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Original Research Article

Anatomical Variations of the Circle of Willis in Human Cadavers: A Cadaveric Study with Clinical Correlation

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Abstract:

Background: Anatomical variations of Circle of Willis (CoW) are common and may influence the risk of cerebrovascular diseases such as stroke and aneurysms. Understanding these variations is essential for clinicians, neurosurgeons, and radiologists.

Objectives: To study the anatomical variations of the Circle of Willis in human cadavers and to correlate these findings with their clinical significance.

Materials and Methods: The Circle of Willis was carefully dissected on 30 adult human cadavers and examined for completeness, symmetry, and variations such as hypoplasia, aplasia, duplication, and fenestration. Arterial diameters were measured where feasible. Data were analyzed using descriptive statistics and expressed as frequencies and percentages.

Results: A complete Circle of Willis was observed in 43.3% of specimens, while 56.7% showed incomplete configurations. Variations were more common in the posterior circulation, particularly involving the posterior communicating artery. Hypoplasia was the most frequent variation (43.3%), followed by aplasia (23.3%) and asymmetry (20.0%).

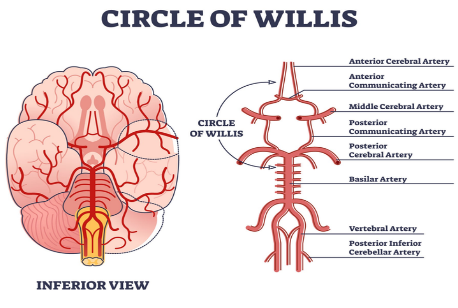
Conclusion: Anatomical variations of the Circle of Willis are common, with incomplete configurations predominating. Posterior circulation, particularly the posterior communicating artery, showed the highest variability.

Keywords: Circle of Willis, anatomical variations, hypoplasia, cerebral circulation, cadaveric study.

Introduction

The Circle of Willis is a vital arterial anastomotic network located at the base of the brain, forming a crucial component of cerebral circulation. It provides a collateral pathway that ensures continuous blood supply to the brain in the event of arterial occlusion or stenosis. Classically, the Circle of Willis is formed by the anterior cerebral arteries connected by the anterior communicating artery, the internal carotid arteries, the posterior communicating arteries, and the posterior cerebral arteries. Although this "complete" configuration is described in standard anatomical texts, numerous studies have demonstrated that anatomical variations are more common than the typical pattern. [1]

Anatomical variations of the Circle of Willis include hypoplasia, aplasia, duplication, fenestration, and asymmetry of its component vessels. These variations can significantly influence cerebral hemodynamics and may predispose individuals to various cerebrovascular disorders. Such variations are of particular clinical importance as they can affect the brain's ability to maintain adequate perfusion during ischemic events. [2] The clinical relevance of these variations has been increasingly recognized, especially in relation to ischemic stroke, aneurysm formation, and subarachnoid hemorrhage. Variations such as hypoplastic or absent posterior communicating arteries may compromise collateral circulation, thereby increasing the risk and severity of ischemic stroke. [3]



Similarly, anomalies in the anterior communicating artery complex are frequently associated with intracranial aneurysms, which are a major cause of subarachnoid hemorrhage and neurological morbidity. [4] Cadaveric studies remain the gold standard for detailed anatomical evaluation, allowing direct visualization and accurate assessment of vascular morphology. While modern imaging techniques such as CT angiography and MR angiography have improved the detection of vascular variations, cadaveric dissection provides unmatched clarity regarding vessel size, course, and structural anomalies. Moreover, cadaver-based studies are invaluable for correlating anatomical findings with potential clinical implications, thereby enhancing the understanding of cerebrovascular pathology. [5]

Material and Methods

Study Settings: A descriptive, observational cadaveric study was done to evaluate the anatomical variations of the Circle of Willis and their clinical correlations at a tertiary care teaching institution using cadavers obtained for routine undergraduate and postgraduate dissection over a period of 18 months from June 2024 to December 2025. A total of 30 adult human cadavers were included in the study.

Inclusion & Exclusion Criteria: Adult human cadavers of either sex with intact Circle of Willis and well-embalmed cadavers with preserved intracranial vessels were included in the study. However cadavers with damaged or distorted brain vasculature or specimens showing evidence of prior cranial surgery or trauma were excluded from the study.

