BMC Neurology

RESEARCH

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Association of circle of willis variants with stroke and aneurysm: insights from a tertiary hospital in Ethiopia

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Abstract

Background The Circle of Willis (CoW) is a crucial cerebral arterial structure that facilitates collateral blood flow to the brain. Anatomical variations within the CoW are prevalent and can have significant clinical implications, particularly concerning strokes, aneurysms and other cerebrovascular disorders. This study aimed to assess the anatomical variations of the CoW in the Ethiopian population presenting with neurological symptoms and to explore the factors associated with these variations. By investigating these relationships, the research seeks to enhance understanding of the CoW's anatomical diversity and its potential impact on cerebrovascular health.

Methods A facility-based cross-sectional study was conducted among adult patients undergone brain CT angiography at St. Paul's Hospital Millennium Medical College. A simple random sampling technique was employed to select participants. Multivariate binary logistic regression analyses were performed to determine relationships between dependent and independent variables. Statistical significance was assessed with a p-value < 0.05.

Results This study of 86 participants (mean age 48.3 years) found that 56 (65.12%) had a complete CoW. Incomplete CoW was more common in females (OR = 3.5, $p = 0.007$) and was significantly associated with stroke (OR = 15.4, $p < 0.001$). Aneurysms had a higher but non-significant association with incomplete CoW (OR = 3.2, $p = 0.14$). Hypoplastic arteries were present in 30% of participants.

Conclusions Hypoplastic arteries are more frequently observed in the posterior portion of the CoW than in the anterior portion. Most importantly, the incompleteness of the CoW is significantly associated with female sex and stroke.

Keywords Circle of willis, Anatomical variations, Hypoplasia, Posterior and anterior communicating artery

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Background

The circle of Willis (CoW) is a critical intracranial collateral circulation system connecting the carotid and vertebrobasilar systems. The CoW is bilaterally symmetrical, ensuring collateral blood flow [1, 2]. A thorough understanding of CoW variations is essential for surgeons and interventional radiologists when planning shunt procedures. Detailed visualization of CoW anatomy and its variants through contrast-enhanced computed tomography (CECT) brain imaging enhances diagnostic accuracy, enables anticipation of potential complications, and supports more effective treatment planning for cerebrovascular diseases [2, 3].

Variations in the CoW are particularly significant in the development of Cerebral Vascular Diseases (CVD). Any alteration in the normal morphology can affect the onset and severity of conditions like aneurysms, infarcts, and other vascular disorders [2–4]. Despite the importance of these variations in CVD and their role in surgical and interventional radiology, limited data exist in developing countries, with no published data on the Ethiopian population. The lack of access to advanced diagnostic technologies and specialized healthcare services exacerbates the burden of cerebrovascular conditions, leading to delayed diagnosis, suboptimal treatment, and poor outcomes [3, 5, 6]. For instance, hypoplasia or incompleteness of the posterior communicating artery (PCoA) and anterior communicating artery (ACoA) are significant contributors to ischemic stroke [7–9]. Intracranial aneurysms commonly occur in the anterior circulation, with mirror aneurysms accounting for 5–10% and linked to congenital wall weakness. Their formation involves genetic defects in vascular development and triggers like hypertension and smoking [10].

Numerous studies have documented variations in the anatomy of the CoW, but it remains unclear whether these variations occur at similar frequencies across different racial populations [11–13]. In Africa, for instance, a study on the Egyptian population found that 46.7% had a complete CoW, with a higher prevalence in females (52.8%) [14]. A similar study in Pakistan observed incomplete anterior and posterior circles in 20% and 77% of participants, respectively, with a complete CoW more common in younger and female individuals [15, 16].

This study investigates the relationship between anatomical variations of the CoW and the prevalence of intracranial aneurysms, strokes, and hypoplastic arteries in adults with neurological symptoms in the Ethiopian population.

