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VARIANT ANATOMY OF THE CEREBRAL ARTERIAL CIRCLE: RELATIONSHIP WITH SKULL SHAPE

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ABSTRACT. ***Introduction.*** The cerebral arterial circle (circle of Willis) is a key structure ensuring intersystemic blood flow. The classical closed configuration is found in no more than 25–50% of cases, and the skull shape may influence the topography of its arterial segments. ***The aim*** of this study was to systematize current knowledge on the variants of the cerebral arterial circle and to analyze the relationship between these variants and craniometric characteristics. ***Materials and methods.*** A review of publications indexed in PubMed, Scopus, and eLibrary databases for the period 2000–2024 was performed. In parallel, the authors' own material was analyzed, comprising MSCT angiographies of patients from a municipal multidisciplinary hospital in Saint Petersburg. ***Results.*** The most common deviations from the classical configuration include hypoplasia or aplasia of one or both posterior communicating arteries, as well as the fetal type of the posterior cerebral artery. Dolichocephalic individuals showed a tendency toward a higher frequency of incomplete variants of the posterior part of the circle, whereas brachycephalic individuals more often exhibited a closed configuration. ***Conclusions.*** Skull shape may be considered one of the predictors of the anatomical variant of the cerebral arterial circle, which is relevant for assessing individual risk of cerebrovascular events.

KEYWORDS: cerebral arterial circle, circle of Willis, variant anatomy, skull shape, craniometry, cephalic index, CT angiography, cerebrovascular pathology

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ВАРИАНТНАЯ АНАТОМИЯ АРТЕРИАЛЬНОГО КРУГА БОЛЬШОГО МОЗГА: ВЗАИМОСВЯЗЬ С ФОРМОЙ ЧЕРЕПА

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РЕЗЮМЕ. ***Введение.*** Артериальный круг большого мозга (виллизиев круг) — ключевое звено, обеспечивающее межсистемный кровоток. Классическое замкнутое строение встречается не более чем в 25–50% наблюдений, а форма черепа может влиять на топографию его артериальных сегментов. ***Цель работы*** — систематизировать современные представления о вариантах строения артериального круга большого мозга и проанализировать связь этих вариантов с краниометрическими характеристиками. ***Материалы и методы.*** Выполнен обзор публикаций в базах данных PubMed, Scopus и eLibrary за период 2000–2024 гг. Параллельно проведен анализ собственного материала, включающего изучение результатов выполнения мультиспиральной компьютерной томографии с ангиографией у пациентов городского многопрофильного стационара города Санкт-Петербурга. ***Результаты.*** Наиболее частыми вариантами отклонений от классического строения являются гипоплазия или аплазия одной или обеих задних соединительных артерий, а также фетальный тип задней мозговой артерии. У долихоцефалов отмечена тенденция к большей частоте разомкнутых вариантов заднего отдела круга, тогда как у брахицефалов чаще встречается замкнутая конфигурация. ***Выводы.*** Форму черепа можно рассматривать как один из предикторов анатомического варианта артериального круга, что имеет значение для оценки индивидуального риска цереброваскулярных событий.

КЛЮЧЕВЫЕ СЛОВА: артериальный круг большого мозга, виллизиев круг, вариантная анатомия, форма черепа, краниометрия, черепной указатель, КТ-ангиография, цереброваскулярная патология

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INTRODUCTION

The cerebral arterial circle, described by Thomas Willis in 1664, continues to attract close attention from anatomists, neurologists, and neurosurgeons. This is only natural: being the principal collateral pathway between the internal carotid and vertebral artery territories, it largely determines the resilience of cerebral hemodynamics to occlusive lesions of the major cervical vessels [1, 2]. The classical description assumes a closed arterial polygon formed by the anterior cerebral arteries, the anterior communicating artery, the internal carotid arteries, the posterior communicating arteries (PCoA), and the posterior cerebral arteries [3]. However, as has been repeatedly emphasized in the literature — and our own practical experience confirms the "classical" closed variant is an idealized norm rather than a typical finding.

