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Anatomical Variations and Clinical Significance of the Cerebral Arterial Circle in Turkish Cadavers

Variaciones Anatómicas y Significancia Clínica del Círculo Arterial Cerebral en Cadáveres Turcos

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SUMMARY: The structure formed by the arteries, which is of great importance in the irrigation of the brain, is called the cerebral arterial circle (Polygon of Willis). Since the cerebral arterial circle provides brain nutrition, vascularabnormalities in this region are highly relevant. Therefore, the aim of our study was to examine the variations of the cerebral arterial circle in cadavers of Turkish individuals. In our study, 32 human cadavers obtained from three different universities were retrospectively examined. Brain tissue obtained from cadavers by craniotomy was kept in 20 % formaldehyde solution for an average of 10 days for fixation. Cerebral arterial circle diagrams were determined in all cadavers by staining and photographs were taken. As a result of the brain examinations, a variation of the cerebral arterial circle was detected in 24/32 brains. Vascular variations have an important place in congenital variations. For this reason, we believe that our brain study will contribute to clinical studies on this topic by investigating variations of the cerebral arterial circle.

KEY WORDS: Cerebral arterial circle; Circle of Willis; Anatomical variations; Turkish individuals.

INTRODUCTION

Cerebral arterial circle (Circle of Willis or Willis Polygon), which was first described by Thomas Willis in the year 1664 and provides nutrition to the brain, is of great importance for the brain (Ansari *et al*., 2011). The brain is supplied by two internal carotid arteries and two vertebral arteries that form a complex anastomosis (cerebral arterial circle) on the base of the brain. Vessels diverge from this anastomosis to supply the various cerebral regions. In general, the internal carotid arteries and the vessels arising from them supply the forebrain, with the exception of the occipital lobe of the cerebral hemisphere, and the vertebral arteries and their branches supply the occipital lobe, the brain stem and the cerebellum. This polygon prevents the brain from being affected by blood pressure differences, by minimizing the pressure differences of the blood coming to the brain from different vessels (Standring, 2016; Nyasa *et al*., 2021). Vessels forming the circle of Willis are as follows: bilateral a. cerebri anterior and a. communicans anterior which links these two arteries, bilateral posterior cerebral artery, posterior communicating artery which links internal carotid artery to posterior cerebral artery and basilar artery in anterior middle part. Internal carotid artery, anterior cerebral arteries, anterior communicating artery and their branches are defined as "anterior circulation/carotis system", posterior cerebral arteries, posterior communicating arteries, vertebral artery and basilar artery are defined as "posterior circulation/vertebrobasilar system" (Karatas *et al*., 2016). Circle of cerebral arterial circle is the main structure that provides constant and regular blood flow to the brain protects the brain from ischemia (Oumer *et al*., 2021). Despite the presence of detailed studies concerning each of the vessels that constitute the cerebral arterial circle, studies regarding the whole of circle are relatively sparse. In addition, a few studies are available in the literature investigating anatomical variations of the cerebral arterial circle within the adult Turkish population. The aim of this study was to determine structural characteristics of the cerebral arterial circle in order to detect its variations that contribute to this structure in cadavers in the Turkish population. Moreover this study can contribute to current clinical practice, human anatomy education and research.

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MATERIAL AND METHOD

In our study, 32 human cadavers (65-72 years old) from three different anatomy departments were dissected and examined retrospectively. Firstly, to remove the brains, the craniums of the cadavers were opened with craniotomy and the brains were taken out of the cranium together with their duramaters. The brains were removed from the cranial cavity and fixed in 20 % formaldehyde for ten days. After fixation, cerebral arterial circle and its branches were exposed by dissection using a dissection set. Arterial coloring was done in order to take pictures of the cerebral arterial circle and its branches more clearly and to schematize the variations more clearly. This was a retrospective study. After removal of the brain from cadavers used in routine educational dissection for students, the anterior communicating artery was dissected and cleaned, then measurements were taken and digitally photographed.

In the arterial coloring section, both sides a.carotis interna and vertebral artery dissection was performed. Later, incisions were made in the exposed arteries in the direction of their axis and catheters of appropriate diameter were placed. Then, the connection of the vessel diameter with the catheter was secured with a thread to prevent leakage. The vein was washed with distilled water and the washed water was aspirated. After waiting for one hour, the mixture of latex and india ink was injected at an appropriate pressure through all the vessels in turn, starting from the internal carotid artery. During this application, while the latex mixture was injected into one artery, the other arteries were clamped. After the injection procedure was completed, the catheters were removed and the vessels were closed. After waiting for 24 hours, dissection was performed.

