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Research Article

ANATOMY OF THE CEREBRAL ARTERIAL CIRCLE: A BRIEF LITERATURE REVIEW

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Abstract

In preparing this work, we addressed the knowledge about the Cerebral Arterial Circle. We can observe the importance of this anatomical structure, as the circle is the main site of blood supply to the brain. Due to the significance of these vessels, we conducted a study on them that allowed us to assess their magnitude and better understand this anastomosis.This polygon is an anatomical structure consisting of nine arteries that form a heptagon in the brain. The brain is the upper part of the central nervous system and is composed of the cerebrum, cerebellum, and brainstem. The human brain is a complex and extensive organ. It is immobile and has a very high consumption of oxygen and glucose, as the nervous system is made up of highly specialized structures that require a permanent and substantial supply for the proper functioning of its metabolism.

Keywords: Anterior Circulation, Posterior Circulation, Brain, Blood Flow, Willis Circle

INTRODUCTION

This polygon is an anatomical structure consisting of nine arteries that form a heptagon in the brain. The brain is the upper part of the central nervous system and is composed of the cerebrum, cerebellum, and brainstem. It is housed in the cranial bony cavity, occupying all its space, and together with the spinal cord and nerves, it makes up the central nervous system. The central nervous system controls the entire human body and is the most vital system of the body; consequently, the Circle of Willis is part of this critically important structural complex, which we will present below. The human brain is a complex and extensive organ. It is immobile and has a very high consumption of oxygen and glucose, as the nervous system is composed of highly specialized structures that require a permanent and substantial supply for the proper functioning of its metabolism. For this reason, blood flow is intense and continuous, constantly nourishing the neurons and other cells present in the central nervous system. It receives approximately 25% of all the blood pumped by the heart, with its flow being surpassed only by the kidneys and the heart itself. It is estimated that in one minute, the brain circulates an amount of blood ranging from approximately 750 milliliters to 1 liter, despite representing only 2% of the total body weight (TORTORA Gerard J. and DERRICKSON Bryan. Principles of Anatomy and Physiology. P. 490). The brain's consumption of oxygen and glucose is approximately 20%, even at rest. Neurons synthesize ATP almost exclusively from glucose through oxygen-dependent reactions. When the activity of neurons and neuroglia increases in a region of the brain, blood flow to that area also increases. Even a brief decrease in cerebral blood flow for more than 7 seconds can cause unconsciousness.

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Drops in glucose and oxygen levels in circulating blood or, on the other hand, the suspension of blood flow to the brain cannot be tolerated for more than 1 or 2 minutes, impairing neuronal function, and total oxygen deprivation for approximately 4 minutes causes permanent damage, as nerve cells do not regenerate. Since almost no glucose is stored in the brain, its supply must also be continuous. If the blood entering the brain has a low glucose content, mental confusion, dizziness, seizures, and loss of consciousness may occur (TORTORA Gerard J. and DERRICKSON Bryan.

Principles of Anatomy and Physiology. P. 491). The brain, therefore, is responsible for all bodily activities and is vascularized through two main systems: Vertebro-Basilar (right and left vertebral arteries) and Carotid (right and left internal carotid arteries). These are the four main arteries specialized in supplying blood to the brain. The cerebral portions located in the anterior and middle cranial fossae are supplied by branches of the internal carotid artery, while the cerebral portions located in the posterior cranial fossa are supplied by branches of the vertebral artery or the basilar artery, which is the result of the union of the two vertebral arteries. These two systems together form the Circle of Willis (also called the cerebral arterial circle or heptagonal vascular circle), which results from various arterial anastomoses at the base of the brain, forming a completely closed arterial circle in the shape of a heptagon, as it has seven sides. It was named after the English physician Thomas Willis (1621–1673).

Objective

The present work aims to study the anatomical structure and topographical composition of the Circle of Willis, also known as the Cerebral Arterial Circle or Willis Arterial Circle.

MATERIALS AND METHODS

The information contained in this work was obtained through a literature review in the PUBMED and Science Direct databases.