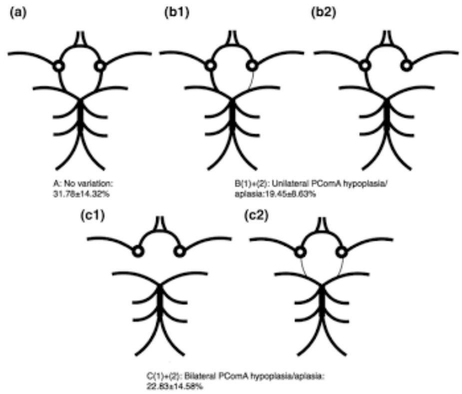
Dissection Procedure: The cranial cavity was opened by removal of the calvaria using standard dissection techniques. Dura mater was carefully incised and reflected. Brain was gently removed from the cranial cavity, preserving the arterial structures at the base. The Circle of Willis was exposed by removing surrounding arachnoid mater and blood clots. Careful dissection was performed to visualize all components of the Circle of Willis, including:

- Anterior cerebral arteries
- Anterior communicating artery
- Internal carotid arteries
- Posterior communicating arteries
- Posterior cerebral arteries

Observation and Data Collection

Each specimen was examined for completeness of the Circle of Willis, presence of hypoplasia or aplasia of vessels, duplication or fenestration of arteries or asymmetry in vessel size and configuration. Measurements of arterial diameters were taken using a digital vernier caliper, where feasible. Photographic documentation of each specimen was performed for record and analysis. The observed variations were categorized based on standard anatomical classifications into:

- Complete Circle of Willis
- Incomplete Circle of Willis
- Variations in anterior circulation
- Variations in posterior circulation



Hypoplasia was defined as arterial diameter less than 1 mm**.**

Clinical Correlation

The anatomical findings were correlated with their known clinical implications, particularly:

- Risk of ischemic stroke
- Association with intracranial aneurysms
- Impact on collateral cerebral circulation

Statistical Analysis: Data obtained was recorded using Microsoft Excel and analyzed SPSS software version 21. Results were expressed as frequencies and percentages and comparative analysis was performed where applicable.

Results

A total of 30 adult human cadavers were examined to study the anatomical variations of the Circle of Willis. The observations are summarized as follow

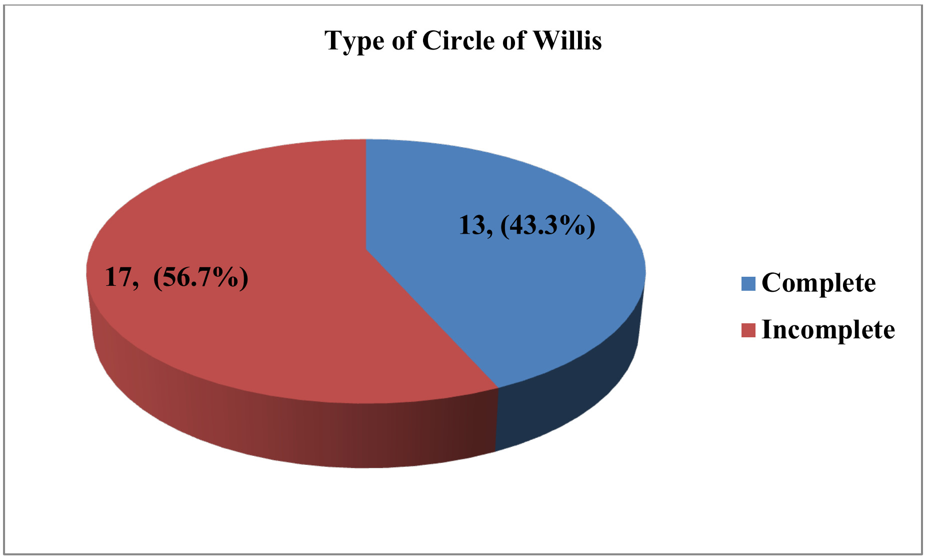


Fig 1: Distribution of Complete and Incomplete Circle of Willis (n = 30)

A complete Circle of Willis was observed in 43.3% of specimens, whereas 56.7% showed incomplete configurations.