According to systematic reviews, a fully formed arterial circle is observed in only 20–49% of subjects, depending on the method of investigation and the evaluation criteria applied [4, 5]. The remaining cases present a wide array of variants, ranging from minor caliber asymmetry of paired arteries to the complete absence of individual segments. Such variability is of more than theoretical interest. In the setting of acute cerebral ischemia, it is the competence of collateral flow through the arterial circle that frequently determines the volume of brain tissue damage and, ultimately, disease prognosis [6].

A parallel and no less fundamental problem concerns the relationship between intracranial vascular architecture and constitutional features of the skull. The shape of the neurocranium, quantified by the cephalic index, reflects the ratio of maximum cranial breadth to maximum cranial length and, consequently, the configuration of the cranial cavity in which the major arterial trunks of the brain base are situated [7, 8]. It appears plausible that differences in the geometric parameters of the cranial cavity may affect the length, branching angles, and caliber of the arterial circle segments.

Nevertheless, targeted studies of this relationship have been relatively few, and the available data are often contradictory. The aim of the present study was to systematize the existing knowledge on the variant anatomy of the cerebral arterial circle and to analyze the possible association between its configuration and craniotype.

MATERIALS AND METHODS

The study was conducted in two sequential stages. The first stage comprised an analytical review of publications retrieved from the PubMed, Scopus, and eLibrary databases using the key search terms "circle of Willis variants", "cerebral arterial circle anatomy ", and "cephalic index AND cerebral arteries" for the period 2000–2024. Inclusion criteria were original studies using autopsy or in vivo (computed tomography angiography, magnetic resonance angiography) material with a sample size of at least 50 cases, as well as systematic reviews and meta-analyses. Case-based publications lacking quantitative analysis were excluded.

The second stage consisted of the authors' own investigation performed on CT angiograms of the brain with simultaneous assessment of craniometric parameters. The cephalic index was calculated as the ratio of maximum cranial breadth to maximum cranial length, multiplied by 100. Patients were allocated into three groups: dolichocephalic (index <74.9), mesocephalic (75.0–79.9), and brachycephalic (≥80.0) [7]. The configuration of the arterial circle was evaluated according to a classification that takes into account the status of both the anterior and posterior segments: completely closed, closed in the anterior segment only, closed in the posterior segment only, and open [9, 10].

Statistical analysis was performed using Pearson's chi-squared test for comparing frequencies of categorical variables. Differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Analysis of the published literature confirms the high variability in the structure of the arterial circle. K.S. Kapoor et al., upon examination of 1,000 brain specimens, found the classical closed configuration in only 45.2% of cases [4]. Similar figures — ranging from 37 to 52% have been reported by other authors working with autopsy material from various populations [5, 11]. When MR angiography is employed, the proportion of the "classical" variant appears somewhat lower, at approximately 28–42%, which is presumably attributable to the limited spatial resolution of the method in visualizing small-caliber vessels [12, 13].

The posterior segment of the arterial circle exhibits substantially greater variability compared with the anterior segment. This finding is well consistent with embryological data: the posterior communicating arteries form later in development and frequently undergo secondary regression in the postnatal period [14]. Hypoplasia or aplasia of one PCoA is detected in 22–34% of cases, according to various estimates, while bilateral changes are reported in 8–18% [5, 11, 15]. The fetal type of the posterior cerebral artery, in which the posterior cerebral arteries receives its blood supply predominantly from the internal carotid arteries rather than the basilar artery, is encountered in 15–32% of subjects [12, 16].

The anterior segment of the circle shows less variability. Nevertheless, aplasia or hypoplasia of the proximal segment (A1) of the anterior cerebral artery is observed in 1–10% of cases, and duplication of the anterior communicating artery in 10–18% [4, 11]. It should be noted that in our own sample, the distribution of variants was generally consistent with the literature, although certain differences presumably of population-specific nature were documented.

The question of the influence of skull shape on intracranial angioarchitectonics was first raised in classical works by Russian anatomists. I.V. Gaivoronsky et al. in their studies of craniological characteristics, pointed to significant differences in the topography of the cerebral base vessels among individuals with different craniotypes [8]. Yet systematic data incorporating modern imaging modalities remained fragmentary until recently.