Cadavers with remarkable alteration in brain arteries and gross pathological lesions such as crush injuries, macroscopically identified tumors and severe hemorrhage were excluded from the study. Ethics committee was not consulted because the study was a multicenter and retrospective study over a wide period of time. Since cadavers used as medical education materials for students are included in the study, there is no unethical situation in their use. These cadavers are still used for medical education. Moreover, all the test procedures were performed according to the Helsinki Declaration of Principles and permission was obtained from the institutions where we performed cadaver dissection for the study.

RESULTS

The cerebral arterial circle was evaluated in 32 fresh adult cadavers. We detected variation in 24 of them. The types, numbers and percentages of variations in our study are summarized in Table I. Variation detected brains are as follows;

Variation 1: In this brain, the number of distal anterior cerebral artery is three. Of these, the anterior cerebral artery, located in the middle, is thinner. These veins extend upward from the sulcus interhemispherica. In the same brain, middle cerebral arteries are normal on the right side and there are two on the left side. Both middle cerebral artery on the left side run side by side in the sulcus lateralis cerebri. In the same brain, there is no posterior communicating artery on the right side. On the left side, its number is two. Out of these two arteries, the outer posterior communicating artery is shorter and is located between the last end of the basilar artery and the left posterior cerebral artery. The posterior communicating artery, which is located on the inner side, is thinner between the left internal carotid artery and the basilar artery. The posterior cerebral arteries in this brain are normal on the right side. However, there is origin asymmetry in the posterior cerebral artery on the left side. While this artery should be the terminal branch of the basilar artery, it branches from the internal carotid artery (Fig. 1a).

Table I. Distribution of arterial variations in the cerebral arterial circle.

	Anterior communicating artery (%)	Posterior communicating artery (%)	Anterior cerebral artery (%)	Posterior cerebral artery (%)	Middle cerebral artery (%)	Total N (%)
Absence	1 (2.13 %)	4 (8.51 %)	0	0	0	5 (10.64 %)
Multiple	0	0	1(2.13 %)			1(2.13 %)
Double	2 (4.26 %)	3 (6.38 %)	0	2(4.26 %)	1(2.13 %)	8(17.02 %)
Simple junction	5(10.64 %)	0	0	0	0	5(10.64 %)
Thinner	0	11(23.40 %)	3(6.38 %)	0	0	14(29.79 %)
Thicker	0	0	3(6.38 %)	0	0	3(6.38 %)
Long and slim	0	3(6.38 %)	0	0	0	3(6.38 %)
Origin variation	0	0	0	8 (17.02 %)	0	8(17.02 %)
Total n (%)	8(17.02 %)	21(44.68 %)	7(14.89 %)	10(21.28 %)	1(2.13%)	47 (100 %)

