A Retrospective study of Intracranial Vertebrobasilar system morphometry and its variations using Non-contrast Magnetic Resonance Angiogram (MRA)

C. Regina[1], J. Kalaivanan[1], S. Muthu Isai[2], K. Sudhakar[3], S. Sathish Kumar[4], K. Vanidha[5]

[1] Department of Anatomy, Vinayaka Mission Medical College and Hospital, Karaikal, Vinayaka Mission's Research Foundation, Salem, India

[2] Department of Radiodiagnosis, Vinayaka Mission Medical College and Hospital, Karaikal, Vinayaka Mission's Research Foundation, Salem, India

[3] Consultant Neurosurgeon, Department of Neuro and Spine Surgery, Bharathi Hospital, Madurai

[4] Department of Biostatistics, Vinayaka Mission Medical College and Hospital, Karaikal, Vinayaka Mission's Research Foundation, Salem, India

[5] Department of Central Research Laboratory for Biomedical Research, Vinayaka Mission Medical College and Hospital, Karaikal, Vinayaka Mission's Research Foundation, Salem, India

SUMMARY

The vertebrobasilar system (VBS) provides 30% of the blood supply to the posterior cerebral fossa. Morphological changes are associated with an increased risk of atherosclerosis and aneurysm development, resulting in cerebrovascular and cardiovascular disorders. This study assesses VBS morphometry and its variations in imaging analyses. A morphometric analysis was performed on 100 adult patients aged 20 to 60 years using non-contrast magnetic resonance angiography (MRA). Demographic information and multiple VBS parameters were documented. The mean length of the basilar artery across all 100 cases was 31.31 mm, with a diameter varying from 3.01 mm to 3.12 mm. The diameters of the right and left vertebral arteries were 2.35 mm and 2.50 mm, respectively. We noted deviations in the branching pattern of the basilar artery at the termination site in 30% of cases, potentially influencing hemodynamics and elevating the likelihood of aneurysm formation. Vertebral artery hypoplasia and atresia were observed in 37% and 2% of patients, respectively. Asymmetrical vertebral arteries led to variable courses of the basilar artery, specifically "C" and "S" configurations, noted in 49% and 11% of cases, respectively. Statistically significant changes were observed in VBS dimensions, basilar artery angle, and the course between age and high-risk groups. No substantial difference was noted between the genders. The findings furnish foundational data for neurosurgeons and radiologists in the diagnosis of cerebral and cardiovascular disorders, as well as in the planning of neurosurgical interventions in the posterior cranial fossa.

Corresponding author:
Dr. C. Regina, Assistant professor. Department of Anatomy, Vinayaka Mission Medical College & Hospital, Karaikal, Vinayaka Mission Research Foundation, Salem, India. Phone: 9626221431. E-mail: chinnarajaregina@gmail.com - ORCID: 0009-0007-0236-6961

Submitted: June 30, 2025 **Accepted:** September 22, 2025

https://doi.org/10.52083/CWUP9560

Key words: Vertebrobasilar system – Hypoplastic vertebral artery – Fetal posterior cerebral artery – Fenestrations – Atherosclerosis.

INTRODUCTION

The vertebrobasilar system (VBS) is the sole arterial system in the human body where the convergence of two vertebral arteries forms a singular basilar artery, characterized by significant geometric variability. It is essential for posterior cerebral circulation, providing blood supply to critical regions of the brainstem, spinal cord, cerebellum, internal auditory meatus, and the posterior aspects of the cerebrum and thalamus, as well as the ventricular system (Standring, 2016). In recent years, VBS has become a common intracranial site for aneurysm development, atherosclerosis, and infarction, mostly due to hemodynamic stress and irregular flow patterns (Mamatha et al., 2012). Globally, 35% of ischemic strokes impact the posterior cerebral circulation, leading to posterior circulation stroke (PCS) (Ikram and Zafar, 2024). The primary etiologies of stroke are embolism originating from cerebral arteries and the heart, atherosclerosis, and vasculopathy. Variations in VBS are often linked to cerebrovascular and cardiovascular illnesses, making it crucial to strategically design endovascular coiling treatments for the treatment of aneurysms and arteriovenous malformations (Satapathy and Mohapatra, 2018).

Many investigators have studied the configuration of intracranial arteries using cadaveric specimens and imaging techniques (Dharshini et al., 2022; Kalaiyarasi, 2022; Mamatha et al., 2012; Omotoso et al., 2021; Wankhede et al., 2014; Vasovic et al., 2012). Only a few studies have systematically investigated the VBS in the general population (Akkasoglu et al., 2019; Songur et al., 2007). In India, the existing literature has documented variations in VBS with fewer parameters in cadaveric specimens; however, studies on imaging modalities are needed (Dharshini et al., 2022; Vijayakumar et al., 2020). Advanced methodologies such as Computed Tomography (CT) and Magnetic Resonance Angiography (MRA) have been implemented to examine the hemodynamics of arterial flow, and are essential for the precise diagnosis of vascular disorders. Consequently, this study aims to gather data on VBS morphometry, which may serve as reference values for different age groups to assess the morphological attributes of the vascular system.

The objective of the work is to evaluate the morphometric variations of the vertebrobasilar system using a non-contrast magnetic resonance angiography (MRA).

MATERIAL AND METHODS

This retrospective record-based study was performed at the Department of Anatomy in collaboration with the Department of Radiology at Vinayaka Mission's Medical College and Hospital (VMMC & H), Karaikal, after approval from the Institutional Ethics Committee (IEC No: IEC/VMMCH/2024/DEC/05). We examined 100 cases from the archives of the Radiology department. The study encompassed patients aged 20 to 60 years with systemic conditions including hypertension (HTN), dyslipidemia (DYS), diabetes mellitus (DM), and coronary artery disease (CAD), as well as individuals who underwent non-contrast MRI angiography for diverse neurological symptoms (severe headache, decreased motor strength, absent or decreased sensations, visual symptoms, memory deficit) from January 2021 to January 2024. Individuals with a history of vascular malformations, cardioembolic stroke, intracerebral hemorrhage or aneurysm, metallic implants, previous head and neck procedures, poor imaging quality, or trauma were excluded. The selection method was established to guarantee the reliability and validity of our results.

All patients underwent MRI using a 1.5 Tesla Siemens system, employing standard T1 and T2-weighted imaging, fluid-attenuated inversion recovery (FLAIR) sequences, and magnetic resonance angiography (MRA). A 16-channel standard head coil will be used for the patient, and three-dimensional time-of-flight (3D-TOF) images were obtained with the following technical parameters: time, 25; echo time, 7 ms; and section thickness, 0.6 mm. The overall imaging duration was roughly 15 minutes, with the 3D-TOF MRA process requiring 3 minutes for completion. The acquired pictures underwent post-processing by maximum intensity projection (MIP). The morphometry of the VBS and its variants was analyzed in different views and time-of-flight sequences (TOF), and the findings were tabulated. The demographic data were recorded following the de-identification of records using code numbers to preserve patient confidentiality. The non-contrast MR angiographic scans were analyzed under the oversight of a qualified consultant from the Department of Radiology to mitigate observer and inter-observer bias.

The various parameters of the VBS were recorded in all 100 cases. In the present study, the length of the intracranial segment of the vertebral artery (VA) was measured from the origin of the posterior inferior cerebellar artery (PICA) to the basilar artery (BA) formation, and the diameter of the VA was assessed 1 cm distal to the origin of the BA (Fig. 1). The length of the BA was quantified from the pontomedullary junction to the pontomesencephalic junction, while the diameter was assessed at three specific locations: proximal to the origin, at the mid-pons, and adjacent to the termination of the BA (Fig. 3). Distinct patterns of BA termination were noted in non-contrast MRA, including the rare variant known as fetal-type posterior cerebral artery (PCA), where the PCA arises directly from the internal carotid artery (ICA), bypassing the BA (Fig. 4).

The angles of the VA and BA were assessed along the geometric plane (Fig. 5). The angle of the VA was determined by constructing two imaginary lines: one along the VA and another at the vertebrobasilar junction. The acute angle formed by the two lines was identified as the vertebral angle (Li et al., 2023). The BA angle was measured according to the course's characteristics. If the artery is linear, the initial imaginary line is delineated from the vertebrobasilar junction to the terminus of the BA, while the subsequent line is drawn along either the right or left VA. If the artery is curved, the initial imaginary line extends from the vertebrobasilar junction to the most curved segment of the BA, whereas the subsequent imaginary line extends from the curved BA to its terminal portion. The acute angle between the lines was referred to as the BA angle (Hong et al., 2009).

The collected data were analyzed using Microsoft Excel and SPSS software version 25.0. The categorical variables were represented as frequencies and proportions, whereas the quantitative variables were presented as means with standard deviations. An independent samples t-test and Mann-Whitney U test were employed to compare the means of two separate groups. One-way ANOVA and the Kruskal-Walli's test were performed to compare means among several groups, while the chi-square test was used to evaluate the relationship between categorical variables. Spearman's rho and Pearson correlation analyses were used to investigate the relationship between continuous variables. All statistical analyses were performed at a 95% significance level, with a p-value below 0.05 being statistically significant.