DISCUSSION

The Circle "forms a crown around the sella turcica; its area corresponds to the optopeduncular rhombus, and its direction is anteroposterior. At the front, it is subjacently to the optic chiasm; behind, the posterior cerebral arteries follow the pedunculo protuberantial course" (TESTUT L. and LATARJET P. 1196). When separating the two cerebral hemispheres, its face is internal. Located in the lower subarachnoid confluence or central reservoir, this reservoir is deep; it measures more than a centimeter in height and extends laterally to the cerebral fissure of Bichat. The arteries of the Circle pulse in a vast space of fluid. It is constituted as follows (TESTUT L. and LATARJET P. 1196): in front, by the two anterior cerebral arteries united by the anterior communicating artery; behind, by the two posterior cerebral arteries; on the sides, by the two posterior or lateral communicating arteries and the two internal carotid arteries. In summary, the anatomical components are:

1. Anterior cerebral artery (left and right).
2. Anterior communicating artery.
3. Internal carotid artery (left and right).
4. Posterior cerebral artery (left and right).
5. Posterior communicating artery (left and right).

The basilar artery with its branches and the middle cerebral artery with its branches, despite supplying the brain, are not considered part of the Circle. The basilar artery, housed in the basilar groove, results from an anastomosis of the two vertebral arteries.

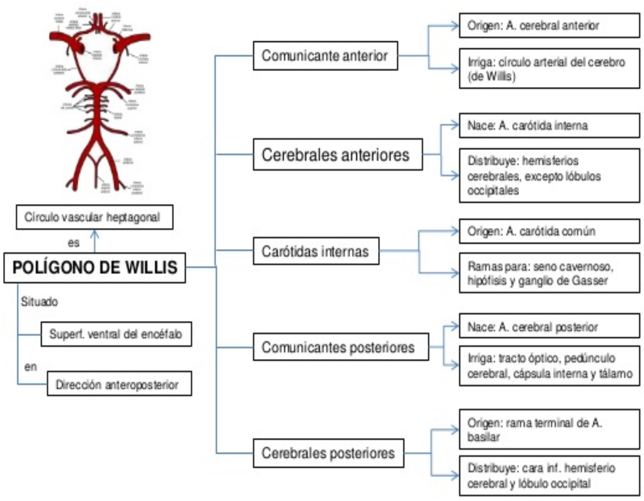


Figure 1. Polygon of Willis

Anterior Cerebral Arteries

A terminal branch of the internal carotid artery; it moves forward and inward, passing the midline above the optic nerve and ascending in the interhemispheric sulcus, where it is united with the one on the opposite side by the anterior communicating artery. It then follows a curve along the corpus callosum, which is why at this point it is called pericallosal. An important branch is the Heubner recurrent artery, which inserts into the anterior perforated substance. The anterior cerebral arteries supply most of the inner face of the cerebral hemisphere. According to the Dorland's Illustrated Medical Dictionary, 27th edition, they present cortical branches (orbital), frontal (parietal), central (including the internal artery of the corpus striatum), and the anterior communicating artery.

Anterior Communicating Artery:

It originates from the pre-communicating portion of the anterior cerebral artery. It connects both right and left anterior cerebral arteries through a transverse anastomosis measuring 1 to 3 millimeters in length (TESTUT L. and LATARJET P. 1195). Sometimes it consists of two arteries that join to form a single trunk, which later divides; it may also be completely or partially divided into two. It emits some of the anteromedial ganglionic vessels (anteromedial perforating central arteries); however, these primarily derive from the anterior cerebral artery (Dorland's Illustrated Medical Dictionary, 27th edition. McGraw Hill Interamericana. 1996).In a study conducted by the Faculty of Medicine in Santiago, Chile, where 36 brains of adult individuals of both sexes were examined, it was observed that the ACoA's caliber was 153 mm in males and 105 mm in females, while its length was 281 mm in males and 233 mm in females (Int. J. Morphol. v.28 n.3 Temuco Sep. 2010), characterizing it as a small artery (Ross p. 445).

