M.O. Kalinichenko
O.Yu. Stepanenko

Kharkiv National Medical University
Kharkiv, Ukraine

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INDIVIDUAL VARIABILITY OF HUMAN CEREBELLAR ARTERIES AND THEIR PERFUSION TERRITORIES

Kalinichenko M.O. ✉, **Stepanenko O.Yu.** **Individual variability of human cerebellar arteries and their perfusion territories.**
Kharkiv National Medical University, Kharkiv, Ukraine.
ABSTRACT. Background. Three paired arteries provide the blood supply of the cerebellum: the superior cerebellar artery, anterior inferior cerebellar artery, and posterior inferior cerebellar artery. The origin of these arteries, the extent of their development and their duplication may serve as factors influencing variations in the vascular supply territories. **The aim** of this study was to determine the characteristics of individual variability of the human cerebellar arteries and their perfusion territory. **Methods.** The study was conducted on 100 samples. Each sample included cerebellum and an adjacent brainstem. They were obtained from adult human cadavers (67 male and 33 female) who died of causes unrelated to brain pathology at the age between 20 and 92. To analyze the variability of perfusion territories of the cerebellar arteries, a method involving sectorial division of the superior and inferior surfaces of the cerebellum was proposed. **Results and conclusion.** In 95 samples, the SCA arose from the basilar artery on both sides as a single vessel. In two samples, it arose as a duplicate trunk from the basilar artery bilaterally. We also found unilateral duplication of the left SCA in three samples. The AICA arose from the lower third of the basilar artery in 69 samples on the right and in 77 on the left; from the middle third in 11 on the right and 11 on the left. It was presented as a common trunk with the PICA in 18 samples on the right and 10 on the left. The AICA was found duplicated in one sample bilaterally. In two samples it was absent on one side. The PICA most often arose from the vertebral artery (82 samples), rarely as a common trunk with AICA. It was duplicated in two samples on the left and absent in four samples on the right and four on the left. In cases of duplication of the PICA, its perfusion territory expands towards the central sectors of the inferior surface of the cerebellum. In the absence of the AICA, the PICA enlarges its perfusion territory, replacing it, and vice versa. Occasionally, the absent or poorly developed PICA is replaced by a PICA from the opposite hemisphere. There were not any cases of simultaneous absence of both AICA and PICA on one side. The probability of the extension of branches of the AICA onto specific sectors of the inferior surface of the cerebellum decreases from anterior to posterior and from the sides towards the center, while for the PICA there is an opposite trend. Additionally, this study describes three variations of the course of the arteries when both AICA and PICA originate as a common trunk from the basilar artery.
Key words: human, anatomy, cerebellum, SCA, AICA, PICA.

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Kalinichenko M.O. 0000-0002-9450-6277
Stepanenko O.Yu. 0000-0002-5686-0857
✉ **kelend13@gmail.com, mokalinichenko.po20@knmu.edu.ua**

Introduction

One of the leading causes of mortality worldwide is cardiovascular diseases, including ischemic and hemorrhagic strokes [1]. Approximately 20 to 30% of ischemic strokes occur within the territory of the vertebrobasilar system [2]. According to several epidemiological studies, 3-4% of all ischemic strokes are represented by cerebellar strokes, the majority of which are unilateral [3-5]. Large cerebellar strokes are typically classified based on the territories supplied by the three paired arteries providing its blood supply: the superior cerebellar artery (a. cerebelli superior, SCA), anterior inferior cerebellar artery (a. cerebelli inferior anterior, AICA), and posterior inferior cerebellar artery (a. cerebelli inferior posterior, PICA) [4, 6-8]. Strokes in the territory of the SCA constitute 36%, AICA – 12%, and PICA – 40%; an additional 12% involve the simultaneous involvement of multiple regions [3].

