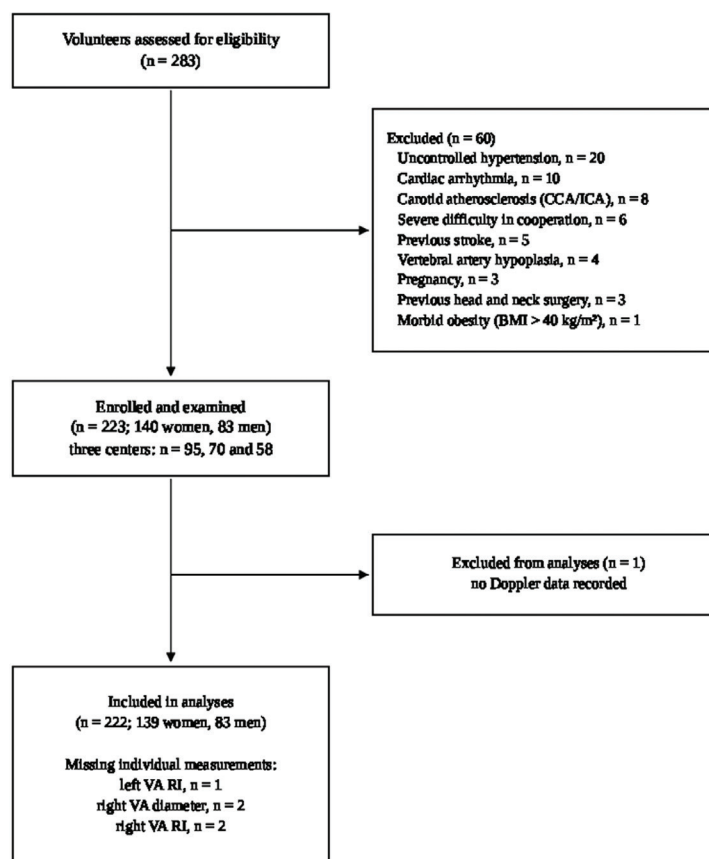


Figure 4. Flow diagram of participant screening, exclusion and inclusion, showing the number of participants available for each analysis.

BMI, body mass index; RI, resistive index; VA, vertebral arterie.

no longer observed after this exclusion ($p = 0.06$, $p = 0.48$) (Supplementary Table S1). The main findings were therefore robust to pooling; however, these weaker associations should be interpreted with caution.

The descriptive statistics for all the Doppler parameters are summarized in Table 1. The left VA had significantly greater diameter, PSV, EDV, and flow volume than the right VA (Table 1). The right VA exhibited significantly higher RI and PI values than the left (Table 1). On average, the left VA diameter was 0.21 mm larger than the right VA diameter (3.73 vs. 3.52 mm), consistent with left-sided predominance.

Right VA diameter differed significantly between male and female participants (median 3.70 mm vs. 3.50 mm, $p = 0.004$; Table 2). There were statistically significant differences between males and females in bilateral RIs and PIs, with higher values in males (Table 2). Female participants had higher right VA EDV than male participants (median 14.25 vs. 13.11 cm/s, $p = 0.037$; Table 2).

Age was negatively correlated with PSV, PI, and RI on both sides (p between -0.13 and -0.30 , all $p < 0.05$), and positively correlated with left VA diameter ($p = 0.19$, $p = 0.006$). No significant correlation was observed between flow volume

and age. BMI correlated negatively with RI, PI, and PSV on both sides, but not with bilateral flow volume (Table 3).

Table 4 shows normal reference percentiles for each parameter, separately for males and females. Fiveth percentile for total flow volume is 124.7 mL/min. Fiveth percentile flow volume values for males and females are 134.96 mL/min and 122 mL/min respectively. Table 5 shows normal reference percentiles for left and right VA by age group.

DISCUSSION

In this prospective study, 223 healthy Turkish adults were examined using VA Doppler ultrasonography to establish a population-specific nomogram. The mean diameters of the VAs were 3.73 ± 0.57 mm for the left VA and 3.52 ± 0.61 mm for the right VA, respectively. Scheel et al.⁴ reported VA diameters ranging from 3.3 ± 0.3 mm to 3.6 ± 0.4 mm. Our measurements of VA diameters are consistent with those found in a study by Yilmaz et al.² which investigated VA Doppler parameters and their correlation with CTA in a Turkish population (right VA diameter 3.4 ± 0.6 mm, left VA diameter 3.7 ± 0.7 mm). In contrast, an Italian twin cohort study by Tarnoki et al.³ reported slightly smaller VA diameters (right VA diameter 3.16 ± 0.77 mm, left VA diameter 3.23 ± 0.77 mm) (Table 6).

