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Original Research

The Association of Vertebrobasilar System Morphology and Geometry with the Posterior and Anterior Ischemic Stroke

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ABSTRACT

Objective: Morphometric and geometric variations in the vertebrobasilar system (VBS) may influence cerebral hemodynamics, potentially contributing to ischemic strokes in both anterior and posterior circulatory territories. This study aimed to investigate the association between VBS morphology and ischemic stroke localization.

Methods*:* This retrospective observational study analyzed multidetector computed tomography angiography images from 431 patients (187 females, 244 males, mean age: 65.3 ± 14.6 years). Patients were categorized into three groups: anterior circulation ischemic stroke (ACIS, n=184), posterior circulation ischemic stroke (PCIS, n=88), and control subjects (n=159). Morphometric parameters were assessed using 3D Slicer software.

Results: Significant differences in basilar artery (BA) length were observed between stroke groups and controls, with ACIS and PCIS groups exhibiting longer BA lengths ($p<0.05$). Males had significantly longer vertebral artery (VA) lengths than females in the control and ACIS groups (p value < 0.05). The vertebrobasilar junction angle was significantly wider in females than in males (p value $= 0.046$). BA bending was predominantly directed to the right across all groups, with no significant differences between the stroke and control groups. VA dominance was more frequent on the left in ACIS and the right in PCIS, while VA hypoplasia was less common in stroke patients compared to controls, contrary to previous reports.

Conclusion*:* While certain morphometric and geometric variations in the VBS were observed, the evidence for a direct association between these characteristics and the localization of ischemic stroke was limited and inconclusive. These findings suggest that vertebrobasilar morphology may not independently determine stroke localization.

Keywords: vertebrobasilar system, hypoplasia, posterior circulation stroke, anterior circulation stroke, computed tomography angiography

INTRODUCTION

The vertebrobasilar system (VBS) is crucial for delivering blood to the temporal and occipital lobes, cerebellum, brainstem, and posterior thalamus [1-3]. This system, consisting of the intracranial segments of the vertebral arteries (VAs), the basilar artery (BA), and their branches, is responsible for providing approximately 20% of the intracranial blood flow and is often referred to as the posterior circulation [3]. The anterior circulation, on the other hand, defines the cerebral areas supplied by the branches of the internal carotid arteries bilaterally and provides blood for most of the brain. Rather than being entirely separate arterial systems, the anterior and posterior circulations are interconnected at the Circle of Willis, which is located at the base of the brain and ensures optimal blood flow for the brain [4]. Therefore, hemodynamic changes in VBS might affect the blood flow in this cerebral arterial circle and may cause pathological findings, not only in the anterior but also in the posterior circulatory territories [5].

The geometric features of the VBS, such as vertebrobasilar junction (VBJ) and basilar bifurcation (BB) angles, have been reported to show a wide range of variations in adults, and these variations may yield a strong influence on VBS blood flow [6-8]. It has also been suggested that the presence of an asymmetric intracranial VA and other anatomical variations, such as hypoplasia and atresia of the VA, would affect the hemodynamics of the VBS [7,9-11]. An uneven, asymmetrical VA blood flow may lead to critical mechanical force around the VBJ and in the BA, which subsequently causes curving of the artery toward the contralateral side of the dominant VA [10,12-14].

Many anatomical parameters, including morphometric measurements of the BA and intracranial segments of the VAs, have been performed by previous authors in healthy subjects [5,15]. Recent studies have shown that the diameter, length, curvature, and angularity of the various components of the VBS might have an impact on the factors that cause vertebrobasilar insufficiency [1,11,14]. The geometric and morphometric variabilities in this system may also influence the occurrence of atherosclerosis, stenosis, and aneurysm, which may have significant roles in the development of stroke in the posterior or anterior circulatory territory [5,7,9,13,16]. Understanding the morphological characteristics of the VBS and their possible association with the posterior and/or anterior ischemic stroke would contribute considerably to the putative morphological basis of the ischemic stroke [17]. Therefore, this study aims to investigate the morphometric and geometric features of the vertebrobasilar system and to shed further light on its possible link with ischemic stroke in the anterior and posterior circulation.

Main Points

- Basilar artery length (BAL) was significantly longer in both anterior and posterior circulation ischemic stroke groups compared to controls, suggesting a possible link between elongated BA and stroke risk.
- No significant differences were observed in vertebrobasilar junction (VBJ) and basilar artery bifurcation (BAB) angles between stroke patients and controls, indicating other factors may be more influential in stroke development.
- Vertebral artery hypoplasia (VAH) was less common in stroke patients than in the control group, challenging previous assumptions about its role in ischemic stroke risk.
- Basilar artery bending showed sex-related differences but was not significantly associated with vertebral artery dominance (VAD) or stroke laterality, suggesting limited predictive value for stroke occurrence.

MATERIALS AND METHODS

Study Population

This study was an observational retrospective study performed on the multidetector computed tomography angiography (MDCTA) images of VBS structures. Images analyzed were obtained from the 431 patients (187 (43%) female and 244 (57%) male) who were admitted to the Istinye University Gaziosmanpaşa Hospital Radiology Department between January 2018 and December 2023. The average age of patients was 65.3±14.6 years (mean ± SD, range: 20–96). Informed consent of all participants was obtained prior to the study. The protocols used in the study were conducted by the Declaration of Helsinki and were approved by the Istinye University Clinical Research Ethics Committee under registration number 3/2022.K-59, Date: 2022/07/01.