Internal Carotid Arteries

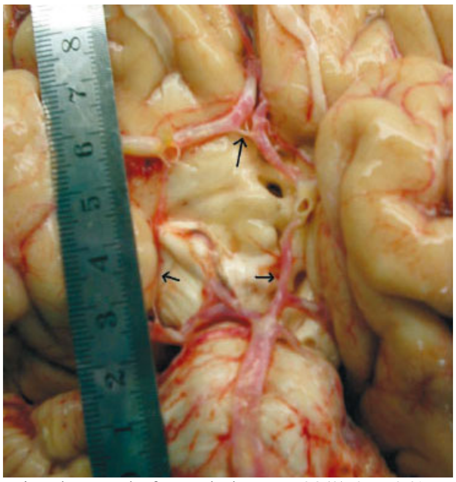
After originating from the primitive carotid artery at the level of the third cervical vertebra, it follows a path in the neck, where it emits no branches; it traverses the retrostyloid space and later enters the middle cranial fossa at the apex of the petrous by the carotid canal, where it has important relations: behind it is the tympanic cavity, externally the Eustachian tube, above the Gasserian ganglion; at this location, it is surrounded by the carotid plexus and emits its first branches: carotidotympanic arteries. Later, it enters the middle cranial fossa through the apex of the petrous and fills the foramen lacerum. It ends at the anterior clinoid process. They supply the middle ear, brain, pituitary gland, orbit, and choroid plexus. The artery then passes through the cavernous sinus, where it emits small meningeal branches and important pituitary branches; upon exiting the cavernous sinus, it gives rise to the ophthalmic artery and, at the level of the anterior and middle clinoid processes, emits the posterior communicating artery and the anterior choroid artery. Its terminal branches are: anterior and middle cerebral arteries, anterior choroid artery, and posterior communicating artery.Currently, the artery is divided into four parts: cervical, petrous, cavernous, and cerebral. However, a more recent classification system proposed by Bouthillier describes seven anatomical segments, often used clinically by neurosurgeons, neuroradiologists, and neurologists; these are: cervical, petrous, lacerum, cavernous, clinoid, ophthalmic, and communicating.

Posterior Cerebral Arteries

They arise from the bifurcation of the basilar artery and are its terminal branch; the basilar artery itself comes from the union of the two vertebral arteries that enter the skull through the foramen magnum and unite at the clivus. After its origin, it moves outward and upon reaching the lateral sulcus of the peduncle, it changes direction and moves outward towards the inferior surface of the cerebral hemisphere. "Previously peduncular, it now becomes hemispheric. With the name of the calcarine artery, it reaches the calcarine fissure and ends at the cuneus" (TESTUT L. p. 1208). It comprises three territories: a cortical, a central, and a peduncular. The posterior cerebral arteries are responsible for irrigating the posterior part of the inferior surface of each cerebral hemisphere, that is, the occipital lobe and the limbic area; it encompasses the entire visual area, and therefore, lesions in its branches cause vision defects. According to the Illustrated Encyclopedic Medical Dictionary by Durand, 27th edition, its collaterals are divided into branches for the temporal and occipital regions, which are: posterior choroid arteries, retromamillary pedicle (or thalamoperforating) artery, and quadrigeminal artery. In the terminal or cortical portion, it continues with the lateral (or anterior) and middle occipital arteries.