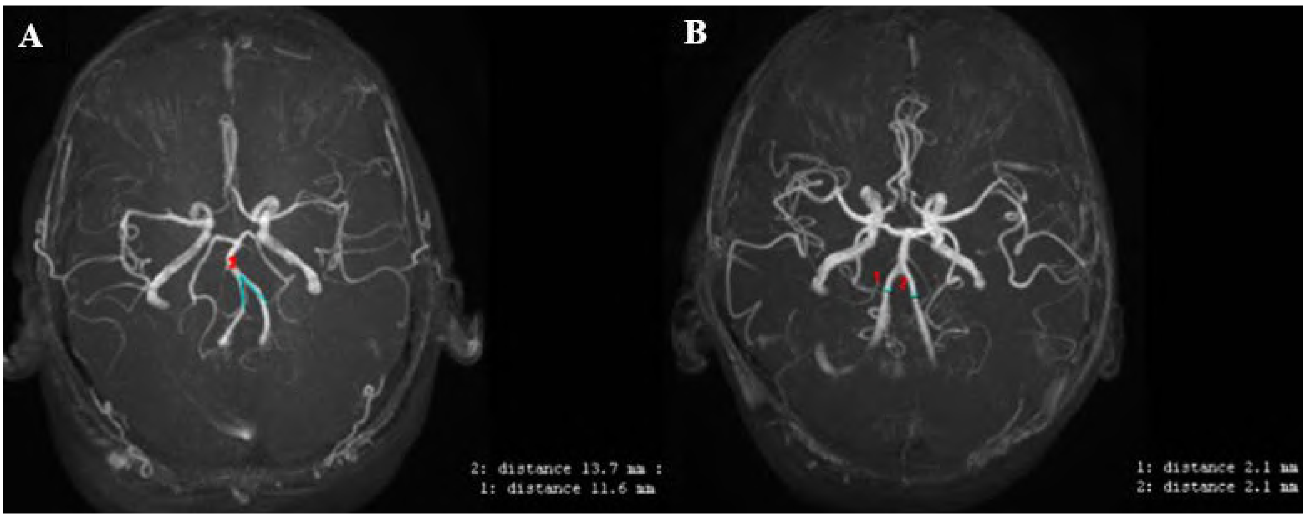

Fig. 1.- Non-contrast MRA showing the measurements of the right and left VA dimensions. A - Right and left VA length (1 & 2) measured from the point of origin of the Posterior inferior cerebellar artery to the VA termination. B – Right (1) and left VA (2) diameters measured 1cm below the BA formation.

Table 1. Demographic variables of the Vertebrobasilar artery (n= 100)

Variables		Frequencies	Percentage (%)
Age group	I - 21-30	25	25%
	II – 31-40	35	35%
	III – 41-50	22	22%
	IV – 51-60	18	18%
Gender	Male	48	48%
	Female	52	52%
Dyslipidaemia (DYS)		16	16%
Hypertension (HTN)		22	22%
Diabetes Mellitus (DM)		30	30%
Coronary artery disease (CAD)		12	12%

RESULTS

This study analyses 100 non-contrast magnetic resonance angiography (MRA) pictures, providing a comprehensive evaluation of demographic characteristics such as age, gender, and high-risk populations.

Distribution of demographic variables

Among 100 cases, the age group distribution was as follows: 25% aged 21-30 years, 35% aged 31-40 years, 22% aged 41-50 years, and 18% aged 51-60 years. The gender distribution was approximately equal, with 48% males and 52% females. Our analysis of high-risk groups, including DYS (16%), HTN (22%), DM (30%), and CAD (12%), was documented in this study (Table 1).

The dimensions of the VA and BA were evaluated in sagittal view using a non-contrast time-of-flight magnetic resonance angiography sequence. The current investigation recorded the right and left VA lengths as 32.31 mm and 33.45 mm, respectively, and the right and left VA diameters as 2.35 mm and 2.50 mm, respectively (Table 2). In approximately 40 cases, the left VA diameters' contribution exceeded that of the right VA; in 8 cases, both the right and left VA diameters exhibited equal caliber. Hypoplastic VA was observed in 37 cases: 18% on the right side, 14% on the left side, and 5% bilaterally. We have observed two cases of left-sided VA atresia, which culminate as the PICA, whereas the contralateral artery persists as the BA (Table 3, Fig. 2). The mean BA length was 31.31 mm, while the average BA diameter was assessed at three locations: proximal (3.12 mm), mid-pons (3.07 mm), and distal to the BA termination (3.01 mm) (Table 2).

The differences in the origin and termination

Table 2. Morphometry of the Vertebrobasilar artery length, diameter and angle (n= 100).

Variables	Mean with SD
BA Length	31.31 ± 1.49 mm
BA diameter at the level of origin	3.12 ± 0.48 mm
BA diameter at the level of Mid-pons	3.07 ± 0.43 mm
BA diameter at the level of termination	3.01 ± 0.41 mm
Right VA Length	32.31 ± 2.05 mm
Left VA Length	33.45 ± 1.86 mm
Right VA diameter	2.35 ± 0.57 mm
Left VA diameter	2.50 ± 0.56 mm
Angle of Right VA	44.54 ± 5.26°
Angle of Left VA	52.31 ± 3.16°
Angle of BA	38.52 ± 4.97°

*BA – Basilar artery, VA – Vertebral artery.

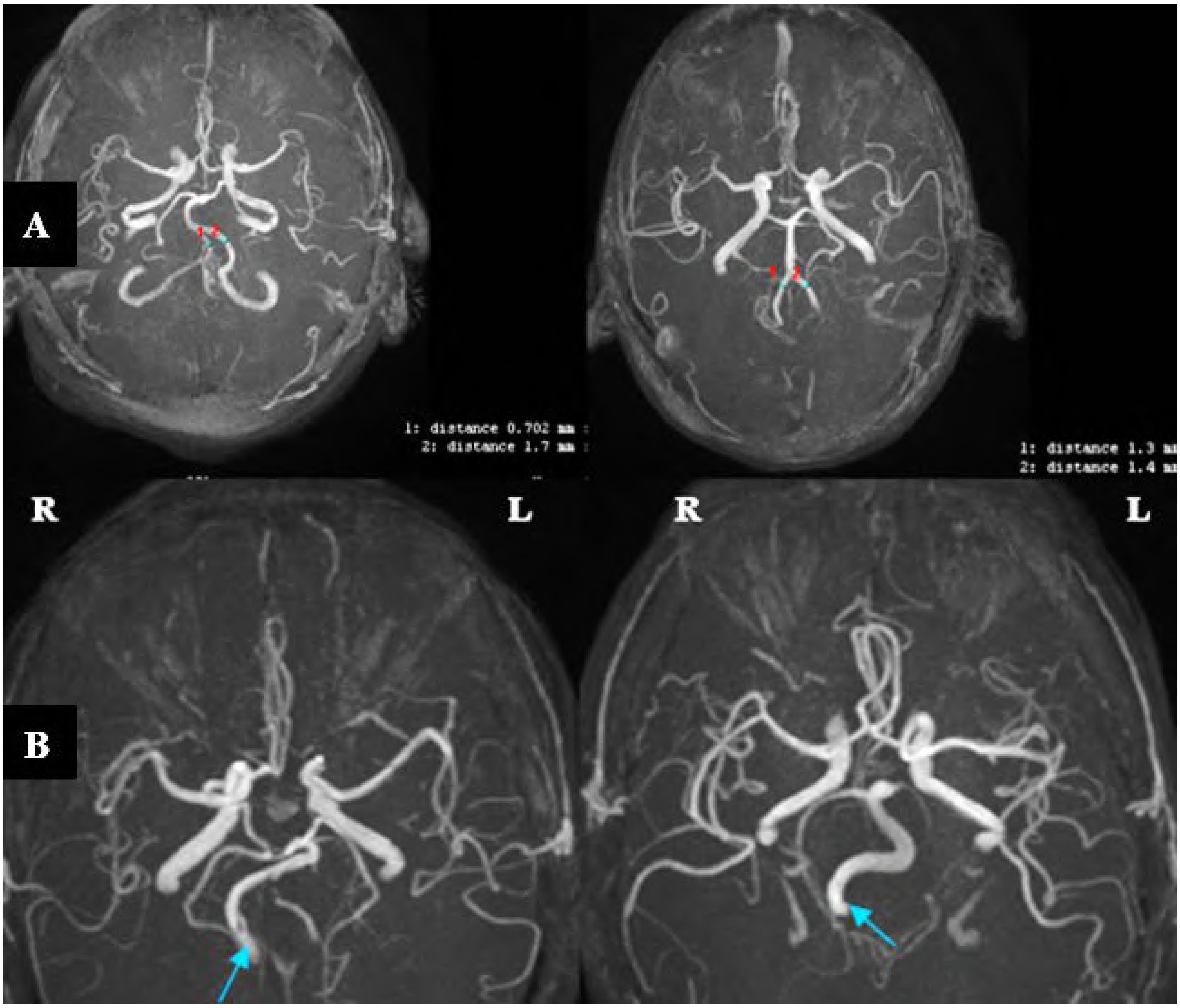

Fig. 2.- Non-contrast MRA showing the VA variations. A – Right and left VA Hypoplasia (VAD <2mm). B – Single VA on the right side (blue arrow), which continues above as the BA and an absent VA on the left side.