Table 1. Vertebral artery Doppler parameters

Parameter	Left VA, mean $\pm$ SD	Right VA, mean $\pm$ SD	P (left vs. right)
Diameter (mm)	3.73 $\pm$ 0.57	3.52 $\pm$ 0.61	<0.001
RI	0.67 $\pm$ 0.08	0.69 $\pm$ 0.08	0.001
PI	1.29 $\pm$ 0.36	1.40 $\pm$ 0.40	0.001
PSV (cm/s)	49.6 $\pm$ 13.9	47.4 $\pm$ 14.2	0.03
EDV (cm/s)	16.4 $\pm$ 6.0	14.5 $\pm$ 6.3	<0.001
FV (mL/min)	126.8 $\pm$ 61.0	107.6 $\pm$ 51.3	<0.001

RI, resistive index; PI, pulsatility index; PSV, peak systolic velocity; EDV, end-diastolic velocity; FV, flow volume; SD, standard deviation; Min, minimum; Max, maximum.

Table 2. Comparison of Doppler parameters between sexes

Parameter	Male, median (IQR)	Female, median (IQR)	P value
BMI (kg/m ²)	25.66 (24.15-27.80)	26.70 (23.40-30.02)	0.20
Left diameter (mm)	3.80 (3.50-4.20)	3.60 (3.30-4.00)	0.08
Left RI	0.69 (0.63-0.74)	0.66 (0.61-0.72)	0.044
Left PI	1.36 (1.08-1.60)	1.21 (1.01-1.38)	0.003
Left PSV (cm/s)	46.10 (41.81-55.78)	46.90 (39.63-57.38)	0.77
Left EDV (cm/s)	15.50 (12.43-18.47)	15.65 (12.60-19.90)	0.25
Left FV (mL/min)	109.00 (79.50-147.50)	117.00 (86.52-162.15)	0.27
Right diameter (mm)	3.70 (3.30-4.20)	3.50 (3.06-3.80)	0.004
Right RI	0.70 (0.67-0.75)	0.69 (0.63-0.73)	0.046
Right PI	1.43 (1.20-1.73)	1.26 (1.10-1.47)	<0.001
Right PSV (cm/s)	45.47 (36.20-51.80)	45.70 (38.15-56.42)	0.34
Right EDV (cm/s)	13.11 (10.62-15.73)	14.25 (11.84-17.76)	0.037
Right FV (mL/min)	100.30 (72.92-124.20)	101.54 (68.71-135.22)	0.62
Total FV (mL/min)	215.60 (174.08-256.50)	222.10 (170.85-297.25)	0.28

Values are medians (interquartile range); P values were obtained with the Mann-Whitney U test. BMI, body mass index; RI, resistive index; PI, pulsatility index; PSV, peak systolic velocity; EDV, end-diastolic velocity; FV, flow volume; IQR, interquartile range; Min, minimum; Max, maximum.

Our RI values for both VAs (left: 0.67 ± 0.08 , right: 0.69 ± 0.08) closely align with those reported by Schöning et al.⁵ (0.66 ± 0.07), Scheel et al.⁴ (0.68 - 0.72), Nemati et al.⁶ (0.69 - 0.71), and Kovacic et al.⁷ (0.70 bilaterally) (Table 6). In contrast, Yılmaz et al.² documented lower RI values of 0.63 bilaterally in a Turkish cohort, which comprised patients exhibiting symptoms of vertebrobasilar insufficiency or anterior circulation issues. The PI values in our study (left: 1.29 ± 0.36 , right: 1.40 ± 0.40) were comparable to those of Schöning et al.⁵ (1.35) and fell within the age-stratified range reported by Scheel et al.⁴ (1.37 - 1.50). Kovacic et al.⁷ reported higher PI values of 1.5 and 1.6 for the left and right VAs, respectively, potentially due to an older study population.⁷ The PSV in our study was 49.6 ± 13.9 cm/s on the left and 47.4 ± 14.2 cm/s on the right side. These PSV values were consistent with those of Kovacic et al.⁷ ($47.2/46.7$ cm/s in women and $44.9/42.3$ cm/s in men) and Scheel et al.⁴ (45 - 52 cm/s across age groups)⁷, but exceeded the values reported by Nemati et al.⁶ (37 - 42 cm/s) and Tarnoki et al.³ (40 - 44 cm/s) (Table 6)^{3,6}. An age-related decline in PSV, as reported by Yazıcı et al.⁸ (from 53 to 48 cm/s), aligns with our correlation analysis ($\rho = -0.20$ to -0.30 , $p < 0.05$).