Posterior Communicating Arteries

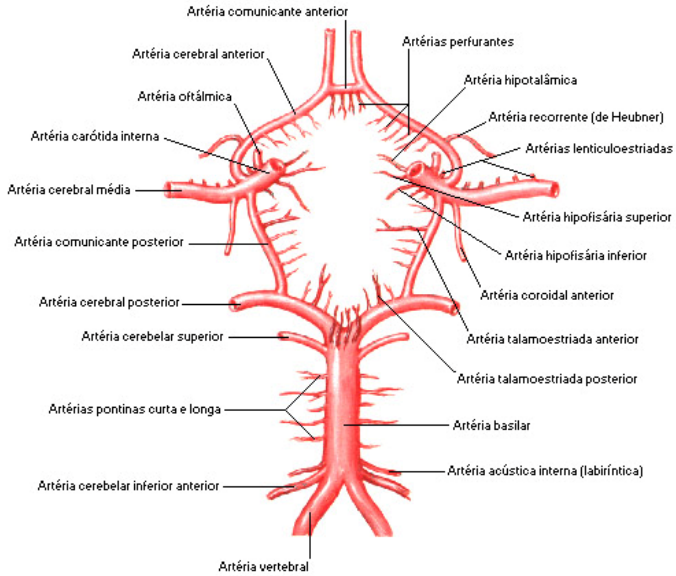
These are a pair of arteries that establish connections on each side between the posterior cerebral artery and the internal carotid artery and are terminal branches of the latter. They connect the three cerebral arteries on the same side: anteriorly, they are part of the terminal trifurcation of the internal carotid artery; the anterior cerebral artery and the middle cerebral artery are the other two branches of this trifurcation. Posteriorly, they communicate with the posterior cerebral artery. Their direction is backward and somewhat inward to unite with the posterior cerebral artery and thus connect the anterior or carotid system with the posterior or vertebral system (TESTUT L. and LATARJET P. 1195). They have branches for the optic chiasm, the common oculomotor nerve, the thalamus, the hypothalamus, and the tail of the caudate nucleus. In males, the average diameter of the PCoA is 107 mm on the right side and 106 mm on the left; in females, it is 112 mm on the right side and 114 mm on the left (Int. J. Morphol. v.28 n.3 Temuco Sept. 2010). According to Ross p. 445, these are small arteries.



Sources: International Journal of Morphology art 28(3):957-961 Sept. 2010

Figure 2. Polygon of Willis; actual size

From the arterial circle or the pillars that constitute it, branches arise for the brain that can be divided into: superficial or gyral arteries; deep or central arteries; ventricular arteries primarily for the choroid plexuses; and basal arteries. These arterial systems, although of common origin, are completely independent in their distribution and do not communicate at any point. The arteries that nourish the brain are terminal arteries and do not have sufficiently anastomosed channels with other arteries to maintain blood flow; for this reason, the nutrition of central nervous system tissue does not exclusively depend on a single system, that is, in the deficiency of one, the other can compensate to some extent by increasing the other, reducing the level of damage that a reduction in blood flow could cause in a certain region; this is due to two foci of communication between the anterior and posterior circulations of the brain, which are the three communicating arteries of the polygon.



Source: NETTER Frank H. Atlas of Human Anatomy. 2nd ed. Porto Alegre: Artmed 2000