Fig. 3.- MRI brain sagittal view showing the measurements of the BA dimensions. [BA length measured by a vertical line drawn from below the pontomedullary junction till the pontomesencephalic junction, and BA diameter was measured at 3 levels: near its origin (1), at mid-pons (2) and near its termination (3)].

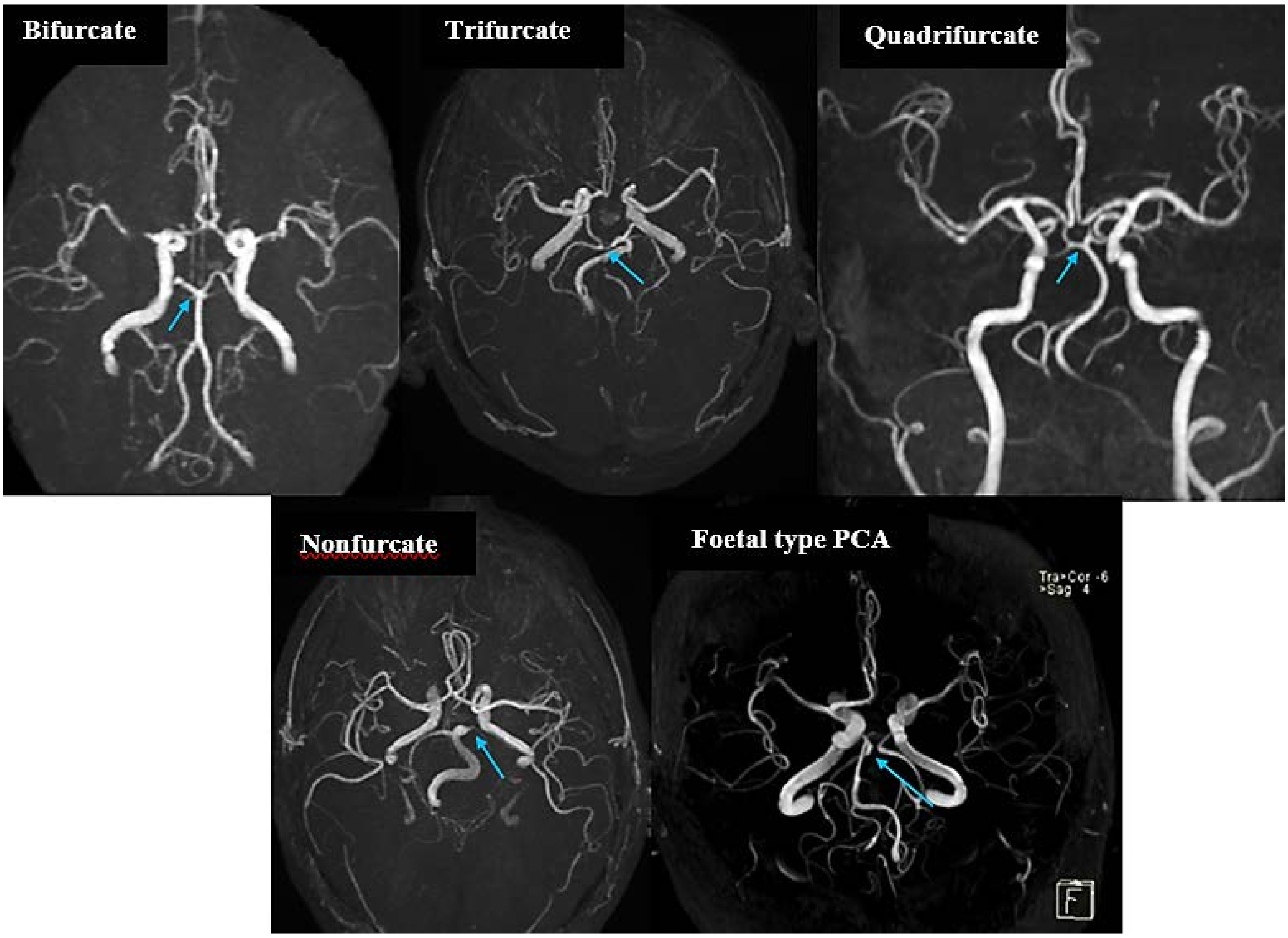

Fig. 4.- Non-contrast MRA showing the different pattern of termination of the BA (blue arrow). Bifurcate – BA terminate as right and left PCA. Trifurcate – BA terminate as three branches: One PCA, one SCA on the right side, and one PCA on the left side. Quadrifurcate - BA terminate as four branches: one PCA, one SCA on the right side and one PCA, one SCA on the left side. Non-furcate – BA terminate as PCA on the right side, and it is absent on the left side. Fetal type PCA – PCA originates directly from the Internal carotid artery without involving the BA.

of the BA were examined using T1-weighted MRI in both axial and sagittal planes. In the current investigation, the predominant origin of BA was observed at the pontomedullary junction (82%), followed by above the junction in 12% and below the junction in 6% of patients. The termination of the BA was observed at the ponto-mesencephalic junction in 88% of cases, above the junction in 8%, and below the junction in 4% (Table 3). The various types of BA termination were examined using non-contrast MRA, and the findings were recorded. The predominant ending pattern is bifurcation, wherein the basilar artery splits into right and left PCAs, occurring in 70% of cases. Another termination pattern identified in our study was trifurcation, characterized by the emergence of three arteries from the BA: two PCA on both sides and one superior cerebellar artery (SCA) on one side, observed in 4% of cases. Quadrifurcation, where four arteries arise from the BA—two PCA and two SCA on either side—was noted in 9% of cases. The non-furcate pattern occurs when the BA does not terminate but continues as a PCA on either the right or left side due to aplasia, which was observed in 4% of cases. The uncommon variation, fetal-type PCA, was identified in 13 cases: on the right side (5%), on the left side (4%), and bilaterally (4%) (Table 3, Fig. 4).

The angulation of the BA, together with the two VAs, was quantified in a geometric plane, and the findings are recorded in Table 2. The right and left VA angles measured 44.54±5.26º and 52.31±3.16º, respectively. The average angle of the BA was 38.52 ± 4.97º. The BA course and fenestrations were examined in non-contrast MRA, revealing that the predominant configuration was "C" shaped (49%), followed by straight (40%) and "S" shaped courses (11%) in the cases. Fenestra-

Table 3. Vertebrobasilar artery morphological variations and their frequencies in the present study

S. No:	Parameters	Variations observed	Frequencies / Percentage
1.	Level of Origin	Below Pontomedullary junction	6 (6%)
		At the level of Pontomedullary junction	82 (82%)
		Above Pontomedullary junction	12 (12%)
2.	Level of Termination	Below Ponto mesencephalic junction	4 (4%)
		At the level of Ponto mesencephalic junction	88 (88%)
		Above Ponto mesencephalic junction	8 (8%)
3.	Mode of Termination	Bifurcate	70 (70%)
		Trifurcate	4 (4%)
		Quadrifurcate	9 (9%)
		Penta-furcate	0 (0%)
		Non-furcate	4 (4%)
		Foetal type PCA	Right – 5 (5%)
			Left – 4 (4%)
			Both – 4 (4%)
4.	Course of BA	Normal / Straight	40 (40%)
		"C" shaped course	49 (49%)
		"S" shaped / Tortuous course	11 (11%)
5.	Other variants	Presence of Fenestrations in BA	5 (5%)
		Presence of Fenestrations in VA	0%
6.	VA hypoplasia	Right side	18 (18%)
		Left side	14 (14%)
		Both sides	5 (5%)
7.	VA atresia	Left side	2 (2%)

*PCA – Posterior cerebral artery.

tions were observed in 5% of the patients, exhibiting a narrow slit-like structure near the origin of the BA (Table 3, Fig. 6).

Statistical analysis

This study conducted a statistical comparison of vertebrobasilar system (VBS) morphometric characteristics in relation to age, gender, and high-risk groups. The results, displayed in Tables 4 and 5, underscore the importance of these findings in vascular anatomy and imaging.