Materials and methods

This cross-sectional study was conducted from January to June 2024 at St. Paul's Hospital Millennium Medical College (SPHMMC) Compressive specialized hospital, a tertiary referral hospital in Addis Ababa, Ethiopia, under the Federal Ministry of Health. The hospital performs approximately 190 brain computed tomography angiographies (CTAs) annually [17]. The study population consisted of all adult patients who underwent brain CT angiography at SPHMMC. Patients were excluded if their brain CT angiography images displayed motion artifacts or foreign body artifacts that, as determined by a radiologist, obscured or distorted the visualization of the CoW anatomy. Additionally, individuals with a documented history of head trauma, craniotomy, or craniectomy, as well as those diagnosed with vasculitis, were excluded as these may affect the normal physiology of circle of wills. Pregnant patients at the time of imaging were also excluded from the study. The independent variables in this study include gender (male or female), age group (20–39 years, 40–59 years, ≥ 60 years), the presence of stroke (yes or no), and the presence of aneurysms (yes or no). These variables are examined for their association with the dependent variable, which is the completeness of the CoW. The completeness of CoW is categorized as either complete or incomplete.

Operational definitions

A complete CoW is defined by angiographic imaging showing a fully formed and functional arterial network, with clear and visible anterior cerebral arteries (ACA) and posterior cerebral arteries (PCA), as well as ACoA and PCoA. These vessels should have normal caliber and morphology, without significant variations like hypoplasia or aplasia. Additionally, there should be no structural anomalies, such as aneurysms or abnormal vessels, which could disrupt or distort normal blood flow [18]. An incomplete CoW in this study refers to deviations from the typical or normal anatomy of the CoW [18].

Hypoplasia: Measurement of the artery's diameter on angiographic imaging should show it to be less than 50% of the expected diameter or less than 1 mm in outer-to-outer diameter.

Aplasia: The artery cannot be identified at any point on the angiographic imaging.

Fenestration: Two lumens are visible within the artery at a particular point on the angiography image, followed by the rejoining of the lumens into one artery.

Collateral Circulation: Visualization of an alternative pathway for blood flow during brain angiography that compensates for the blockage in the primary artery.

Aneurysms: The dilation greater than 1.5 times the normal diameter of the artery at the site of the bulge [19].

Ischemic Stroke**:** Look for hypodense areas, early hyperdense MCA signs, and brain swelling (midline shift) without evidence of hemorrhage [20].

Hemorrhagic Stroke: Look for hyperdense areas in the brain or ventricles, with associated mass effect (midline shift or edema) [21].

Data collection

Each patient was assigned a unique identifier (ID), and a random number generator was employed to randomly select the participants from the pool. Data collection was performed using a structured checklist that was adapted and modified from several prior studies. These included research on the configurations of the CoW and a study of anatomical variations, and a retrospective study on middle cerebral artery variations. Additionally, criteria for the diagnosis and management of hemorrhagic and ischemic strokes were informed by previous two studies respectively [11, 22–26]. The first section focused on demographic information, including patient age and gender. The clinical presentation section recorded the main neurologic symptoms at presentation such as hemiparesis.

Imaging

The CTA was performed using Siemens Somatom Definition AS + 128 slice Multidetector Computed Tomography (MDCT) scanner. All patients were scanned in a 128 slice MDCT scanner using standard imaging parameters of the department. Both pre- and post-contrast brain CT images were independently reviewed by a senior radiologist and a neuroradiologist. The primary focus of the assessment was on the anatomical characteristics of the CoW, specifically evaluating completeness, presence of hypoplasia, absence of components, and any detectable aneurysms. Any discrepancies between the two reviewers were addressed and resolved through consensus discussion. Vessel diameters were measured digitally with integrated imaging software to ensure precision. Anonymized images of the CoW were captured and securely stored for further analysis, following stringent data protection protocols. All collected data were recorded, coded, and entered into Microsoft Excel, with double-checking post-entry to ensure accuracy.

Analysis

Data collected from the hospital were entered into Epi Info version 7.2 and analyzed with SPSS v.27. Missing data were handled and any discrepancies identified during data entry were resolved by reviewing the original records. Binary and multivariate logistic regression models were used to assess associations between independent and dependent variables. Given the limited number of variables, multivariate analysis was performed, with statistical significance defined as $p \leq 0.05$. The strength of associations was expressed using odds ratios (ORs) and 95% confidence intervals (CIs).