A number of international studies have attempted to correlate the cephalic index with the configuration of the arterial circle. B. Eftekhar et al., based on 102 CT angiograms, found a trend toward a higher frequency of incomplete posterior segment variants in dolichocephalic individuals [17]. The authors attributed this phenomenon to the greater anteroposterior extent of the skull base, resulting in “stretching” of the posterior communicating arteries and their functional insufficiency. Conversely, in brachycephalic subjects — with a more compact configuration of the posterior cranial fossa — the distance between the basilar artery bifurcation and the carotid siphons is reduced, which presumably favors the preservation of fully developed PCoAs.

Our study yielded similar results. In dolichocephalic individuals, a completely closed arterial circle was identified significantly less frequently than in brachycephalic subjects. The difference was statistically significant ($p < 0.05$) and was driven primarily by variations in the posterior segment (Fig. 1).

The anterior segment showed minimal differences between the two groups, which is in agreement with published data on its relative stability.

These results, for all their consistency, require cautious interpretation. First, the cephalic index is a relatively crude parameter that does not capture all the nuances of the posterior cranial fossa geometry. Second, the configuration of the arterial circle is determined by multiple factors, including the genetic characteristics of angiogenesis, hemodynamic conditions during the embryonic

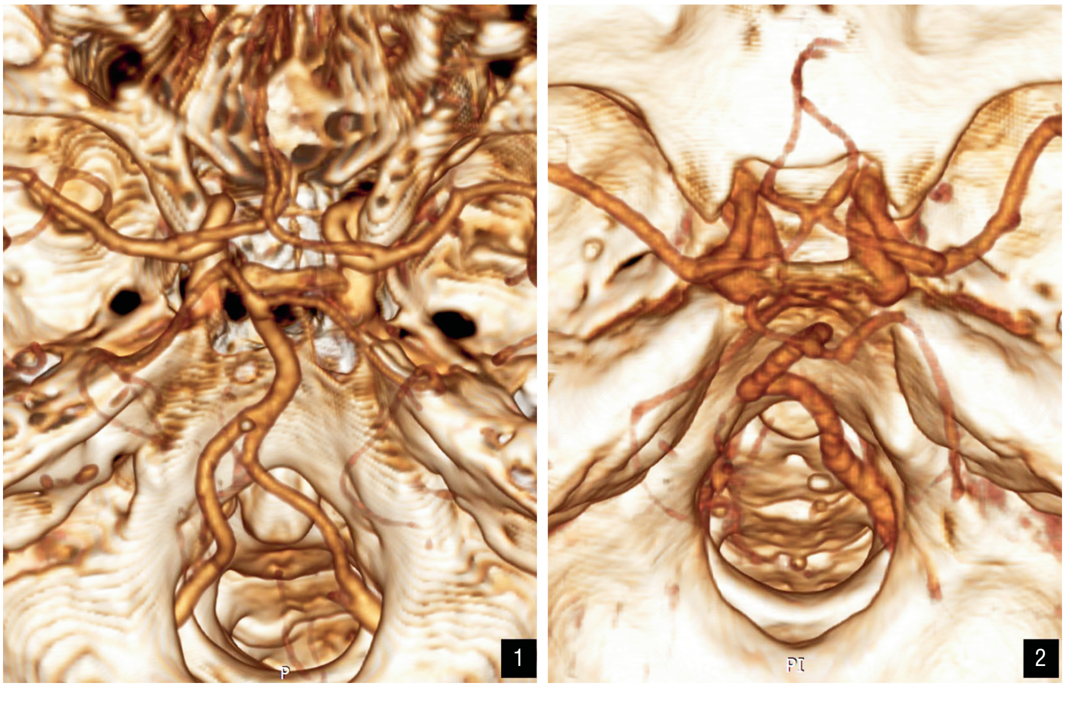

Fig. 1. Anatomical variants of the circle of Willis: absence of all communicating arteries (1) and absence of both posterior communicating arteries (2) (results of original radiological studies by L.Yu. Artyukh, 2025)