Images were obtained from the Picture Archiving and Communication System (PACS) software, and only the MDCTA images with high image quality and clear visibility of the VBS arteries were included. A specialized interventional radiologist (SA) examined and chose the images that were included in the study. A total of 519 3D reconstructed images were examined, and 88 of these images were excluded from the study. Exclusion criteria were as follows: the presence of vasculitis, dissection and/or cardio-embolism in VA or BA, anatomic anomalies including vertebrobasilar dolichoectasia, previous surgery or occlusion of the carotid artery, and intervention in the VBS. MDCTA images with invisible VA or BA and/or low-quality image analyses were also excluded from the study.

A total of 431 MDCTA images were then allocated into three groups: (a) anterior circulation ischemic stroke (ACIS) group (n = 184), (b) posterior circulation ischemic stroke (PCIS) group (n = 88) and (c) control group (n = 159). ACIS and PCIS groups were determined depending on the location of the stroke. In contrast, control group subjects involved patients with no history of stroke and/or any other discernible neurological disease.

MDCTA Imaging Protocol and Reconstruction

The images examined were obtained by a 128-slice multidetector CT scanner (Somatom Definition AS, Siemens, Erlanger, Germany) with the scanning protocol as follows: 120 kVp, 35 mAs, beam collimation 128 × 0.6 mm, gantry rotation time 0.33 s, section thickness of 0.6 mm, and reconstruction interval of 0.6 mm. During the procedure, 70 mL of non-ionic iodinated contrast, followed by 40 mL saline, were injected via a double power injector (Medex Flowers, Geubert USA) into the patient's antecubital vein (4 mL/s).

3D Slicer (version 4.10.2) software program (https://www.slicer.org/) was used to analyze the VBS in the MDCTA images—all images, which were in DICOM format and uploaded to the 3D Slicer program. On DICOM images, 3D multi-planar reconstruction and volume rendering were conducted. Variations in the VBS were then examined, radiographic measurements were performed, and hypoplasia and side dominance of the vertebral artery were determined.

Radiographic Measurements

Apart from the morphometric and geometric parameters measured and given in Table 1, VA dominance (VAD) and VA hypoplasia (VAH) were also estimated in the MDCTA images. There is no well-established consensus on a standard definition of VAD and VAH. In the present study, the VA was considered dominant if the difference in side-to-side diameter between the two VA was greater than 0.3 mm, as suggested in the literature [9, 10, 12–14]. This threshold has been used in prior imaging-based and hemodynamic studies and is considered sufficient to indicate a clinically and functionally relevant asymmetry in VA flow contribution. Similarly, a VA diameter of ≤2 mm was accepted as hypoplastic, in line with earlier studies [2,11,17], as this value is associated with reduced perfusion capacity and has been linked to posterior circulation stroke risk.

Table 1. Morphometric and geometric parameters measured on MDCTA images

Parameter	Description	Figure	References
Diameter of VA	The average value obtained from measurements taken at three places in a row on right & left VA (*3 mm distal to the foramen magnum, midpoint, 3 mm proximal to the VBJ*)	Figs. 1a & 1b	**[10, 17]**
Diameter of BA	The average value obtained from measurements taken at three places in a row on BA *(at the point of the confluence of bilateral VA, midpoint, proximal to point of bifurcation)*	Figs. 1c & 1d	**[3, 9]**
Length of VA	Actual length of right and left VA measured by tracing the course of the vessel from foramen magnum to VBJ	Figure 2a	**[17]**
Length of BA	Actual length of BA (BAL) measured by tracing the course of the vessel from the point of origin at the VBJ to the point of the BA bifurcation	Figure 2a	**[9, 12, 19]**
VBJ angle	The angle between the inner walls of both vertebral arteries at the VBJ	Figure 2b	**[7, 17]**
BA bifurcation (BAB) angle	The angle between the apex of the basilar artery and the left P1 segment and right P1 segment of the posterior cerebral artery	Figure 2b	**[5, 24]**
BA bending side	line was drawn between the top of the BA bifurcation and VBJ for reference and the bending side of the BA determined by identifying which side ≥60% of the BA deviated from the midline (a threshold based on prior morphometric and hemodynamic studies) (toward the left side, right side or straight)	Figure 3	**[9, 15, 16, 23]**
Basilar artery bending length (BABL)	The length from the centre of maximum BA bending at the most lateral point of BA to a line passing through the bifurcation of BA and VBJ (known as BA standard line)	Figure 3	**[12, 15, 19]**

Following the measurements of morphometric and geometric parameters and estimation of VA dominance (VAD) and VA hypoplasia (VAH) in the MDCTA images, the relationship between the dominant side of the VA and the bending side of the BA in patients with ischemic stroke was also assessed to understand whether VA dominance can cause a morphological or structural adaptation of the vessel that results in BA curvature.

Statistical Analysis

All data analyses were performed using IBM Statistical Package for Social Sciences (SPSS) version 25 (IBM Corp., Armonk, New York, USA), and p-values less than 0.05 were considered statistically significant. Categorical variables were analyzed using the Chi-square test and Fisher's exact test. A Shapiro-Wilk test was used to assess the normal distribution of continuous data. In comparing continuous data with categorical variables, a one-way ANOVA test and student's t-test were used for the data with normal distribution, while the Kruskal Wallis H test and Mann-Whitney U tests were used when the data did not show a normal distribution. Pearson correlation analysis was used to determine the direction and degree of the relationship between the variables. The morphometric measurements related to all these parameters were independently reviewed by two researchers (AA and BA) blinded to clinical data.

