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Anatomy Section

Original Article

Anatomical Variability in the Origin, Length and Termination of Basilar Artery and its Clinical Implications

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ABSTRACT

Introduction: Basilar artery is one of the frequent locations for cerebrovascular lesions like aneurysm, thrombosis and haemorrhage. Hence,an intricate knowledge of its variant anatomy is essential for diagnostic procedures like Computed Tomography (CT) brain and Magnetic Resonance (MR) angiography. An accurate interpretation of the arterial pattern will help in performing surgeries of brain stem precisely. Any misinterpretation of arterial pattern may affect the diagnosis, treatment and prognosis of the disease.

Aim: To elucidate the anatomical variability in the origin, length and termination of basilar artery.

Materials and Methods: This cross-sectional study was conducted from May 2019 to April 2020, on 100 human cadaveric brain specimens available in the Department of Anatomy at Government Medical College Pudukkottai, Tamil Nadu, India. The morphology of the basilar artery was studied with respect to the level of the origin, length, level and mode of termination of the basilar artery.

Results: Among the 100 human cadaveric brain specimens dissected and examined (mean age of 63.4 years), the mean length of basilar arteries was 2.792±0.32 cm. In all 100 specimens, the basilar artery was formed by the union of right and left vertebral arteries. The basilar artery was found to originate at the level of pontomedullary junction in 84%, below the pontomedullary junction in 14% and above the pontomedullary junction in 2% of specimens. The termination of basilar artery was at the level of upper border of pons in 90%, below the upper border of pons in 7% and above in the interpeduncular fossa in 3% of specimens. The mode of termination was 'V' shaped in 83%, 'T' shaped in 10%, trifurcation in 3%, quadrifurcation in 3% and pentafurcation in 1% of specimens. Fenestration of basilar artery was seen in 1%. Other variations of basilar artery like duplication were not detected.

Conclusion: The level and mode of origin and termination of basilar artery are important with regard to surgical procedures in the lower basilar region. Variations in the basilar artery should be identified preoperatively so that neurosurgeons can modify the surgical approaches.

Keywords: Cadaveric study, Brain specimens, Morphological variations, Surgical significance

INTRODUCTION

The brain is richly supplied with blood through vertebrobasilar and carotid systems of arteries. The vertebrobasilar system constitutes intracranial part of right and left vertebral arteries, basilar artery and their branches. The circle of Willis, which is formed by branches of basilar and internal carotid arteries, provides collateral circulation in case of occlusion of either carotid or basilar system of arteries. This value of cerebral arterial circle, as potential anastamosis may be impaired by anatomical variations [1]. Basilar artery, formed by the union of right and left vertebral arteries, is an important artery which supplies the hindbrain. Anatomical variations of basilar artery are associated with increased incidence of vascular lesions like aneurysms or haemorrhage [2]. Hence, the knowledge about these variations is mandatory in performing surgical procedures and radiological interpretations.

Basilar artery variations are common. There may be variations in the origin and level of origin of the basilar artery. It may be the continuation of single vertebral artery [3,4] or it may be a branch of cervical part of internal carotid artery [5]. Usually, it arises at the level of pontomedullary junction. Variations like duplication or fenestration of basilar artery have been reported [3]. Basilar artery usually terminates at the level of upper border of pons but it may terminate at the interpeduncular fossa and is the most frequent site for aneurysm [4,6]. An understanding of anatomical variability of basilar artery is essential for diagnostic procedures like CT brain and MR angiography. These variations have to be considered in the treatment of aneurysms and while performing microsurgery of skull base tumours.

There are many studies on variations in the basilar artery available by imaging techniques, but these indirect methods have limited resolution and accuracy compared to direct visualisation. Various morphological studies of basilar artery in cadavers also have been done but on a limited sample and they have documented mainly its length, level of origin and level of termination [7-11]. There are very few studies that have documented the variations in the mode of termination of basilar artery [12-14]. These multiple branching patterns are believed to be the lodging points for thromboembolic phenomena and aneurysms. Aneurysms at these branching points would also lead to nerve compressions [15].

Hence, this cadaveric study was conducted with the aim to describe the morphological variations of the basilar artery including all these criteria in the population of Tamil Nadu which will create an awareness about the occurrence of frequency of variations in the level of origin and termination, and mode of termination of basilar artery. This awareness will ensure better interpretation of anomalies and safe surgical procedures.