In our study, the EDV was recorded at 16.4 ± 6.0 cm/s for the left VA and 14.5 ± 6.3 cm/s for the right VA. These results align with those reported by Schöning et al.⁵ (16 cm/s bilaterally), Tarnoki et al.³ (16.5 cm/s for the left and 15.5 cm/s for the right), Scheel et al.⁴ (12 - 17 cm/s), and Yazıcı et al.⁸ (15 - 18 cm/s across various age groups). Conversely, Kovacic et al.⁷ documented lower EDV values, which corresponded with the older population demographic in their study, differing from both our findings and those in the existing literature.⁷ A consistent left-sided predominance has been reported (Table 6). In our study, the VA diameter exhibited a marked left-sided predominance (left 3.73 ± 0.57 mm, right 3.52 ± 0.61 mm), consistent with literature data. Yılmaz et al.² reported left VA dominance (3.7 vs. 3.4 mm) in a Turkish study population, while Kovacic et al.⁷ noted wider left VA diameters in both sexes.⁷ Yazıcı et al.⁸ found no significant side-to-side difference in VA diameter (3.6 ± 0.4 mm in men and 3.5 ± 0.4 mm in women). The right VA

diameter in our study was similar to that reported by Yazıcı et al.,⁸ at 3.52 mm. The left-side predominance observed in our study likely reflects the larger sample size, providing sufficient power to detect this difference compared to that in Yazıcı et al.⁸ The bilateral average VA diameter was 3.16 - 3.23 mm in the twin study by Tarnoki et al.³ which was smaller than that in our study. The authors reported moderate heritability for variation in VA diameter. Our VA diameters were also slightly larger than those reported by Nemati et al.⁶ (3.25 - 3.42 mm, Iranian study population, Table 6).⁶ These results may indicate genetic and anthropometric differences between populations. Scheel et al.⁴ and Yazıcı et al.⁸ reported age-related VA dilation. We observed a positive correlation between age and left VA diameter ($\rho = 0.19$, $p = 0.006$), but not between age and right VA diameter ($\rho = 0.04$, $p = 0.57$). This asymmetry may reflect the left VAs larger baseline diameter and greater hemodynamic load, leading to more pronounced age-related remodeling. Alternatively, it may be a chance finding, given the modest correlation coefficient. Further studies are required to confirm this side-specific effect. Notably, the absence of this correlation after excluding the center with older participants ($\rho = 0.06$, $p = 0.48$; Supplementary Table S1) supports the possibility of a chance or center-related finding.

In our study, the flow volume (left: 126.8 ± 61.0 mL/min, right: 107.6 ± 51.3 mL/min; total: 234.4 mL/min) was significantly higher than the values reported by Schöning et al.⁵ (approximately 85 mL/min per side; total: 171 mL/min), Scheel et al.⁴ (74 - 87 mL/min per side), and Yazıcı et al.⁸ (approximately 85.8 mL/min per side; total: 171 mL/min). Yılmaz et al.² reported a left VA flow volume of 97.6 mL/min and a right VA flow volume of 78.6 mL/min, which are also lower than our findings (Table 6). Nemati et al.⁶ observed a flow volume of 117 - 130 mL/min per side without significant age-related differences, which aligns with our results, as we also found no significant correlation between flow volume and age on either side.⁶ Yazıcı et al.⁸ compared participants aged 20 - 50 years with those aged 51 - 80 years and identified an age-related decrease in VA flow volume (86 vs. 77 mL/min per side); however, this difference