RESULTS

Demographic Results

Out of 431 cases included in the study, 244 were males (57%), and 187 were females (43%), and the mean ages of the males and females were 65.5 ± 13.6 and 65 ± 15.8 years (ranging between 20–96 years), respectively. Gender and average age distribution between the individual groups are shown in Table 2.

Results of the Morphometric Measurements

The results of morphometric measurements (VA diameter and length, BA diameter and length, VBJ and BA, bifurcation angles, and basilar artery bending lengths) in all cases, females and males, as the mean ± standard deviation, are presented in Table 3. No significant differences were observed between the groups except for the actual BA lengths ($p < 0.01$) when the results of all cases (females and males) in the groups were compared. When the data was broken into gender, significant differences in BA, right, and left VA lengths were found only in males ($p < 0.01$ for BA, $p < 0.05$ for right and left VA lengths).

Post hoc comparisons for BA length revealed that actual BA length was found to be significantly longer in the ACIS group compared to control groups in males ($p < 0.01$). Besides, actual lengths of the right VA were found to be significantly shorter in the PCIS group compared to both control ($p < 0.01$) and ACIS groups ($p < 0.05$). In contrast, a similar significant difference for left VA lengths was ($p < 0.01$) in males (Table 3).

When the diameters and actual lengths of VA and BA, VBJ and BAB angles, and BABL were compared between the genders, actual VA lengths on both sides were found to be significantly longer in males than in females for the control group (right, p = 0.001; left, p = 0.000) and male patients with ACIS had significantly longer actual length compared to females (32.9 ± 4.9 mm versus 31.4 ± 4.3 mm; p = 0.028). A significant difference in VBJ angle was also observed between females and males in control groups, with VBJ angle being significantly higher in females (88.5 ± 20.5 mm) compared to males (82.1 ± 19.3 mm) (p = 0.046). The mean BABL was also found to be significantly lower in female cases for both ACIS (female, 3.3 ± 3.2 mm vs. male, 4.3 ± 3.5 mm, p = 0.046) and PCIS (female, 2.2 ± 2.9 mm vs. male, 3.5 ± 3.7 mm, p = 0.039), respectively. It was observed that BABL was longer on the left side in all groups ($p < 0.0001$) (Table 3). Post hoc comparisons for BABL revealed that this length was significantly longer in males with right BA bending in the ACIS group compared to the PCIS and control groups ($p < 0.05$ for both comparisons).

Table 2. Gender distribution and average ages of the individual groups

		Control Group	Patient Groups	
			ACIS	PCIS
Gender n (%)	All cases	159 (37%)	184 (43%)	88 (20%)
	Female	81 (51%)	79 (43%)	27 (31%)
	Male	78 (49%)	105 (57%)	61 (69%)
Age Mean ± SD	All cases	60.3 ± 16.7	68.1 ± 12.5	68.2 ± 12.1
	Female	60.5 ± 17.6	69.2 ± 13.4	66.1 ± 13.7
	Male	60.2 ± 15.9	67.3 ± 11.9	69.1 ± 11.3

Table 3. Comparative results of the vertebrobasilar system for patients with ischemic stroke and control group

Variables			Control	Patients		P value
				ACIS	PCIS	
Right VA Diameter (mm)		*All cases*	2.8 ± 0.8	2.9 ± 0.8	3.0 ± 0.8	0.157
		Female	2.7 ± 0.7	2.8 ± 0.7	2.7 ± 0.7	0.787
		Male	2.8 ± 0.8	2.9 ± 0.8	3.1 ± 0.8	0.166
Left VA Diameter (mm)		*All cases*	2.8 ± 0.8	3.0 ± 0.7	3.0 ± 0.7	0.297
		Female	2.9 ± 0.8	3.1 ± 0.7	2.8 ± 0.7	0.192
		Male	2.8 ± 0.8	2.9 ± 0.7	3.1 ± 0.8	0.104
BA Diameter (mm)		*All cases*	3.5 ± 0.6	3.6 ± 0.7	3.4 ± 0.6	0.246
		Female	3.4 ± 0.5	3.5 ± 0.6	3.3 ± 0.6	0.277
		Male	3.5 ± 0.6	3.6 ± 0.7	3.4 ± 0.5	0.589
Right VA Length (mm)		*All cases*	36.4 ± 6.1	36.8 ± 5.8	35.2 ± 5.6	0.099
		Females	34.8 ± 5.8	35.9 ± 5.1	35.5 ± 6.0	0.459
		Male	38.1 ± 6.0	37.6 ± 6.2	35.1 ± 5.4	**0.010**
Left VA Length (mm)		*All cases*	35.9 ± 6.4	36.2 ± 5.4	34.9 ± 5.6	0.180
		Female	34.0 ± 5.7	35.8 ± 4.8	34.8 ± 5.8	0.106
		Male	38.0 ± 6.5	36.5 ± 5.8	34.9 ± 5.5	**0.012**
BA Length (BAL) (mm)		*All cases*	30.8 ± 4.6	32.3 ± 4.7	31.4 ± 4.3	**0.003**
		Female	30.8 ± 4.4	31.4 ± 4.3	30.2 ± 3.6	0.348
		Male	30.9 ± 4.8	32.9 ± 4.9	31.9 ± 4.6	**0.003**
VBJ Angle (°)		*All cases*	85.4 ± 20.1	83.3 ± 21.8	83.9 ± 20.5	0.951
		Female	88.5 ± 20.5	83.3 ± 22.1	87.7 ± 19.6	0.663
		Male	82.1 ± 19.3	83.3 ± 21.7	82.2 ± 20.9	0.910
BAB Angle (°)		*All cases*	122.9 ± 21.9	123.1 ± 25.2	122.4 ± 23.9	0.897
		Female	121.6 ± 22.1	120.8 ± 26.4	128.8 ± 24.4	0.091
		Male	124.2 ± 21.6	124.8 ± 24.3	119.6 ± 23.3	0.460
BABL (mm)	*Right Bending*	*All cases*	4.8 ± 2.6	5.5 ± 2.5	4.9 ± 3.3	0.057
		Female	4.6 ± 2.0	5.0 ± 2.6	4.4 ± 2.7	0.570
		Male	5.1 ± 3.1	5.9 ± 2.4	5.1 ± 3.5	**0.042**
	Left Bending	*All cases*	4.9 ± 2.6	5.9 ± 2.9	5.0 ± 2.8	0.301
		Female	4.4 ± 2.1	5.2 ± 2.5	2.6 ± 1.1	0.235
		Male	5.3 ± 2.9	6.4 ± 3.0	5.2 ± 2.8	0.388