MATERIALS AND METHODS

This observational cross-sectional study was done on 100 intact human brain specimens, available in the Department of Anatomy, Government Medical College Pudukkottai, Tamil Nadu, India, and from routine dissections. Institutional Ethical Committee approval was obtained (IEC. No: 12/2019 dated 16/4/2019). The study spanned one year, from May 2019 to April 2020.

Inclusion criteria: Adult brain specimens with intact basilar artery and its branches were included.

Exclusion criteria: Brain specimens that were structurally damaged, and specimens belonging to children were excluded from the study.

The base of the brain was examined and the basilar artery over the ventral surface of the pons was dissected. The origin of basilar artery was clearly identified. The level of formation of basilar artery was noted and classified according to its relation with the pontomedullary junction. The length of basilar artery was measured from its site of formation to site of termination and measured using a measuring scale and recorded in metric system. The level of termination of basilar artery was noted with regard to its relation with the junction of pons and midbrain. The mode of termination and the terminal branching pattern of the basilar artery was carefully dissected and the observations were classified. The observations were recorded and photographs taken.

STATISTICAL ANALYSIS

The findings were analysed using standard descriptive statistical analytical methods. Results on continuous measurements are presented as mean±SD (minimum-maximum), and results on categorical measurements are presented as percentages.

RESULTS

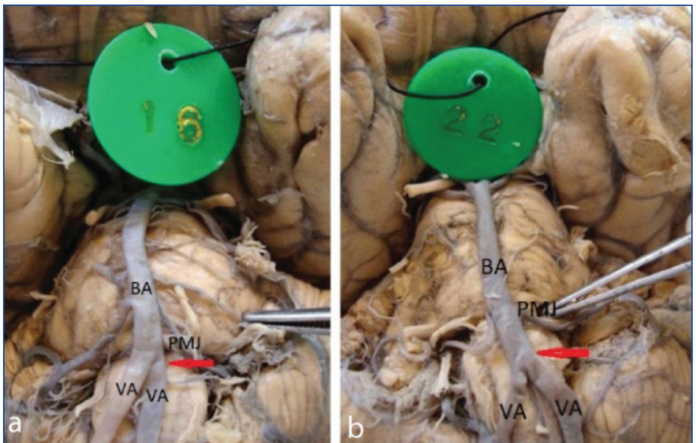
Total of 100 cadaveric brain specimens analysed, age ranging from 45 to 70 years (mean age of 63.4 years). Basilar artery was found in the median sulcus over the ventral surface of the pons in all the 100 specimens. The artery was formed by the union of right and left vertebral arteries in all specimens.

The length of basilar artery was found to be within the normal range of 2.6-3.0 cm in 73% of specimens. The mean length was found to be 2.792±0.32 cm-the minimum length being 2.3 cm, and maximum length being 4.8 cm [Table/Fig-1].

Length of basilar artery	Frequency (n)
2-2.5 cm	19
2.6-3.0 cm	73
3.1-3.5 cm	7
>3.5 cm	1

[Table/Fig-1]: Frequency of the length of basilar artery; Total N=100 specimens.

The level of origin of basilar artery or the Vertebro-Basilar Junction (VBJ) was found to be at pontomedullary junction in 84 specimens [Table/Fig-2a]. It was located below the pontomedullary junction in 14 specimens [Table/Fig-2b], and above that level in 2 specimens.



[Table/Fig-2]: a) Level of formation of basilar artery at Pontomedullary Junction (PMJ); b) Level of formation of basilar artery below Pontomedullary junction (PMJ).
BA: Basilar artery; VA: Vertebral artery; Arrow: level of formation

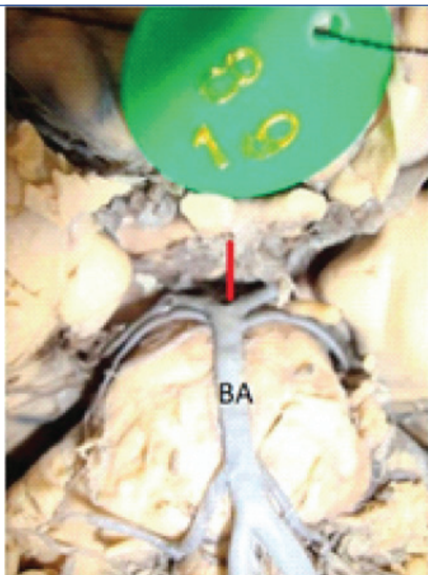
Depending upon the level of origin and level of termination of basilar artery the specimens were divided into three groups [Table/Fig-3, 4a and 4b]. The mean length of basilar artery was 3.1±0.07 cm in specimens where the level of origin of basilar artery was below the pontomedullary junction. [Table/Fig-2b]. The level of termination was at the level of upper border of pons in 90% [Table/Fig-2a,2b,4a].

