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ANATOMICAL VARIATIONS OF THE CIRCLE OF WILLIS AND RISK OF CEREBROVASCULAR ACCIDENTS

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ABSTRACT

Background: Cerebrovascular accidents remain a leading cause of morbidity and mortality worldwide. The Circle of Willis plays a crucial role in maintaining cerebral perfusion through collateral circulation. Anatomical variations in this arterial network may influence susceptibility to stroke, particularly ischemic events.

Objectives: To evaluate the anatomical variations of the Circle of Willis and assess their association with cerebrovascular accidents in patients attending a tertiary care hospital in Bihar.

Methods:A hospital-based cross-sectional observational study was conducted over five months (July–November 2022) including 120 adult patients who underwent CT angiography or MR angiography. Data on demographic characteristics, clinical profiles, and Circle of Willis configurations were collected. Variations were classified based on standard anatomical criteria. Statistical analysis was performed using SPSS version 22.0, and associations were assessed using Chi-square test, with $p < 0.05$ considered statistically significant.

Results: Incomplete Circle of Willis was observed in 61.7% of participants, while 38.3% had a complete configuration. Hypoplasia of the posterior communicating artery was the most common variation (28.3%). A statistically significant association was found between incomplete Circle of Willis and ischemic stroke ($p = 0.03$). Additionally, posterior communicating artery hypoplasia showed a significant association with ischemic events ($p = 0.02$), whereas other variations did not demonstrate significant correlations.

Conclusion: Anatomical variations of the Circle of Willis, particularly incomplete configurations and posterior communicating artery hypoplasia, are associated with an increased risk of ischemic cerebrovascular accidents. Evaluation of these variations through imaging may provide valuable insights for risk assessment and clinical management.

Keywords: Circle of Willis; cerebrovascular accident; ischemic stroke; anatomical variation; collateral circulation; CT angiography; MR angiography

INTRODUCTION

Cerebrovascular accidents (CVAs), commonly referred to as strokes, remain a leading cause of mortality and long-term disability worldwide. According to global estimates, stroke accounts for a substantial proportion of neurological morbidity, particularly in low- and middle-income countries where healthcare infrastructure and preventive strategies may be limited [1]. The burden of stroke is rapidly increasing in developing nations, including India, due to demographic transitions, urbanization, and rising prevalence of vascular risk factors such as hypertension, diabetes mellitus, and dyslipidemia [2]. Early identification of anatomical and physiological risk determinants is therefore critical for improving outcomes and guiding preventive strategies.

The Circle of Willis (CoW), a polygonal arterial anastomotic system located at the base of the brain, plays a pivotal role in maintaining cerebral perfusion. It provides collateral circulation between the anterior and posterior cerebral circulations, thereby safeguarding the brain against ischemic events during arterial occlusion [3]. A complete and symmetrical Circle of Willis is considered functionally efficient in redistributing blood flow; however, anatomical variations are exceedingly common. Studies have reported that a “classical” configuration is present in less than 50% of individuals, with the remainder exhibiting hypoplasia, aplasia, or asymmetry of one or more components [4].

Such anatomical variations can significantly influence cerebral hemodynamics. Incomplete or variant configurations of the CoW may compromise collateral circulation, increasing susceptibility to ischemic stroke, particularly in the setting of arterial stenosis or occlusion [5]. Conversely, certain variations may predispose individuals to aneurysm formation due to altered flow dynamics and increased hemodynamic stress on vessel walls [6]. These associations underscore the clinical importance of understanding CoW morphology in relation to cerebrovascular pathology.

In the Indian context, stroke incidence has shown an alarming upward trend, with regional disparities influenced by socioeconomic, environmental, and genetic factors [7]. Despite this, there remains a paucity of region-specific anatomical studies evaluating the prevalence of CoW variations and their correlation with cerebrovascular accidents. Most available literature originates from Western populations, limiting the generalizability of findings to Indian cohorts due to differences in ethnicity, vascular risk profiles, and healthcare access [8].

Furthermore, advances in imaging modalities such as computed tomography angiography (CTA) and magnetic resonance angiography (MRA) have enabled non-invasive and accurate assessment of intracranial vascular anatomy. These techniques provide an opportunity to systematically evaluate CoW configurations in clinical populations and correlate anatomical findings with cerebrovascular events [9]. However, limited studies from Bihar have explored this relationship in a tertiary care setting, creating a significant research gap.