The values are presented as the mean ± standard deviation. P-values < 0.05 are shown in **bold** to indicate statistical significance. *VBJ*, vertebrobasilar junction; *BAB*, basilar artery bifurcation; *VA*, vertebral artery; *BABL*, basilar artery bending length; *BAL*, actual length of basilar artery.

Numbers and percentages of BA bending sides observed in the three study groups are presented in Table 4. The most common bending side for the BA was the right side (50%, 51%, and 49% for control, ACIS, and PCIS groups, respectively). This is followed by midline BA with no discernible bending to the other side, while the left side bending was the least common type in all groups. When the bending side of BA was compared between the study groups, no significant difference was observed between the groups (p = 0.8451).

Numbers and percentages of VA dominancy and hypoplasia observed in the three study groups are also given in Table 4. Symmetrical VAs without any side dominancy were the most common type in all three groups. This is followed by left VA dominancy in the control (36%) and ACIS (35%) groups and right VA dominancy in the PCIS (32%) group. Right VA dominancy was the least common type in the control (27%) and ACIS (26%) groups, while left was the least common type in the PCIS group (28%). No significant difference was found for vertebral artery dominancy between the three groups when groups were compared for all cases, females and males (p>0.05, for all comparisons). When the data was broken into gender, right VAD was significantly higher in males (33%) compared to those observed in females (15%) only in the ACIS group (p = 0.018) but not in control or PCIS groups. When the images were analyzed in line with the hypoplasia criterion explained above, VAH (right, left, and bilateral) was observed in a total of 42 cases out of 159 (26%) in the control group. In contrast, the total incidence of VAH was found to be lower in both ACIS (16%) and PCIS (18%) groups.

Finally, when the relationship between the dominant side of the VA and the bending side of the BA in patients with ischemic stroke was assessed, a significant negative correlation was observed between VA dominancy and BA bending side in both groups ($r = -0.101$ in ACIS, $r = -0.02$ in PCIS, $P < 0.0001$). Fifty-five patients in the PCIS group and 126 patients in the ACIS group had lateral displacement of the BA, and a directional relationship was detected between the dominant VA side and the BA curvature in the opposite direction in 17 (19.5%) patients with PCIS (17/87; p < 0.001) and 46 (25.1%) patients with ACIS (46/183; p < 0.001) (Table 5).

Correlation Analysis

Correlation analysis of the parameters measured for the vertebrobasilar system in both ischemic groups is shown in Table 6. A positive correlation between left VA length and right VA length in the ACIS group (p = 0.740) was observed. Similarly, in the PCIS group, the right and left VA lengths showed a strong positive correlation with each other (p = 0.797). A moderate positive relationship was also observed between left VA diameter and right VA diameter in the PCIS (p = 0.526) and ACIS (p = 0.399) groups. Furthermore, we found a negative correlation between left VA diameter and right VA length (p = -0.249), between right VA diameter and left VA length (p = -0.255) in PCIS, and between right VA length and left VA diameter (p = -0.187) in ACIS group (Fig. 1-3, Table 6).

Table 4. Comparative results of the vertebrobasilar system for basilar artery bending side and vertebral artery hypoplasia or dominancy

Variables		Control	Patients		p
			ACIS	PCIS	
BA bending side [n (%)]	Right	80 (51%)	92 (50%)	43 (49%)	0.845
	Left	27 (17%)	34 (19%)	12 (14%)	
	Midline	51 (32%)	57 (31%)	32 (37%)	
VA dominancy [n (%)]	Right	43 (27%)	47 (26%)	28 (32%)	0.724
	Left	57 (36%)	65 (35%)	25 (28%)	
	Symmetric	59 (37%)	72 (39%)	35 (40%)	
VA hypoplasia [n (%)]	Right	19 (12%)	15 (8%)	8 (9%)	0.334
	Left	18 (11%)	10 (5%)	5 (6%)	
	Bilateral	5 (3%)	5 (3%)	3 (3%)	
	No	117 (74%)	154 (84%)	72 (82%)	

The values are presented as the number (percentages within the study groups). *ACIS*, anterior circulation ischemic stroke, *PCIS*, posterior circulation ischemic stroke, *BA*, basilar artery, *VA*, vertebral artery.