Intracranial part of the Vertebral artery (V4 segment)

In all 100 cases, the length and diameter of the left VA were considerably higher than those of the right VA (Table 4). We noted left VA dominance in 40%, right dominance in 13%, and equivalent diameters of both right and left VAs in 8% of the patients. Statistically significant changes in VA length and diameter ($p<0.05$*) were noted across various age groups. High-risk groups, including DYS, HTN, and DM, have demonstrated statistically significant variations in VA dimensions ($p<0.05$*). A positive correlation and statistically significant difference were noted between the lengths of the right and left VAs ($r=0.288$, $p=0.004$). The right and left VA diameters exhibited a statistically significant positive correlation and notable differences ($r=0.19$, $p=0.04$). In the current study, the VA's diameter was greater in females than in males, irrespective of age. Regardless of age, there were no substantial gender disparities. No statistically significant positive association or notable changes were found between the right and left vertebral angles. Hypoplastic VA was observed in 37% of cases, with a notable prevalence of 18% in the 51-60-year-old age group. Nonetheless, no

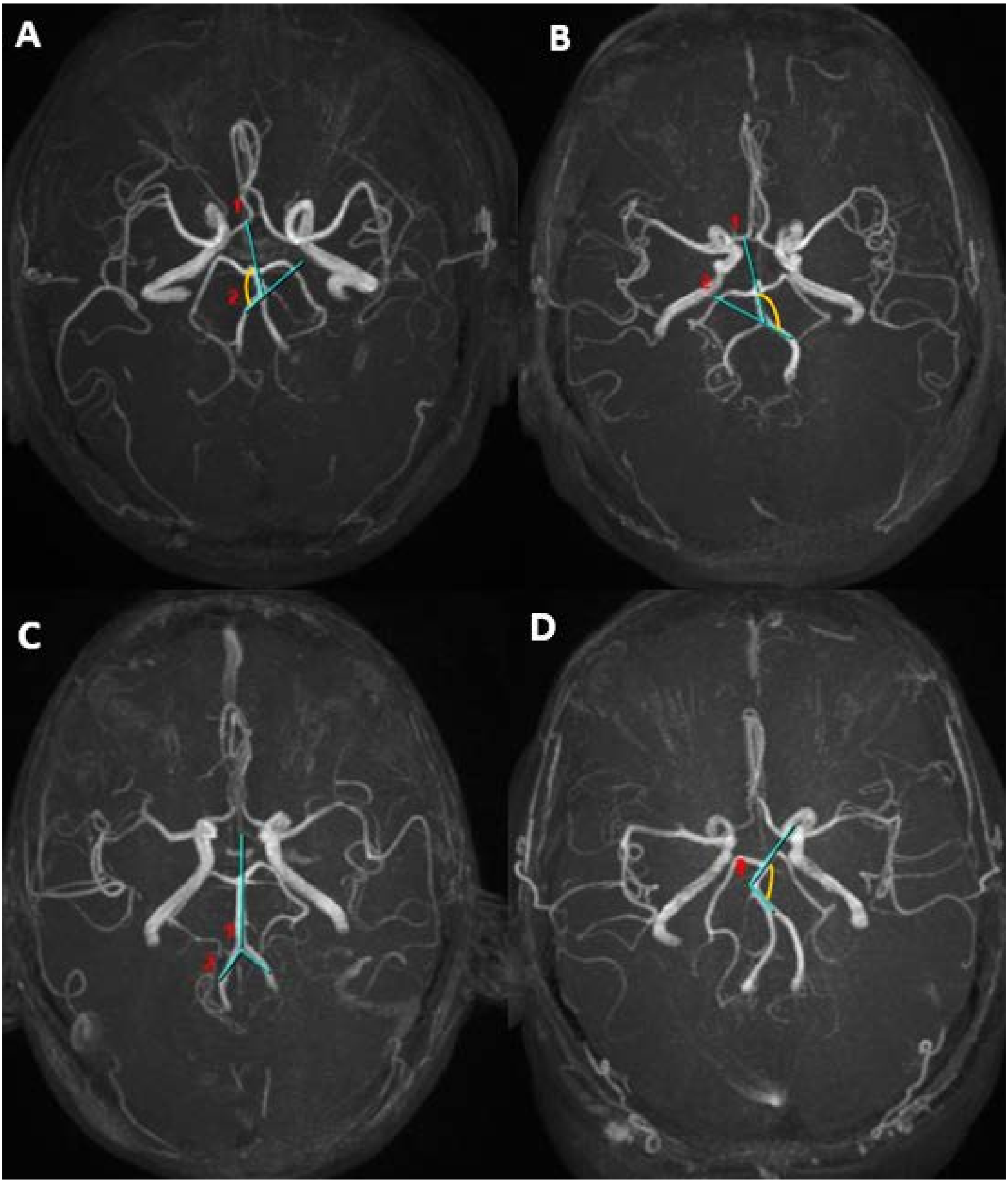

Fig. 5.- Non-contrast MRA showing the measurements of the angle of the BA and the VA. A- Right Vertebral artery angle, B – Left Vertebral artery angle, C- Basilar artery angle in straight course, D – Basilar artery angle in abnormal course.

statistically significant variations were seen in the hypoplastic VA with respect to age, gender, and high-risk groups.

Basilar artery

With advancing age, both the length and diameter of the BA exhibit statistically significant differences and positive relationships across various age groups ($p<0.0001^*$) (Table 5). Likewise, high-risk groups like those with HTN, DYS, DM, and CAD have demonstrated statistically significant variations in the BA dimensions. Statistically significant positive relationships were identified be-

Table 4. Statistical analysis of variables compared with VA dimensions and angle.

Variables		VA length		VA diameter		VA angle	
		Right	Left	Right	Left	Right	Left
Age group	21 – 30	30.22±1.49	32.57±1.53	2.19±0.56	2.38±0.28	43.93±5.25°	53.12±3.30 °
	31 – 40	31.75±1.53	32.49±1.64	2.29±0.62	2.50±0.69	44.91±5.63°	51.81±2.69 °
	41 – 50	34.07±1.25	34.84±1.62	2.34±0.45	2.54±0.63	43.49±4.86°	51.53±3.98°
	51 – 60	34.12±0.47	34.82±1.02	2.50±0.63	2.60±0.54	45.98±5.01°	53.12±2.41°
P - value		**<0.0001***	**<0.0001***	**0.0001***	**0.0001***	0.400	0.170
Gender	Male	32.25±2.12	33.59±1.65	2.32±0.50	2.47±0.56	44.22±5.23°	52.15±3.10°
	Female	32.36±2.01	33.31±2.04	2.39±0.64	2.53±0.57	44.84±5.33°	52.46±3.25°
P - value		0.796	0.435	0.446	0.588	0.526	0.423
Dyslipidaemia (DYS)	Yes	33.46±1.81	33.83±2.01	2.09±0.66	2.27±0.57	44.31±6.24°	51.80±3.04°
	No	32.09±2.03	32.02±3.68	2.40±0.55	2.65±0.55	44.59±65.10°	52.41±3.20°
P - value		**0.012***	**0.039***	**0.047***	**0.045***	0.892	0.255
Hypertension (HTN)	Yes	33.76±1.27	32.49±1.47	2.01±0.57	2.16±0.61	44.52±4.61°	52.35±2.80°
	No	31.90±2.05	32.15±1.87	2.37±0.58	2.51±0.56	44.55±5.46°	52.30±3.28°
P - value		**<0.0001***	**0.003***	**0.047***	**0.042***	0.997	0.947
Diabetes milliteus (DM)	Yes	33.79±1.34	34.58±1.58	2.08±0.62	2.66±0.58	45.76±5.40°	52.42±3.49°
	No	31.67±1.98	32.96±1.77	2.39±0.56	2.43±0.55	44.02±5.15°	52.26±3.04°
P - value		**<0.0001***	**<0.0001***	**0.038***	**0.007***	0.132	0.820
Coronary artery disease ©AD	Yes	34.03±1.01	34.80±1.40	2.12±0.63	2.72±0.61	45.90±4.41°	52.06±3.51°
	No	32.07±2.05	33.26±1.85	2.39±0.56	2.47±0.55	44.36±5.36°	52.35±3.13°
P - value		**0.002***	**0.007***	0.296	0.055	0.343	0.771

* Indicates statistically significant

tween the BA dimensions and both the right and left VA dimensions. Statistically significant differences in the BA angle were noted across various age groups (P<0.002*) and in individuals with DM and CAD (P<0.0001*). We documented four cases of BA dolichoectasia in individuals aged 41 to 50 years; three cases occurred in patients with HTN and one in a patient with DM; however, no statistically significant differences were noted. A statistically significant association and difference in the course of the BA were observed among different age groups (Table 6). The BA course ("C" type) is prevalent across all age demographics, particularly among individuals aged 41-50 years, with a notable incidence of 15% in diabetic patients. Nevertheless, no statistically significant disparities were detected among high-risk groups. The right VA diameter has a positive correlation with the BA course, suggesting that the curvature of the BA may be mostly orientated towards the left side (r=0.36, p=0.002). Fenestrations of the BA exhibit considerable and statistically significant variations among age groups (p<0.11*) and in patients with HTN and CAD, underscoring the necessity for increased clinical vigilance to avert neurological consequences (Table 6). No statistically significant changes in BA characteristics were observed between genders.