S. no	Parameters studied	Variations observed		Numbers (%)	Length of basilar artery
1	Level of origin	At pontomedullary junction		84 (84%)	2.9±0.3 cms
		Below pontomedullary junction		14 (14%)	3.1±0.07 cms
		Above pontomedullary junction		2 (2%)	2.7±0.03 cms
2	Level of termination	At pontomesencephalic junction		90 (90%)	-
		Below pontomesencephalic junction		7 (7%)	-
		Above pontomesencephalic junction		3 (3%)	-
3	Mode of termination	Bifurcation	V-shaped	83 (83%)	-
			T-shaped	10 (10%)	-
		Trifurcation		3 (3%)	-
		Quadrifurcation		3 (3%)	-
		Pentafurcation		1 (1%)	-
4	Others	Fenestration		1 (1%)	-

[Table/Fig-3]: Morphological variations of Basilar artery and their frequencies observed in the present study.

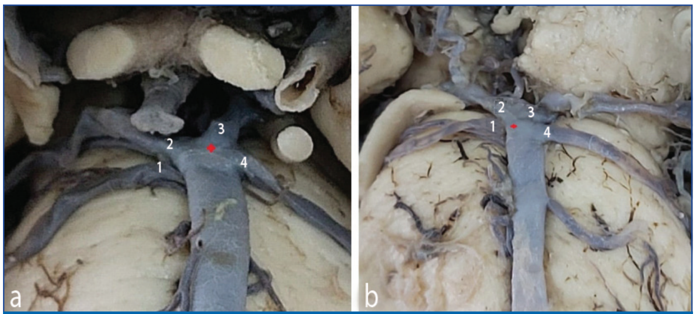
The basilar artery terminated into right and left posterior cerebral arteries by 'V' shaped bifurcation in 83% [Table/Fig-3,5] and by 'T' shaped bifurcation in 10%. Trifurcation into two Posterior Cerebral Artery (PCA) and one Superior Cerebellar Arteries (SCA) was seen in 2% and two SCA and one PCA was seen in 1% [Table/Fig-6a and 6b].

[Table/Fig-4]: a) Level of termination of basilar artery at Pontomesencephalic junction; b) Level of termination below pontomesencephalic junction.
BA: Basilar artery; Arrow: Level of termination



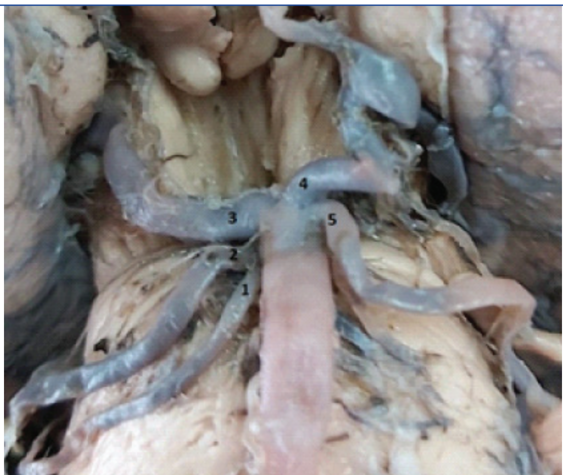
[Table/Fig-5]: V-shaped termination of basilar artery.
BA: Basilar artery; Arrow: Termination

In 3%, the artery terminated by quadrifurcation in a point where bilateral superior cerebellar arteries and bilateral posterior cerebral arteries originate. [Table/Fig-7a and 7b]. Pentafurcation of two posterior cerebral arteries, two right superior cerebellar arteries and one left superior cerebellar artery was seen in 1% [Table/Fig-8]. There was fenestration in the basilar artery in one specimen at the level of its formation [Table/Fig-9].