Table 5. Relationship between dominant side of the VA and the incidence of bending side of the BA

Bending side of the basilar artery		Dominant side of the vertebral artery			Total
		Right	Left	Symmetric	
ACIS	Right	20	36	36	92
	Left	10	9	15	34
	Midline	16	20	21	57
	Total	46	65	72	183
PCIS	Right	14	12	17	43
	Left	5	3	4	12
	Midline	9	9	14	32
	Total	28	24	35	87

Spearman's rank correlation, r = -0.101 (ACIS), r = -0.02 (PCIS), p < 0.0001. ACIS, anterior circulation ischemic stroke, PCIS, posterior circulation ischemic stroke.

Table 6. Correlation analysis between the measurements of the vertebrobasilar system in both ischemic groups

		VBJ Angle	BABL	BAB Angle	Right VA Diameter	Left VA Diameter	Right VA Length	Left VA Length	BA Diameter	BA Length
ACIS	VBJ Angle	1	0.079	0.079	0.005	0.020	-0.063	-0.025	-0.079	0.061
	BABL		1	0.159*	-0.053	0.050	0.163*	0.184*	0.085	0.266**
	BAB Angle			1	-0.129	0.055	0.035	0.099	-0.120	0.053
	Right VA Diameter				1	0.399**	0.016	-0.030	0.247**	0.172*
	Left VA Diameter					1	-0.187*	-0.008	0.140	0.125
	Right VA Length						1	0.740**	0.147*	0.066
	Left VA Length							1	0.188*	0.070
	BA Diameter								1	0.334**
	BA Length									1
PCIS	VBJ Angle	1	0.238*	0,045	-0,031	0.001	0.019	0.066	0.108	0.012
	BABL		1	-0,051	0,119	0.243*	-0.293**	-0.084	0.088	0.277**
	BAB Angle			1	-0,110	-0.070	0.279*	0.263*	0.153	-0.104
	Right VA Diameter				1	0.526**	-0.190	-0.255*	0.265*	0.208
	Left VA Diameter					1	-0.249*	-0.149	0.185	0.126
	Right VA Length						1	0.797**	-0.034	-0.174
	Left VA Length							1	-0.074	-0.107
	BA Diameter								1	0.446**
	BA Length									1

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

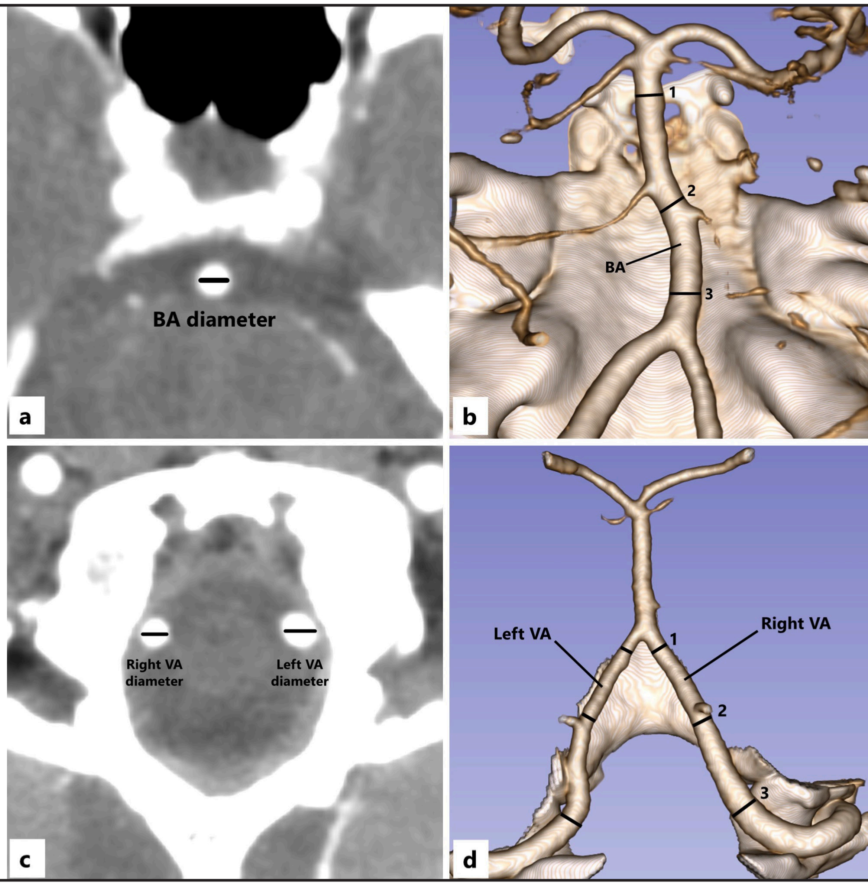

Figure 1. The MDCTA (a, c) and the 3-dimensional reconstructed (b, d) images of the VBS show the right and left VA (a, b) and BA (c, d) measurements. The diameters of both VA and BA are measured from the A-P view at three distinct locations, as described in Table 1, to ensure the accuracy of the dimensions.

