ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 12, Issue, 01, pp. 53678-53683, January, 2022
https://doi.org/10.37118/ijdr.23865.01.2022

RESEARCH ARTICLE

OPEN ACCESS

MORPHOMETRY AND ANATOMICAL VARIATIONS OF POSTERIOR CEREBRAL ARTERY IN NORTHEAST BRAZIL

Júlio César Claudino dos Santos[1], Guilherme Cordeiro Bezerra[2], Larissa Eleutério Gomes[2], Kauany Maia Ribeiro[2], Maria Regina Cardoso Linhares Oliveira Lima[2], Beatriz Vieira Loiola Coutinho[2], João Pedro Benati de Andrade Farias[2], Andressa Gabriella Duarte de Queiroz[3], Fábio Antônio Serra de Lima Júnior[3], Desiré Dominique Diniz de Magalhães[3], Amanda do Nascimento Oliveira Carneiro[3] and André de Sá Braga Oliveira[4]

[1]Laboratory of Neuroscience, Department of Neurology and Neurosurgery, Federal University of São Paulo, São Paulo, SP, Brazil. Zip code: 04021-001, São Paulo, SP, Brazil; [2]Christus University Center, Department of Morphology, Fortaleza, Ceará, Brazil. Health Sciences Center, Department of Morphology, Christus University Center. Zip code: 60.192-245, Fortaleza, Ceará, Brazil; [3]Federal Universityof Paraíba, Medical Sciences Center, João Pessoa, Paraíba, Brazil. Health Sciences Center, Department of Morphology, Federal University of Paraíba, Campus I, Zip code: 58.051-900, João Pessoa, Paraíba, Brazil; [4]Federal University of Paraíba, Department of Morphology, João Pessoa, Paraíba, Brazil. Health Sciences Center, Department of Morphology, Federal University of Paraíba, Campus I, Zip code: 58.051-900, João Pessoa, Paraíba, Brazil

ARTICLE INFO

Article History:

Received 17th October, 2021
Received in revised form
06th November, 2021
Accepted 20th December, 2021
Published online 30th January, 2022

Key Words:

Anatomy. Circle of Willis. Arteries. Posterior Cerebral Artery. Stroke.

****Corresponding author:***
Júlio César Claudino dos Santos

ABSTRACT

Background: The posterior cerebral artery (PCA) is a vessel of the Circle of Willis. Variations are observed in the first segments of the PCA and its branches, especially in the thalamoperforating arteries (TPAs) and in the artery of Percheron (AP). Anatomical presentation of these arteries is of relevant clinical importance for safer neurosurgical approaches. **Objective:** To identify the most frequent PCA and TPA patterns and the morphometry of P1 and P2 branches in human brains from the Northeastern region of Brazil. **Methods:** Specimens of human cadavers from Northeast Brazil were isolated. PCAmorphology, TPAs classification and prevalence of APwere evaluated. The length and diameter of the P1 and P2 segments of the PCA were measured. Values of p <0.05 were considered significant. **Results:** The adult pattern was the most frequent. There were two (22.22%) cases of unilateral PCA trifurcation. No vascular fenestration or bifurcation was found. The type of TPA was mainly bilateral multiple (36,3%). The prevalence of AP was 18,2%. No differences were observed between the right and left sides in themorphometric variables (p> 0.05). **Conclusion:** In this study, the adult pattern of PCA was the most frequent and trifurcation of PCA, a rare anomaly, was found in 22,2% of specimens. TPAsweremostly bilateral multiple type. No differences between sides in the length and diameter of the segments P1 and P2 were found. These data can contribute to safer approaches to neurological pathologies in this population in Northeast Brazil.

Citation: ***Júlio César Claudino dos Santos, Guilherme Cordeiro Bezerra, Larissa Eleutério Gomes, Kauany Maia Ribeiro, Maria Regina Cardoso Linhares Oliveira Lima, et al.*** "Morphometry and anatomical variations of posterior cerebral artery in northeast Brazil*", International Journal of Development Research*, 12, (01), xxxxxxxxxxxxxx.