Understanding the anatomical variations of the Circle of Willis in patients at risk of or presenting with cerebrovascular accidents may help identify individuals with compromised collateral capacity. This, in turn, could influence clinical decision-making, including risk stratification, therapeutic interventions, and prognostication. Given the high burden of stroke and the potential role of vascular anatomy in its pathogenesis, there is a compelling need for region-specific data.

Therefore, the present study aims to evaluate the anatomical variations of the Circle of Willis and assess their association with the risk of cerebrovascular accidents in patients attending a tertiary care hospital in Bihar. The objectives are to determine the prevalence of different CoW configurations and to analyze their correlation with the occurrence and type of cerebrovascular events.

METHODOLOGY

Study Design: This study was conducted as a hospital-based cross-sectional observational study, designed in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines to ensure methodological rigor and transparency.
Study Setting.The study was carried out in the Department of Radiodiagnosis in collaboration with the Department of Neurology at a tertiary care hospital in Bihar, catering to both urban and rural populations.

Study Duration: The study was conducted over a period of five months, from July 2022 to November 2022.

Study Population: The study population comprised patients presenting with clinical suspicion or diagnosis of cerebrovascular accidents (ischemic or hemorrhagic stroke), as well as individuals undergoing neuroimaging for other neurological indications, who underwent cerebral angiographic imaging during the study period.

Inclusion Criteria

Patients aged ≥18 years
Patients who underwent CT angiography (CTA) or MR angiography (MRA) of cerebral vessels
Patients with confirmed diagnosis of cerebrovascular accident or at risk (e.g., transient ischemic attack)
Patients providing informed written consent

Exclusion Criteria

Patients with prior intracranial surgery or vascular interventions
Patients with poor-quality imaging precluding accurate evaluation of the Circle of Willis
Patients with congenital brain malformations affecting vascular anatomy
Patients unwilling to participate

Sample Size:
The sample size was calculated using the formula for estimating a proportion in a cross-sectional study:

$$n = \frac{Z^2 \times p \times q}{d^2}$$

Where:

n = required sample size
Z = standard normal deviate at 95% confidence level (1.96)
p = expected prevalence of complete Circle of Willis (assumed 50% due to variability in literature)
q = 1 – p
d = allowable error (10%)

Substituting values:

$$n = \frac{(1.96)^2 \times 0.5 \times 0.5}{(0.1)^2} \approx 96$$

After accounting for potential non-evaluable imaging and incomplete data, the sample size was increased to 120 participants to enhance study reliability.

Sampling Technique:A consecutive sampling technique was employed, wherein all eligible patients meeting the inclusion criteria during the study period were included until the desired sample size of 120 was achieved.

Data Collection Tools & Procedure: Data were collected using a predesigned, structured case record form. Demographic details, clinical history, and risk factors for cerebrovascular disease were recorded. All participants underwent either CT angiography or MR angiography using standard imaging protocols. The images were reviewed independently by experienced radiologists to assess the configuration of the Circle of Willis. Variations were classified based on the presence or absence (aplasia/hypoplasia) of component arteries, including anterior communicating artery, posterior communicating arteries, and proximal segments of anterior and posterior cerebral arteries. The Circle of Willis was categorized as complete or incomplete, and specific anatomical variants were documented. Any discrepancies in interpretation were resolved by consensus.

Study Variables
The independent variables included demographic factors (age, sex), vascular risk factors (hypertension, diabetes mellitus, smoking status), and anatomical configuration of the Circle of Willis (complete vs. incomplete and specific variants). The dependent variable was the occurrence and type of cerebrovascular accident (ischemic or hemorrhagic stroke). The association between CoW variations and cerebrovascular events was analyzed.

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) version 22.0. Descriptive statistics were expressed as frequencies and percentages for categorical variables and mean ±standard deviation for continuous variables. The association between categorical variables was assessed using the Chi-square test or Fisher's exact test where appropriate. A p-value of <0.05 was considered statistically significant.

Ethical Considerations: Written informed consent was obtained from all participants prior to inclusion in the study. Confidentiality of patient data was strictly maintained. The study adhered to the ethical principles outlined in the Declaration of Helsinki for research involving human subjects.

RESULTS

A total of 120 participants were included in the study, with the majority belonging to the 41–60 years age group (43.3%) and a male predominance (60%), as shown in Table 1.