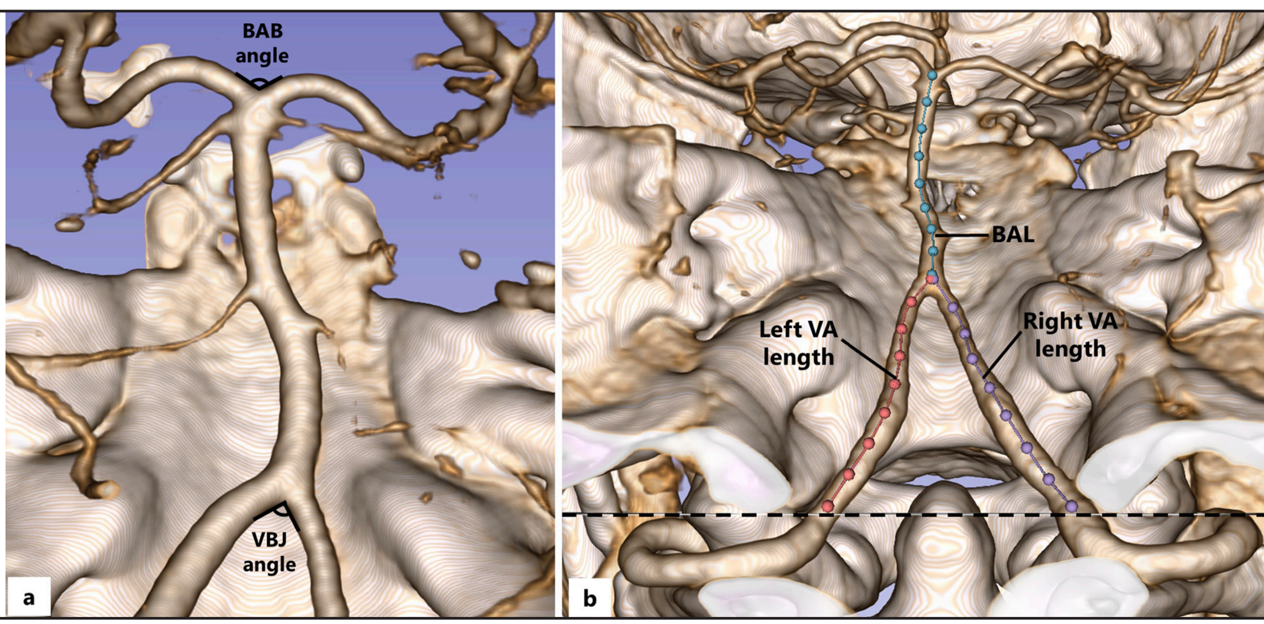

Figure 2. 3D-MDCTA reconstructed images to show (a) measurements of the actual lengths of the left and right vertebral arteries and the basilar artery and (b) the angles of the vertebrobasilar junction and basilar artery bifurcation. BAB, basilar artery bifurcation; VBJ, vertebrobasilar junction; BAL, basilar artery length; VA, vertebral artery.

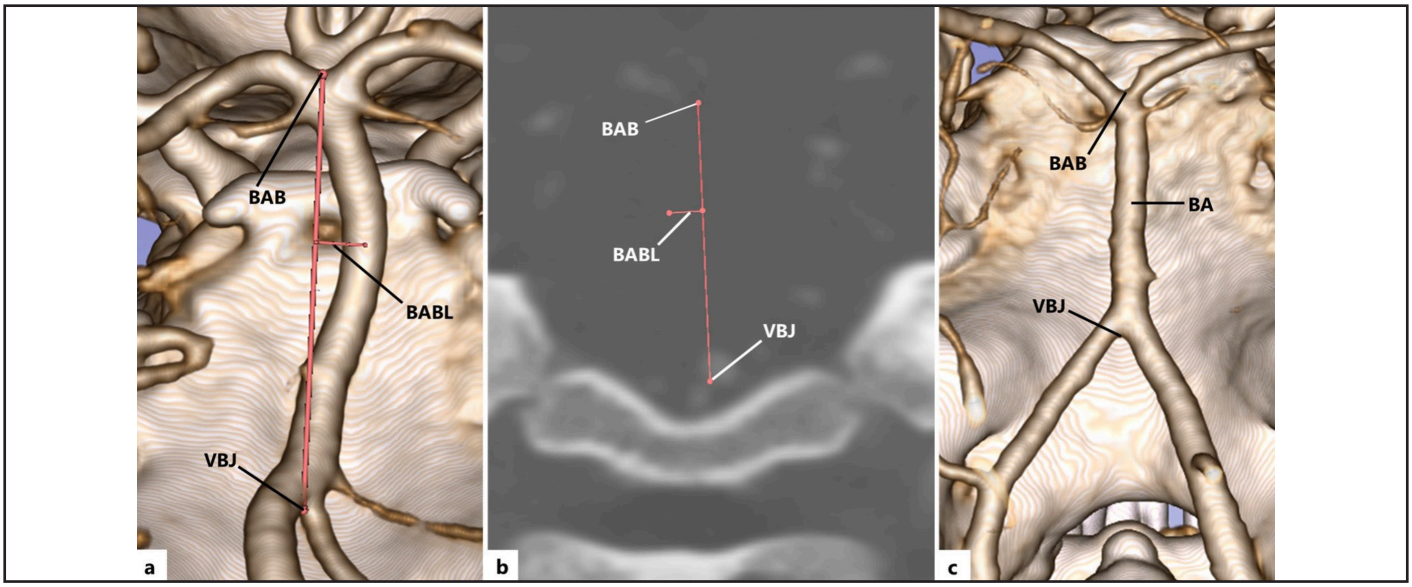

Figure 3. Multidetector computed tomography angiography (MDCTA) (b) and 3-dimensional reconstructed images (a, c) of the vertebrobasilar system (VBS), illustrating basilar artery (BA) bending length (a and b) and direction of BA deviation (a and c). In (a), the BA is deviated from the midline toward the patient's right side (right side bending), using the mid-sagittal plane and brainstem as anatomical references. In contrast, (c) demonstrates a midline-positioned, non-deviated (straight) BA. Non-deviated BAs were defined as those with less than 60% of their course deviating laterally from the midline [9, 15]. BAB, basilar artery bifurcation; VBJ, vertebrobasilar junction; BA, basilar artery; BABL, basilar artery bending length.