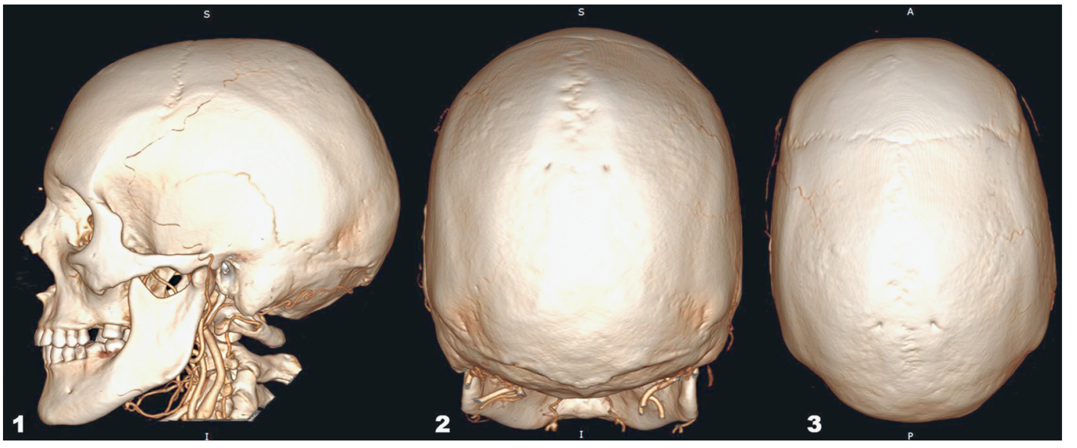

Fig. 2. **Three-dimensional volume rendering technique (3D VRT) of multislice computed tomography angiography studies of patients for skull shape determination (authors' own results). 1 — lateral view (norma lateralis); 2 — occipital view (norma occipitalis); 3 — vertical view (norma verticalis) (results of original radiological studies by L.Yu. Artyukh, 2025)**

and postnatal periods, and the presence of systemic vascular disease [14, 18]. In our view, skull shape is more likely one of the "modifying" factors rather than the sole determinant (Fig. 2).

The practical significance of the obtained data is defined by the fact that incompetence of collateral circulation through the arterial circle substantially increases the risk of ischemic stroke in patients with steno-occlusive disease of the extracranial arteries [6, 19]. As noted by V.G. Lelyuk and S.E. Lelyuk, in the ultrasound assessment of compensatory capacity of cerebral hemodynamics, the completeness of the circle of Willis determines the pattern of blood flow redistribution within the arterial ring at the base of the brain [3].

Consequently, consideration of craniotype — alongside neuroimaging data may be useful in planning carotid endarterectomy and stenting. If an incomplete posterior segment of the circle is identified in a particular dolichocephalic patient, the risk of hemodynamic stroke in the setting of ipsilateral carotid stenosis is potentially higher. This hypothesis, of course, requires prospective clinical validation.

The limitations of the present study should also be acknowledged. The review component does not claim the completeness of a systematic review with meta-analysis; our own sample, while sufficient to identify a statistical trend, requires expansion in order to refine the quantitative parameters of the association. Furthermore, we did not have data on the hemodynamic significance of the identified anatomical variants — a task that may be addressed in future studies employing transcranial Doppler ultrasonography and functional stress tests.

CONCLUSION

The cerebral arterial circle is characterized by high anatomical variability, with its posterior segment being considerably more variable than the anterior one. Skull shape, as assessed by the cephalic index, may be regarded as one of the factors associated with the configuration of the arterial circle.

ADDITIONAL INFORMATION

Authors' contribution. All authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study.

Competing interests. The authors declare that they have no competing interests.

Consent for publication. Written consent was obtained from the patient for publication of relevant medical information within them anu script.

