

ORIGINAL ARTICLE**Preliminary Study of Morphological Variability in the Circle of Willis and Its Clinical Significance in Ethiopia: A Cadaveric Study****Guta Bulcha^{1,2}, Asegedech Bekele¹, Abebe Muche^{3*}****OPEN ACCESS**

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Affiliation and Correspondence:

¹Department of Human Anatomy, School of Medicine College of Medicine and Health Sciences, University of Gondar, Gondar, Ethiopia

²Department of Human Anatomy, Adama Science and Technology University, Adama, Ethiopia

³Department of Human Anatomy, Biomedical Science Division, School of Medicine, University of Global Health Equity, Kigali, Rwanda
Email: abemuche@yahoo.com

ABSTRACT

BACKGROUND: The Circle of Willis (COW) is a vital cerebral arterial network that maintains balanced blood flow in the brain. Despite initial insights from Thomas Willis, recent research has highlighted its complex anatomical variations.

Objective: This study aims to evaluate the anatomical variations of the COW in Ethiopian cadavers.

METHODS: We employed a descriptive observational approach on thirty-two cadavers. Detailed morphological examinations of the COW were performed following meticulous dissection at various Ethiopian universities.

RESULTS: Significant anatomical variations were observed, particularly in the anterior divisions of the COW, with 57.14% of cases exhibiting notable differences. Variations in the anterior communicating artery (62.5%) and anterior cerebral artery (37.5%) were particularly diverse. In the posterior segment, 66.6% of anomalies involved unilateral right hypoplastic posterior communicating arteries, and bilateral hypoplastic posterior cerebral arteries were noted in two male cadavers. Essential vessels were present in all specimens.

CONCLUSION: Comparative analysis with global studies reveals both similarities and differences, highlighting genetic and methodological influences. Recognizing these variations is crucial for diagnosing cerebrovascular diseases and managing intracranial aneurysms. Further longitudinal studies using advanced imaging techniques are recommended to enhance understanding in the Ethiopian population and beyond.

KEYWORDS: Circle of Willis, anterior cerebral artery, posterior cerebral artery, anterior communicating artery, posterior communicating artery

INTRODUCTION

Thomas Willis (1621–1675) first depicted the Circle of Willis (COW) in his 1664 work *Cerebri Anatome*, though his illustrations did not fully capture the communicating arteries. Vesling (1598–1649) later provided a more complete representation of the posterior communicating arteries but did not definitively show the union of the anterior cerebral arteries (1,2). The comprehensive understanding of the COW, including its anastomotic properties, was achieved through Willis' research (1,2).

The COW, also known as the cerebral arterial circle, is an arterial polygon formed by the anastomosis of the internal carotid and vertebral systems around the optic chiasm and pituitary stalk in the suprasellar cistern (3). It consists of two divisions: the anterior division, comprising the ACA and the anterior communicating artery (AComA), and the posterior division, including the PCA, terminal branches of the basilar artery, and the posterior communicating arteries (PcomA), which connect the internal carotid arteries (ICA) with the PCA (4).

Over the past sixty years, various anatomical variations of the COW have been documented, including absent or aplastic arteries, fenestrated arteries, hypoplastic arteries, duplicated arteries, and accessory vessels (5-12). Understanding these variations is crucial, as the COW facilitates collateral circulation and pressure equalization in the brain. Variations can affect blood flow, potentially increasing the risk of cerebrovascular diseases (13,14). The prevalence of COW variants is higher in stroke patients and recognizing these variations aids in understanding cerebral ischemic disease (15,16). Additionally, the COW's arterial pulsations contribute to cerebrospinal fluid drainage in the interpeduncular cistern (12).

Research on COW variations has been diverse, but generalizing findings to different populations can be challenging (17). The influence of genetic and developmental factors on COW variability is significant. However, the spectrum of COW anatomy in Ethiopia remains largely unexplored. This study aims to examine COW anatomical variations in Ethiopian cadavers.