DISCUSSION

The vertebrobasilar system (VBS) plays a critical role in the cerebral circulation, supplying blood to essential structures such as the brainstem, cerebellum, occipital lobes, and thalamus [1-3]. The anatomical and geometric variations of the VBS have been implicated in cerebrovascular diseases, including ischemic stroke [6,8,16,17]. In recent years, numerous anatomical variants of the VBS encompassing different populations have been described [2,6,9,12,13,17,18]. However, studies comparing patients with anterior and posterior ischemic strokes are limited, and no attempts have been made to characterize these variants of changes in the VBS. Our study aimed to investigate the morphometric and geometric characteristics of the vertebrobasilar arteries and their association with anterior circulation ischemic stroke (ACIS) and posterior circulation ischemic stroke (PCIS). The findings provide valuable insights into the structural differences between stroke patients and control subjects, contributing to the growing body of research on the role of vascular morphology in stroke pathogenesis.

Morphometric and Geometric Variability of the VBS

The results of our study demonstrate significant variability in the morphometric and geometric parameters of the vertebrobasilar system. Notably, the basilar artery length (BAL) was significantly longer in both ACIS and PCIS groups compared to the control group. This finding aligns with previous reports suggesting that an elongated BA may be associated with altered hemodynamics, potentially predisposing individuals to ischemic events. The significance of increased BA length may extend beyond anatomical variation and could indicate pathological vascular remodeling. Arterial elongation is known to occur with aging and advanced atherosclerosis due to progressive loss of vessel elasticity, medial thinning, and increased hemodynamic stress [19,22]. Such remodeling can lead to increased arterial tortuosity, which may disturb laminar blood flow and promote the development of localized low shear stress zones — conditions that are conducive to plaque formation and thrombus development [12,20,25]. In the vertebrobasilar system, where collateral circulation is limited, these geometric and structural changes may have a more pronounced effect on distal perfusion and embolic susceptibility. Our findings of longer BA lengths in stroke patients, particularly in males with ACIS, may reflect these adaptive or pathological changes and suggest that BA elongation could be a marker of increased cerebrovascular vulnerability.

The BAL averaging 32.3 mm in ACIS and 31.4 mm in PCIS in our study are higher than reports that it varies between 23.1 mm and 27.1 mm using different measurement techniques (MRI vs. cadaver) [6,13,15]. A review of the literature showed the length of the BA from 26.3 mm to 28.9 mm in lacunar or pontine infarction groups [21,22]. The mean BA diameters in our study were consistent with prior literature but varied based on population differences and imaging modalities used in previous studies. The mean diameters of the BA in the present study (3.6 mm in ACIS, 3.4 mm in PCIS) are similar to a previous report by Ogeng'o et al. [6] (3.32 mm) and Szalontai et al. [13] (3.42 mm) in a Kenyan and Hungarian population, respectively.

Another notable finding of this study was that the significantly lower VA lengths observed in males with PCIS were compared to both the control and ACIS groups. The mean length of the left and right intracranial VA observed in our series is similar to the values reported by Ballesteros et al. [23] and Dharshini et al. [24]. Hong et al. [14] examined the diameter of the VA in diffusion-weighted imaging of patients with PCIS, while Zhu et al. [25] investigated it in posterior circulation ischemia using contrast-enhanced magnetic resonance angiography [14,25]. Compared to the previous reports mentioned above, we observed a larger diameter in both patient groups. The discrepancy might be due to the sample size, ethnicity, and methodological differences. Interestingly, there were no significant differences across the groups, sides, and gender in our samples; however, we found a negative correlation between diameter on one side and length on the other side in patient groups. Additionally, a positive correlation was observed between the left and right VA lengths and between the left and right VA diameters in both the ACIS and PCIS groups.

The vertebrobasilar junction (VBJ) angle and basilar artery bifurcation (BAB) angle, both important determinants of cerebrovascular flow dynamics [6,7], showed no significant differences between stroke groups and control subjects. In this study, the mean BAB angle measurements for the ACIS and PCIS groups were 123.1º and 122.4º, respectively. These findings contrast with some previous reports suggesting that larger BAB angles may contribute to hemodynamic stress and aneurysm formation [6,26-28]. In a three-dimensional angiographic study conducted on a Chinese population, the average BAB angle was measured as 141.1° in patients with BA bifurcation aneurysms and 106.5° in control subjects [28]. The angle of confluence in cadaveric and angiographic studies varies between 10º and 160º [2,6-8,17,18]. In the present study, the angle at the VBJ averaging 83.3° in ACIS and 83.9° in PCIS is consistent with literature reports. The absence of significant variation in these angles in our study suggests that other anatomical and physiological factors may be more influential in stroke development.