The perfusion territories of the SCA, AICA and PICA are variable. The SCA typically supplies the superior surface of the cerebellum (quadrangular and superior semilunar lobules), superior vermis (central lobule, culmen, declive and folium), deep cerebellar nuclei, cerebellar peduncles, midbrain and brainstem. The primary role of the AICA lies in supplying the tegmentum of the midbrain and the middle cerebellar peduncles. In comparison to the SCA, the AICA has a smaller territory of blood supply specifically to the cerebellum (anterior surfaces of the gracile, superior and inferior semilunar lobules and the flocculus). The PICA supplies pyramid, uvula, nodule, tuber and sometimes the declive of the vermis. It supplies the central and inferior portions of the inferior semilunar, gracile, biventer lobules and the tonsil. The PICA also gives off branches to the lateral surface of the pons, the olivary, fastigial and dentate nuclei.

The perfusion territories of the cerebellar arteries are interrelated and can replace one another. The origin of these arteries, the extent of their development and their duplication may serve as factors influencing variations in the vascular supply territories. Comprehensive evaluation of the distribution of superficial cerebellar arteries has not been conducted previously.

The aim of this study was to determine the characteristics of individual variability of the human cerebellar arteries and their perfusion territory.

Materials and methods

The study was conducted on 100 samples. Each sample included cerebellum and an adjacent brainstem. They were obtained from adult human cadavers (67 male and 33 female) who died of causes unrelated to brain pathology at the age between 20 and 92. The Commission on Bioethics of the Kharkiv National Medical University established that the research does not contradict the basic bioethical standards of the Helsinki Declaration, the Council of Europe Convention on Human Rights and Biomedicine (1977), relevant WHO regulations and laws of Ukraine.

To analyze the course of superficial cerebellar arteries and to determine their perfusion territories, the surface of the cerebellum was divided into sectors.

The superior surface of the cerebellar hemisphere was divided into six sectors (Fig. 1). An angle was constructed, formed by two lines belonging to the superior surface of the cerebellum. One line runs along the anterior edge of the cerebellum, while the other originates at the intersection of the mid-sagittal plane and the superior vermis. The angle was divided into three equal parts corresponding to the lateral, central, and medial sectors. The superior posterior fissure of the cerebellum divides the sectors of the quadrangular lobule (quadrangular lateral (Q_l), quadrangular central (Q_c) and quadrangular medial (Q_m)) and the sectors of the superior semilunar lobule (superior semilunar lateral (S_l), superior semilunar central (S_c) and superior semilunar medial (S_m)). The opposite hemisphere is divided in a similar manner.

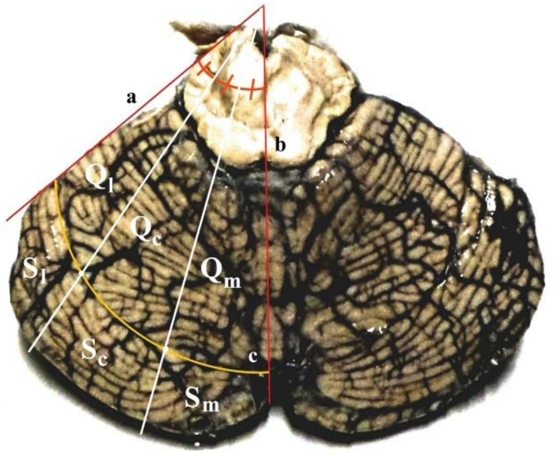

Fig. 1. Division of the superior surface of the left hemisphere of the cerebellum into sectors: a – the line running along the anterior edge of the cerebellum; b – the line originating at the intersection of the mid-sagittal plane and the superior vermis; c – the superior posterior fissure of the cerebellum.