Results

The study included 86 study participants, with mean age of 48.3 (standard deviation, 18.1) years, and 46 (53%) male. The need for brain CT-angiography imaging was prompted by a variety of symptoms: headache in 39 (45.3%), left or right body weakness respectively in 15 (17.4%) and 14 (16.3%), hearing and visual disturbances in 10 (11.6%), and loss of consciousness in 8 (9.3%) patients.

52 patients (60.5%) were found to have a complete CoW. Hypoplastic arteries were present in 30% of participants, the most involved artery being the right and left PCoA accounting for 14% and 8.1% respectively, with double right PCoA and ACoA accounts 5.8%. Arterial agenesis and arterial fenestration were observed in one patient (1.2%) for each variant. Arterial aneurysms were seen in 13 (15%), while 10 (12%) had an acute hemorrhagic stroke.

Incomplete CoW was more likely in females, with an odds ratio (OR) of 3.5 (95% CI: 1.4–8.9; $p = 0.007$). Patients in the age groups 40–59 years and ≥ 60 years had comparable odds of incomplete CoW compared to the 20–39 years group, with ORs of 0.9 (95% CI: 0.3–2.6; $p = 0.7$) and 1.2 (95% CI: 0.5–3.1; $p = 0.8$), respectively. The presence of stroke significantly increased the odds of incomplete CoW, with an OR of 15.4 (95% CI: 3.4–49.5; $p < 0.001$). Regarding aneurysms, patients with aneurysms had higher odds of incomplete CoW (OR 3.2; 95% CI: 0.9–11.4; $p = 0.14$), though the association was not statistically significant (Table 1).

Discussion

This study revealed that 39.5% of participants had an incomplete CoW, with a higher prevalence among females (70.5%) compared to males (29.5%), suggesting potential sex-related anatomical variations. The prevalence of CoW incompleteness in our study was lower than the rates reported in Egypt (51.3%) and Kenya (37.2%) but higher than the 14.6% observed in Turkey

Table 1 Association of Aneurysm, Stroke and demographics with variants of COW among study participants who had undergone CT angiography of the brain in SPHMMC from January 2024 to Jun 2024

	Category (n)	Incomplete CoW, n (%)	OR, 95% CI	*p* value
Sex	**Female** (45)	24 (70.5)	3.5 (1.4; 8.9)	0.006
	Male (41)	10 (29.5)	1	
Age	**20–39** (31)	11 (32.3)	1	
	40–59 (26)	10 (29.4)	0.9(0.3; 2.6)	0.7
	≥ 60 (29)	13 (38.2)	1.2(0.5; 3.1)	0.8
Stroke	**No** (76)	10 (58.8)	1	< 0.001
	Yes (10)	7 (41.2)	15.4 (3.4; 49.5)	
Aneurysm	**No** (73)	12 (70.6)	1	0.14
	Yes (13)	5 (29.4)	3.2 (0.9; 11.4)	

[9, 13, 14]. These differences could be attributed to variations in study populations or imaging techniques. Additionally, 30% of participants had hypoplastic arteries, with the right PCoA most frequently affected (14%), followed by the left PCoA (8.1%), consistent with findings from Turkey, Nepal, and Pakistan [13, 24, 27].

However, our findings differ from those of studies conducted in Turkey, where the ACoA was the most frequently affected variation, reported in 11.8% of cases, and in Egypt, where it was affected in 21.3% of cases [13, 14]. This discrepancy may be attributed to differences in sample sizes across studies.

Frequencies of arterial agenesis and arterial fenestration were rare (1.2% each), and slightly higher than previous studies (0.06% and 0.48%) ([7], 32).

Females were significantly more likely to have an incomplete CoW compared to males, with an odds ratio (OR) of 3.5 (95% CI: 1.4–8.9; $p = 0.007$). This finding aligns with prior studies indicating sex-based differences in vascular anatomy [1, 22]. Potential explanations include hormonal influences on vascular development and remodeling [10]. These observations emphasize the importance of considering sex differences when assessing cerebrovascular risk and planning interventions.