DISCUSSION

With the rising incidence of cerebrovascular accidents, it is essential to understand the anatomical and morphological aspects of cerebral circulation. Recent morphological alterations in the VBS have increased the likelihood of developing vertebrobasilar insufficiency. Therefore, patients with PCS result in higher mortality and morbidity rates compared to anterior circulation strokes, attributed to vascular geometric changes (Ikram and Zafar, 2024). Variations in the VBS hold substantial clinical relevance for the diagnosis of posterior circulation syndromes, including pontine infarction, cranial nerve palsy, cerebellar dysfunction,

Table 5. Statistical analysis of variables compared with the BA dimensions and angle

Variables		BA Length	BA diameter			BA angle
			At origin	Mid-pons	At termination	
Age group	21 – 30 yrs	30.69±1.17	2.84±0.25	2.75±0.24	2.69±0.25	37.39±4.23°
	31 – 40 yrs	30.06±0.96	3.00±0.38	2.94±0.38	2.91±0.39	37.84±5.38°
	41 – 50 yrs	31.36±1.30	3.31±0.41	3.27±0.35	3.21±0.33	40.19±4.64°
	51 – 60 yrs	33.48±0.67	3.50±0.63	3.51±0.30	3.40±0.25	40.80±4.99°
P - value		**<0.0001***	**<0.0001***	**<0.0001***	**<0.0001***	**0.002***
Gender	Male (48)	31.32±1.50	3.08±0.49	3.07±0.40	3.04±0.39	39.24±4.81°
	Female (52)	31.30±1.49	3.15±0.47	3.07±0.45	2.98±0.43	37.85±5.07°
P - value		0.961	0.464	0.990	0.515	0.613
DYS	Yes (16)	32.77±1.54	3.44±0.44	3.40±0.36	3.31±0.32	39.32±5.05°
	No (84)	30.22±1.47	3.06±0.46	3.01±0.41	2.95±0.40	38.37±4.97°
P - value		**0.004***	**0.003***	**0.001***	**0.001***	0.486
HTN	Yes (22)	32.24±1.48	3.44±0.41	3.40±0.36	3.30±0.33	38.82±5.02°
	No (78)	31.05±1.39	3.03±0.46	2.97±0.40	2.93±0.40	38.44±4.99°
P - value		**0.001***	**<0.0001***	**<0.0001***	**<0.0001***	0.751
DM	Yes (30)	32.36±1.53	3.37±0.57	3.35±0.39	3.25±0.37	41.18±3.98°
	No (70)	30.86±1.23	3.01±0.39	2.95±0.38	2.91±0.39	37.38±4.94°
P - value		**<0.0001***	**0.001***	**<0.0001***	**<0.0001***	**<0.0001***
CAD	Yes (12)	33.18±1.01	3.72±0.29	3.63±0.28	3.50±0.21	42.32±1.57°
	No (88)	31.05±1.36	3.04±0.44	2.99±0.38	2.94±0.38	38.00±5.06°
P - value		**<0.0001***	**<0.0001***	**<0.0001***	**<0.0001***	**0.004***

cortical deficits, vestibular complaints, and visual field anomalies (Songur et al., 2007). The embryological origin is a primary factor in head and neck vascular abnormalities. Our research may significantly influence surgical techniques by offering essential information regarding arterial dimensions.

In the fourth week of embryonic development, the brain is supplied with blood by the primitive carotid artery. The three paired longitudinal neural arteries—the primitive trigeminal, primitive hypoglossal, and primitive pro-atlantal arteries—developed along the ventral surface of the hindbrain and coalesced to form the basilar arterial plexus. The carotid arteries primarily supply these three arteries via four significant artery anastomoses: the trigeminal, otic, hypoglossal, and pro-atlantal intersegmental (Larsen, 2015). Shortly after its formation, the ipsilateral longitudinal neural artery connects cranially with the distal internal carotid artery (ICA), which subsequently develops into the posterior communicating artery. Upon establishment of communication, the anastomotic vascular begins to regress in the following order: otic, hypoglossal, trigeminal, and proatlantal arteries. Consequently, defects or failures in the fusion of the longitudinal arteries lead to different malformations in the basilar artery, including persisting primitive arteries. The enduring foetal configuration of the posterior cerebral artery from the internal carotid artery in adults may lead to a foetal-type posterior cerebral artery. Persistent trigeminal and hypoglossal arteries represent the predominant variant, often correlated with cerebral aneurysms and arteriovenous malformations (Shaban et al., 2013). The extensive course of the VA (V1-V4 segments) originates from two sources: cervical intersegmental arteries and pro-atlantal arteries. Delayed fusion and anastomosis of the pro-atlantal and other cervical intersegmental arteries may lead to the emergence of VA hypoplasia or atresia (Ballesteros et al., 2013).

Table 6. Statistical analysis of variables compared with the BA course and fenestrations

Variables		BA Course			Fenestrations	
		Straight	"C"	"S"	Yes	No
Age group	21-30 years (25)	**8**	**14**	**3**	**0**	**25**
	31-40 years (35)	18	13	4	0	35
	41-50 years (22)	4	16	2	4	18
	51-60 years (18)	10	6	2	1	17
	P-value	**0.033***	**0.027***	**0.031***	**0.011***	
Gender	Male (48)	19	25	4	3	45
	Female (52)	21	24	**7**	2	50
	P-value	0.235	0.281	0.252	0.582	
DYS	Yes (16)	3	11	2	2	14
	No (84)	37	38	9	3	81
	P-value	0.093	0.085	1.000	0.133	
HTN	Yes (22)	6	12	4	4	18
	No (78)	34	37	7	1	77
	P-value	0.168	0.556	0.252	**0.001***	
DM	Yes (30)	12	15	3	3	27
	No (70)	28	34	8	2	68
	P-value	0.622	0.896	1.000	0.133	
CAD	Yes (12)	3	8	1	2	10
	No (88)	37	41	10	3	85
	P-value	0.353	0.192	1.000	**0.048***	

Table 7. Comparison of VA dimensions and angle among various studies

Variables	Dharshini P et al., 2022 (50 CT images)	Songur et al., (109 cadavers)	Akkasoglu S et al., 2019 (250 CTA)	Ballesteros et al., (100 cadavers)	Omotoso B.R et al., 2021 (554 CTA)	Present study, 2025 (100 Non-contrast MRA)
VA length - Right	32.3 mm	-	-	32.47mm	31.50 mm	32.31±2.05 mm
VA length - Left	33.4 mm	-	-	33.89 mm	32.36 mm	33.15±3.47 mm
VA diameter - Right	3.25 mm	2.85 mm	2.4 mm	3.03±0.81mm	3.17 mm	2.35±0.57 mm
VA diameter - Left	3.27 mm	3.02 mm	2.5 mm	3.12±0.85mm	3.17 mm	2.50±0.56 mm
VA angle – Right	-	VBJ angle – 52.2	48.95°	-	VBJ angle – 46 °	44.19 ± 6.67°
VA angle- Left			52.2°	-		52.31± 3.16°

- Indicates absence of measurement, CTA – Computerized Tomography Angiography, MRA – Magnetic Resonance Angiogram

Intracranial section of the Vertebral artery (V4 segment)

The vertebral arteries arise from the subclavian artery and follow a lengthy, tortuous course through the cervical and cranial areas. The structure is broadly categorised into four segments (V1 to V4), with segments V1-V3 traversing extracranially and segment V4 being intracranial, extending from the foramen magnum to the BA origin (Standring, 2016). The configuration of the BA primarily relies on the predominant pattern of the VA. Morphological alterations account for 25% of PCS and represent a prevalent cerebral location for aneurysm development (Dzierzanowski et al., 2017). This study reported the morphometrics of the intracranial portion of the VA (V4 segment), with results compared to other studies in Table 7. The findings regarding VA length and diameter in this study were consistent with those of previous research, despite racial variations and the methodology employed (Akkasoglu et al., 2019; Dharshini et al., 2022). Our observations indicated that left VA dominance was significantly greater than that of the right, consistent with prior studies (Ballesteros et al., 2013; Omotoso et al., 2021).

Hypoplastic VA is an uncommon embryonic anomaly defined by a luminal diameter of less than 2 mm, with a prevalence between 1.9% and 26.5% (Songur et al., 2007). In this study, a VA diameter of less than 2 mm, measured 1 cm below the BA origin, was classified as hypoplasia. It occurred more frequently on the right side, aligning with prior studies. This is due to an embryological fact that the left subclavian artery originates directly from the aortic arch, which experiences elevated shear stress. Therefore, it leads to augmented blood flow to the dominant left VA and diminished flow to the right side, culminating in hypoplasia. Songur et al. (2007) and Ballesteros et al. (2013) have documented VA hypoplasia in 39.4% and 18.9% of cadaveric specimens, respectively. Hypoplastic VA results in hypoperfusion and vertebrobasilar insufficiency, typically presenting asymptomatically in the initial stages. Therefore, it is regarded as a benign anatomical variety. In recent years, it has earned attention due to its long-term risk of neurological consequences, including vertebrobasilar stroke, particularly affecting the posterior inferior cerebellar artery (PICA), migraine, vestibular neuronitis, and medullary syndrome (Akkasoglu et al., 2019).