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Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

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REFERENCES

1. Efimov A.P. Variant anatomy of the cerebral arterial circle. *Morfologiya*. 2005;127(1):68–72. (In Russ.).
2. Health of the population of Russia and the activity of healthcare institutions in 2022. Moscow: Rosstat; 2023. (In Russ.).
3. Lelyuk V.G., Lelyuk S.E. Ultrasound angiology. Moscow: Real'noe Vremya; 2003. (In Russ.).
4. Kapoor K., Singh B., Dewan L.I.J. Variations in the configuration of the circle of Willis. *Anat Sci Int*. 2008;83(2):96–106. https://doi.org/10.1111/j.1447-073X.2007.00216.x.
5. Iqbal S. A comprehensive study of the anatomical variations of the circle of Willis in adult human brains. *J Clin Diagn Res*. 2013;7(11):2423–2427. https://doi.org/10.7860/JCDR/2013/6580.3563.
6. Liebeskind D.S. Collateral circulation. *Stroke*. 2003;34(9):2279–2284. https://doi.org/10.1161/01.STR.0000086465.41263.06.
7. Gaivoronskii I.V., Fandeeva O.M. Determination of somatic sex of an adult by the skull. Saint Petersburg: ELBI-SPb; 2008. (In Russ.).
8. Aleshkina O.Yu., Nikolenko V.N. Craniometric characteristics of the skull and their relationship with the topography of cerebral base vessels. *Morfologiya*. 2011;140(4):52–56. (In Russ.).
9. Lazorthes G., Gouazé A., Salamon G. Vascularisation et circulation de l'encéphale. Paris: Masson; 1976. (In French).
10. Riggs H.E., Rupp C. Variation in form of circle of Willis. The relation of the variations to collateral circulation: anatomic analysis. *Arch Neurol*. 1963;8(1):8–14. https://doi.org/10.1001/archneur.1963.00460010024002.
11. De Silva K.R.D., Silva R., Gunasekera W.S.L. et al. Prevalence of typical circle of Willis and the variation in the anterior communicating artery: a study of a Sri Lankan population. *Ann Indian Acad Neurol.* 2009;12(3):157–161. https://doi.org/10.4103/0972-2327.56314.
12. Krabbe-Hartkamp M.J., van der Grond J., de Leeuw F.E. et al. Circle of Willis: morphologic variation on three-dimensional time-of-flight MR angiograms. *Radiology.* 1998;207(1):103–111. https://doi.org/10.1148/radiology.207.1.9530305.
13. Li Q., Li J., Lv F. et al. A multidetector CT angiography study of variations in the circle of Willis in a Chinese population. *J Clin Neurosci*. 2011;18(3):379–383. https://doi.org/10.1016/j.jocn.2010.07.137.
14. Padget D.H. The development of the cranial arteries in the human embryo. *Contrib Embryol Carnegie Inst.* 1948;32:205–261.
15. Gunnal S.A., Farooqui M.S., Wabale R.N. Anatomical variations of the circulus arteriosus in cadaveric human brains. *Neurol Res Int.* 2014;2014:687281. https://doi.org/10.1155/2014/687281.
16. van Raamt A.F., Mali W.P., van Laar P.J. et al. The fetal variant of the circle of Willis and its influence on the cerebral collateral circulation. *Cerebrovasc Dis*. 2006;22(4):217–224. https://doi.org/10.1159/000094007.
17. Eftekhar B., Dadmehr M., Ansari S. et al. Are the distributions of variations of circle of Willis different in different populations? Results of an anatomical study and review of literature. *BMC Neurol*. 2006;6:22. https://doi.org/10.1186/1471-2377-6-22.
18. Aliev M.A., Shchegolev A.I. Angiogenesis factors in the development of cerebral arterial circle variants. *Arkhiv patologii*. 2019;81(3):63–69. (In Russ.). https://doi.org/10.17116/patol20198103163.
19. Henderson R.D., Eliasziw M., Fox A.J. et al. Angiographically defined collateral circulation and risk of stroke in patients with severe carotid artery stenosis. *Stroke*. 2000;31(1):128–132. https://doi.org/10.1161/01.STR.31.1.128.