Age-related differences in CoW anatomy were also evident. Patients aged 40–59 years and those ≥ 60 years had comparable odds of incomplete CoW compared to the 20–39 years group, with ORs of 0.9 (95% CI: 0.3–2.6; $p = 0.7$) and 1.2 (95% CI: 0.5–3.1; $p = 0.8$), respectively. Interestingly, age groups 30–39 and 40–49 years demonstrated the highest likelihood of having a complete CoW, consistent with study which reported a higher prevalence of CoW completeness in younger populations [14]. The reduced completeness in older age groups may be attributed to vascular remodeling and degenerative changes associated with aging [15].

The presence of stroke significantly increased the odds of incomplete CoW, with an OR of 15.4 (95% CI: 3.4–49.5; $p < 0.001$). This association aligns with previous studies suggesting that an incomplete CoW may limit collateral flow and increase vulnerability to ischemic events ([5], 34). These findings highlight the clinical relevance of CoW anatomy in predicting and managing cerebrovascular diseases.

Patients with aneurysms had higher odds of incomplete CoW (OR 3.2; 95% CI: 0.9–11.4; $p = 0.14$), although this association was not statistically significant. Prior research suggests that certain CoW configurations may predispose individuals to aneurysm formation [5, 8]. However, differences in study populations, methodologies, and sample sizes may account for variability in findings. Future research with larger and more diverse populations is needed to clarify this relationship and its clinical implications.

Conclusions

In this study, hypoplastic arteries are more frequently observed in the posterior portion of the CoW than in the anterior portion. Most importantly, the incompleteness of the CoW is significantly associated with female sex and stroke.

Abbreviations

CoW	Circle of willis
CT	Computed tomography
CTA	Computed tomography angiography
PCoA	Posterior communicating artery
ACoA	Anterior communicating artery
CVD	Cerebral vascular disease
OR	Odds ratio
SPHMMC	Saint Paul's hospital millennium medical college
MCA	Middle cerebral artery
MDCT	Multidetector computed tomography
MRI	Magnetic resonance imaging

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12883-025-04082-y.

Supplementary Material 1.

Acknowledgements

The researcher would like to thank Saint Pawl Millennium Medical College Comprehensive Specialized Hospital for their contributions to this research. Special thanks to the Department of Radiology, Saint Pawl Millennium Medical College for providing the opportunity to conduct this study and for their financial support.

Clinical trial registration

This study is an observational prospective cohort study; therefore, a clinical trial number is not applicable to maintain fairness and voluntary participation.

Authors' contributions
HMN: Conceptualization, investigation, data collection, methodology, and writing the original draft. MAK: Conceptualization, investigation, data collection, methodology, and writing the original draft. ADA: Data collection, methodology, and writing the original draft. SHA: Data collection, methodology, and writing the original draft. ABW: Data collection, methodology, and writing the original draft. HTM: Data collection, methodology, and writing the original draft. YYM: Data collection, methodology, and writing the original draft. MMM: Data collection, methodology, and writing the original draft.

Funding
This study was supported by funding from Saint Paul millennium medical college. The funding did not cover the publication fees.

Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval consent to participate
Ethical approval was obtained from St. Paul's Hospital Millennium Medical College (SPHMMC) ethical review board (IRB) (Ref No:PM/23/1362). A formal letter from the college facilitated communication with official administrators and ensured compliance with institutional policies and declaration of Helsinki. After being informed about the purpose, objectives, procedures, and potential risks of the study, all participants provided written informed consent. The ethics committee approved the use of written consent as culturally appropriate for the study setting. The study was conducted in compliance with the Declaration of Helsinki. All data were anonymized using coded identifiers, and no personal identifiers were collected.

Consent for publication
Written informed consent was obtained from all participants for the publication of their data, including images.

Competing interests
The authors declare no competing interests.

Received: 18 November 2024 Accepted: 11 February 2025
Published online: 22 February 2025

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