Figure 3. Polygon of Willis - superior view

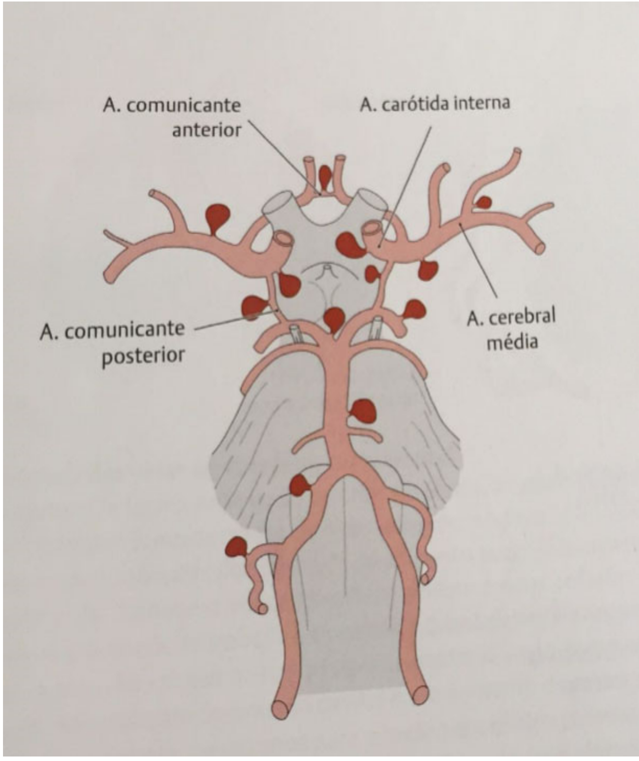
Internal Components

The polygon of Willis is formed by the previously mentioned arteries forming a crown around the sella turcica. It surrounds the optic tracts – chiasm and nerve – the infundibulum or pituitary stalk, the pituitary gland, mammillary bodies, the base of the hypothalamus, and the common oculomotor nerve. Some important veins are also inserted within the polygon, such as the efferent hypophyseal and long hypophyseal portal veins. The four cerebral ventricles produce cerebrospinal fluid (CSF), more specifically in the choroid plexus, which projects into the internal CSF space; externally, it is located in the subarachnoid space, both presenting dilations or cisterns. When describing the Polygon of Willis, it is worth mentioning that the interpeduncular, right and left carotid, and chiasmatic cisterns in the third ventricle are surrounded by it. (Schunke Michael. Prometheus Atlas of Anatomy: head and neuroanatomy pp. 194-195).

Clinical Correlation

"The Circle of Willis is the most common site of cerebral aneurysms" (FELTEN David L. - Netter's Atlas of Human Neuroscience p. 51); an aneurysm is a balloon-shaped bulge that forms in one or more cerebral arteries as a result of a weakening of the vessel wall. The rupture of arteries located at the base of the brain can lead to subarachnoid hemorrhage with loss of perfusion to vital territories of the central nervous system and represents 5% of all strokes (according to Bähr and Frotscher).

Aneurysms are usually located in the areas shown in the image below; the most commonly affected arteries are the anterior communicating artery (about 30 to 35%), followed by the internal carotid artery, posterior communicating artery, and the middle cerebral artery, each with about 20%. (Schunke Michael. Prometheus Atlas of Anatomy: head and neuroanatomy p. 263).



Source: PROMETHEUS p. 26.

Figure 4. Location of aneurysms at the base of the brain

Most causes of cerebral aneurysms are due to congenital defects of the tunica media of the vascular wall and are often associated with other diseases such as polycystic kidney disease or fibromuscular dysplasia. If a cerebral aneurysm presses on nerves in the brain, it can cause symptoms. These may include: Double vision or other visual changes, pain above or behind the eye, a dilated pupil, prostration and photophobia, a sudden onset severe headache located in the frontal or temporal region, nausea, vomiting, and neck stiffness, and numbness or weakness on one side of the face or body. The diagnosis of subarachnoid hemorrhage is made by computed tomography or lumbar puncture. The location of the aneurysm is established by cerebral arteriography (Great Atlas of the Human Body p. 672).Currently, there are five options for treating cerebral aneurysms: surgical clipping, embolization of cerebral aneurysms and fistulas, endovascular embolization, cerebral aneurysm repair, and intracranial vascular treatment.

Histological Structure

Structurally, the internal carotid arteries, anterior cerebral arteries, and posterior cerebral arteries of the polygon are characterized by rare elastic tissue; the external elastic membrane is absent, thus they are classified according to Ross p. 445 as large-type arteries since their diameter is greater than 10 mm.The anterior and posterior communicating arteries on the right and left are small arteries; these arteries have a diameter of 1 to 2 mm (Ross p. 445).

Anatomical Variations

The cerebral arteries may present changes in their distal territorial course and/or site of origin, the so-called anatomical variations. According to a study conducted in the anatomy laboratories of the Department of Morphology at the Federal University of Paraíba, which aimed to assess the presence of anatomical variations in the anterior (carotid) circulation of the Arterial Circle, it was possible to identify the presence of 10 variations in 16 brains, indicating a considerable occurrence of anatomical variations compared to what was described as the typical Polygon of Willis in 1664 by Thomas Willis.

Several other studies corroborate this finding, making it very common to find anomalies in this arterial structure. Thus, it can be reported that the version of the Polygon of Willis described in anatomy books, which was based on a series of 1,413 brains, is actually only seen in 34.5% of cases; the rest are anatomical variations. Vascular connections in the arterial circle can show significant individual differences; the hypoplasias of a part of a vessel shown here generally do not affect normal function.