VA atresia is characterized as hypoplastic terminal VA, a rare embryological defect with a prevalence of 9% (Omotoso et al., 2021). Kovac et al. identified this anomaly in nine patients, while Omotoso et al. (2021) recorded it in 6.7% of cases.

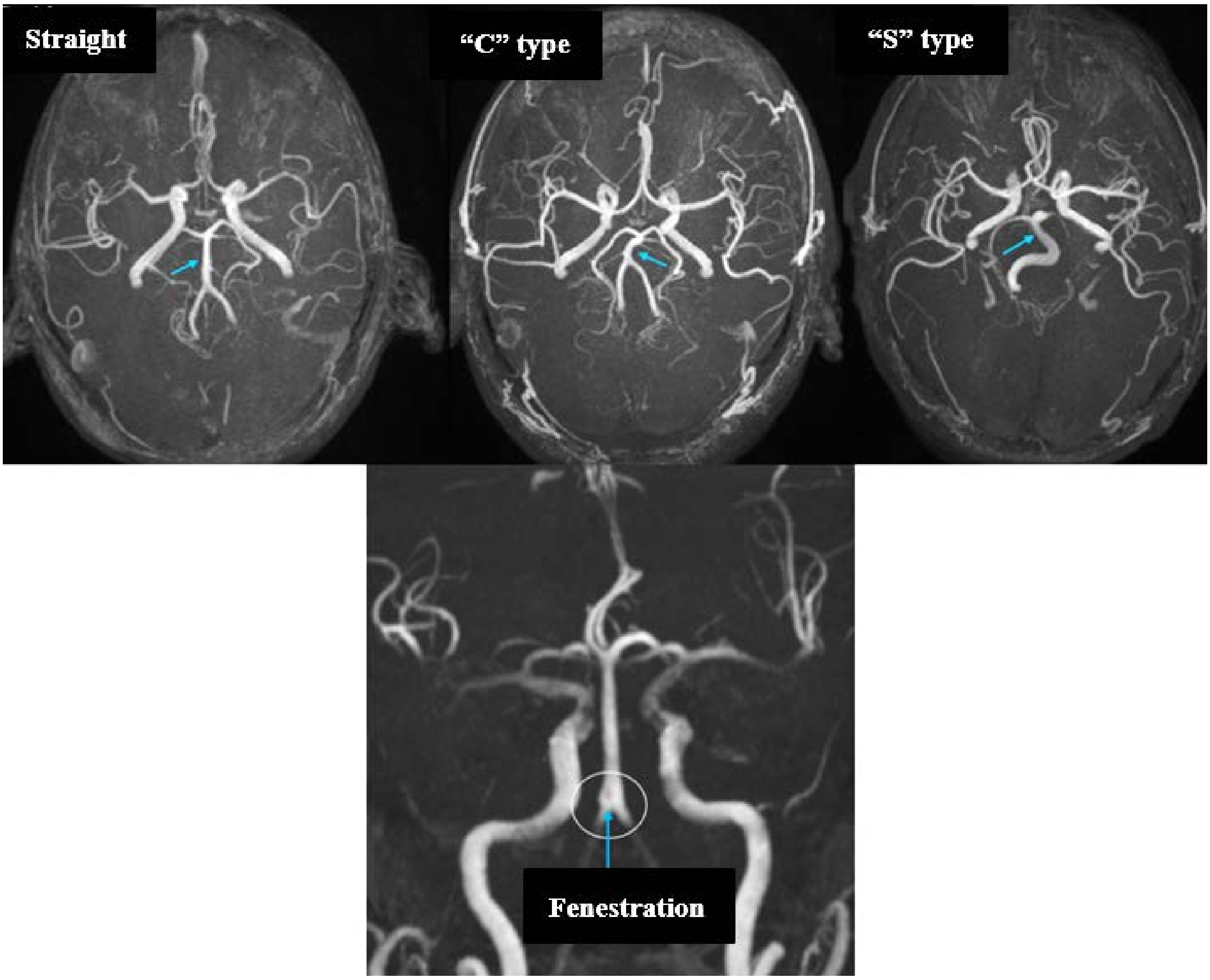

Fig. 6.- Non-contrast MRA showing the variant BA Course (Blue arrow – indicates curvature). Straight – BA course along straight, “C” type – BA bent towards right side, “S” type – BA bent towards left side in the middle of its course. Presence of Fenestrations near the BA origin (blue arrow encircled).

Table 8. Comparison of the BA dimensions and angle among various studies

Studies	Mode of study	No. of brains	Average BA length	Average BA diameter	Angle of BA
Mamatha et al., 2012.	Cadaver	20	33 ± 3 mm	2.6 – 3.5 mm	45 – 70º
Vijayakumar et al., 2020.	Cadaver	96	31 ± 0.3 mm	2 to 5 mm	45 – 70º
Akkasoglu et al., 2019.	CTA	250 cases	-	-	32 ± 12.15º
Celebioglu EC et al., 2017.	MRA	100 cases	-	3.20 ± 0.428 mm	-
Zhang et al., 2013.	MRA	60 cases	33.77 mm	3.29 ± 0.45 mm	-
Present study, 2024	Non-contrast MRA	100 cases	31.31± 1.49 mm	3.01 to 3.12 mm	38.52 ± 4.97º

We have recorded two cases of hypoplastic terminal VA on the left side, terminating as the PICA, as illustrated in Fig. 2A. In these cases, the contralateral VA proceeds to form a BA. The current investigation did not document further variants, including fenestrations and duplications in the VA.

Dimensions of the basilar artery

The length and diameter of the BA were measured (Fig. 3), and the findings are compared with other studies in Table 8. The study findings aligned with previous literature due to varying research methodologies (Akkasoglu et al., 2019; Vijayakumar et al., 2020; Zhang et al., 2014). Intracranial arterial dolichoectasia is an asymptomatic clinical syndrome characterized by an increase in the length and diameter of arteries resulting from congenital vasculopathy. The incidence varies from 0.06% to 5.8% in healthy individuals, and to 12% in stroke patients (Vasovic et al., 2012). The VBS is the most frequently impacted intracranial segment, known as vertebrobasilar dolichoectasia (VBD), with a frequency of 6.48% in the general population (Vasovic et al., 2012). Basilar artery dolichoectasia occurs in 3.1 to 13.9% of ischemic patients, and 1.3% of healthy individuals. VBD was first proposed by Smoker et al. in 1968, who mentioned that a VA and BA diameter over 4.5 mm, regardless of the course, constituted the diagnostic criterion. In the current investigation, 4% of individuals had basilar artery ectasia, but no cases of VA involvement were reported.

Patients with VBD exhibit significant disabilities, including ischemic stroke, hydrocephalus, cerebellar dysfunction, and brainstem compression, resulting from increased arterial stiffness and vascular resistance (Ballesteros et al., 2013). Radiologists and neurosurgeons often fail to identify this problem, as it represents a normal variance in healthy individuals. The diagnosis of VBD must be based on the clinical manifestation of posterior circulation dysfunction, with or without accompanying occlusive illness (Vasovic et al., 2012). Recent studies have indicated that an enlarged BA diameter is independently linked to cardiovascular mortality, attributable to carotid intima-media thickness (IMT), a significant predictor of myocardial infarction (Celebioglu et al., 2017). Consequently, pre-operative awareness of the BA dimensions is crucial for neurosurgeons to evaluate cerebrovascular and cardiovascular incidents (Mamatha et al., 2012).