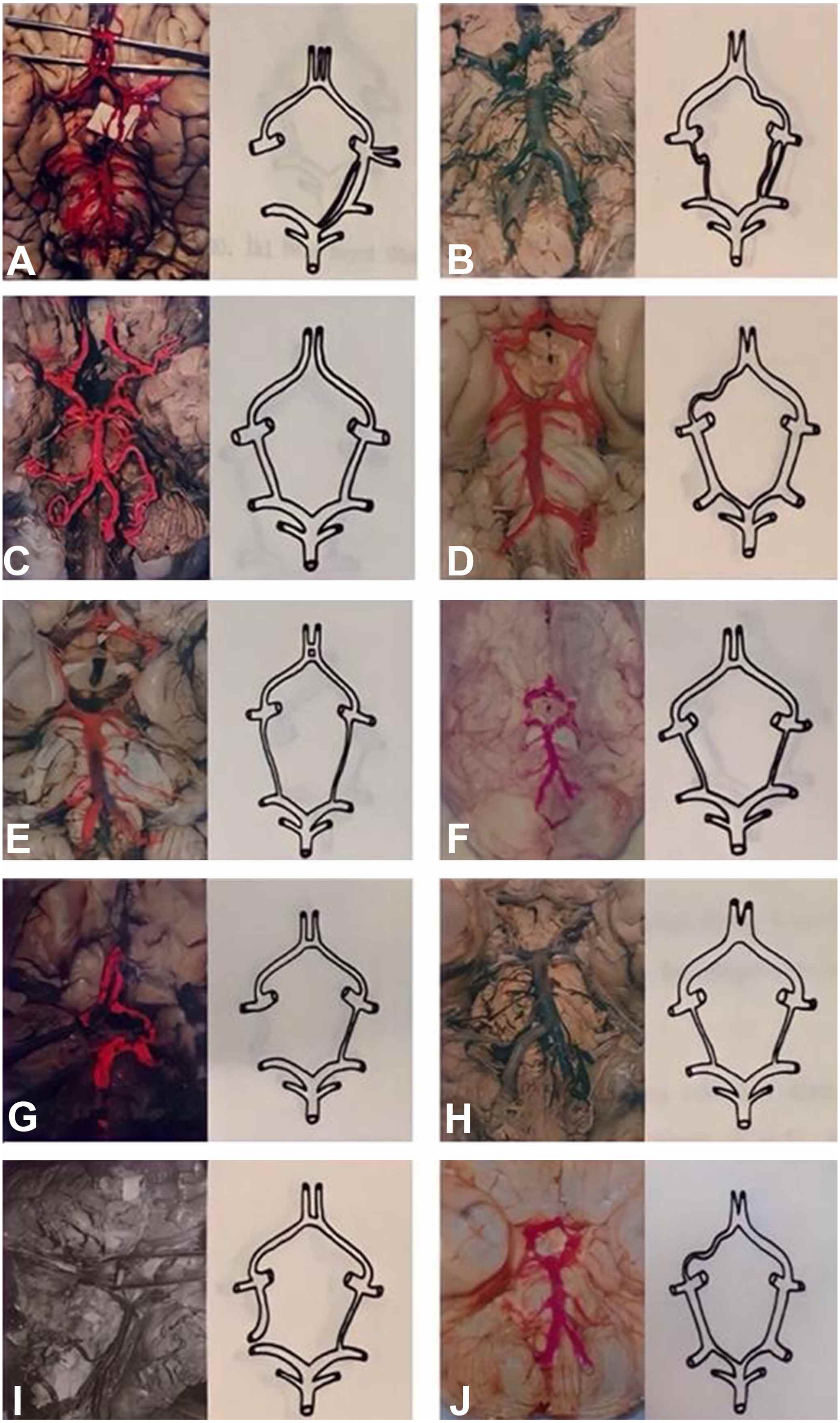

Fig. 1. arterial variations in the cerebral arterial circle with schematic and real images in adult cadavers.

Figure 1a, Variation 1;
Figure 1b, Variation 6;
Figure 1c, Variation 2;
Figure 1d, Variation 7;
Figure 1e, Variation 3;
Figure 1f, Variation 8;
Figure 1g, Variation 4;
Figure 1ı, Variation 5;
Figure 1j, Variation 9.

Variation 2: There is no anterior communicating artery in this brain. Therefore, there is no anastomosis between both anterior cerebral artery. Other formations of the cerebral arterial circle were observed in accordance with the normal anatomical structure (Fig. 1c).

Variation 3: One of the variations we see here is that the anterior communicating artery is double. From the paired arteries, it provides anastomosis between the proximal anterior cerebral artery at the back and the other between the distal anterior cerebral artery. Another variation in this brain is that the posterior communicating artery on the right and left are thinner and longer than normal. Other arteries are normal (Fig. 1e).

Variation 4: Variation in this brain; posterior communicating artery is absent on the right side. Therefore, anastomosis will not occur between the internal carotid artery and posterior cerebral artery on the right side (Fig. 1g).

Variation 5: Variation in this brain; posterior cerebral artery is two. This second posterior cerebral artery branches from the internal carotid artery. In addition, there is no anastomosis between these two posterior cerebral arteries. Therefore, there is no posterior communicating artery on the same side (Fig. 1i).

Variation 6: This is variation in the brain; anterior communicating artery is in a simple junctional style. In addition, macroscopically, the proximal anterior cerebral arteries follow a thinner and more curved path on the left side than on the right side. Likewise, posterior communicating artery, which provide anastomosis between the internal carotid artery and posterior cerebral arteries, are quite curved on both sides. In addition, there are two left posterior communicating artery (Fig. 1b).

Variation 7: Variation in this brain; anterior communicating artery simple is in junctional style and forms the anastomosis between anterior cerebral arteries. When we compared the proximal anterior cerebral arteries, we found that the left anterior cerebral artery was thicker and smoother than the right, and the right one was curved. Also, posterior cerebral arteries originate from internal carotid artery on both sides. Therefore, the posterior communicating artery is between the basilar artery and the posterior cerebral arteries (Fig. 1d).