Table 3. Spearman correlations with age and BMI

Parameter	ρ (Age)	p (Age)	ρ (BMI)	p (BMI)
Left diameter (mm)	0.19	0.006	0.08	0.23
Left RI	-0.15	0.02	-0.18	0.006
Left PI	-0.18	0.006	-0.19	0.005
Left PSV (cm/s)	-0.30	<0.001	-0.30	<0.001
Left EDV (cm/s)	-0.15	0.03	-0.11	0.10
Left FV (mL/min)	-0.05	0.43	-0.02	0.80
Right diameter (mm)	0.04	0.57	0.09	0.18
Right RI	-0.13	0.049	-0.18	0.008
Right PI	-0.18	0.008	-0.14	0.03
Right PSV (cm/s)	-0.20	0.002	-0.24	<0.001
Right EDV (cm/s)	-0.14	0.038	-0.12	0.07
Right FV (mL/min)	-0.04	0.56	-0.04	0.55
Total FV (mL/min)	-0.04	0.57	-0.03	0.67

RI, resistive index; PI, pulsatility index; PSV, peak systolic velocity; EDV, end-diastolic velocity; FV, flow volume; Min, minimum; Max, maximum.

is numerically small. The relative stability of VA flow volume is attributed to the preserved metabolic demand of the brainstem compared with that of the cerebral cortex.

Males exhibited a significantly larger right VA diameter (median 3.70 mm vs. 3.50 mm, $p = 0.004$) and RI and PI indices bilaterally, as shown in Table 2. In contrast, female participants exhibited a higher right VA EDV ($P = 0.037$). No statistically significant differences were observed in the PSV and flow volume between the sexes. Consistent with our findings, Scheel et al.⁴ and Schöning et al.⁵ reported no sex differences in flow volume. Similarly, Yazıcı et al.⁸ found no differences in VA diameter or flow volume between males and females, although they did report higher EDV in females, aligning with our results. Kovacic et al.⁷ identified higher velocities in females up to 60 years of age and suggested a correlation between increased velocity and reduced arterial stiffness in premenopausal women.⁷ Kovacic et al.⁷ found higher PSV and EDV in premenopausal women.

The elevated EDV values in our female participants support Kovacic et al.'s⁷ finding of higher velocities in premenopausal women, possibly reflecting reduced arterial stiffness. However, our study did not consider the menopausal status or hormonal factors of female participants; therefore, this interpretation remains speculative. Future studies should stratify participants by menopausal status to test this hypothesis.

Our study is the first in the literature to include BMI as a possible covariate in VA Doppler evaluation.

Interestingly, while BMI was negatively correlated with PSV, RI, and PI, it was not correlated with flow volume. This suggests that BMI affects vascular resistance and pulsatility without altering overall perfusion, possibly due to compensatory changes in vessel diameter or collateral flow. Another reason for the lack of correlation can be the relatively narrow BMI range in our sample (mean 26.9 ± 4.5 kg/m², with morbid obesity excluded). This finding requires further investigation to confirm its validity.

Table 4. Reference percentiles by sex

Parameter	Sex	n	Mean $\pm$ SD	Median	P5	P95
Left diameter (mm)	Female	139	3.68 ± 0.57	3.60	2.88	4.60
	Male	83	3.80 ± 0.57	3.80	2.90	4.60
Left RI	Female	139	0.67 ± 0.07	0.66	0.55	0.80
	Male	82	0.69 ± 0.09	0.69	0.53	0.81
Left PI	Female	139	1.23 ± 0.32	1.21	0.82	1.89
	Male	83	1.39 ± 0.41	1.36	0.81	2.12
Left PSV (cm/s)	Female	139	49.30 ± 13.54	46.90	33.36	71.03
	Male	83	50.13 ± 14.59	46.10	32.59	75.82
Left EDV (cm/s)	Female	139	16.64 ± 5.56	15.65	9.69	25.58
	Male	83	15.91 ± 6.56	15.50	9.33	24.29
Left FV (mL/min)	Female	139	130.50 ± 62.79	117.00	54.31	230.10
	Male	83	120.59 ± 57.69	109.00	56.99	235.00
Right diameter (mm)	Female	137	3.42 ± 0.56	3.50	2.50	4.23
	Male	83	3.68 ± 0.65	3.70	2.52	4.69
Right RI	Female	138	0.68 ± 0.08	0.69	0.55	0.80
	Male	82	0.71 ± 0.08	0.70	0.60	0.84
Right PI	Female	139	1.33 ± 0.37	1.26	0.85	1.98
	Male	83	1.51 ± 0.43	1.43	1.01	2.14
Right PSV (cm/s)	Female	139	48.17 ± 14.44	45.70	27.44	76.58
	Male	83	46.18 ± 13.72	45.47	27.32	69.12
Right EDV (cm/s)	Female	139	15.21 ± 7.04	14.25	7.57	24.57
	Male	83	13.39 ± 4.63	13.11	5.76	19.90
Right FV (mL/min)	Female	139	109.46 ± 54.04	101.54	32.80	202.10
	Male	83	104.39 ± 46.47	100.30	46.47	178.90
Total FV (mL/min)	Female	139	239.96 ± 89.67	222.10	122.00	407.20
	Male	83	224.98 ± 72.37	215.60	134.96	360.70
Total FV (mL/min)	Overall	222	234.4 ± 83.6	218.2	124.7	391.8