Vertebral and Basilar arteries angle

The angle of the VA and BA is crucial in the surgical management of aneurysms, representing 4% of the posterior cerebral fossa (Dzierzanowski et al., 2017). The VBA angle was assessed and compared with previous studies in Tables 7 and 8. Limited studies have quantified VBA angle in imaging investigations, and their findings align with the current study (Akkasoglu et al., 2019). Conversely, some authors have documented a greater mean VA angle of approximately 95° (Dzierzanowski et al., 2017). A recorded VBA angle at the vertebrobasilar junction was 51° in Black patients, 47° in Caucasians, and 42° in Indians (Omotoso et al., 2021). The discrepancy may arise from the asymmetrical configuration of VA, leading to a pronounced or obtuse edge on its confluence site. The hemodynamic influence of vertebral blood flow dictates the angle of the BA. Yangchen et al. (2023) have introduced a novel concept, "dominant VA angle > 80°", indicative of

Table 9. Comparison of the BA formation and termination among various studies in cadaveric brains

Variables		Vijayakumar et al., 2020 (n - 96)	Wankhede et al.,2014 (n - 40)	Kalaiyarasi et al., 2022 (n - 100)	Satapathy et al.,2022 (n - 38)	Patel et al., 2015 (n - 60)	Present study., (n - 100)
Variations in the Origin	Above P.Med., junction	8 (8.3%)	10 (25%)	2 (5.26%)	2 (2%)	4 (6.67%)	12(12%)
	At P.Med junction	65 (67.7%)	25 (62.50%)	53 (92.11%)	84 (84%)	53 (88.33%)	82 (82%)
	Below P.Med., Junction	23 (24%)	5 (12.50%)	1 (2.63%)	14 (14%)	3 (5%)	6 (6%)
Variations in the termination	Above P.Mes., junction	10 (10.4%)	13 (32.50%)	2 (5.26%)	3 (3%)	2 (3.33%)	8 (8%)
	At PMes junction	66 (68.8%)	20 (50%)	34 (89.47%)	90 (90%)	57 (95%)	88 (88%)
	Below P.Mes., junction	20 (20.8%)	7 (17.50%)	2 (5.26%)	7 (7%)	1 (1.67%)	4 (4%)

*P.Med., – Pontomedullary, P.Mes., - Pontomesencephalic.

an elevated risk for atheromatous plaque development in the BA, ultimately resulting in posterior circulation stroke. The VBS shape significantly affects the distortion of the velocity profile and shear stress on the vessel wall, potentially leading to the development of atherosclerotic plaques. Fluctuations in the vertebrobasilar angle complicate the design of implants for interventional neurosurgery operations by neurosurgeons (Vijayakumar et al., 2020).

Basilar artery formation and termination

The basilar artery anatomically originates at the pontomedullary junction and typically concludes as the posterior cerebral arteries bilaterally at the ponto-mesencephalic junction (Standring, 2016). The most common point of BA origin reported in our study was at the level of the pontomedullary junction. Many authors have reported similar findings in their literature, and few studies have documented contrary results (Table 9). Akar et al. (1994) have documented a higher incidence of BA originating above the pontomedullary junction, with 54%, followed by 36% at the level, and 10% below the junction. Songur et al. (2007) reported a more significant number of BA formations below the pontomedullary junction in 67%, followed by 20% at the level and 13% above the level. Similarly, BA termination was significantly seen at the level of the ponto-mesencephalic junction, which coincides with previous reports (Patel et al., 2015; Satapathy, 2018).

Few authors have reported different branching patterns of BA at the termination site in the cadaveric specimens, and the results are compared in Table 10 (Li et al., 2023; Nagawa et al., 2018). No literature was reported on the variations at the termination site in imaging studies. This is the first study to document the variant branching pattern of BA in our population using imaging studies (Fig. 4). According to Gunnal, the variations in the mode of termination were classified as bifurcation, trifurcation, quadri-furcation, penta-furcation, and non-furcation (Sonlanmasinin and Degiskenligi, 2015). The most common termination mode observed in the present study was bifurcation, which was consistent with previous studies (Table 10).

Another common variant was fetal-type PCA, in which embryological derivation of PCA from the internal carotid artery had a prevalence of 15-32% in healthy subjects and 5-36% in patients with cerebral infarction (Shaban et al., 2013). It can be classified into complete and partial types. In the complete type, PCA entirely originates from the ICA with no connection with the basilar artery.

Table 10. Comparison of the morphological variations in the termination of the BA among various studies

Mode of Termination	Kalaiyarasi et al., 2022 (n – 100)	Nagawa E et al., 2018 (n-115)	Gunnal S et al., 2014 (n-170)	Present study., 2024 (n-100)
Bifurcation	93 (93%)	56 (48.7%)	140 (82.35%)	70 (74%)
Trifurcation	3 (3%)	26 (22.6%)	9 (5.29%)	4 (4%)
Quadrifurcation	3 (3%)	25 (21.7%)	10 (5.88%)	9 (9%)
Pentafurcation	1 (1%)	7 (6.1%)	6 (3.52%)	-
Non-furcation	-	-	5 (2.94%)	4 (4%)
Fetal type PCA	-	-	-	Right – 5 (5%) Left – 4 (4%) Both – 4 (4%)

In the partial type, PCA originates from the ICA with a slight connection with the basilar artery (Vijayakumar et al., 2020). In patients with fetal PCA, a significant part of the brain is dominantly supplied by the anterior circulation. Since the MCA and PCA are connected to the ICA above the tentorium and the vertebrobasilar artery below the tentorium, there is failure of leptomeningeal collaterals between the ICA and the vertebrobasilar system in the complete type (Shaban et al., 2013).

The variations in the branching pattern of BA at the termination site are mostly congenital in origin. The embryological cause is mainly due to varying extents and inconsistent degrees of fusion between longitudinal neural arteries at the craniocaudal end, which may result in different patterns of BA (Songur et al., 2007). Clinically, variant origin and termination of the BA are the most frequent sites for the formation of atherosclerosis and saccular aneurysm due to abnormal flow patterns (Wankhede et al., 2014). The position of the BA termination also governs the type of surgical approach to be taken to treat an aneurysm. Patients with fetal-type PCA are more prone to develop stroke because it shuts down the blood supply to either side of the hemispheres (Vijayakumar et al., 2020). Consequently, a comprehensive understanding of the variations in origin and termination is crucial for the diagnosis and treatment of aneurysms. This necessitates meticulous precautions to avoid injury to critical structures, such as the mammillary body and optic chiasma at the termination site (Mamatha et al., 2012).

Basilar artery course and fenestrations

The BA usually courses straight along the ventral part of the pons. Asymmetrical blood flow with a variable internal diameter of the VA induces greater curving of the BA, which may subsequently cause atherogenesis and peri-vertebrobasilar junctional infarcts (Zhang et al., 2014). The most frequently observed curvature in this study is the "C" type, and very few investigators have documented a "J"-shaped course, and the results of the variant course of the BA are compared in Table 11. Previous studies have proved that the difference in the right and left VA diame-

Table 11. Comparison of the BA course among various studies

Studies	Mode of study	No. of brains	Variations in the course
Wankhede et al., 2014.	Cadavers	40	C – 37.50%, S – 5%, Straight – 55%
Akkasoglu et al., 2019.	CTA	250	C – 55.8%, S – 34.6% Straight – 9.6%
Zhang et al., 2013.	MRA	60	C – 33%, S – 8%Straight – 19%
Ngo MT et al., 2020.	MRI	154	C – 67%, S – 6%, Straight – 15%, J – 15%
Present study, 2024	Non-contrast MRA	100	C – 49%, S – 11%, Straight – 40%

ter was the only independent predictor that confirmed moderate to severe BA curvature (Ngo et al., 2020). The predisposing factor for abnormal curvature is arteriosclerosis due to loss of elasticity and arterial wall thickening, which causes extension, elongation, and bending. It may also slow down the blood flow and make them susceptible to the formation of microthrombi and atherosclerotic plaques, eventually leading to microvascular obstruction. Increased vascular resistance in a curved BA can cause hypoperfusion, infarction, and wall shear stress, which may sometimes compress the pontine perforating artery, resulting in pontine infarction (Zhang et al., 2014). Recent studies have documented that patients with asymptomatic vertebrobasilar tortuosity experienced more cardiovascular events. Therefore, patients with abnormal BA curvature should receive more clinical attention to overcome neurological complications (Hong et al., 2009).

Fenestration consists of a single artery with two channels that may or may not share the adventitial layer. It is a rare variant of the intracranial artery. However, the BA is the most common site for fenestration among cerebral arteries due to incomplete fusion of bridging areas between two longitudinal arteries in a craniocaudal direction (Dodevski et al., 2011). It can occur anywhere along the course of the BA, but the most frequent site is the proximal segment close to the VA. The incidence of BA fenestrations has been reported as 0.28–5.26% in cadavers, 0.3–0.6% in angiographic studies, and 1–2.07% in magnetic resonance angiography (Sanders, 1983). In the present study, the fenestration was close to the BA origin (Figure 6), and the results of previous literature were compared in Table 12. Sander et al. have reported a prevalence of 7% aneurysms at the site of fenestrations. Clinically, it is strongly associated with aneurysms, cerebral arteriovenous malformations (AVMs), and pontine infarction due to hemodynamic stress, the absence of tunica media, and the presence of turbulent blood flow at the vertebrobasilar junction (Tasker and Byrne, 1997). Sometimes, it may also be misdiagnosed as arterial thrombosis or dissection in patients with stroke, requiring angiographic studies to confirm the diagnosis (Dodevski et al., 2011).

Limitation

This study was limited by the sample size of non-contrast MRA images, which may affect the generalizability of the findings. Future research with a larger sample is recommended to better represent these variations.