MATERIALS AND METHODS

Study design: A descriptive observational study was conducted to assess the morphological variations of the COW in Ethiopian cadavers.

Study area: The study was conducted at the University of Gondar (747 km from Addis Ababa), Bahir Dar University College of Medicine and Health Science (565 km), and Adama Science and Technology University (175 km). Fourteen specimens were examined: 10 from the University of Gondar, 2 from Bahir Dar, and 2 from Adama Science and Technology University.

Study population: The study included cadavers available for teaching purposes at the above-mentioned universities during the study period.

The following operational definitions are used

- **Normal architecture of COW:** A symmetrical ring of arteries at the brain's base providing redundant blood flow paths in case of blockages.
- **Variant architecture of COW:** Deviations from the typical structure, including missing, duplicated, or asymmetrically sized arteries, which may affect blood flow compensation.
- **Fenestration:** Division of the arterial lumen into separate channels with distal convergence.
- **Duplication:** Presence of two distinct arteries with separate origins and no distal convergence.

While cadavers without trauma, prepared for teaching at the University of Gondar, Bahir Dar University College of Medicine, and Adama Science and Technology University were considered as inclusion criteria; Cadavers with evidence of brain pathology or trauma affecting arterial topography were used as exclusion criteria.

Sampling method: Purposive sampling technique was used.

Data collection procedure and materials: Two senior anatomy technicians received one week of training on dissection techniques. After a pre-assessment, they proceeded with dissection. A detailed examination of 32 formalin-preserved cadaver brains was conducted. The dissection involved careful removal of the brain and identification of the COW, with documentation of anatomical variations such as hypoplasia, aplasia, duplication, and fenestrations. Observations were recorded, and photographs were taken for comprehensive analysis.

Data analysis procedure: Data was checked for completeness, accuracy, and clarity. Analysis was performed manually using a scientific calculator, with results presented in figures, tables, and percentages.

Ethical considerations: Ethical clearance was obtained from the Research and Publication Office of the University of Gondar. Official letters were

submitted to the university hospitals, and the study's purpose and importance were explained.

RESULTS

This study analyzed 32 cadavers, consisting of 23 males and 9 females, aged between 32 and 70

years. We thoroughly examined and photographed the entire COW structure, assessing its typicality, completeness, symmetry, and associated blood vessels. Among the 32 cadavers, 18 (56.25%) exhibited a typical COW architecture (**Fig. 1**), while 14 (43.75%) showed variations.