[Table/Fig-6]: Trifurcation of basilar artery- a) 2 PCA and 1 SCA b) 2 SCA and 1 PCA. PCA: Posterior cerebral artery; SCA: Superior cerebellar artery; 1: Right SCA; 2: Right PCA; 3: Left PCA; 4: Left SCA

[Table/Fig-7]: (a) & (b) Quadrifurcation of basilar artery showing termination of basilar artery giving rise to right and left posterior cerebral arteries and right and left Superior cerebellar arteries.
PCA: Posterior cerebral artery; SCA: Superior cerebellar artery; 1. Right SCA 2: Right PCA; 3: Left PCA; 4: Left SCA



[Table/Fig-8]: :Pentafurcation of Basilar artery-2 right SCA, 1 right PCA, 1 left PCA and 1 left SCA.
PCA: Posterior cerebral artery; SCA: Superior cerebellar artery; 1 and 2: Right SCA 3: Right; PCA 4: Left PCA; 5: Left SCA

[Table/Fig-9]: Fenestration of basilar artery.
BA: Basilar artery; VA: Vertebral artery; Arrow: Fenestration

DISCUSSION

The basilar artery is a single median vessel formed by the union of the right and left vertebral arteries at the level of pontomedullary junction. Occasionally, it may be the continuation of single vertebral artery or may be a branch of cervical part of internal carotid artery. It lies in the median groove on the ventral surface of the pons in the cisterna pontis, on the basilar part of the occipital bone and the dorsum sellae of the sphenoid [6]. In the present study, the basilar artery was formed by the union of right and left vertebral arteries in all the specimens. No variation in its formation was observed.

The normal length of basilar artery ranges from 2.6 cms to 3 cms. [16]. According to Pai BS et al., the length of basilar artery varied from 2.4 cm to 3.5 cm, with mean length of 2.49 cm [7]. The study by Hosapatna M et al., [8] reported the range of length of basilar artery to be 25-37 mm, and the mean length was 28.5±2.8 mm. The mean length was 25.58±3.57 mm according to Satapathy BC and Mohapatra C [9]. Iqbal S [10] reported the length of basilar artery to range between 18-37 mm. The length of the basilar artery ranged from 25 mm-38 mm in other studies [12,17,18]. In the present study, it was found to be within normal range of 2.6-3.0 cm in 73% of specimens-mean length being 2.792±0.32 cm.

There were variations in the mean length of basilar artery depending upon the level of its origin. Thus, the basilar arteries which arose below the level of pontomedullary junction showed increased length (3.1±0.07 cm), and also found to be associated with some variations in the origin of its branches and duplication of superior cerebellar artery. The level of origin and the length of basilar artery are important factors to be assessed prior to planning for surgery in lesions of basilar artery.

Normally, the level of origin of basilar artery is located at Pontomedullary Junction (PMJ). However significant variations in its level of origin either below or above the pontomedullary junction were observed. In the present study, in 84% the level of origin was at pontomedullary junction, in 14% it was below the PMJ and in 2% it was located above the PMJ. This is in contrast with many other studies which report a higher incidence of termination either above or below pontomedullary junction [Table/Fig-10] [8-10,11,16-22]. Iqbal S et al [10], Wankede HA et al., [11] and Akar ZC et al., [19] have reported higher incidence of termination above PMJ while others reported greater percentage of termination below PMJ [18, 20, 21] [Table/Fig-2b].

Name of study	Number of specimens	At PMJ Numbers (%)	Below PMJ Numbers (%)	Above PMJ Numbers (%)
Stopford JSB, (1916) [22]	160	117 (73%)	30 (19%)	13 (8%)
Akar ZC et al., (1994) [19]	11	4 (36%)	1 (10%)	6 (54%)
Songur A et al., (2007) [20]	110	22 (20%)	74 (67%)	14 (13%)
Padmavathi G et al., (2011) [21]	54	24 (45%)	21 (39%)	9 (16%)
Hosapatna M et al., (2012) [8]	20	13 (65%)	5 (25%)	2 (10%)
Iqbal S (2013) [10]	50	35 (70%)	13 (26%)	2 (4%)
Wankhede HA et al., (2014) [11]	40	25 (62.5%)	5 (12.5%)	10 (25.5%)
Patel S et al., (2015) [17]	60	53 (88.33%)	3 (5%)	4 (6.67%)
Sreenivas RK et al., (2018) [18]	20	8 (40%)	9 (45%)	3 (15%)
Satapathy BC and Mohapatra C, (2018) [9]	38	35 (92.11%)	1 (2.63%)	2 (5.26%)
Vijayakumar AU et al., (2020) [16]	96	65 (67.7%)	23 (24%)	8 (8.3%)
Present study	100	84 (84%)	14 (14%)	2 (2%)