Vertebral Artery Hypoplasia and Dominance

Our analysis of vertebral artery hypoplasia (VAH) and vertebral artery dominance (VAD) yielded some unexpected results. While previous studies have suggested that asymmetric vertebral arteries may alter vertebrobasilar geometry and predispose individuals to stroke through hemodynamic changes [10,12,25], our study found a lower prevalence of VAH in stroke patients (16% in ACIS and 18% in PCIS) compared to controls (28%). This finding contrasts with earlier reports linking VAH to increased posterior circulation stroke risk [2,11,17,18,29]. Several explanations may account for this discrepancy, including methodological differences in defining VAH, variations in population characteristics, or potential selection bias within the control group. Alternatively, it is plausible that individuals with VAH who remain stroke-free possess more effective collateral circulation or exhibit adaptive hemodynamic mechanisms that mitigate ischemic risk. While no significant association was observed between VAH and specific stroke localization in our cohort, further studies incorporating larger populations and advanced flow-based imaging are warranted to clarify the complex role of VAH in cerebrovascular vulnerability.

Regarding vertebral artery dominance, our results indicate that left VAD was more frequently observed in patients with ACIS, while right VAD predominated in those with PCIS. Although this distribution may suggest a pattern in vascular asymmetry, the absence of clinical data on the side of stroke (i.e., laterality) prevents any definitive conclusions regarding a relationship between VA dominance and the side of ischemic involvement. Asymmetrical blood flow distribution and vessel wall shear stress may play a role in cerebrovascular vulnerability; however, the physiological implications of VA dominance remain uncertain, and the criteria for defining VAD vary across studies. To obtain stronger conclusions regarding the role of VAD in ischemic stroke, future studies should incorporate cerebral hemodynamic assessments along with clinical data on stroke hemisphere.

Basilar Artery Bending and Stroke Risk

The bending patterns of the basilar artery (BA) have been proposed as potential risk factors for ischemic stroke [9,15,22].

In our study, BA bending was most frequently observed toward the right side across all groups, consistent with previous reports [5,9]. However, no significant differences in bending direction were found between stroke patients and control subjects. A review of the literature showed that the bending length of the BA in healthy individuals ranges from 2.02 mm to 2.57 mm using magnetic resonance angiography (MRA) [12,13,15], whereas Zhang et al. [22] reported a mean bending length of 5.54 mm in patients with acute pontine infarction. Our current findings (3.9 mm in ACIS, 3.1 mm in PCIS) fall between these values. We also found that the basilar artery bending length (BABL) was significantly longer in male patients and more pronounced on the left side ($p < 0.0001$), suggesting a possible sex-related and geometric variation that warrants further investigation. Interestingly, the BA curved less frequently toward the side opposite the dominant VA in both ischemic groups (25.1% for ACIS, 19.5% for PCIS), which contrasts with findings from Hong et al. [14] and Yu et al. [16]. However, since stroke laterality data were not available, the clinical relevance of these morphological patterns remains unclear. Our results do not support a direct link between VA dominance and BA curvature and suggest that the curved course of the BA is unlikely to be an independent predisposing factor for ischemic stroke in either the anterior or posterior circulation.

Limitations, Clinical Implications, and Future Directions

While our study provides valuable insights into the anatomical variations of the vertebrobasilar system, several limitations should be acknowledged. First, the retrospective nature of the study and reliance on computed tomography angiography (CTA) limit our ability to assess dynamic blood flow characteristics. Another limitation is the relatively small sample size of the PCIS subgroup (n = 88), which may have limited the statistical power to detect significant differences in subgroup analyses. Therefore, findings related to this group should be interpreted with caution. Additionally, the lack of adjustment for important clinical covariates such as age, hypertension, diabetes, smoking, and atherosclerosis limits the causal interpretation of our findings. Future studies incorporating these variables into multivariate models are needed to further validate the observed associations. Finally, the absence of clinical data regarding the laterality (i.e., left or right hemisphere) of the stroke site is a significant limitation, particularly when interpreting relationships involving vertebral artery dominance and basilar artery curvature. Without stroke laterality data, no conclusions can be drawn about potential side-specific associations, and any implications regarding directional vascular influence should be interpreted with caution.

Future studies should incorporate larger, multi-center cohorts with longitudinal follow-ups and detailed clinical information to validate our findings. Additionally, integrating imaging techniques such as transcranial Doppler ultrasound and magnetic resonance angiography (MRA) could provide a more comprehensive understanding of hemodynamic alterations associated with VBS geometry. Investigating the genetic and ethnic influences on VBS morphology may also yield important insights into stroke susceptibility.

CONCLUSIONS

Our findings highlight the complexity of the relationship between vertebrobasilar morphology and ischemic stroke. While no single morphometric or geometric parameter consistently predicted stroke risk across all cases, several measurements — including basilar artery length and vertebral artery length — demonstrated statistically significant differences, particularly in subgroup and gender-specific analyses. These results suggest that specific anatomical features of the vertebrobasilar system may have potential relevance in stroke risk stratification. In contrast, other expected risk factors, such as vertebral artery hypoplasia and basilar artery bending, did not show consistent associations in our sample. Overall, these findings underscore the importance of a multifactorial approach that incorporates anatomical, hemodynamic, and clinical variables. Further prospective studies are warranted to clarify the role of VBS characteristics in stroke pathogenesis and guide targeted preventive strategies.

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Authors' Contributions: ID designed this study, interpreted the findings and wrote the manuscript. AL analyzed the data. AA and KCK researched the literature, assessed the images. BA and SeA contributed to data collection and analyses. ShA played a role in data collection. MAK provided critical comments/ revisions of the manuscript. All authors reviewed and edited the manuscript and approved the final version of the manuscript.

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