INTRODUCTION

The posterior cerebral artery (PCA) is a remarkable component of the Circle of Willis (*Circulus Arteriosus Cerebri*), which gives off branches to the midbrain, subthalamic nucleus, basal nucleus, thalamus, temporal, occipital and occipitoparietal cortices [1].

Both PCAs emerge from the basilar artery‛s bifurcation and are divided into four segments: P1 (pre-communicating) begins at the end of the basilar artery and ends at the origin of the anastomosis with posterior communicating artery (PComA); P2 extends from the PComA and lies in peduncular and ambiens cistern, terminating at the posterior part of midbrain; P3 starts posteriorly to the pulvinar, goes through the quadrigeminal cistern and ends at the anterior extremity of the calcarine fissure; P4 includes the cortical branches of PCA [2, 3].

In some cases, PCA presents anatomical variations, such as its fetal pattern, when the main blood supply comes from the carotid system, instead of the vertebrobasilar system. Unusual PCA patterns are found unilaterally on 10% of specimens and bilaterally on 5%, while the adult pattern is seen in most cases [4]. Adult pattern is defined when P1 diameter is greater than PComA's, suggesting the main source of supply is the vertebrobasilar system. On fetal pattern, PComA diameter is greater than P1's, suggesting main supply from the carotid system. The transitional pattern is defined when both arteries have similar diameters, allowing both systems to provide blood to the PCA [4, 5, 6]. The thalamoperforating arteries (TPAs) are important P1 branches that arise on various presentations. Recognizing its patterns is essential in treatment planning of basilar terminus aneurysms [7]. Lang and Brunner [8] classified TPAs into four types: type I (bilateral multiple); type II (unilateral multiple, unilateral single); type III (bilateral single); type IV (one side only single). The type IV is a classic anatomical variation, the artery of Percheron (AP), a common arterial trunk of TPAs that arises from only one P1 but provides bilateral arterial supply to thalamic and rostral midbrain. AP's ischemia might be associated with coma, ocular movement disorders and even severe bradicardia [9]. In fact, Percheron, in his study "The anatomy of the arterial supply of the human thalamus" [10], classified the AP in 3 types: type I (bilateral single); type IIA (unilateral multiple only); type IIB (unilateral single supplying both thalami); type III (bilateral single with median anastomosis). The type IIB is the most known worldwide and is called AP. This artery has also been related to cases of Holmes tremor [11]. This classification recognizes an arterial pattern that was not predicted by Lang and Brunner classification [8], when two single bilateral trunks present a median anastomosis. This variation might represent an anatomical substratum to collateral circulation in the presence of proximal obstructions.

METHODS

To dissect the arterial circle of the brain, the brain was previously fixed in 10% formaldehyde. After this stage, a section was performed at the base of the intracranial segment of the vertebral arteries and in the clinoid segment of the internal carotid arteries. After extracting the aforementioned vessels, those without lesions were selected and then preserved in formaldehyde solution again. Through this procedure, we isolated 11 Circle of Willis, whose PCAs were sectioned at the posterior aspect of the midbrain, allowing its analysis since its origin to the P2 segment. Two Circle could not be analyzed due to damage of structures related to the objectives of this study. We qualitatively assessed the PCA pattern (Figure 1), the TPA classification (Tables 1 and 2), the prevalence of APs, bifurcation, trifurcation or fenestration of the ACP and other remarkable anatomical variations. We measured, by using a Mitutoyo® 150mm Vernier caliper (uncertainty = 0,05mm), with a measuring capacity of 0 to 150 mm made by ZAAS (Rio de Janeiro/Brazil), the length of P1 and P2, defined, respectively, as the distance between the bifurcation of basilar artery and the beginning of PComA, and the distance between PComA and the distal extremity of the artery (intentionally sectioned at the posterior aspect of the midbrain). To obtain the diameter (D) value the caliper was used to measure the length of the internal circumference of the segment. Considering the mathematical formula for the length of a circle (Lc): $Lc = D \times \pi$, the value measured by the caliper was divided by 3.14159265. We plotted data on a Numbers 10.3.5 software, then transferred it to IBM SPSS version 26 to perform descriptive and inferential analysis. Categorical variables were described as relative frequencies. Quantitative data was submitted to the Shapiro-Wilk normality test, parametric variables were described with mean and standard deviation and non-parametric variables were described by median and interquartile interval. In order to compare differences between sides for parametric variables, we performed a dependent T-test for paired samples, while the Wilcoxon signed-rank test was performed to compare sides for non-parametric variables. We performed a Fisher's exact test to evaluate association between binary categorical variables. The results were considered significant when $p < 0.05$. The present study's sample was selected in accordance to the Brazilian Federal Law 8.501 (November 30, 1992) and an institutional and ethics approval was obtained.

