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ORIGINAL ARTICLES

Anatomical Variations of the Vertebral Arteries, and their Impact on Cerebral Circulation

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ABSTRACT

Background: The vertebral arteries are integral to the vertebrobasilar system, contributing approximately 20% of cerebral blood flow and ensuring perfusion of the posterior brain and spinal cord. Anatomical variations such as hypoplasia and dolichoectasia may compromise posterior circulation hemodynamics and influence cerebrovascular risk.
Objective: To investigate the prevalence, diameter, and gender distribution of vertebral artery variations and assess their potential clinical implications for posterior cerebral circulation.
Materials and Methods: A retrospective observational study was conducted on 60 patients (25 females, 41.7%; 35 males, 58.3%; mean age 45.0 ± 12.0 years). Radiological evaluation included Magnetic Resonance Angiography, Doppler ultrasonography, and Computed Tomography. Vertebral artery morphology was classified as normal, hypoplastic, or dolichoectatic.
Results: Hypoplasia was the most frequent variation. In females, hypoplasia was observed in 28.0% of left and 40.0% of right vertebral arteries. In males, it was present in 20.0% of left and 22.9% of right arteries. Dolichoectasia was more prevalent in males. These findings highlight gender-related differences and underscore the importance of vascular imaging in patients with posterior circulation symptoms.
Conclusion: Vertebral artery variations are relatively common and clinically significant. Recognition of these variations is essential for accurate diagnosis, risk stratification, and management of cerebrovascular disorders involving posterior circulation.
Keywords: Vertebral artery; anatomical variations; hypoplasia; dolichoectasia; posterior cerebral circulation

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INTRODUCTION

Anatomical variations of the vertebrobasilar system are relatively common, and many of them are considered benign. Numerous studies have reported unilateral hypoplasia of the vertebral arteries, variations in the posterior and anterior inferior cerebellar arteries, as well as differences in the origin and branching patterns of the vertebral and basilar arteries.

These variations are believed to arise due to developmental errors during embryogenesis (1,2). Hemodynamic assessment of the vertebrobasilar system (VBS) plays an important role in identifying factors that influence cerebral circulation abnormalities and anatomical–physiological deviations. Such evaluations may help predict potential sites of pathological changes, enable early detection of cerebrovascular disease, and contribute to the assessment of treatment options and therapeutic efficacy (3,4).

Clinically, the vertebral arteries are divided into four segments (V1–V4), each with a distinct anatomical course from their origin in the subclavian artery to their formation of the basilar artery at the vertebrobasilar junction (5). Variations in this system are mainly related to vessel origin, diameter asymmetry, and branching patterns (6,7).

The most frequently reported anatomical variations include vertebral artery asymmetry, hypoplasia, fenestration of the basilar artery, aplasia of a vertebral artery, trifurcation of the basilar artery, and agenesis of the posterior cerebral arteries (8–10). These anomalies may have significant clinical implications, including an increased risk of ischemia, posterior circulation infarctions, aneurysm formation, and other cerebrovascular disorders (11,12).

Vertebrobasilar insufficiency (VBI) represents a clinically important condition characterized by reduced blood flow to the posterior part of the brain. It may result from atherosclerotic changes, vascular occlusion, or embolic events, and can lead to transient or permanent neurological deficits (13,14).

The basilar artery, as a key vessel supplying the brainstem and posterior cerebral hemispheres, plays a crucial role in maintaining adequate cerebral perfusion through its contribution to the Circle of Willis (CW) (15,16).

Given the potential clinical significance of these anatomical variations, their early identification is essential for understanding cerebrovascular risk and improving diagnostic and therapeutic strategies.

Purpose of the work:

The purpose of this study is to evaluate the frequency and diameter of anatomical variations of the vertebral arteries (left and right vertebral artery), analyze their distribution according to gender, and assess their potential clinical significance in posterior cerebral circulation and vertebrobasilar hemodynamics.

MATERIALS AND METHODS

This study was designed as a retrospective observational analysis. A total of 60 patients were included, comprising 25 females (41.67%) and 35 males (58.33%), with a mean age of 45.0 ± 12.0 years. The patients were examined over a one-year period in the Departments of Neurosurgery and Traumatology at Klinička Bolnica Tetovo.

Clinical indications for imaging included head trauma, dizziness, cervical complaints, neck trauma, and other neurological symptoms. Radiological evaluation was performed using Magnetic Resonance Angiography (MRA), color Doppler ultrasonography, and Computed Tomography (CT). The diameters of the left and right vertebral arteries were systematically analyzed.

Vertebral artery hypoplasia was defined as a vessel diameter of less than 2.0 mm, while dolichoectasia was defined as a diameter greater than 3.7–4.0 mm, in accordance with previously established criteria in the literature (15,16).

Due to the absence of a healthy control group, the obtained results were interpreted and compared with data reported in the international literature.