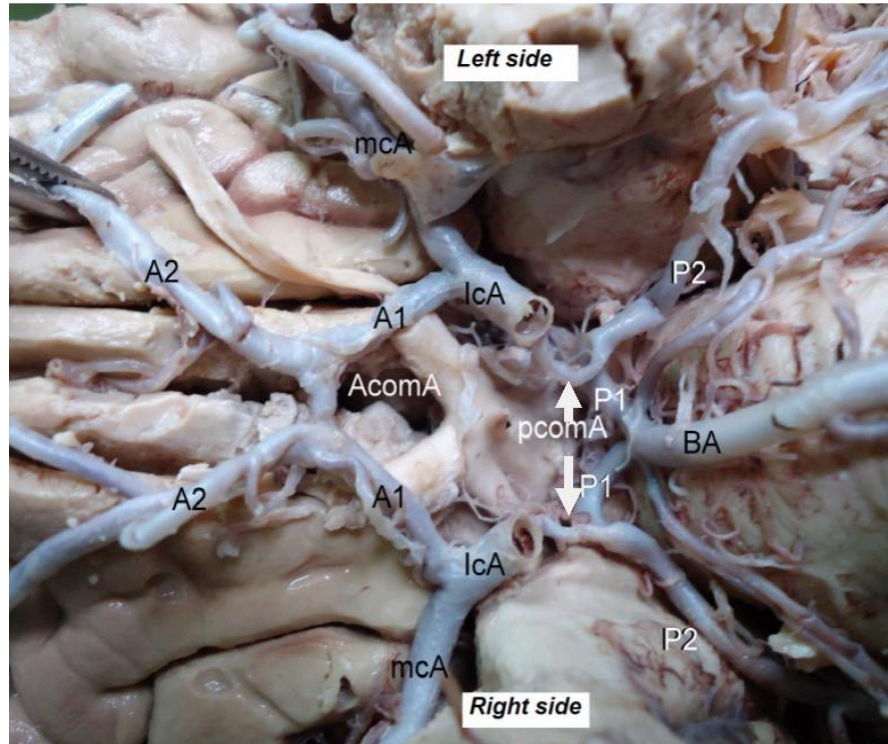


Figure 1: Photograph of a typical adult Circle of Willis from selected specimens.

Variations were most frequently observed in the anterior half of the COW, accounting for 57.14% of cases, with the anterior communicating artery (AComA) responsible for 62.5% of these variations. Posterior variations comprised 42.86% of the total, with the posterior communicating artery (PComA) representing 66.7% of these anomalies.

We found that most variations in the COW were concentrated in the anterior half, particularly involving the AComA, which contributed to 62.5% of the observed variations. The most common anomaly was a duplicated plexiform AComA, seen in 4 cases (50% of anterior variations; see **Table 1** and **Fig. 2A, B, C and D**). Crossed ACA (25%) and double AComA (12.5%) were also noted.

Table 1: Frequency and percentage of arterial variations in the Circle of Willis.

Variant Artery	Male	Female	Total
Double AComA	1 (11.11%)	0 (0%)	1 (7.14%)
Duplicated Plexiform AComA	3 (33.33%)	1 (20%)	4 (28.57%)
Crossed ACA	0 (0%)	2 (40%)	2 (14.29%)
Fenestration and Fused ACA	1 (11.11%)	0 (0%)	1 (7.14%)
Hypoplastic Right PComA	2 (22.22%)	2 (40%)	4 (35.71%)
Hypoplastic PCA	2 (22.22%)	0 (0%)	2 (14.29%)
Total	9 (100%)	5 (100%)	14 (100%)

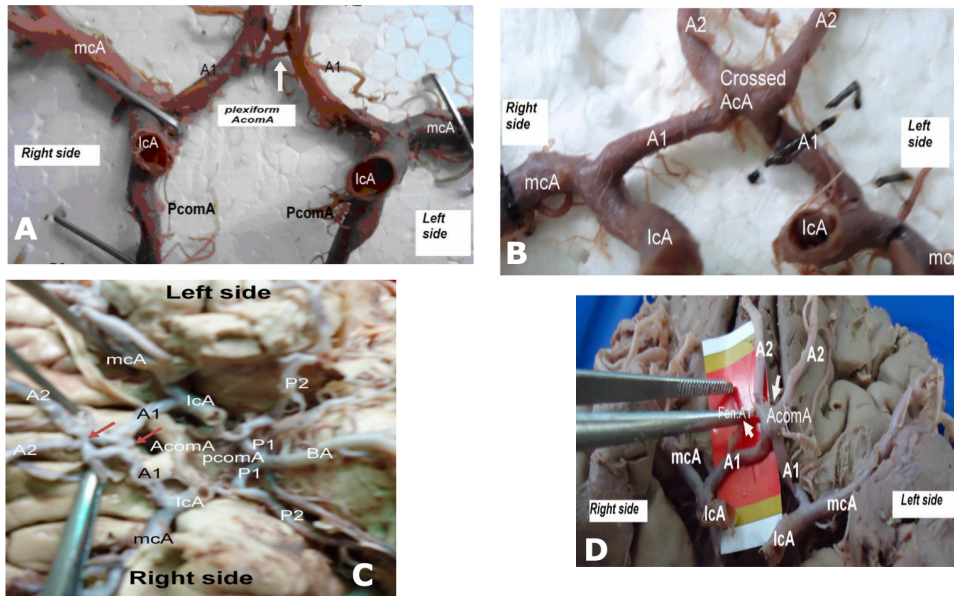


Figure 2: Figure showing (A) a duplicated plexiform AComA (indicated with a white arrowhead), (B) crossed ACA from selected specimens, (C) a double AComA (indicated with a red arrowhead) and (D) A1 fenestrations and fusion of the ACA (indicated with a white arrowhead)