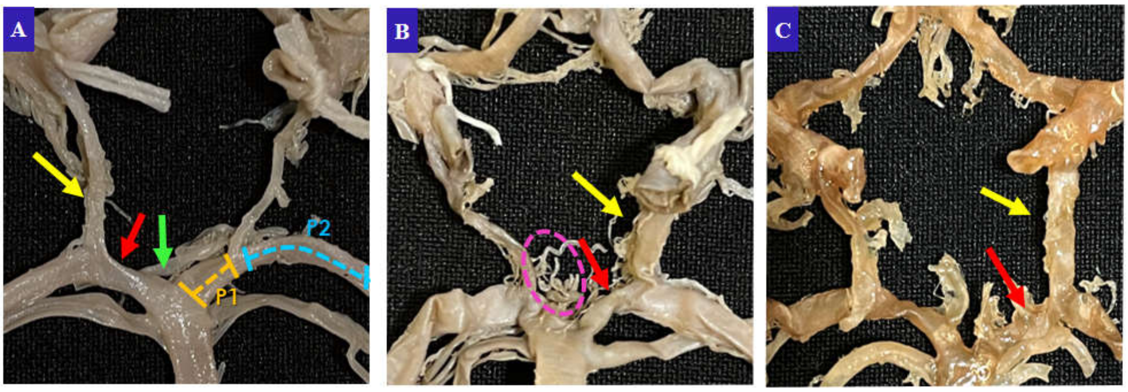

Figure 1. Classification of posterior cerebral artery pattern [5]. The yellow arrow shows the posterior communicating artery (PComA) and the red arrow shows the posterior cerebral artery (PCA). (A) Adult patern (PCA>PComA), with the presence of artery of Percheron (green arrow). (B) Fetal pattern (on the left– PCA<PComA), (C) Transitional pattern (PCA=PComA). The area delimited by the orange line marks the P1 segment (pre-communicating). The area delimited by the blue line onwards marks the P2 segment (post-communicating). The pink circle features some thalamoperforating arteries

The study of anatomical variations on brain arterial system is essential to clinical practice, due to its correlation with cerebrovascular diseases. Brain aneurysms, for example, are more prevalent in the presence of some variations that cause hemodynamic changes [12]. This is associated with local structural factors, which may predispose vessel dilation. However, some variations, such as collateral circulation, may reduce the risk of ischemic stroke [13]. Cerebrovascular diseases might be a public health issue, increasing death and hospitalization rates, system operational cost and severe morbidity, as motor disability, depression and cognitive disorders [14]. Studying anatomical variations on brain vessels not only amplifies our academic knowledge, but also helps surgical planning and prophylactic clinical treatment. This study aims to identify the most frequent PCA and TPA patterns and the morphometry of P1 and P2 branches in human brains from the Northeastern region of Brazil.

RESULTS

After excluding damaged specimens, 9 were included for most of the analysis of this study.

Table 1. Classification of thalamoperforating arteries according to Lang and Brunner [8]

Classification	Characteristics
Type I	Bilateral multiple TPAs
Type II	Unilateral single and unilateral multiple TPAs
Type III	Bilateral single TPAs
Type IV	One sided single TPA (AP)

TPA: Thalamoperforating artery; AP: Artery of Percheron.

Table 2. Percheron classification of thalamoperforating arteries according to Percheron [10]

Classification	Characteristics
Type I	Bilateral single TPAs
Type IIA	Unilateral multipleTPAs
Type IIB	Unilateral single TPA supplying both thalami (AP)
Type III	Bilateral single, with median anastomosis

TPA: Thalamoperforating artery; AP: Artery of Percheron.