ЛИТЕРАТУРА

1. Ефимов А.П. Вариантная анатомия артериального круга большого мозга. *Морфология*. 2005;127(1):68–72.
2. Здоровье населения России и деятельность учреждений здравоохранения в 2022 году. М.: Росстат; 2023.
3. Лелюк В.Г., Лелюк С.Э. Ультразвуковая ангиология. М.: Реальное Время; 2003.
4. Kapoor K., Singh B., Dewan L.I.J. Variations in the configuration of the circle of Willis. *Anat Sci Int*. 2008;83(2):96–106. https://doi.org/10.1111/j.1447-073X.2007.00216.x.
5. Iqbal S. A comprehensive study of the anatomical variations of the circle of Willis in adult human brains. *J Clin Diagn Res*. 2013;7(11):2423–2427. https://doi.org/10.7860/JCDR/2013/6580.3563.
6. Liebeskind D.S. Collateral circulation. *Stroke*. 2003;34(9):2279–2284. https://doi.org/10.1161/01.STR.0000086465.41263.06.
7. Гайворонский И.В., Фандеева О.М. Определение соматического пола взрослого человека по черепу. СПб.: ЭЛБИ-СПб; 2008.
8. Алешкина О.Ю., Николенко В.Н. Краниометрические характеристики черепа и их связь с топографией сосудов основания мозга. *Морфология.* 2011;140(4):52–56.
9. Lazorthes G., Gouazé A., Salamon G. Vascularisation et circulation de l'encéphale. Paris: Masson; 1976. (In French).
10. Riggs H.E., Rupp C. Variation in form of circle of Willis. The relation of the variations to collateral circulation:

anatomic analysis. *Arch Neurol*. 1963;8(1):8–14. https://doi.org/10.1001/archneur.1963.00460010024002.

11. De Silva K.R.D., Silva R., Gunasekera W.S.L. et al. Prevalence of typical circle of Willis and the variation in the anterior communicating artery: a study of a Sri Lankan population. *Ann Indian Acad Neurol.* 2009;12(3):157–161. https://doi.org/10.4103/0972-2327.56314.
12. Krabbe-Hartkamp M.J., van der Grond J., de Leeuw F.E. et al. Circle of Willis: morphologic variation on three-dimensional time-of-flight MR angiograms. *Radiology.* 1998;207(1):103–111. https://doi.org/10.1148/radiology.207.1.9530305.
13. Li Q., Li J., Lv F. et al. A multidetector CT angiography study of variations in the circle of Willis in a Chinese population. *J Clin Neurosci*. 2011;18(3):379–383. https://doi.org/10.1016/j.jocn.2010.07.137.
14. Padget D.H. The development of the cranial arteries in the human embryo. *Contrib Embryol Carnegie Inst.* 1948;32:205–261.
15. Gunnal S.A., Farooqui M.S., Wabale R.N. Anatomical variations of the circulus arteriosus in cadaveric human brains. *Neurol Res Int.* 2014;2014:687281. https://doi.org/10.1155/2014/687281.
16. van Raamt A.F., Mali W.P., van Laar P.J. et al. The fetal variant of the circle of Willis and its influence on the cerebral collateral circulation. *Cerebrovasc Dis*. 2006;22(4):217–224. https://doi.org/10.1159/000094007.
17. Eftekhar B., Dadmehr M., Ansari S. et al. Are the distributions of variations of circle of Willis different in different populations? Results of an anatomical study and review of literature. *BMC Neurol*. 2006;6:22. https://doi.org/10.1186/1471-2377-6-22.
18. Алиев М.А., Щеголев А.И. Факторы ангиогенеза в развитии вариантов артериального круга мозга. *Архив патологии*. 2019;81(3):63–69. https://doi.org/10.17116/patol20198103163.
19. Henderson R.D., Eliasziw M., Fox A.J. et al. Angiographically defined collateral circulation and risk of stroke in patients with severe carotid artery stenosis. *Stroke*. 2000;31(1):128–132. https://doi.org/10.1161/01.STR.31.1.128.

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