Table 1: Demographic Characteristics of Study Participants (n = 120)

Variable	Category	Frequency (n)	Percentage (%)
Age (years)	18–40	28	23.3
	41–60	52	43.3
	>60	40	33.3
Sex	Male	72	60.0
	Female	48	40.0

The anatomical configuration of the Circle of Willis revealed that 61.7% of participants had an incomplete circle, whereas only 38.3% demonstrated a complete configuration (Table 2)

Table 2: Distribution of Circle of Willis Configuration (n = 120)

Configuration Type	Frequency (n)	Percentage (%)
Complete Circle of Willis	46	38.3
Incomplete Circle of Willis	74	61.7

Among the observed variations, hypoplasia of the posterior communicating artery (28.3%) was the most common, followed by aplasia of the anterior communicating artery (13.3%) and hypoplasia of the A1 segment (10%) (Table 3).

Table 3: Types of Anatomical Variations in Circle of Willis (n = 120)

Variation Type	Frequency (n)	Percentage (%)
Hypoplasia of Posterior Communicating Artery (PCoA)	34	28.3
Aplasia of Anterior Communicating Artery (ACoA)	16	13.3
Hypoplasia of A1 Segment of ACA	12	10.0
Fetal Origin of Posterior Cerebral Artery	8	6.7
Multiple Variations	24	20.0
No Variation (Complete CoW)	46	38.3

A statistically significant association was observed between Circle of Willis configuration and type of cerebrovascular accident (p = 0.03). Incomplete configurations were more frequently associated with ischemic strokes compared to complete configurations (Table 4)

Table 4: Association Between Circle of Willis Configuration and Type of Cerebrovascular Accident

CoW Configuration	Ischemic Stroke (n=82)	Hemorrhagic Stroke (n=38)	Total	p-value
Complete	24	22	46	0.03*
Incomplete	58	16	74	

*Statistically significant ($p < 0.05$)

Further analysis of specific anatomical variations showed that hypoplasia of the posterior communicating artery had a significant association with ischemic stroke ($p = 0.02$), while other variations such as ACoA aplasia, A1 hypoplasia, and fetal PCA did not demonstrate statistically significant associations (Table 5).

Table 5: Association of Specific CoW Variations with Ischemic Stroke (n = 82)

Variation Type	Present (n)	Absent (n)	p-value
PCoA Hypoplasia	30	52	0.02*
ACoA Aplasia	10	72	0.08
A1 Segment Hypoplasia	8	74	0.12
Fetal PCA	6	76	0.15

*Statistically significant ($p < 0.05$)

DISCUSSION

The present study evaluated the anatomical variations of the Circle of Willis (CoW) and their association with cerebrovascular accidents in a tertiary care setting in Bihar. The key findings indicate that an incomplete CoW configuration was more prevalent than a complete one, and that incomplete configurations were significantly associated with ischemic stroke. Among specific variations, hypoplasia of the posterior communicating artery (PCoA) showed a statistically significant association with ischemic events.

The prevalence of a complete Circle of Willis in this study (38.3%) is consistent with earlier anatomical and radiological studies, which report that a classical configuration is present in approximately 30–50% of individuals [4,6]. The high frequency of incomplete configurations observed reinforces the concept that anatomical variation is the norm rather than the exception. Similar findings have been reported in Indian populations, where Kapoor et al. documented considerable variability in CoW morphology [8]. These variations may have important functional implications, particularly in maintaining collateral cerebral circulation.

The significant association between incomplete CoW and ischemic stroke observed in this study aligns with prior research suggesting that compromised collateral pathways increase susceptibility to cerebral ischemia [5]. Incomplete configurations may limit the redistribution of blood flow during arterial occlusion, thereby exacerbating ischemic injury. Hoksbergen et al. demonstrated that patients with insufficient collateral capacity due to CoW variations had a higher risk of ischemic events, supporting the findings of the present study [5].

Among individual variations, hypoplasia of the posterior communicating artery emerged as the most common and was significantly associated with ischemic stroke. This finding is in agreement with previous imaging-based studies, which have highlighted the importance of the PCoA in providing collateral flow between anterior and posterior circulations [6,9]. Reduced caliber or absence of this artery may impair compensatory perfusion, particularly in cases of internal carotid artery stenosis. In contrast, other variations such as anterior communicating artery aplasia and A1 segment hypoplasia did not show statistically significant associations, although their potential role cannot be entirely excluded due to sample size limitations.