CONCLUSIONS

The present study has documented all the morphometric variables of VBS in an imaging study of non-contrast MRA. The intracranial part of the VA dimensions was higher on the left side than the right. We have reported many variations, such as hypoplastic VA, single VA with atresia, variations in the BA termination, and different types of curvature with fenestrations in the BA. The morphometric variables of VBS dimensions have shown statistically significant differences among different age groups and high-risk groups. As age advances, morphological variations in the VBS may facilitate vascular ischemic events in the posterior cerebral circulation. Therefore, the results of VBS morphometry obtained in our study could be used as a reference value for various age groups and high-risk groups to evaluate and diagnose

Table 12. Comparison of the BA fenestrations among various studies

Studies	Mode of study	No. of brains	Presence of Fenestrations
Vijayakumar et al., 2020.	Cadavers	96	2%
Wankhede et al., 2014.	Cadavers	40	2.5%
Dodevski A et al., 2011.	CTA	50	4%
Tasker AD., 1997.	CTA	103	8%
Present study, 2024	Non-contrast MRA	100	5%

cerebral and cardiovascular pathologies and plan for neurosurgical procedures in the posterior cranial fossa.

ACKNOWLEDGEMENTS

The researchers acknowledge the Department of Radiology and Neurology, VMMC & H, Karaikal, professors, for providing data and briefly reviewing this manuscript. The authors sincerely thank the patients from whom the data were collected for participating in the research. Results from such research can potentially increase humankind's overall knowledge, which can then improve patient care.

AUTHOR CONTRIBUTIONS

Conceptualization: Dr. C. Regina, J. Kalaivanan, Dr. K. Sudhakar. Data acquisition, analysis and interpretation: Dr. C. Regina, Dr. S. Muthu Isai Drafting and critical revision of the manuscript: Dr. C. Regina. Statistical analysis: Dr. S. Sathish Kumar, K. Vanidha. Approval of the final version of the manuscript: all authors.

ABBREVIATIONS

3D-TOF – Three-dimensional time-of-flight

BA – Basilar artery

CAD – coronary artery disease

CT – Computed Tomography

DM – Diabetes Mellitus

DYS – Dyslipidaemi

HTN – Hypertension

MRA – Magnetic Resonance Angiogram

PCA – Posterior cerebral artery

PCS – Posterior circulation stroke

VA – Vertebral artery

VAD – Vertebral artery diameter

VBD – Vertebral artery dolichoectasia

VBS – Vertebrobasilar system

REFERENCES

AKAR ZC, DUJOVNY M, SLAVIN KV, TORTOSA GE, AUSMAN JI (1994) Microsurgical anatomy of the intracranial part of vertebral artery. *Neurol Res*, 16(3): 171-180.

AKKASOGLU S, ALDUR M, SARGON M, CELEBIOGLU EC, CALISKAN S (2019) Morphometry and geometry of the formation of basilar artery. *Med-Science,* 8(4): 980-985.

BALLESTEROS L, FORERO P, QUINTERO I (2013) Morphological expression of the anterior spinal artery and the intracranial segment of the vertebral artery: a direct anatomic study. *Rom J Morphol Embryol*, 54(3): 513-518.

ÇELEBIOĞLU EC, ALDUR MM, TUNALI S, HAYRAN M, TAŞÇIOĞLU AB, SARGON FM (2017) A comparison of basilar artery diameters measured by T2WI and TOF MR angiography. *Surg Radiol Anat*, 39: 1243-1247.

DHARSHINI P, RAGHUNATH G, GURUSAMY K, BEGUM Z, DHAMODARAN S, KARUNAKARAN B, MARIA FRANCIS Y, KAVERIPAKKAM V (2022) Morphometric study of the intracranial segment of the vertebral artery. *Cureus*, 14(2): e22137.

DODEVSKI A, LAZARESKA M, TOSOVSKA-LAZAROVA D, ZHIVADINOVIK J, STOJKOSKI A (2011) Basilar artery fenestration. *Folia Morphol*, 70(2): 80-83.

DZIERŻANOWSKI J, SZARMACH A, BAŚCIK B, CZAPIEWSKI P, MUC A, PISKUNOWICZ M, KRAKOWIAK M, SZMUDA T, SŁONIEWSKI P, SZUROWSKA E, WINKLEWSKI PJ (2017) Intracranial region of the vertebral artery: morphometric study in the context of clinical usefulness. *Folia Morphol*, 76(3): 379-387.

HONG JM, CHUNG CS, BANG OY, YONG SW, JOO IS, HUH K (2009) Vertebral artery dominance contributes to basilar artery curvature and peri-vertebrobasilar junctional infarcts. *J Neurol Neurosurg Psych*, 80(10): 1087-1092.

IKRAM A, ZAFAR A (2024) Basilar Artery Infarct. (Updated 2023 Aug 8). StatPearls Publishing. Available from: https://www.ncbi.nlm.nih.gov/books/NBK551854/

KALAIYARASI S, SIVAKAMI T, SUMATHI S (2022) Anatomical variability in the origin, length and termination of basilar artery and its clinical implications. *Int J Anat Radiol Surg*, 11: AO09-AO13.

KOVAČ JD, STANKOVIĆ A, STANKOVIĆ D, KOVAČ B, ŠARANOVIĆ D (2014) Intracranial arterial variations: a comprehensive evaluation using CT angiography. *Med Sci Monit*, 20: 420-427.

LARSEN'S (2009) *Human Embryology*. 5th Edition. Churchill Livingstone, New York, pp 350-352.

LI Y, GUO R, ZHANG X, YANG Y, YAN Y, YUAN X, WANG C, XIE S (2023) Effect of dominant vertebral artery angle on basilar artery curvature and plaque. *Quant Imaging Med Surg*, 13(9): 5748-5758.

MAMATHA H, D'SOUZA AS, PALLAVI, SUHANI S (2012) Human cadaveric study of the morphology of the basilar artery. *Singapore Med J*, 53(11): 760-763.

NAGAWA E, OKELLO M, KIRYOWA H, MWAKA E (2018) Terminal end variations and common pathological abnormalities of the basilar artery among the Ugandan population: a human autopsy study. *J Morphol Sci*, 35: 110-115.

NGO MT, KWAK HS, CHUNG GH (2020) Change in basilar artery length and bending according to aging and vertebral artery dominance: A longitudinal study. *Sci Rep*, 10(1): 8904.

OMOTOSO BR, HARICHANDPARSAD R, SATYAPAL KS, MOODLEY IG, LAZARUS L (2021) Radiological anatomy of the intracranial vertebral artery in a select South African cohort of patients. *Sci Rep*, 11(1): 12138.

PATEL S, ZALAVADIYA D, GANATRA D, NAGDEV K, VANIYA V (2015) Morphometry of basilar artery in population of Gujarat. *J Anat Soc India*, 64(1): 62-66.

SANDERS WP, SOREK PA, MEHTA BA (1993) Fenestration of intracranial arteries with special attention to associated aneurysms and other anomalies. *Am J Neuroradiol*, 14(3): 675-680.

SATAPATHY B, MOHAPATRA C (2018) Morphometric study of basilar artery in the Eastern Indian population. *Asian J Neurosurg*, 13(03): 689-692.

SHABAN A, ALBRIGHT KC, BOEHME AK, MARTIN-SCHILD S (2013) Circle of Willis variants: fetal PCA. *Stroke Res Treatment*, 2013(1): 105937.

SMOKER WR, CORBETT JJ, GENTRY LR, KEYES WD, PRICE MJ, MCKUSKER S (1986) High-resolution computed tomography of the basilar artery: Vertebrobasilar dolichoectasia: clinical-pathologic correlation and review. *AJNR Am J Neuroradiol*, 7: 61-72.

SONGUR A, GONUL Y, SZEN SA, KUCUKER H, UZUN I, BAS O, TOKTAS M (2007) Variations in the intracranial vertebrobasilar system. *Surg Radiol Anat*, 30(3): 257-264.

SONLANMASININ İK, DEĞIŞKENLIĞI A (2015) Anatomical variability in the termination of the basilar artery in the human cadaveric brain. *Turk Neurosurg*, 25(4): 586-594.

STANDRING S (2016) *Gray's Anatomy. The Anatomical Basis of Clinical Practice*. 41st Edition. Elsevier, UK, pp 283-286.

TASKER AD, BYRNE JV (1997) Basilar artery fenestration in association with aneurysms of the posterior cerebral circulation. *Neuroradiology*, 39: 185-189.

VASOVIC L, TRANDAFILOVIC M, JOVANOVIC I, UGRENOVIC S, VLAJKOVIC S (2012) Vertebral and/or basilar dolichoectasia in human adult cadavers. *Acta Neurochirurg*, 154: 1477-1488.

VIJAYAKUMAR AU, SUDHAKARAN M, YOVEL LJ (2020) Human basilar artery: morphology & variations. *AIMS Medical Science*, 7(4): 278-292.

WANKHEDE HA, HOSMANI PB, NIMJE DA (2014) Morphological study of the basilar artery in adult human cadavers. *Int J Anat Res*, 2(03): 497-502.

ZHANG DP, ZHANG SL, ZHANG JW, ZHANG HT, FU SQ, YU M, REN YF, JI P (2014) Basilar artery bending length, vascular risk factors, and pontine infarction. *J Neurol Sci*, 338(1-2): 142-147.