The adult pattern, according to Saiki and Rhoton [5], was the most frequent in our sample, being found in 7 (77,77%) specimens bilaterally. The fetal pattern was identified in one (11,11%) specimen, and only unilaterally on the left side. A transition pattern was also found in only one (11,11%) specimen bilaterally (Table 3). There were two (22,22%) cases of unilateral trifurcation of PCA on the left side among the specimens studied. In the first case, it was interesting to find also a latero-lateral anastomosis between the superior and intermediate PCAs and both superior cerebellar arteries emerging from the PCA. In the other case, the trifurcation was associated with an ipsilateral duplication of the superior cerebellar artery. These variations are illustrated on Figure 2. It was not found any vascular fenestration or bifurcation (Table 3).

Eleven specimens wereanalyzed for the TPA classification. According to Lang and Brunner classification [8], mostly were of type I (36,3%) and type II (36,3%), followed by type IV (18,2%) and type III (9,1%). On the other hand, classifying the arteries according to Percheron [10, 11], there were found 36,3% oftype I PCAs,36,3% type IIA, 18,2% type IIB and 9,1% type III. The prevalence of the AP was 18,2% (2 specimens). The length of pre-communicating (LP1) segment of the PCA had a median value of 5,80 mm (IQR = 2,33 mm) on the right side and 6,30 mm (IQR = 3,18 mm) on the left, while the P2 segment (LP2) of the artery had a mean value of 14,97±6,15 mm on the right and 11,89±3,55 mm on the left. The pre-communicating segment of the PCA had a diameter median value (DP1) of 3,02 mm (IQR = 0,31 mm) on the right side and a mean value of 2,80±0,35 mm on the left. The P2 segment of the artery had a diameter median value (DP2) of 2.79 mm (IQR = 0.53 mm) on the right and side a mean value of 2.76±0.39 mm) on the left. It was not found significant statistical difference between sides ($p>0.05$), suggesting both segments of PCA are symmetrical (Table 4).

DISCUSSION

The PCA path is divided into P1 and P2 segments by the anastomosis with posterior communicating artery (PComA). In literature, the length of P1 segment has been reported in a range of 5.63mm to 7.80mm [15,16,17,18,19], showing similarity with the 6,05 mm found in the present study. However, there was a significant variation in the length of P2 segment, which has a range from 19.17mm to 52.20mm. This contrast may be associated with the form of sample collection, due to the use of different tools, such as different digital calipers, and the different removal and preservation technique, for example, the application of a colored silicone injection or a complex mixture for an arterial embalming fluid. According to previous studies, the mean diameter of P1 was described from 1.77 mm [20] to 2.80 mm [16]