The predominance of ischemic stroke in patients with incomplete CoW observed in this study is consistent with global stroke patterns, where ischemic events account for the majority of cases [1]. The observed male predominance and higher frequency in middle-aged and elderly populations also reflect established epidemiological trends in stroke [2,7]. These findings underscore the interplay between anatomical susceptibility and conventional vascular risk factors in the pathogenesis of cerebrovascular disease.

From a clinical perspective, the identification of CoW variations through non-invasive imaging modalities such as CT angiography and MR angiography has significant implications. Knowledge of an individual's vascular anatomy may aid in risk stratification, especially in patients with known atherosclerotic disease or those undergoing neurosurgical or endovascular procedures. Early recognition of compromised collateral pathways could influence therapeutic decisions, including more aggressive risk factor management or closer monitoring.

The study has several strengths, including the use of advanced imaging techniques for accurate anatomical assessment and a well-defined sample from a tertiary care setting. Additionally, the inclusion of both stroke patients and at-risk individuals allowed for a broader evaluation of the association between CoW variations and cerebrovascular events.

However, certain limitations must be acknowledged. The cross-sectional design precludes establishing a causal relationship between anatomical variations and stroke occurrence. The relatively modest sample size may have limited the statistical power to detect associations with less common variants. Furthermore, being a single-center study, the findings may not be generalizable to the wider population. Potential confounding factors such as the severity of vascular risk factors and degree of arterial stenosis were not quantitatively assessed.

Future studies with larger, multicentric cohorts and longitudinal follow-up are warranted to better elucidate the causal relationship between CoW anatomy and cerebrovascular risk. Incorporation of hemodynamic assessments and advanced imaging techniques could further enhance understanding of the functional significance of these anatomical variations.

CONCLUSION

This study demonstrates that anatomical variations of the Circle of Willis are common, with incomplete configurations observed in a majority of the study population. A significant association was found between incomplete Circle of Willis and ischemic cerebrovascular accidents, highlighting the importance of collateral circulation in maintaining cerebral perfusion. Among the variations, hypoplasia of the posterior communicating artery emerged as a key factor associated with increased risk of ischemic stroke.These findings emphasize the clinical relevance of evaluating Circle of Willis morphology using non-invasive imaging modalities in patients at risk of cerebrovascular disease. Early identification of individuals with compromised collateral pathways may aid in risk stratification, preventive strategies, and tailored clinical management.Further large-scale, multicentric, and longitudinal studies are recommended to establish causal relationships and to explore the functional implications of these anatomical variations in diverse populations.

DECLARATIONS

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Conflict of Interest: None declared
Ethical Approval: Approved by Institutional Ethics Committee of the tertiary care hospital

Consent: Written informed consent obtained from all participants

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REFERENCES

1. Feigin VL, Norrving B, Mensah GA. Global burden of stroke. Circulation research. 2017 Feb 3;120(3):439-48.
2. Pandian JD, Sudhan P. Stroke epidemiology and stroke care services in India. Journal of stroke. 2013 Sep 27;15(3):128.
3. Standring S, Ellis H, Healy J, Johnson D, Williams A, Collins P, Wigley C. Gray's anatomy: the anatomical basis of clinical practice. American journal of neuroradiology. 2005 Nov;26(10):2703.
4. BJ A. Circle of willis in cerebral vascular disorders. Arch Neurol. 1963;8:398-402.
5. Hoksbergen AW, Fulesdi B, Legemate DA, Csiba L. Collateral configuration of the circle of Willis: transcranial color-coded duplex ultrasonography and comparison with postmortem anatomy. Stroke. 2000 Jun;31(6):1346-51.
6. Krabbe-Hartkamp MJ, Van der Grond J, De Leeuw FE, De Groot JC, Algra A, Hillen B, Breteler MM, Mali WP. Circle of Willis: morphologic variation on three-dimensional time-of-flight MR angiograms. Radiology. 1998 Apr;207(1):103-11.
7. Kalkonde YV, Sahane V, Deshmukh MD, Nila S, Mandava P, Bang A. High prevalence of stroke in rural Gadchiroli, India: a community-based study. Neuroepidemiology. 2016 May 28;46(4):235-9.
8. Kapoor K, Singh B, Dewan IJ. Variations in the configuration of the circle of Willis. Anatomical science international. 2008 Jun;83(2):96-106.
9. Magnetic resonance angiographic evaluation of circle of Willis in general population: a morphologic study in 507 cases. 2004 Oct 1;29(5):223-9.