P5 and P95 are non-parametric (empirical) percentiles calculated with linear interpolation; 90% confidence intervals for the overall and sex-specific limits are given in Supplementary Table S2. N is the number of participants with a valid measurement (see Results). RI, resistive index; PI, pulsatility index; PSV, peak systolic velocity; EDV, end-diastolic velocity; FV, flow volume; Min, minimum; Max, maximum.

Table 5. Reference percentiles by age group

Parameter	Age group	n	Mean $\pm$ SD	Median	P5	P95
Left diameter (mm)	18-29	59	3.53 $\pm$ 0.50	3.50	2.78	4.23
	30-39	63	3.84 $\pm$ 0.52	3.90	3.00	4.60
	40-49	53	3.67 $\pm$ 0.63	3.60	2.62	4.55
	50-59	30	3.84 $\pm$ 0.64	3.86	3.00	4.72
	60+	17	3.96 $\pm$ 0.55	3.90	3.20	4.91
Left RI	18-29	59	0.70 $\pm$ 0.07	0.70	0.60	0.80
	30-39	63	0.66 $\pm$ 0.08	0.67	0.54	0.79
	40-49	52	0.65 $\pm$ 0.08	0.64	0.55	0.79
	50-59	30	0.67 $\pm$ 0.08	0.67	0.55	0.81
	60+	17	0.70 $\pm$ 0.08	0.70	0.60	0.82
Left PI	18-29	59	1.44 $\pm$ 0.34	1.37	1.00	2.07
	30-39	63	1.27 $\pm$ 0.35	1.27	0.83	1.84
	40-49	53	1.13 $\pm$ 0.33	1.06	0.80	1.76
	50-59	30	1.25 $\pm$ 0.35	1.18	0.81	1.88
	60+	17	1.43 $\pm$ 0.31	1.41	0.94	1.87
Left PSV (cm/s)	18-29	59	55.70 $\pm$ 16.12	52.30	37.73	90.88
	30-39	63	49.10 $\pm$ 10.96	46.80	35.43	66.79
	40-49	53	46.91 $\pm$ 13.01	43.00	32.58	71.65
	50-59	30	45.84 $\pm$ 11.18	42.77	32.85	67.78
	60+	17	45.47 $\pm$ 16.82	44.76	26.29	81.89
Left EDV (cm/s)	18-29	59	16.20 $\pm$ 4.69	15.80	10.66	22.94
	30-39	63	17.54 $\pm$ 7.36	16.40	10.13	25.47
	40-49	53	16.40 $\pm$ 5.01	15.65	9.22	24.73
	50-59	30	15.21 $\pm$ 5.15	14.80	8.82	25.51
	60+	17	14.54 $\pm$ 7.65	12.08	9.65	25.16
Left FV (mL/min)	18-29	59	129.29 $\pm$ 69.65	109.00	54.58	245.40
	30-39	63	125.22 $\pm$ 55.99	113.00	54.93	216.20
	40-49	53	129.14 $\pm$ 53.89	122.00	69.32	228.60
	50-59	30	126.96 $\pm$ 67.86	113.00	53.74	236.65
	60+	17	116.36 $\pm$ 60.86	103.50	60.60	220.60
Right diameter (mm)	18-29	59	3.53 $\pm$ 0.50	3.50	2.59	4.31
	30-39	62	3.50 $\pm$ 0.69	3.60	2.31	4.57
	40-49	53	3.46 $\pm$ 0.64	3.50	2.44	4.59
	50-59	30	3.49 $\pm$ 0.56	3.59	2.54	4.17
	60+	16	3.82 $\pm$ 0.62	3.88	2.95	4.62
Right RI	18-29	59	0.70 $\pm$ 0.06	0.71	0.61	0.80
	30-39	63	0.71 $\pm$ 0.10	0.72	0.56	0.82
	40-49	52	0.68 $\pm$ 0.08	0.67	0.55	0.82
	50-59	29	0.68 $\pm$ 0.08	0.67	0.57	0.81
	60+	17	0.69 $\pm$ 0.07	0.70	0.56	0.77
Right PI	18-29	59	1.44 $\pm$ 0.31	1.40	1.01	2.12
	30-39	63	1.47 $\pm$ 0.47	1.37	0.90	2.04
	40-49	53	1.35 $\pm$ 0.43	1.21	0.85	2.15
	50-59	30	1.26 $\pm$ 0.33	1.21	0.86	1.87
	60+	17	1.38 $\pm$ 0.36	1.28	1.01	1.88