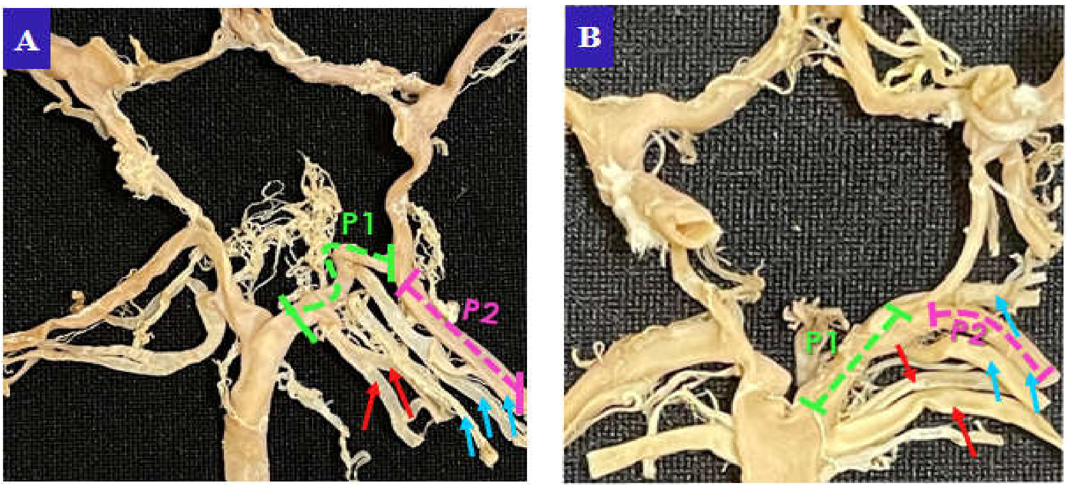

Figure 2: Anatomical variations – trifurcation of PCA in two specimens. The area delimited by the green line marks the P1 segment (pre-communicating). The area delimited by the pink line onwards marks the P2 segment (post-communicating). The red arrows feature the superior cerebellar arteries. The blue arrows show the PCAs.A. On the left side, both superior cerebellar arteries emerge from PCA. B. On the left side, the trifurcation is associated with an ipsilateral duplication of the superior cerebellar artery.

Table 3. PCA's anatomical variations and pattern according toSaeki and Rhoton [5]

PW	Anatomical Variations				Presenceof AP	Pattern
	F	B	T	O		
1	No	No	No	None	No	Adult
2	No	No	No	None	No	Adult
3	No	No	No	Double SCA - L	No	Transition
4	No	No	No	None	No	Adult
5	No	No	No	B SCA - R	No	Adult
6	No	No	No	Double SCA - L	Yes - R	Adult
7	No	No	No	Hypoplasia in P1 - L	No	Adult R / Fetal L
8	No	No	Yes - L	SCA R and L leaving ACP	No	Adult
9	No	No	Yes - L	None	Yes - L	Adult

PW - Polygon of Willis; F - Fenestration; B - Bifurcation; T - Trifurcation; O - Others; AOP - Artery of Percheron (AP); PCA: Posterior cerebral artery; SCA - Superior Cerebellar Artery; L - left; R - right.

while the mean diameter of P2 was described from 1.70 mm [17] to 2.70 mm [16]. The present study found a median diameter for P1 segment of 2.99 mm and 2.81 for P2 segment (Table 5). This difference may be a result of ethnical variability or even from measurement technique variations. The relationship between the diameter of the PCA and PComA helps to understand the blood flow that supplies the brain and possible clinical conditions. We use the definition that classifies this relationship into three patterns: adult, fetal and transitional [4, 5, 6].

side [4, 15, 1719, 20, 23]. In the current study, we founded one case (5.5%) with a unilateral fetal pattern in the left side. For the transitional pattern, Silva et al. [4] founded that one in 2.2% cases, El et al.[15] in 7.47% and Pai et al. [19] in 12%. In the present study, we founded it in 11.11% of the cases (Table 6). A possible justification for the high value of transitional pattern in the percentage spectrum presented in the literature may be due to the small number of specimens in our study, but it appears to be most likely due to the diversity in the nomenclature of this variation.

Table 4. Morphometric analysis of left and right PCAs. Data were expressed as Mean (mm) ± SD (Minimum - Maximum) for diameter measurement and Median (mm) - Interquartile Range (Minimum - Maximum) for lenght measurement. N=9

	Rightside		Leftside	
Para meters	Min- Max	Mean/Median (SD/IQR)	Min- Max	Mean/Median (SD/IQR)
LP1	3,15–19,00	5,80 (2,33)	4,60–14,00	6,30 (3,18)
LP2	1,60–21,55	14,97 (6,15)	6,25–17,00	11,89 (3,55)
DP1	2,55–3,12	3,02 (0,31)	2,23–3,15	2,80 (0,35)
DP2	2,04–3,12	2,79 (0,53)	2,04–3,15	2,76 (0,39)

LP1 - length of segment P1; LP2 - length of segment P2; DP1 - diameter of segment P1; DP2 - diameter of segment P2; R - right; L - left.

Table 5. Comparison of morphometry of PCA with previous studies (mean and median in millimeters)

PCA	Present study (2021)	Kocak et al. (2020)	El et al. (2018)	Gunnal et al. (2015)	Párraga et al. (2011)	Park et al. (2009)	Pai et al. (2007)
N	18	512	370	340	70	52	50
LP1	6.05	-	5.63	7.80	7.70	5.70	7.15
LP2	13.43	-	-	52.20	23.60	-	19.17
DP1*	2.99	1.77	1.82	2.80	-	-	2.63
DP2*	2.81	-	2.00	2.70	1.70	-	-

PCA - Posterior cerebral artery; N – number of PCAs; LP1 - length of segment P1; LP2 - length of segment P2; DP1 - diameter of segment P1; DP2 - diameter of segment P2. * - median.