The inferior surface of the cerebellar hemisphere was divided into ten sectors (Fig. 2). An angle was constructed, formed by two lines belonging to the anterior surface of the cerebellum. One line runs along the medial edge of the tonsil, while the other follows the anterior part of the horizontal fissure. This angle was divided into three equal parts corresponding to the anterior, central, and posterior sectors. The secondary fissure of the cerebellum divides the sector of the tonsil (T) and the sectors of the biventral lobule (biventral anterior (B_a), biventral central (B_c) and biventral posterior (B_p)). The anteroinferior and posterolateral fissures divide the sectors of the gracile lobule (gracile anterior (G_a), gracile central (G_c), gracile posterior (G_p)). The horizontal fissure divides the superior semilunar lobule and the sectors of the inferior semilunar lobule (inferior semilunar anterior (I_a), inferior semilunar central (I_c) and inferior semilunar posterior (I_p)). The opposite hemisphere is divided in a similar manner.

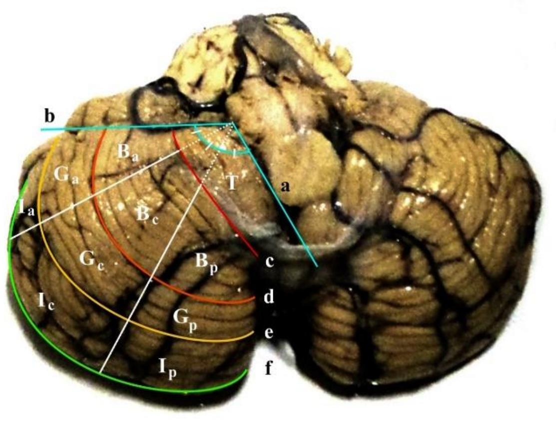

Fig. 2. Division of the inferior surface of the right hemisphere of the cerebellum into sectors: a – the line running along the medial edge of the tonsil; b – the line running along the anterior part of the horizontal fissure; c – the secondary fissure of the cerebellum; d – the anteroinferior fissure; e – the posterolateral fissure; f – the horizontal fissure.

Results

SCA

In 95 samples, the SCA arose from the basilar artery on both sides as a single vessel. In two samples, it arose as a duplicate trunk from the basilar artery bilaterally. We also found unilateral duplication of the left SCA in three samples. In cases of duplication of the SCA, its more caudal branch typically runs alongside the first one and parallel to it, heading towards the most lateral sectors of the superior surface of the cerebellum (Q_l, S_l).

Sometimes, in cases of duplication of the SCA, its more caudal branch originated from the middle third of the basilar artery (1 case on the right, 2 cases on the left). In this variant, the first segment [9] of this branch takes a more oblique course in the rostral direction. No significant differences in perfusion territory were observed in cases of SCA duplication.

As evident from the data in Figure 3, the terminal branches of the SCA, distributing over the superior surface of the cerebellum, may be absent over a relatively large area. In two samples, instead of the SCA, the terminal branches of the PICA extended to these areas from the inferior surface of the cerebellum. In the remaining 10 samples (4 on the right, 6 on the left), no arteries were observed in these sectors at all, resulting in "gray zones". This could be explained by the continuation of the course of these arteries in deeper layers of the cortex.

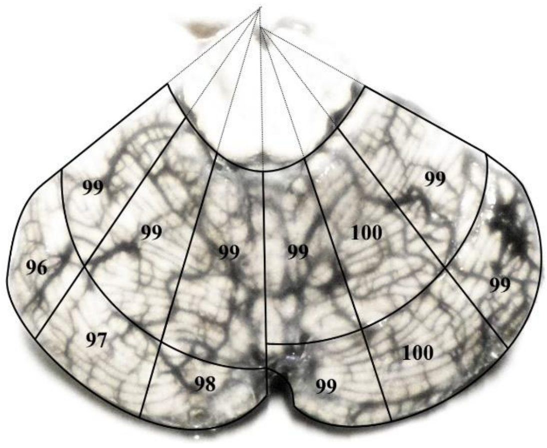

Fig. 3. Distribution of terminal branches of the SCA across sectors of the superior surface of the cerebellum (indicated the number of cases of typical distribution).