For the posterior COW variations, unilateral right hypoplastic PComA was observed in two males

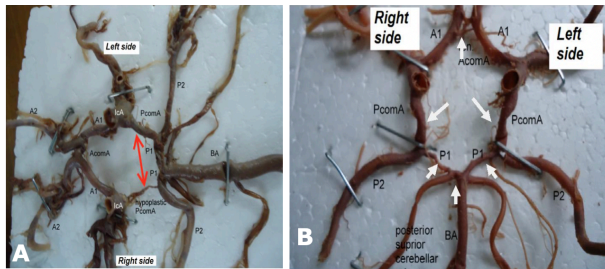


Figure 3: Figure representing (A) a hypoplastic right PComA (indicated with double headed arrow) and (B) bilateral fetal-type PComA and variations in posterior cerebral arteries (indicated with white arrowheads)

DISCUSSION

Despite constituting only 2% of the body's mass, the brain consumes a significant portion of cardiac output and oxygen, making it highly sensitive to disruptions in blood supply (18). The COW plays a

(Fig. 3A) and two females (66.7% of posterior anomalies). Bilateral hypoplastic PCA was noted in two male cadavers (Fig. 3B).

Despite these variations, no essential component vessels were entirely absent in any of the specimens.

crucial role in ensuring a stable blood supply to the brain, as first described by Thomas Willis in 1662 (19). Variations in the COW, often influenced by genetic factors, can involve the loss or persistence of vessels or the formation of new vessels due to hemodynamic factors (3,5,17).

While these anatomical variations generally do not significantly affect brain function due to compensatory collateral circulation (20,21), they are important in clinical settings. The COW provides a critical collateral flow to affected brain regions in cases of arterial insufficiency and is significant in preventing ischemia (22,23). Variations in the COW are also associated with a higher prevalence of intracranial aneurysms, particularly at junctions such as the ICA-PComA or AComA (23).

Our study found a notable prevalence of variations in the anterior segments of the COW (57.14%), with significant involvement of the

ACoMA (62.5%). In contrast, posterior anomalies were dominated by unilateral right hypoplastic PCoMA (66.7%). These findings underscore the importance of understanding COW variations in clinical practice.

Comparing with previous studies, our findings align with Gautam *et al.* (17), who reported a typical COW in over 50% of specimens. However,

other studies have reported lower prevalence rates for typical COWs, which may be influenced by geographical or methodological differences (**see, Table 2**). Our study shows a higher incidence of anterior segment anomalies compared to some regional studies, highlighting the variability in COW anatomy.

Table 2: Comparison of anterior and posterior divisions of the Circle of Willis among various studies.

Study	Total	Typical	Anterior Division	Posterior Division	Anterior & Posterior Division
Riggs and Rupp, (11)	994	192(19.3%)	129 (13%)	320 (32.2%)	353 (35.5%)
El Khamlichi <i>et al.</i> , (7)	100	18 (18%)	13 (13%)	42 (42%)	27 (27%)
Fisher, (8)	414	20 (4.8%)	6 (1.4%)	221 (53.4%)	167 (40.3%)
Lazorthes <i>et al.</i> , (9)	200	29 (14.5%)	12 (6%)	86 (43%)	73 (36.5%)
Eftekhari <i>et al.</i> , (6)	102	29 (28.4%)	0 (0%)	51 (50%)	12 (11.8%)
De Silva <i>et al.</i> , (5)	225	32 (14.2%)	38 (16.9%)	82 (36.4%)	73 (32.4%)
Klimek Piotrowska <i>et al.</i> , (24)	100	27 (27%)	2 (2%)	30 (30%)	41 (41%)
Ciliers <i>et al.</i> , (25)	39	16 (41%)	3 (8%)	13 (33%)	7 (18%)
Gautam <i>et al.</i> , (17)	107	92 (86%)	9 (8.4%)	5 (4.7%)	1 (0.9%)
Present Study	32	18 (56%)	7 (21.9%)	5 (15.6%)	1 (3.1%)