Table 6. Comparison of PCA pattern (in percentage [%]) according toSaeki and Rhoton [5]

Pattern	Present study (2021)	Kocak et al. (2020)	El et al. (2018)	Párraga et al. (2011)	Silva et al. (2009)	Pai et al. (2007)	Horikoshi et al. (2002)
N	18	512	370	70	225	50	434
F	5.5	6.53	13.22	16	4.4	10	29.5
A	83.3	NA	43.24	NA	93.3	78	61.8
T	11.11	NA	7.47	NA	2.2	12	NA

N – Number of PCAs, F - fetal; A - adult; T - transitional; NA - not applicable.

Table 7. The Prevalence (%) of the Posterior Cerebral Artery Anomalies (per PCA)

	Present study (2021)	Cilliers et al. (2019)	Gunnal et al. (2015)	Uchino et al. (2015)	Kovač et al. (2014)	Kapoor et al. (2008)
N	18	40	340	4700	910	2000
F	0	5	1.17	0.34	0	0
D	5	0	2.35	0.04	0.2	2.6
T	11	0	0	0	0	0.8

N – Number of PCAs analyzed; CW - Circle of Willis; F - Fenestration; B - Bifurcation; T - Trifurcation.

Table 8. Comparison of Thalamoperforating arteries (TPAs) [7, 8, 10, 11, 18, 27]

Description	Present study (2021)	Kocaeli et al. (2012)	Park et al. (2009)	Uz (2005)
Bilateral multiple Multiple branches arose from the P1 segment on each side	36,3%	55.8 %	38,50%	20%
Unilateral multiple, unilateral single A single branch on one side of P1 segment and multiple branches on the other side	27,3%	11.7 %	26.9%	33%
Bilateral single A single thick branch on each P1 segment	0	20.5 %	19.2%	40%
Unilateral single Unilateral single branch and the other with no branch	18,2%	11.7 %	11.5%	0
Unilateral multiple Unilateral multiple and the other with no branch	9,1%	0	3.8%	7%

According to Masoud et al. [21], the most frequent abnormal pattern is the fetal one, defined as the configuration resulting from hypoplasia or the ipsilateral absence of the P1 segment of the PCA. In this perspective, a percentage range for the fetal pattern of 4.4% - 29.5% of cases was found in the literature, with a preponderance on the left

For example, according with Horikoshi et al. [23], there are six different patterns while our study used only three patterns. The use of softwares to evaluate this pattern and the number of brains used in the studies could also explain these differences. The presence of these abnormal patterns that reduce the diameter of the P1 segment is associated with the occurrence of cerebral aneurysms and impaired neurological activity [4]. This is due to the alteration in cerebral hemodynamics, generated by an overload in the internal carotid artery (ICA), since it starts to cover a larger supply territory than the "normal" pattern, because the largest flow will be from it in the system [24]. This event is justified by the irrigation that reaches P2 from PComA, since the P1 segment is smaller than the ideal diameter for efficient irrigation. In this situation, a dependency on the ICA is created, which will supply the entire hemisphere. In case of vascular insufficiency, the ICA could harm any portion of the hemisphere. Thus, in case of transfer of thrombotic material or reduced flow in the ICA, vascular insufficiency may develop in the areas irrigated by the posterior and middle cerebral arteries [23]. Variations in the Circle of Willis have clinical interest, as this structure plays an important role in cerebral hemodynamics as a collateral anastomotic network. Thus, people who have effective circulations have a lower risk of facing adversities such as transient ischemic attack and stroke than those with impaired circulation [22]. As shown in Table 7, PCA duplication has been reported with a prevalence in the range of 0- 2.6% [3,16,25,26,28]. Trifurcation is a very rare anomaly, being reported in the literature only by Kapoor et al. [28], which was found in 16 PCA's (0.8%). That difference found in the results could be a consequence of the number of specimens collected. The thalamoperforating arteries (TPAs) are branches that originate from the P1 segment of the PCA and can be one or more. They supply important parts of the brain, such as thalamus, hypothalamus, cranial nerve nuclei, etc. Due to the diversity of forms that can be presented, their classification varies greatly from one author to another [7,8, 10, 11, 18, 27].