Among all the perfusion territories of the SCA, the folium of the vermis is the most variable. This variability is associated with its location on the border between the territories of the SCA and PICA. The folium is supplied by the SCA alone in 51 samples, by PICA in 20 samples and by branches of both arteries simultaneously in 24 samples. In the absence of PICA, the folium receives blood supply from the AICA in two samples and from both SCA and AICA in three samples.

AICA

The AICA arose from the lower third of the basilar artery in 69 samples on the right and in 77 on the left; from the middle third in 11 on the right and 11 on the left. No significant differences in the course of artery branches were observed with these variations of its origin.

As evident from the data in Figure 4, the AICA typically supplies sectors B_a, G_a, and I_a. Due to the course features of the AICA branches, the probability of their extension onto specific sectors of the inferior surface of the cerebellum decreases from anterior to posterior and from the sides towards the center.

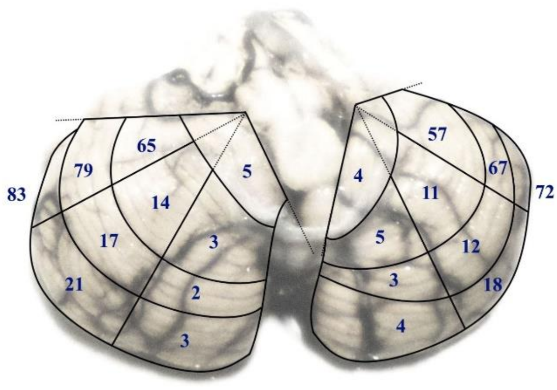

Fig. 4. Distribution of terminal branches of the AICA across sectors of the inferior surface of the cerebellum (indicated the number of cases of typical distribution).

The AICA was absent in only two cases (1 on the right, 1 on the left). In these cases, the origin and course of the PICA from the same side remained unchanged, but its perfusion territory expanded to the flocculus and anterior sectors (B_a, G_a, I_a). This expansion occurred due to additional branches of the PICA that branched off at the level of the tonsillomedullary segment [9], before it makes the first loop in the cranial direction. In one case of the AICA absence, the vascular structure of the SCA also underwent changes: its lateral branch extended to sectors G_a and I_a.

The duplication of the AICA was observed bilaterally in one sample, simultaneously with the absence of the PICA on the left. In this case, the caudal branch originated from the lower third of the basilar artery, and the rostral branch – from the middle third. On both sides, the duplicated AICAs ran close and parallel to each other up to the ponto-medullary junction, after which they repeated the course of the rostral and caudal branches of the classical AICA. Another distinctive difference was the larger diameter of these vessels and the pattern of their distribution across the inferior part of the cerebellar cortex. On the right, the rostral branch reached sectors G_a, G_c, I_a, I_c, and the caudal branch – B_a, B_c. On the left, in the absence of PICA, the rostral branch reached sectors B_a, G_a, I_a, and the caudal branch occupied all other sectors of the inferior surface of the left hemisphere.

PICA

The PICA most often arose from the vertebral artery (78 on the right, 86 on the left), near the inferior olivary complex of the medulla oblongata.

As seen from the data in Figure 5, the PICA most frequently supplies sectors T, B_p, G_p, I_p, with lower probability sectors B_c, G_c, I_c, and the least probability sectors B_a, G_a, I_a. The distribution pattern in the data regarding the “gray zones” of the inferior surface of the cerebellum is different (Fig. 6). The probability of their appearance decreases from anterior to posterior and from the center towards the sides.

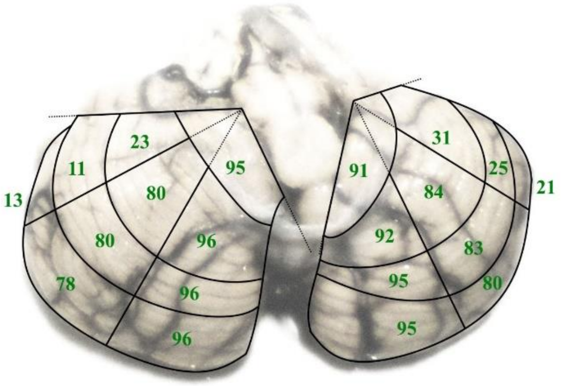

Fig. 5. Distribution of terminal branches of the PICA across sectors of the inferior surface of the cerebellum (indicated the number of cases of typical distribution).