Anterior communicating artery (ACoMA): We observed duplicated plexiform ACoMA in 28.57% of cases and double ACoMA in 7.1%. Historical studies have documented variations in ACoMA, with duplication reported in up to 7.2% of cases (26). Other studies report varying incidences of ACoMA hypoplasia, from 14% to 0% (5-9, 11).

Anterior cerebral artery (ACA): Anatomical variations in the ACA were observed in 37.5% of cases, including configurations such as crossed and fused ACAs. Previous studies have reported similar variations, including the fusion of ACAs into a single azygous artery, which is common in animals (10, 28-31). Our study's incidence of hypoplastic A1 segments (7.14%) is higher compared to some studies (6-9, 11).

In conclusion, our study highlights the anatomical variations within the COW, particularly within its anterior division. These variations often involve combinations of different formative vessels, especially the communicating arteries, which are essential for facilitating collateral circulation and reducing functional impairment. Recognizing these variations is critical in clinical practice, especially concerning cerebrovascular diseases and intracranial aneurysms. We recommend a comprehensive longitudinal study of

COW variations within the Ethiopian population using advanced imaging techniques. Clinicians must remain vigilant for anomalies in key arteries. Additionally, collaboration among anatomists, clinicians, and researchers is crucial to advance diagnostic and therapeutic approaches, ultimately improving patient care.

REFERENCES

1. Ustun C. NEUROwords Dr. Thomas Willis' famous eponym: the circle of Willis. *J Hist Neurosci.* 2005 Mar;14(1):16-21.
2. William AN. Thomas Willis' understanding of cerebrovascular disorders. *J Stroke Cerebrovasc Dis.* 2003;12:280-4.
3. Nyasa C, Mwakikunga A, Tembo L, Dzamalala C, Ihunwo AO. Distribution of variations in anatomy of the circle of Willis: results of a cadaveric study of the Malawian population and review of literature. *Pan Afr Med J.* 2021;38:11
4. Oumer M, Alemayehu M, Muche A. Association between circle of Willis and ischemic stroke: a systematic review and meta-analysis. *BMC Neurosci.* 2021;22:3.
5. De Silva KR, Silva R, Amaratunga D, Gunasekera WS, Jayasekera RW. Types of the