Because of this variation in the description of the types, a classification was built based on the main authors in the literature that consists of 5 types: bilateral multiple, unilateral multiple/unilateral single, bilateral single, unilateral single and unilateral multiple (Table 8). When analyzing the literature, it was concluded that the most frequent form in these studies is bilateral multiple, which corresponds to Lang and Brunner's type I classification [8, 11]. The literature is in agreement with the result of the present study, but an interesting finding is that there was no bilateral single TPA in our study, while others have up to 40% of this type [7, 18, 27]. The artery of Percheron is a variant of the TPAs with a significant function, since it supplies the thalamus bilaterally, which is an important part of Reticular Activating System (RAS). The occlusion of that artery causes a rare vascular cerebral event: bilateral medial thalamic and rostral mesencephalic infarctions. This can originate vision problems, coma, ophthalmoplegia, aphasia, prostration, confabulation, mental confusion and ataxia. [9,18, 29]. In the literature, this artery appeared in a range of 7% to 11.7% of cases [18, 19,20], which is inferior to our result of 18,2 %, possibly justified by the sample size.

CONCLUSION

The adult pattern was the most frequent PCA conformation. Trifurcation of PCA is a rare anomaly in the literature, but it was found in 22,2% of specimens of the present study. There were no significative differences between right and left sides in length and diameter of P1 and P2 segments. The thalamoperforating arteries were mostly bilateral multiple. The artery of Percheron had a 18,2% prevalence, a little higher than specialized literature. This study is crucial for neurosurgeons and neurologists for a better understanding of PCA anatomy and safer approaches to its affections in Northeastern Brazil. The increase of sample and other morphological studies of PCA can trace a more accurate profile and a realistic frequency of this population in order to solve neurological problems, such as aneurysms and infarctions.

Limitations: The number of PCAs studied was a limiting factor to reach more representative conclusions. In addition, there are many classifications in the literature for the TPA's anatomy, making standardization difficult for an acurate comparison between populations.

Conflict of Interest: No potential conflict of interestrelevant to this article was reported.

REFERENCES

Abe, I. M.; Goulart, A. C.; Santos Júnior, W. R.; Lotufo, P. A.; BANSEÑOR, I. M. Validation of a stroke symptom questionnaire for epidemiological surveys. São Paulo Medical Journal. 2010; 128(4): 225-231.

Asavaaree, Chompunut. Doyle, Cara. Smithason, Saksith. Artery of Percheron infarction results in severe bradycardia: A case report. 2018: 9(230).

Cilliers K, Page BJ. Variation and anomalies of the posterior cerebral artery: Review and pilot study. Turk Neurosurg. 2019; 29(1): 1–8.

El Falougy H, Weismann P, Lukacikova P, Mifkovic A, Perzelova A, Sivakova I, Kubikova E. The vascular patterns of the posterior part of the circulus arteriosus cerebri (Willisi). Bratisl Med J. 2018; 119 (11): 679 – 683.

Fagundes-Pereyra WJ, Furtado AN, Barcelos FM, Motta J. Infarto Talâmico Bilateral por Oclusão da Artéria de Percheron. JBNC. 2018; 25(1): 22 -5.

Gunnal S, Farooqui M, Wabale R. Study of middle cerebral artery in human cadaveric brain. Ann Indian Acad Neurol. 2019; 22(2): 187–94.

Henderson RD, Eliasziw M, Fox AJ, Rothwell PM, Barnett HJ. Angiographically defined collateral circulation and risk of stroke in patients with severe carotid artery stenosis. North American Symptomatic Carotid Endarterectomy Trial (NASCET) Group. Stroke. 2000; 31(1): 128–132.

Horikoshi T, Akiyama I, Yamagata Z, Sugita M, Nukui H. Magnetic resonance angiographic evidence of sex-linked variations in the circle of Willis and the occurrence of cerebral aneurysms. J Neurosurg. 2002; 96(4): 697–703.