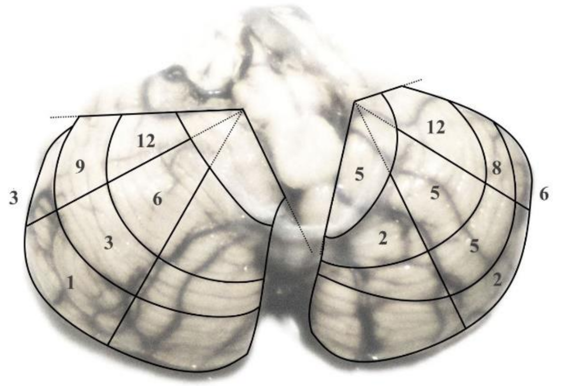

Fig. 6. Distribution of “gray zones” across the sectors of the inferior surface of the cerebellum.

The PICA was absent in four cases on the right and four cases on the left. In these cases, the terminal branches of the caudal AICA had a larger diameter, extended to the central sectors of the corresponding hemisphere's inferior surface (B_c, G_c, I_c) and branched into smaller vessels within these sectors.

Duplication of the PICA was observed twice on the left side. In these cases, the more rostral PICA originated 1.5-2 cm above the caudal one, ran parallel to it and supplied sectors B_c, G_c, I_c.

Sometimes (in two samples on the right and in two on the left), the sectors B_p, G_p or I_p received blood from the contralateral PICA. Such redistribution of the vascular bed occurred to compensate for the weakly developed PICA, which shared a common segment with the AICA (one case on the left) or in the absence of PICA (two cases on the right, one on the left).

Common trunk AICA-PICA

In 18 cases on the right and 10 cases on the left (including four cases bilaterally), the AICA and PICA originated as a common trunk from the basilar artery. We observed three variants of the vascular pattern associated with this variation, characterized by differences in the length of the common segment, the course of the arteries, and the perfusion territories.

The first variant was observed 9 times on the right and 2 times on the left (Fig. 7). The common trunk follows the course of the classical AICA and then its caudal branch extends to the middle part of the flocculus, where it bifurcates into two branches: AICA and PICA. In some cases (3 on the right), the bifurcation occurs earlier, immediately after crossing the oculomotor nerve. The AICA continues along the horizontal fissure, giving off a rostral branch near the lateral part of the flocculus, then turns back, goes medially and caudally, encircling the flocculus. The AICA then often extends its branches to sector I_c. The PICA makes a sharp turn backward, following the medial edge of the tonsil, encircling it, and then branching into smaller vessels on the inferior surface of the cerebellum.

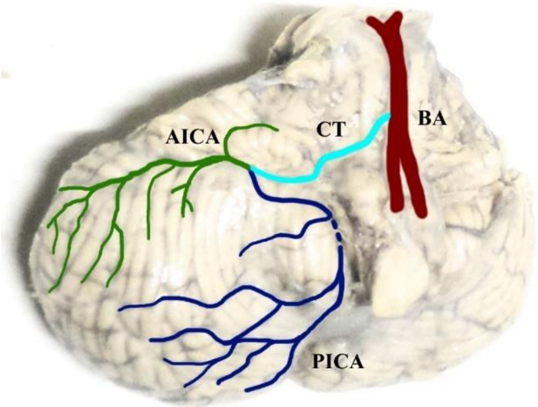

Fig. 7. Schematic representation of the course of superficial arteries of the cerebellum, view from below and on the right. Common segment of AICA and PICA, first variant. Note: CT – common trunk, BA – basilar artery (here and in Fig. 8, 9).