Statistical processing of the material examined

Statistical analysis was performed using descriptive statistical methods. Categorical variables were presented as absolute numbers (n) and percentages (%), while continuous variables were expressed as arithmetic mean (mean) and standard deviation (SD). Due to the absence of a control group, comparisons with international studies were carried out using a descriptive approach.

RESULTS

In the female group (n = 25), the left vertebral artery showed normal morphology in 17 cases (68.0%), hypoplasia in 7 cases (28.0%), and dolichoectasia in 1 case (4.0%). The right vertebral artery demonstrated normal morphology in 14 cases (56.0%), hypoplasia in 10 cases (40.0%), and dolichoectasia in 1 case (4.0%).

In the male group (n = 35), the left vertebral artery was normal in 25 cases (71.4%), while hypoplasia and dolichoectasia were observed in 7 (20.0%) and 3 (8.6%) cases, respectively.

The right vertebral artery showed normal morphology in 23 cases (65.7%), hypoplasia in 8 cases (22.9%), and dolichoectasia in 4 cases (11.4%).

Overall, hypoplasia was the most frequent anatomical variation, with a higher prevalence observed in females, particularly affecting the right vertebral artery.

Table 1. Left and right vertebral artery distribution, female **Female (n = 25)**

Vertebral artery	Normal morphology	hypoplasia	dolichoectasia
Left	17 (68.0%)	7 (28.0%)	1 (4.0%)
Right	14 (56.0%)	10 (40.0%)	1 (4.0%)

Table 2. Left and right vertebral artery distribution, male **Male (n=35)**

Vertebral artery	Normal morphology	hypoplasia	dolichoectasia
Left	25 (71.4%)	7 (20.0%)	3 (8.6%)
Right	23 (65.7%)	8 (22.9%)	4 (11.4%)

DISCUSSION

In our study, the prevalence of vertebral artery hypoplasia was notably higher compared to most international reports. *Valenzuela-Fuenzalida et al.* (2024) (15) reported an average prevalence of approximately 11% in the general population. Similarly, *Park et al*. (2007) (16) demonstrated that vertebral artery hypoplasia is associated with ischemic stroke territory involvement and is more frequently observed in patients with posterior circulation ischemia

In our material, hypoplasia was identified in 28.0% of females on the left side and 40.0% on the right side, while in males it was present in 20.0% on the left side and 22.9% on the right side. These values are considerably higher than those reported in the international literature.

This discrepancy may be explained by the fact that our study population consisted of symptomatic patients rather than a healthy general population. *Katsanos et al*. (2017) (17) also demonstrated that vertebral artery hypoplasia is significantly more common in patients with posterior circulation ischemia compared to those with anterior circulation ischemia, supporting the clinical relevance of our findings.

The findings of this study suggest that anatomical variations of the vertebral arteries (VA) are relatively common in the examined group of patients. Among these variations, hypoplasia was the most frequent, especially in females, with the highest rate observed in the right vertebral artery (40.0%).

This result aligns with the work of *Park et al*. (2007), (16) who highlighted the relationship between vertebral artery hypoplasia and changes in posterior cerebral circulation.

Bruneau et al. (2006) (18) also pointed out that understanding these vascular variations is important in clinical practice, particularly during surgical procedures in the cervical region, where unexpected anatomical differences may increase procedural risk.

The higher frequency (f) of hypoplasia in our study compared to the meta-analysis by *Valenzuela-Fuenzalida et al.* (2024) (15) may be explained by the fact that our study included symptomatic patients, who are more likely to present vascular abnormalities.

Dolichoectasia was more commonly observed in males. Although the number of cases was limited, this finding is still clinically important, as vessel dilation can influence blood flow within the vertebrobasilar system.

One limitation of this study is the lack of a healthy control group. However, comparison with previously published international studies provides useful context and helps support the interpretation of the results.

CONCLUSION:

Anatomical variations of the vertebral arteries were relatively common in the examined population. Hypoplasia was the most frequent variation, particularly among females, whereas dolichoectasia was observed more often in males.

The prevalence of hypoplasia in our study was higher than that reported in the international literature, which is likely related to the symptomatic nature of the study sample. These morphological changes may have important clinical implications for the hemodynamics of posterior cerebral circulation and should be taken into account during radiological and neurological evaluation of symptomatic patients.

Editorial Statements

Ethics Approval and Consent to Participate

This study involved the analysis of data from human participants. The research protocol was reviewed and approved by the Institutional Ethics Committee and was conducted in accordance with institutional regulations, the principles of the Declaration of Helsinki, and internationally accepted standards for biomedical research ethics.

Data Availability Statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author Contributions (CRediT): Conceptualization & Methodology: GZ, SB; Data Curation, Investigation and Writing – Original Draft: TK: Formal Analysis: SB, ZB: Writing – Review & Editing: KC, SB: Supervision: GZ. All authors have read and approved the final version of the manuscript.

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The authors used a generative artificial intelligence tool solely for language editing and grammar improvement. All scientific content, data analysis, interpretation, and conclusions were independently developed, verified, and approved by the authors.

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