[Table/Fig-10]: Comparison of various studies on level of origin of basilar artery [8-10,11,16-22].
PMJ: Pontomedullary junction

The basilar arteries, which arose below the level of pontomedullary junction, were found to be associated with variations in the origin of superior cerebellar artery, labyrinthine artery and duplication of superior cerebellar artery [12]. The level of origin (localisation of vertebro-basilar junction) of basilar artery is especially important with regard to surgical procedures using lateral basal and transpetrosal approaches for treatment of aneurysm in this region [22]. Variation in level of origin should be identified preoperatively so that neurosurgeons can modify the surgical approaches.

Normally, basilar artery terminates at the upper border of pons into right and left posterior cerebral arteries. However, it may terminate above or below the pontomesencephalic junction. Rhoton AL et al., [23] described the termination of basilar artery at three levels with normal bifurcation at pontomesencephalic junction in 72%, above pontomesencephalic junction in 24% of cases (high bifurcation), below pontomesencephalic junction in 4% cases (low bifurcation).

The termination of basilar artery above the pontomesencephalic junction is of higher incidence as, it has been reported in various literatures [7,11,18,23]. However, in the present study the incidence of termination above pontomesencephalic junction was less (3%) as also been reported by Hosapatna M et al., [8] and Iqbal S [10]. Further the incidence of termination below the pontomesencephalic junction was also less (7%) similar to the observations by Rhoton AL [23] and Kalaivanan J [24] [Table/Fig-11].

Author	Number of specimens	At pontomesencephalic junction Numbers (%)	Above pontomesencephalic junction Numbers (%)	Below pontomesencephalic junction Numbers (%)
Pai B et al., (2007) [7]	25	14 (56%)	11 (44%)	0 (0%)
Rhoton AL (2003) [23]	50	36 (72%)	12 (24%)	2 (4%)
Hosapatna M et al., (2012) [8]	20	14 (70%)	1 (5%)	5 (25%)
Iqbal S, (2013) [10]	50	32 (64%)	2 (4%)	16 (32%)
Wankhede HA et al., (2014) [11]	40	20 (50%)	13 (32.5%)	7 (17.5%)
Patel S et al., (2015) [17]	60	57 (95%)	2 (3.33%)	1 (1.67%)
Sreenivas RK et al., (2018) [18]	20	9 (44.4%)	6 (29.6%)	5 (26%)
Kalaivanan J (2016) [24]	50	42 (85%)	5 (10%)	3 (5%)
Vijayakumar AU et al., (2020) [16]	96	66 (68.8%)	10 (10.4%)	20 (20.8%)
Present	100	90 (90%)	3 (3%)	7 (7%)

[Table/Fig-11]: Comparison of various studies on level of termination of basilar artery.

The level of termination is important in surgical approaches in basilar tip region, which is the most common site of aneurysms of posterior circulation. A transsylvian approach is required to reach high basilar artery bifurcation while for low and normal bifurcation, the surgeon will adapt sub temporal approach [20].

Usually, the basilar artery terminates by bifurcating into right and left posterior cerebral arteries. The mode of termination is either 'V' shaped or 'T' shaped. According to Grant BJ [25], T shaped termination is common. In the present study, 93% showed bifurcation of which 83% was 'V' shaped and 10% was 'T' shaped.

Mode of termination can be explained on embryological basis. Basilar artery is formed by the fusion of two longitudinal channels, the primitive neural arteries which differentiate on the ventral surface of hindbrain. Later this artery gets connected cranially with caudal part of internal carotid artery and caudally with vertebral arteries. Caudal part of internal carotid artery gives rise to Posterior Cerebral Artery (PCA) and posterior communicating artery. Lack of normal fusion at the cranial end results in the variation of basilar artery termination [26]. 'V' shaped termination is due to caudal fusion of PCA's with basilar artery and 'T' shaped termination is due to cranial fusion of PCA's [27].

Basilar tip aneurysms are frequently associated with caudal fusion than with a cranial fusion of PCA [27]. Though the 'V' shaped termination is prone for basilar tip aneurysm, the authors found that this was the most common mode of termination in present study population. The different modes of termination of basilar artery were studied and classified as bifurcation, trifurcation, quadrifurcation, pentafurcation and non furcation. Bifurcation is the most common mode of termination of basilar artery [12]. The incidence of trifurcation, quadrifurcation and pentafurcation in the present study was similar to that reported by Gunnal S et al., [12] and Ogeng'o JA et al., [13]. Nagawa E et al., have reported higher incidence of these three types of termination in the population of Uganda [14] [Table/Fig-12].