The second variant was observed 7 times on the right and 4 times on the left (Fig. 8). The common trunk extends to the central part of the ponto-cerebellar angle and bifurcates into the AICA and PICA before crossing the VII and VIII nerves. The AICA then follows the course of its classical rostral branch, encircling the flocculus laterally and from above. It also gives off a caudal branch that starts near the lateral part of the flocculus, encircles it from below and branches around the horizontal fissure. The PICA descends to the anterior part of the tonsil, then crosses it diagonally, passing somewhat laterally compared to the first variant. No significant difference in perfusion territory was observed.

The third variant was observed three times on the right and three times on the left (Fig. 9). The course of the AICA and PICA is similar to the second variant; however, the degree of branching of the PICA is comparatively greater. Near the anterior part of the tonsil, it branches into several large branches that cover most of the inferior surface of the cerebellum (all sectors except I_a).

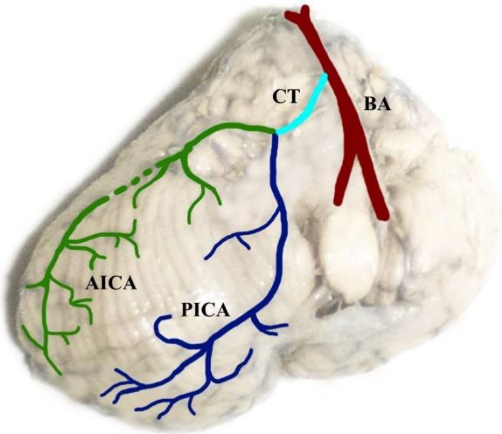

Fig. 8. Schematic representation of the course of superficial arteries of the cerebellum, view from below and on the right. Common segment of AICA and PICA, second variant.

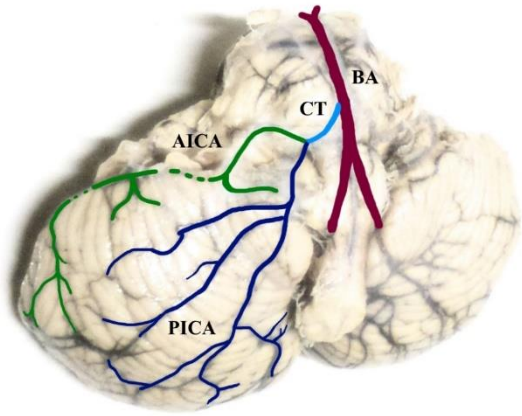

Fig. 9. Schematic representation of the course of superficial arteries of the cerebellum, view from below and on the right. Common segment of AICA and PICA, third variant.

Discussion

The descriptions of the perfusion territories of the cerebellar arteries have previously been based on three surfaces of the cerebellum [7, 8]. In this study, for the first time, a method was applied to divide the superior and inferior surfaces of the cerebellum into sectors. This method allows for the identification of features of the superficial vascular structure and defining the perfusion territories and their boundaries.

The comparison of data regarding the variability of cerebellar arteries is presented in Tables 1-3.

Table 1

Comparison of data on the variability of the SCA with findings from other authors

Author	Type of SCA variation						
	Origin			Duplication		Triplication	Absence
	BA	PCA	Common trunk with PCA from BA	All cases	Bilateral		
[10]	98,5*	0	0	28	3	1,5	1,5
[6]	96	4	0	14	-	0	0
[11]	100	0	0	0	0	0	0
[12]	89,4	4,6	5,9	8	4	0	4
[13]	74,6	0	25,3	23,3	-	2	0
[14]	98,2	1,8	0	1,8	0,9	0	0
[15]	93,4	4	2,5	21,3	2	0	0
[16]	95	1,9	3,1	17,5	0	1,9	0
[17]	98,3	1,7	0	22,1	-	0	3,2
This study	100	0	0	3,5	1	0	0

Note: BA – basilar artery; PCA – posterior cerebral artery; * – Data is given as percentages.