Table 5. Continued

Parameter	Age group	n	Mean $\pm$ SD	Median	P5	P95
Right PSV (cm/s)	18-29	59	51.05 $\pm$ 13.66	48.22	35.33	80.17
	30-39	63	49.06 $\pm$ 15.61	45.70	27.31	80.78
	40-49	53	44.85 $\pm$ 13.47	44.76	24.53	69.43
	50-59	30	42.66 $\pm$ 13.06	38.60	26.94	67.05
	60+	17	45.21 $\pm$ 11.36	41.92	32.69	65.63
Right EDV (cm/s)	18-29	59	15.99 $\pm$ 8.47	14.25	9.74	21.84
	30-39	63	14.17 $\pm$ 5.60	13.50	5.70	22.71
	40-49	53	14.35 $\pm$ 5.39	13.90	6.32	24.39
	50-59	30	13.74 $\pm$ 5.33	12.60	6.45	21.23
	60+	17	12.78 $\pm$ 2.71	12.08	9.31	16.75
Right FV (mL/min)	18-29	59	109.99 $\pm$ 44.11	107.00	46.11	185.40
	30-39	63	103.03 $\pm$ 47.10	98.43	32.88	187.81
	40-49	53	108.29 $\pm$ 55.38	102.00	30.28	215.00
	50-59	30	109.82 $\pm$ 57.72	98.30	42.10	212.45
	60+	17	109.70 $\pm$ 67.55	88.00	43.40	208.20
Total FV (mL/min)	18-29	59	239.29 $\pm$ 93.48	218.44	120.85	399.10
	30-39	63	228.26 $\pm$ 73.67	227.00	133.68	355.40
	40-49	53	237.43 $\pm$ 76.87	219.00	139.32	395.40
	50-59	30	236.78 $\pm$ 84.48	224.70	134.28	377.85
	60+	17	226.05 $\pm$ 108.24	207.67	111.10	404.80

Percentile estimates for the 50-59 (n=29-30) and ≥ 60 (n=16-17) age groups are based on small samples and are imprecise, particularly at the 5th and 95th percentiles (with n < 20, P5 and P95 approximate the sample minimum and maximum); they should be interpreted with caution.

RI, resistive index; PI, pulsatility index; PSV, peak systolic velocity; EDV, end-diastolic velocity; FV, flow volume.

An important finding of our study is 5th percentile overall and sex-specific flow volume (124.7 mL/min overall, 134.96 mL/min males, 122.0 mL/min females). An arbitrary threshold value of 200 mL/min has been proposed for VA volume in evaluating vertebrobasilar insufficiency.⁹ However 5th- 95th percentiles of VA flow volume in healthy individuals were reported as 102.4-301.0 mL/min in the study by Seidel et al.¹⁰ This study questions the utility of the 200 mL/min threshold for the diagnosis of vertebrobasilar insufficiency. The lower bound for normal VA flow volume in our study is higher than that reported by Seidel et al.¹⁰ This difference is most likely due to our younger cohort compared to Seidel et al.¹⁰ (mean age 39.4 versus 55.8). In a study by Lee et al.,¹¹ the association between VA flow volume and stroke risk was investigated. Almost all the patients (93.6%) in the control group (n=235) had a VA flow volume larger than 100 mL/min. The mean age for the control group was 63.5, which was significantly older than that in our study. This difference can be explained by an age-related decline in VA flow volume. Studies, including ours, that aim to determine the lower limit of normal for VA flow volume have clearly shown values below 200 mL/min, the proposed threshold used to diagnose vertebrobasilar insufficiency. Although there are differences, literature data indicate that the 5th percentile value for VA flow is between 100-125 mL/min.⁹⁻¹¹