- cerebral arterial circle (circle of Willis) in a Sri Lankan population. *BMC Neurol.* 2011; 11:5.
6. Eftekhari B, Dadmehr M, Ansari S, Ghodsi M, Nazparvar B, Ketabchi E. 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.
 7. El Khamlichi A, Azouzi M, Bellakhdar F, Ouhcein A, Lahlaoui A. Anatomic configuration of the circle of Willis in the adult studied by injection techniques Apropos of 100 brains. *Neurochirurgie.* 1985;31(4):287-93.
 8. Fisher CM. The circle of Willis: Anatomical variations. *Vasc Dis.* 1965;2:99-105.
 9. Lazorthes G, Gouaze A, Santini JJ, Salamon G. The arterial circle of the brain (circulus arteriosus cerebri). *Anatomia Clinica* 1979;1:241-57.
 10. Prasanna LC, Andrade LS, Ravichandra P, Hosapatna M. An insight into the circle of willis, its variation in the formation and component vessels in the adult human cadavers. *Ethiop Med J.* 2020; 58(2):145-50.
 11. Riggs HE, Rupp C. Variation in form of circle of Willis: the relation of the variations to collateral circulation-anatomic analysis. *Arch Neurol* 1963; 8:8-14.
 12. Singh R, Kannabathula AB, Sunam H, Deka D. Anatomical variations of circle of Willis - a cadaveric study. *Int Surg J.* 2017;4 (4):1249-1258.
 13. Sforza DM, Putman CM, Cerebral JR. Hemodynamics of cerebral aneurysms. *Annu Rev Fluid Mech.* 2009;41:91-107.
 14. Tanaka H, Fujita N, Enoki T, Matsumoto K, Watanabe Y, Nakamura H. Relationship between variations in the circle of Willis and flow rates in internal carotid and basilar arteries determined by means of magnetic resonance imaging with semi-automated lumen segmentation: reference data from 125 healthy volunteer. *Am J Neuroradiol.* 2006;27(8):1770-5.
 15. De Caro J, Ciacciarelli A, Tessitore A, Buonomo O, Calzoni A, Francalanza I, et al. Variants of the circle of Willis in ischemic stroke patients. *J Neurol.* 2021;268(10):3799-3807.
 16. Hoksbergen AW, Legemate DA, Ubbink DT, Jacobs MJ. Collateral variations in circle of Willis in atherosclerotic population assessed by means of transcranial color-coded duplex ultrasonography. *Stroke.* 2000;31(7):1656-60.
 17. Gautam J, Adhikari B, Bhandari R, Shrestha A, Ranjit N. Variation of arteries forming circle of Willis in adult human cadavers. *IJOM Nepal.* 2020;42(1):17-20.
 18. Gunnai SA, Farooqui MS, Wabale RN. Anatomical variations of the circulus Arteriosus in cadaveric human brains. *Neurol Res Int.* 2014;2014:687281.
 19. Paul S, Mishra S. Variations of the anterior cerebral artery in human cadavers: a dissection study. *J Anat Soc India.* 2004;53 (1):15-16.
 20. Satheesha NB, Somayaji SN, Soumya KV. Variant arteries at the base of the brain. *IJAV.* 2009;2:80-81.
 21. Stehbens WE. Aneurysms and anatomical variation of the cerebral arteries. *Arch Pathol.* 1963;75:45-64.
 22. Robben D, Türetken E, Sunaert S, Thijs V, Wilms G, Fua P, et al. Simultaneous segmentation and anatomical labeling of the cerebral vasculature. *Med Image Anal.* 2016;32:201-15.
 23. Schievink WI. Intracranial aneurysms. *N Engl J Med* 1997;336(1):28-40.
 24. Klimek-Piotrowska W, Rybicka M, Wojnarska A, Wójtowicz A, Koziej M, Hołda MK. A multitude of variations in the configuration of the circle of Willis: an autopsy study. *Anat Sci Int.* 2016 91(4):325-33.
 25. Cilliers K, Vorster W, Page BJ. The anatomical variation of the circulus arteriosus cerebri in a cadaver cohort representing the population dynamics of the Western Cape. *Br J Neurosurg* 2018;32(1):61-67.
 26. Fawcett E, Blackford JV. The circle of Willis: An examination of 700 specimens. *J Anat Physiol.* 1905;40 (Pt 1):63,2-70.
 27. Vare AM, Bansal PC. Arterial pattern at the base of the human brain. *J Anat Soc India* 1970;19(3):71-9.
 28. Kardile PB, Ughade JM, Joshi RA. Study of anatomical variations of anterior cerebral artery. *Int J Anat Res.* 2016;4(3):2778-83.

29. Alpers BJ, Berry RG, Paddison RM. Anatomical studies of the circle of Willis in normal brain. *AMA Arch. Neurol. Psychiatry.* 1959;81(4):409-18.
 30. Macchi C, Catini C, Federico C, Gulisano M, Pacini P, Cecchi F, et al. Magnetic resonance angiographic evaluation of circulus arteriosus cerebri (circle of Willis): a morphologic study in 100 human healthy subjects. *Ital J Anat Embryol.* 1996;101(2):115-23.
 31. Kane AG, Dillon W, Barkovich AJ, Norman D, Dowd CF, Kane TT. Reduced caliber of the internal carotid artery: a normal finding with ipsilateral absence or hypoplasia of the A1 segment. *Am J Neuroradiol.* 1996;17(7):1295-301.
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