Kapoor K, Singh B, Dewan LIJ. Variations in the configuration of the circle of Willis. Anat Sci Int. 2008; 83(2): 96–106.

Kayembe, K. N.; Sasahara, M. Hazama, F. Cerebral aneurysms and variations in the circle of Willis. Stroke, Dallas. 1984; 15(5): 846-850.

Kocaeli H, Yilmazlar S, Kuytu T, Korfali E. The artery of Percheron revisited: A cadaveric anatomical study. Acta Neurochir (Wien). 2013; 155(3):533–9.

Kocak MN, Sade R, Ay M, Polat G, Pirimoglu B, Yalcın A, et al. Analysis of posterior circulation diameters depending on age, sex and side by CTA. Folia Morphol (Warsz). 2020;

Kovač JD, Stanković A, Stanković D, Kovač B, Šaranović D. Intracranial arterial variations: A comprehensive evaluation using CT angiography. Med Sci Monit. 2014; 20: 420–427.

Kuybu O, Tadi P, Dossani RH. Posterior Cerebral Artery Stroke. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2021.

Lang J, Brunner FX. Über die rami centrales der aa. Cerebri anterior and media. Gegenbaurs Morph Jb. 1978; 124(3): 364-374.

Masoud, Hesham; Nguyen, Thanh N.; Thatcher, Joshua; Barest, Glenn. Duplication of the Posterior Cerebral Artery and the 'True Fetal' Variant. Interventional Neurology. 2015; 4(1-2): 64-67;

Norbash, Alexander M.De Silva, K.R.D., Silva, R., Amaratunga, D. et al. Types of the cerebral arterial circle (circle of Willis) in a Sri Lankan Population. BMC Neurol. 2011; 11(5).

Pai BS, Varma RG, Kulkarni RN, Nirmala S, Manjunath LC, Rakshith S. Microsurgical anatomy of the posterior circulation. Neurology India. 2007; 55(1): 31–41.

Park SQ, Bae HG, Yoon SM, Shim JJ, Yun IG, Choi SK. Morphological characteristics of the thalamoperforating arteries. J Korean Neurosurg Soc. 2010; 47(1): 36–41.

Párraga RG, Ribas GC, Andrade SEGL, De Oliveira E. Microsurgical anatomy of the posterior cerebral artery in three-dimensional images. World Neurosurg. 2011; 75(2): 233–257.

Percheron G. The anatomy of the arterial supply of the human thalamus and its use for the interpretation of the thalamic vascular pathology. Z Neurol. 1973; 205(1): 1–13.

Poudel, P. P.; Bhattarai, C. Anomalous formation of the circulus arteriosus and its clinico-anatomical significance. Nepal Med. Coll. J. 2010; 12(2): 72-75.

Raamt, A. F. V.; Mali, W.P.T.M; Laar, P.J.V.; Graaf, Yolanda v. The Fetal Variant of the Circle of Willis and Its Influence on the Cerebral Collateral Circulation. Cerebrovasc Dis. 2006; 22(4): 217–224.

Saeki, N., &Rhoton, A. L. Microsurgical anatomy of the upper basilar artery and the posterior circle of Willis. Journal of Neurosurgery. 1977; 46(5): 563–578.

Silva, K. R. D.; Silva, T. R. N.; Gunasekera, W. S. L.; Jayesekera, R. W. Variation in the origin of the posterior cerebral artery in adult Sri Lankans. Neurology India. 2009; 57(1): 46-49.

Uchino A, Saito N, Takahashi M, Okano N, Tanisaka M. Variations of the posterior cerebral artery diagnosed by MR angiography at 3 tesla. Neuroradiology. 2016; 58(2): 141–6.

Uz A. Variations in the origin of the thalamoperforating arteries. J Clin Neuroscience. 2007; 14(2): 134–137.

Wei TS, Hsu CS, Lee YC, Chang ST. Degeneration of paramedian nuclei in the thalamus induces Holmes tremor in a case of artery of Percheron infarction. Med (United States). 2017; 96(46): 0–5.

Zeal, A. A., &Rhoton, A. L., Jr. Microsurgical anatomy of the posterior cerebral artery. Journal of Neurosurgery. 1978; 48(4): 534-559.

****