Study Limitations

This study has several limitations. First, one center enrolled an older subgroup (mean age, 42.8 vs. 38.0-38.3 years), which may have introduced heterogeneity. A sensitivity analysis excluding this center confirmed the main findings; however, the weaker associations (the sex difference in RI and the correlation between age and left VA diameter) were no longer significant. Second, we excluded individuals with BMI >40 kg/m², limiting the generalizability of our BMI findings across the full obesity spectrum. Third, we did not validate our Doppler measurements against an independent imaging modality (e.g., CTA or MRA); therefore, the measurement accuracy relative to the true vessel dimensions is unknown. Fourth, inter-rater and intra-rater reliability were not formally assessed, although all examiners were experienced and followed a standardized protocol. Fifth, the cross-sectional design precludes causal inference about the effects of age or BMI on VA hemodynamics; longitudinal studies are needed to confirm these associations. Sixth, heart rate and blood pressure were not recorded at the time of the examination. Because heart rate strongly influences RI and PI, differences in heart rate may have contributed to the observed sex- and age-related differences in these indices. Seventh, some age strata were small (n=16-17 in the ≥ 60 group and

Table 6. Comparison of vertebral artery reference values across published studies

Study	Population	Diameter L/R (mm)	RI L/R	PI L/R	PSV L/R (cm/s)	EDV L/R (cm/s)	Flow volume L/R (mL/min)
Present study	Turkish, n=223 healthy, 3 centers pooled, mean age 39.4y	3.73 / 3.52	0.67 / 0.69	1.29 / 1.40	49.6 / 47.4	16.4 / 14.5	126.8 / 107.6 (total 234.4)
Schöning et al. ⁵ 1994	German, n=48 healthy, mean age 35y	NR / NR	0.66 / 0.66	1.35 / 1.35	48 / 48	16 / 16	85 / 85 (total 171)
Scheel et al. ⁴ 2000	German, n=78 healthy, age 20–85y, 3 age groups	3.3–3.6 / 3.3–3.6	0.68–0.72 / 0.68–0.72	1.37–1.50 / 1.37–1.50	45–52 / 45–52	12–17 / 12–17	74–87 / 74–87
Nemati et al. ⁶ 2009	Iranian, n=96 healthy, age 23–95y	3.25–3.42 / 3.25–3.42	0.69–0.71 / 0.69–0.71	NR	37–42 / 37–42	NR	117–119 / 101–130
Yılmaz et al. ² 2021	Turkish, n=77, mean age 53.6y	3.7 / 3.4	0.63 / 0.63	NR	24.2 / 24.3	8.9 / 8.9	97.6 / 78.6
Tarnoki et al. ³ 2017	Italian twins, n=172, mean age 50y	3.23 / 3.16	NR	NR	44.0 / 40.9	16.5 / 15.5	NR
Kovacic et al. ⁷ 2022	Croatian, n=227 healthy, age 30–86y	3.6 / 3.4 (F); 3.9 / 3.6 (M)	0.7 / 0.8	1.5 / 1.6	47.2 / 46.7 (F); 44.9 / 42.3 (M)	12.0 / 11.5 (F); 10.9 / 10.4 (M)	NR
Yazıcı et al. ⁸ 2005	Turkish, n=96 healthy, age 20–80y, 2 age groups	3.5–3.6/3.5–3.6	0.65–0.68/0.65–0.68	NR	48–53 / 48–53	15–18 / 15–18	85.8 / 85.8 (total 171.6)

L/R, left / right; NR, not reported; RI, resistive index; PI, pulsatility index; PSV, peak systolic velocity; EDV, end-diastolic velocity; Min, minimum.

n=29–30 in the 50–59 group), so the 5th and 95th percentile estimates for these groups are imprecise and should be applied with caution until confirmed in larger samples. Our findings are specific to a Turkish population and may not generalize to other ethnic or geographic groups.

CONCLUSION

Our reference values for VA Doppler measurements broadly align with existing literature for diameter, PI, RI, and EDV. However, our values for PSV and flow volume are at the higher end of the published range, likely due to the younger mean age and the community-based, healthy-volunteer study design. Compared to prior Turkish studies (e.g., Yazıcı et al.,⁸ n=96), our multicenter sample of 223 participants provides greater statistical power to detect sex and side differences and enables the derivation of age- and sex-stratified percentile norms, which were not available in earlier single-center datasets. This study provides population-specific normative reference values for six VA Doppler parameters in 223 healthy Turkish adults, stratified by sex and age—the first such dataset to incorporate BMI as a covariate and to derive percentile-based norms from a multicenter Turkish cohort. Notably, the lower limit of normal for total VA flow volume (124.7 mL/min) is well below the commonly cited 200 mL/min threshold, which should therefore not be used on its own to diagnose vertebrobasilar insufficiency.