As evident from the data in Table 1, the variability of the origin and development of the SCA is less than that observed in the AICA or PICA. The SCA typically originates from the basilar artery, as reported by most authors with a probability of 95-100%, a finding consistent with the results of this study. Additionally, the SCA may arise from the posterior cerebral artery in approximately 1.8% of cases, or sharing a common trunk with the posterior cerebral artery from the basilar artery, occurring in approximately 3.7% of cases [6, 10-17].

Nearly all authors have reported cases of duplication of the SCA, with an average occurrence of 14%. Cases of bilateral duplication, triplication or absence of the SCA were much less common, with averages of 1.6%, 0.5%, and 0.9%, respectively [6, 10-17].

Table 2

Comparison of data on the variability of the AICA with findings from other authors

Type of AICA variation			Author				
			[10]	[6]	[11]	[18]	This study
Origin	BA	All cases	95*	92	63,7	79,1	85
		Middle third	17	-	-	0,7	11
		Lower third	78	-	-	78,4	74
	PICA		0	2	0	0	0
	Common with PICA from BA		0,7	6	0	10,4	14
	VA		2	0	0	3,7	0
	BA-VA junction		0	0	0	3,7	0
Duplication			0	26	0	10,4	1
Absence			1,3	0	36,3	3,1	1

Note: BA – basilar artery; VA – vertebral artery; * – Data is given as percentages (here and in Tab. 3).

There are significantly more variations of the origin of the AICA compared to the SCA (Tab. 2). Most commonly, the AICA originates from the vertebral artery, with its lower third being the predominant location (averaging 83%). The origin of the AICA from the PICA was observed in only one study, accounting for 2% of cases [6]. There is considerable variability in the data regarding the AICA originating as a common trunk with the PICA from the basilar artery (0-14%). The rarest cases involve the AICA arising from the vertebral artery or the junction of the vertebral and basilar arteries, averaging 1.1% and 0.7%, respectively. Data on duplication and absence of the PICA show wide ranges (0-26% and 0-36.3%, respectively) [6, 10, 11, 18]. There is no data on triplication of the AICA.

Table 3

Comparison of data on the variability of the PICA with findings from other authors

Type of PICA variation		Author (number of arteries)			
		[10]	[6]	[11]	This study
Origin	VA	86,5*	82	56,3	82
	BA	1,5	10	0	0
	AICA	0	6	0	0
	Common with AICA from BA	1,5	2	0	14
Duplication		1,5	0	0	2
Absence	All cases	10,5	0	43,7	4
	Bilateral	3	0	-	0

The PICA has fewer variations of its origin compared to the AICA, but the most common variant averages only 76.7% (Tab. 3). Besides the vertebral artery, the PICA may originate from the basilar artery, the AICA, or as a common trunk with the AICA from the basilar artery (averaging 2.9%, 1.5%, and 4.4%, respectively). Duplication of the PICA occurs on average less frequently than that of the SCA or the AICA (0.9%). The PICA has the highest maximum rate of absence among the three cerebellar arteries (43.7%), averaging 14.6%, with bilateral absence accounting for 1% [6, 10, 11].

None of the studies reported the simultaneous absence of both cerebellar arteries on one side.

The data on the variability and perfusion territories of the SCA, AICA and PICA, presented in this study, can be used in the prevention and diagnosis of neurological disorders, guiding surgical interventions for neurological conditions, and localizing areas of large ischemic strokes [19]. The significant variability in the perfusion territories of cerebellar arteries poses challenges in reliably localizing small strokes; however, accurate identification of the affected territory contributes to determining their etiology [20].

Conclusion

This study analyzed the variability of the origin and perfusion territories of the SCA, AICA and PICA. To investigate the variability of the perfusion territories of the cerebellum, a method of sectoral division of the superior and inferior surfaces of the cerebellum was proposed.