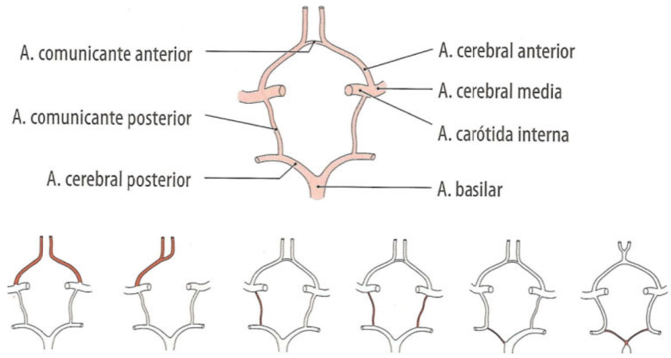


Figure 5. Variations of the arterial circle of the brain

Variations of the arterial circle of the brain (of Willis) (according to Lippert and Pabst)

a. In 40% of cases, the arterial circle is formed by the following arteries: anterior communicating artery, anterior cerebral artery, internal carotid artery, posterior communicating artery, and posterior cerebral artery.
b. The anterior communicating artery is absent (1% of cases).
c. The two anterior cerebral arteries originate from the same internal carotid artery (10% of cases).
d. On one side, the posterior communicating artery is absent or is a rudimentary vessel (10% of cases).
e. On both sides, the posterior communicating arteries are absent or rudimentary (10% of cases).
f. The posterior cerebral artery originates from the internal carotid artery on one side (10% of cases).
g. The posterior cerebral artery originates from the internal carotid artery on both sides (5% of cases).

Note important: The percentages are rounded.

Conclusion

The Circle of Willis is a crucial anatomical structure in the brain, providing a network of collateral circulation that helps ensure a continuous supply of blood to the brain. Despite its importance, the collateral capacity of the Circle of Willis varies greatly among individuals, and anatomical variations are common. Understanding the anatomy and function of the Circle of Willis is essential for diagnosing and treating cerebrovascular diseases such as aneurysms and ischemic strokes.

REFERENCES

1. Article from the Faculty of Medicine, Universidad Andrés Bello, Santiago, Chile, and Faculty of Medicine, Universidad de la Frontera, Temuco, Chile.** Published in the International Journal of Morphology, v.28 n.3 Temuco, Sep. 2010. Mandiola, E; Alarcón, E; Oñate, J. C.; del Sol, M. & Olave, E. Communicating Arteries of the Cerebral Arterial Circle: Biometric Characteristics and Relationship with the Cephalic Index. Available at: https://scielo.conicyt.cl/scielo.php?script=sci_arttext&pid=S0717-95022010000300048
2. CANDIA, Jesus M. and BÓIS, R. V. Manual Instructivo de Anatomía Humana. 2nd edition, 2017.
3. FELTEN, David L. MD, PhD and JÓZEFOWICZ, Ralph F. MD.** Netter's Atlas of Human Neuroscience. Porto Alegre: Artmed, 2005.
4. HILL, McGraw. Dorland's Illustrated Medical Dictionary. 27th edition. Interamericana, 1996.
5. PAULSEN and WASCHKE, J. Sobotta – Atlas of Human Anatomy. Head, Neck and Neuroanatomy. 23rd edition. Rio de Janeiro: Guanabara Koogan, 2007.
6. Revista Saúde e Ciência online, December 2017 edition.Available at: http://www.ufcg.edu.br/revistasaudeeciencia/index.php/RSCUFCG/article/viewFile/82/74
7. ROSS, Michael H. and PAWLINA, Wojciech. Histology: A Text and Atlas with Cell and Molecular Biology.
8. SCHÜNKE, Michael; SCHULTE, Erik, and SCHUMACHER, Udo in collaboration with Jürgen Rude; illustrations by Markus Voll, Karl Wesker. Prometheus, Atlas of Anatomy: Head and Neuroanatomy. Rio de Janeiro: Guanabara Koogan, 2007.
9. TESTUT, L. and LATARJET, A. Treatise on Human Anatomy. Angiology – Central Nervous System; Volume 2. Salvat Editores S.A.
10. TORTORA, Gerard J. and DERRICKSON, Bryan. Principles of Anatomy and Physiology. Translated by Alexandre Lins, 12th ed. Rio de Janeiro: Guanabara Koogan, 2007.
11. VIGUE, Jordi and MARTIN ORTE, Emilio.Great Atlas of the Human Body. Anatomy, Histology, Pathologies. Manole Publishing.

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