Ethics

Ethics Committee Approval: Ethics committee approval was obtained from Tekirdağ İsmail Fehmi Cumalıoğlu City Hospital Clinical Research Ethics Committee (approval no.: AN-262105-45, date: 21.05.2026).

Informed Consent: Written informed consent was obtained from the participants.

Footnotes

Author Contributions

Concept Design – A.T.A., Data Collection or Processing – A.T.A., M.F.B., S.A.A., Analysis or Interpretation – A.T.A., Literature Review – M.F.B., S.A.A., Writing, Reviewing and Editing – A.T.A.

Declaration of Interests: The authors declare no conflict of interest.

Funding: The authors declare no financial support or funding.

Supplementary Tables Link: <https://d2v96fxpocvxx.cloudfront.net/b37683d5-c547-4565-8c20-fa38c0b1ec76/content-images/14d94f50-bec8-4373-8911-61df99f61ec7.pdf>

REFERENCES

1. Maitas O, Bob-Manuel T, Price J, et al. Vertebral artery interventions: a comprehensive updated review. *Curr Cardiol Rev.* 2023;19(1):e170322202296. [\[CrossRef\]](#)
2. Yılmaz BK, Ergün E, Koşar PN, Şimşek Karataş B, Turgut AT. Color Doppler ultrasonography findings of vertebral arteries: a correlation with 64-slice CTA. *J Surg Med.* 2021;5(7):705-709. [\[CrossRef\]](#)
3. Tarnoki AD, Fejer B, Tarnoki DL, et al. Vertebral artery diameter and flow: nature or nurture. *J Neuroimaging.* 2017;27(5):499-504. [\[CrossRef\]](#)
4. Scheel P, Ruge C, Schöning M. Flow velocity and flow volume measurements in the extracranial carotid and vertebral arteries in healthy adults: reference data and the effects of age. *Ultrasound Med Biol.* 2000;26(8):1261-1266. [\[CrossRef\]](#)
5. Schöning M, Walter J, Scheel P. Estimation of cerebral blood flow through color duplex sonography of the carotid and vertebral arteries in healthy adults. *Stroke.* 1994;25(1):17-22. [\[CrossRef\]](#)
6. Nemati M, Babil AS, Taheri N. Comparison of normal values of Duplex indices of vertebral arteries in young and elderly adults. *Cardiovasc Ultrasound.* 2009;7:2. [\[CrossRef\]](#)
7. Kovacic S, Sovic S, Hucika Z, Vrhovnik L, Samec I, Abicic A. Doppler flow velocity measurements in the extracranial internal carotid and vertebral arteries in healthy adults. *Am J Biomed Sci Res.* 2022;17(2):117-125. [\[CrossRef\]](#)
8. Yazıcı B, Erdoğan B, Tugay A. Cerebral blood flow measurements of the extracranial carotid and vertebral arteries with Doppler ultrasonography in healthy adults. *Diagn Interv Radiol.* 2005;11(4):195-198. [\[CrossRef\]](#)
9. Bendick PJ, Glover JL. Vertebrobasilar insufficiency: evaluation by quantitative duplex flow measurements. A preliminary report. *J Vasc Surg.* 1987;5(4):594-600. [\[CrossRef\]](#)
10. Seidel E, Eicke BM, Tettenborn B, Krummenauer F. Reference values for vertebral artery flow volume by duplex sonography in young and elderly adults. *Stroke.* 1999;30(12):2692-2696. [\[CrossRef\]](#)
11. Lee HH, Huang LK, Chang HJ, et al. Association between net vertebral artery flow volume and non-AF stroke: a retrospective 2-year analysis. *Front Neurol.* 2019;9:1198. [\[CrossRef\]](#)
12. Clinical and laboratory standards institute. Defining, establishing, and verifying reference intervals in the clinical laboratory; approved guideline-third edition. CLSI document EP28-A3c. Wayne, PA: Clinical and Laboratory Standards Institute; 2008. [\[CrossRef\]](#)