In trifurcation, three branches- 2 PCAs and 1 SCA arise from a common terminal point of basilar artery. It is further divided into 3 subtypes. In quadrifurcation, four branches (2 PCAs and 2 SCAs) arise from common point of termination. Five branches (2PCAs and 3 SCAs including one duplicated SCA) were found to arise from common terminal point of basilar artery in pentafurcation. Direct continuation of basilar artery into a single PCA was termed as non furcation [15]. These multiple branching points interrupt the haemodynamics resulting in aneurysms and thromboembolism. Aneurysms associated with such points would lead to nerve compressions and ocular lesions [15].

These variations in termination particularly trifurcation result from lack of normal fusion of the basilar artery at the origin of the superior cerebellar artery during development of basilar artery [28,29]. Gunnal S et al., theorise that the primitive longitudinal neural arteries join together in the caudocranial direction to form the basilar artery. If the terminal point of fusion is cranial to the origin of SCA then normal bifurcation pattern is formed. If the terminal point of fusion is more proximal at the level of origin of SCA quadrifurcation occurs [12]. If there is cranial or caudal shift of one of the two primitive longitudinal neural arteries it may develop incongruence resulting in various types of trifurcation. According to Padget DH, the caudal portions of well-defined internal carotid channels anastomose with the cranial parts of the longitudinal neural arteries via posterior communicating arteries which further continues as posterior cerebral artery [30]. Thus, the posterior cerebral artery developing from the internal carotid artery anastomosis with the basilar artery caudally. If this anastomosis occurs at a point lower than the normal site, this abnormal fusion leads to multiple branches bifurcating close to the

Author	Number of specimens	Bifurcation numbers (%)	Trifurcation numbers (%)	Quadrifurcation numbers (%)	Pentafurcation numbers (%)	Hexafurcation/Nonfurcation numbers (%)
Ogeng'o JA et al., (2012) [13]	173	142 (82.1%)	18 (10.4%)	10 (5.8%)	3 (1.7%)	Nil
Gunnal S et al., (2015) [12]	170	140 (82.4%)	9 (5.3%)	10 (5.88%)	6 (3.5%)	Nonfurcation- 5 (2.94%)
Nagawa E et al., (2018) [14]	115	56 (48.7%)	26 (22.6%)	25 (21.7%)	7 (6.1%)	Hexafurcation-1 (0.6%)
Present study (2020)	100	93 (93%)	3 (3%)	3 (3%)	1 (1%)	Nil

[Table/Fig-12]: Comparison of the frequency of the different patterns of termination of basilar artery in various studies.

trunk of the basilar artery instead of the normal lateral bifurcation, with the number of terminal branches depending on the extent of fusion [30].

Fenestrations in the Vertebrobasilar System (VBS) typically occur in the Vertebrobasilar Junction (VBJ) or the proximal basilar artery. Fenestration in the Basilar artery has a reported angiographic prevalence of 0.022-0.6% but the cadaveric studies have reported a prevalence of 1.3-5.26% [20]. In the present study, fenestration at the proximal part of basilar artery was seen in 1% of specimens which was similar to other cadaveric studies [7,12,20] [Table/Fig-3,9].

Fenestration in the VBS is a factor, which increases the incidence of aneurysms in this region. Fenestrations occur due to an endothelium-lined partial intraluminal septa within the artery. These sites act as points of turbulence and initial sites for potential thrombosis [31]. These anatomic and hemodynamic changes at the proximal ends of fenestrations may cause intracranial saccular aneurysms [32].

Limitation(s)

The present cadaveric study did not correlate the cadavaric findings clinically with the angiographic findings for reliable results.

CONCLUSION(S)

An understanding of these significant variations in the level of origin and termination, length and mode of termination of basilar artery enables better interpretation of radioimaging studies of posterior circulation and also enhances safety of surgery in vascular lesions of posterior cranial fossa by providing basis for accurate operative approaches. A future comparative study correlating clinically the frequency of the anatomical variations in the cadaveric study and angiographic study, is recommended to produce more complete and reliable data, important for performing various neurosurgical procedures.

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