Variation 8: The anterior communicating artery simple junctional providing anastomosis between both anterior cerebral arteries. There are also two posterior cerebral artery on the right. This second artery branches from the internal carotid artery. There is also no posterior communicating artery on the right side (Fig. 1f).

Variation 9: In this brain, the posterior communicating artery appear macroscopically thin on both sides. Other formations are in normal anatomical structure (Fig. 1h).

Variation 10: In this brain, anterior communicating artery is simple junctional. In addition, posterior communicating arteries are thinner than normal on both sides (Fig. 1j).

Brain 11-24: In the other 14 brains, the variations were generally found similar to the other variations. These can be summarized as follows; Brains with simple style of posterior communicating artery (3), those with macroscopic diameter differences between anterior cerebral arterys (right; 1, left; 2), and those with macroscopic diameter and height differences in posterior communicating artery (5, especially thin and long structure).

DISCUSSION

Anatomical variations of the cerebral arterial circle are important in the understanding of neurovascular diseases such as ischaemic stroke. The function of the cerebral arterial circle is to protect the brain from ischemia and infarction. It is the main structure that provides constant and regular arterial blood flow into the brain. Therefore, any variation that may occur in the vessels here is of vital importance. Because 15.2 million of the 56.9 million deaths in 2016 were due to stroke (Ayre *et al*., 2022). Moreover, stroke has remained the second leading cause of death globally in the last fifteen years. It is also the leading cause of serious adult disability. Interlinked problems related to ischemic stroke are increasing today. Oumer *et al*. (2021), also found positive association between the cerebral arterial circle and ischemic stroke in their metaanalysis study. Furthermore, in cerebrovascular disease patients, cerebral arterial circle can maintain adequate blood flow and reduce the damage of the affected areas through its potential redistribution role and, notably, this compensation lies on the anatomical morphology of cerebral arterial circle (Qiu *et al*., 2015). Therefore, in our study, we analyzed the anatomical variations of the cerebral arterial circle in human cadaver brains.

Similar to our study, there are studies in the literature conducted with human cadaver brains of different races, examining the variations of the cerebral arterial circle. Nyasa *et al*. (2021) found that variation of posterior communicating artery was the highest with 12 variations on the cadaveric Malawian population in their study. The posterior communicating artery was widest and longest vessels while the anterior communicating artery was the shortest vessel.

They also reported 7 cases of vessel aplasia and 12 cases of vessel hypoplasia. In addition, Dumitrescu *et al*. (2022), identified eight types of anatomical variants in 46.42 % of the Romanian cadavers in their examination. They stated that the most common anatomical variants were hypoplasia (20.91 %) and absence of arteries (3.06 %). Moreover, Fattahian *et al*. (2018), found that in Kurdish cadavers 51.4 % had hypoplasia and 67.3 % had asymmetry anatomical variation. Cadavers with hypoplasia, hypoplasia was located in posterior communicating artery sinistra in 76.3 % and posterior communicating artery sinistra and dextra in 23.7 %. Tripathi *et al*. (2021), in their study in Human Cadaveric Brains in Western Uttar Pradesh Region, found the anterior communicating artery was absent in 3 %, oblique in 56 % of specimens and horizontally placed in the remaining 44 %. In other words, they stated that the variations of anterior communicating artery were common. Also, Gunnal *et al*. (2014), found twenty-one different types of cerebral arterial circle in their study. Normal and complete cerebral arterial circle was found in 60 %. In particular, cerebral arterial circle with gross morphological variations was seen in 40 %. Maximum variations were seen in the posterior communicating artery followed by the anterior communicating artery in 50 % and 40 %, respectively. On the other hand, De Silva *et al*. (2011), reported 15 types of variations of cerebral arterial circle out of 22 types previously described and one additional type: hypoplastic precommunicating part of the anterior cerebral artery and contralateral posterior communicating artery 5(2 %) on Sri Lankan adult cadaver brains. Karatas *et al*. (2016) observed that in the Turkish adult population, hypoplasia was the most common variation in posterior communicating artery (85 %) and aplasia was the second most common variation after hypoplasia and again the most common in posterior communicating artery (5 %). Similarly to the literature, in our study, the most variation was detected in posterior communicating artery (44.68 %). Variations such as thinner (23.40 %), absence (8.51 %), double (6.38 %), long and slim (6.38 %) were seen in posterior communicating artery. The second most common variation was posterior cerebral artery (21.28 %). Variations of posterior cerebral artery include double (4.26 %) and origin variation (17.02 %).Moreover, these variations are followed by the variation of anterior cerebral artery 14.89 %) and anterior communicating artery (17.02 %). Anterior communicating artery had absence (2.13 %), double (4.26 %), and simple junction (10.64 %), while anterior cerebral artery was found to be multible (2.13 %), thinner (6.38 %), and thicker (6.38 %).Additionally, the lowest variation was noticed in arteria cerebri media (2.13 %). In this variation, arteria cerebri media branched from the internal carotid artery as two on the left side. Also, the most common variation styles were thinner (29.79 %), duplication (17.02 %), and origin (17.02 %).In addition, we found that the posterior cerebral artery originates from the internal carotid artery in 12.5 % (1.5 % right side, 1.5 % left side and 9.5 % bilateral). In our study, posterior communicating artery is the vessel in which the cerebral arterial circle variations are most common. Therefore, the variation was found to be more common in the posterior circulation, which is consistent with the literature on the adult Turkish population. The reason why the variations in the literature have different distribution may be related to racial factors. It is also necessary to evaluate genetic, racial, environmental and hemodynamic factors or a combination of these components.