Most commonly, the SCA originates from the upper third of the basilar artery, distributing its branches across the entire superior surface of the cerebellum, including the central lobule, culmen, declive, and folium of the vermis. The classical AICA begins from the lower third of the basilar artery, with its terminal branches reaching sectors B_a, G_a and I_a. The PICA typically arises from the vertebral artery, supplying sectors B_c, B_p, G_c, G_p, I_c, I_p.

In addition to the classical variations, we observed duplications of the SCA (unilateral and bilateral), the origin of the AICA from the middle third of the basilar artery or as a common segment with the PICA from the basilar artery, as well as duplication (bilateral) and absence of the AICA. We also noted duplications and absence of the PICA. In cases of duplication of the PICA, its perfusion territory expands towards the central sectors of the inferior surface of the cerebellum. In the absence of the AICA, the PICA enlarges its perfusion territory, replacing it, and vice versa. Occasionally, the absent or poorly developed PICA is replaced by a PICA from the opposite hemisphere. There were not any cases of simultaneous absence of both AICA and PICA on one side. The probability of the extension of branches of the AICA onto specific sectors of the inferior surface of the cerebellum decreases from anterior to posterior and from the sides towards the center, while for the PICA there is an opposite trend. Additionally, this study describes three variations of the course of the arteries when both AICA and PICA originate as a common trunk from the basilar artery.

Prospects for further investigations

Further research will help better understand the causes of cerebellar vascular pathologies.

Conflicts of interest

There are no potential or actual conflicts of interest associated with this manuscript at the time of publication, and none is anticipated.

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Калініченко М.О., Степаненко О.Ю. Індивідуальна мінливість артерій мозочка людини та зон їх кровопостачання.

РЕФЕРАТ. Обгрунтування. Кровопостачання мозочка забезпечують три парні артерії: верхня, передня нижня і задня нижня мозочкові артерії. Походження артерій мозочка, ступінь їх розвитку та наявність подвоювання можуть бути факторами зміни зони кровопостачання цих артерій. **Мета дослідження** – визначення особливостей індивідуальної мінливості артерій мозочка людини та зон їх кровопостачання. **Методи**. Дослідження проводили на 100 препаратах, які являли собою мозочок разом зі стовбуром мозку. Для аналізу мінливості зон кровопостачання мозочка було запропоновано метод секторального розподілу верхньої та нижньої поверхонь мозочка. **Результати та підсумок**. На 95 препаратах ВМА починалась від основної артерії з двох сторін. Подвоєння цієї артерії спостерігали на 2 препаратах білатерально і ще у 3 випадках зліва. ПНМА починається від нижньої третини основної артерії на 69 препаратах справа і 77 – зліва, від середньої третини – на 11 справа і 11 зліва. ПНМА і ЗНМА починалися спільним сегментом від основної артерії у 18 випадках справа і 10 зліва (з них на 4 препаратах білатерально). Подвоєння ПНМА спостерігали білатерально на одному препараті. Вона була відсутньою у 2 випадках (1 справа, 1 зліва). ЗНМА у 78 випадках справа і 86 зліва брала початок від хребтової артерії, рідше вона починалася спільним сегментом з ПНМА від основної артерії. Подвоєння ЗНМА спостерігали 2 рази зліва, вона була відсутньою у 4 випадках справа і 4 зліва. При подвоєнні ПНМА, її зона кровопостачання розширюється до центральних секторів нижньої поверхні мозочка. За відсутності ПНМА, ЗНМА розширює свою зону кровопостачання, замінюючи її, і навпаки. Інколи відсутню або слабко розвинену ЗНМА замінювала однойменна артерія з протилежної півкулі. Випадків одночасної відсутності ПНМА і ЗНМА з одного боку не спостерігалося. Вірогідність поширення гілок ПНМА на певні сектори нижньої поверхні мозочка зменшується спереду назад і з боків до центру, ЗНМА – навпаки. Також у даному дослідженні описано три варіанти ходу артерій при походженні ПНМА і ЗНМА спільним сегментом від основної артерії.

Ключові слова: людина, анатомія, мозочок, ВМА, ПНМА, ЗНМА.