In the literature, apart from cadaver studies, there are current studies examining the anatomical variations of the cerebral arterial circle in Magnetic Resonance Imaging, Magnetic resonance Angiography, Computed Tomography Angiography, Computed Tomography Perfusion, Non-Contrast CT and Transcranial color-coded ultra sonography methods. In these studies, the main anatomical variants of the cerebral arterial circle were found as hypoplasia, absent vessels and accessory vessels (duplications or triplications). As the reviewed articles show, posterior communicating artery hypoplasia was associated with the risk of ischemic stroke and was particularly common in ipsilateral thalamic lacunar infarcts with or without occipital lobe involvement. However, they reported that having a larger diameter of posterior communicating artery may improve collateralization between the anterior and posterior circulations, reducing the risk of stroke. On the other hand, the absence of an unilateral or bilateral vessels was found to be positively associated with stroke by incomplete posterior and anterior circulation of the cerebral arterial circle (Badacz *et al*., 2015; Shahan *et al*., 2017; van Seeters *et al*., 2016).

CONCLUSION

Variations are individual, race-specific and can be caused by many internal and external factors. In our study, we found that only 8 of 32 cadavers were compatible with the normal anatomical structure. Thus, with this study, we have contributed to human cadaver studies examining the limited number of the cerebral arterial circle variations in the Turkish population. Moreover, knowing the prevalence, incidence and types of anatomical anomalies of the cerebral arterial circle can guide surgeons in planning surgical interventions in ruptured intracranial aneurysms and predicting the hemodynamics of the patient's cerebral circulation. We suggest that similar studies be produced with more cadavers, in which genetic, racial, environmental and hemodynamic factors or a combination of these components are also evaluated. In addition, our limitations are the lack of information about the health histories of the cadavers and the inability to discuss the relationship between variations and health histories.

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RESUMEN: La estructura formada por las arterias que tiene una gran importancia en la irrigación del cerebro se denomina círculo arterial cerebral (Polígono de Willis). Dado que el círculo arterial cerebral proporciona la irrigación cerebral, las anomalías vasculares en esta región son muy relevantes. Por lo tanto, el objetivo de nuestro estudio fue examinar las variaciones del círculo arterial cerebral en cadáveres de individuos turcos. En nuestro estudio, se examinaron retrospectivamente 32 cadáveres humanos obtenidos de tres universidades diferentes. El tejido cerebral de los cadáveres fue obtenido por craneotomía y se mantuvo en solución de formaldehído al 20 %, durante 10 días en promedio para su fijación. Se determinaron los diagramas de círculo arterial cerebral en todos los cadáveres mediante coloración y se tomaron fotografías. Como resultado de los exámenes, se detectó una variación del círculo arterial cerebral en 24/32 de los cerebros. Las variaciones vasculares tienen un lugar importante en las variaciones congénitas. Por esta razón, creemos que nuestro estudio contribuirá a estudios clínicos sobre el tema al pesquisar las variaciones del círculo arterial cerebral.

PALABRAS CLAVE: Círculo arterial cerebral; Polígono de Willis; Variaciones anatómicas; Individuos turcos.

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