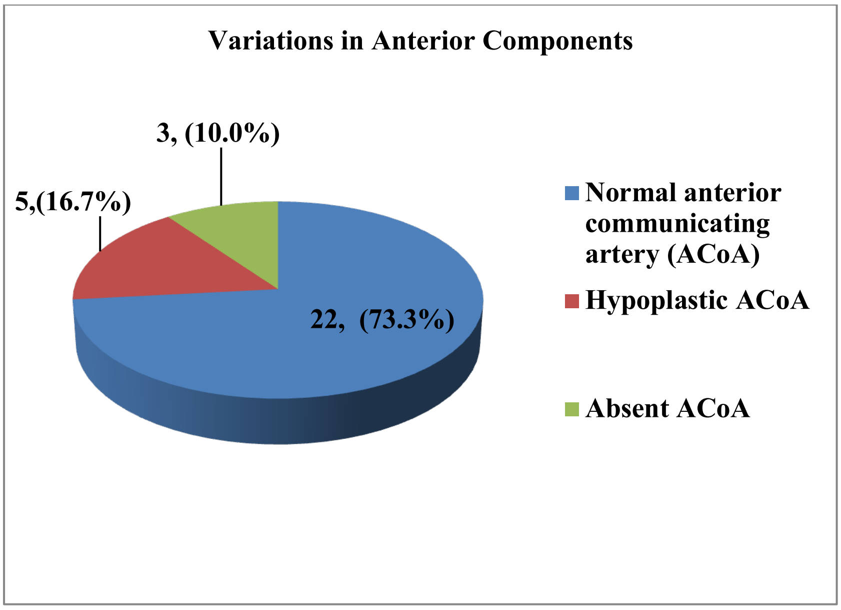


Fig 2: Variations in Anterior Components

Variations in the anterior communicating artery were noted in 26.7% of cases.

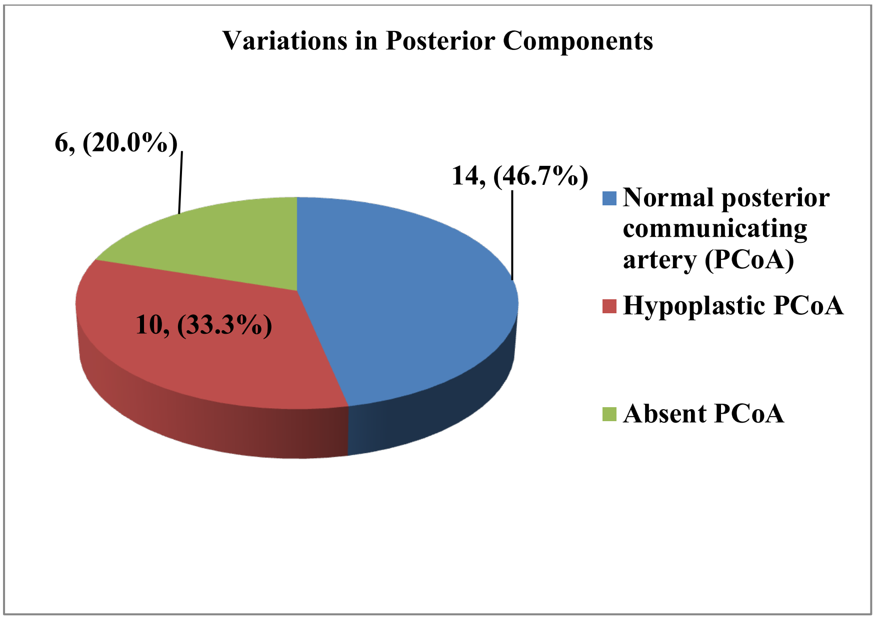


Fig 3: Variations in Posterior Components

Posterior circulation showed a higher frequency of variations compared to anterior circulation.

Table 1: Spectrum of Anatomical Variations

Type of Variation	Number	Percentage (%)
Hypoplasia	13	43.3
Aplasia (absence)	7	23.3
Asymmetry	6	20.0
Duplication/Fenestration	4	13.4

Hypoplasia was the most commonly observed variation.

Table 2: Regional Distribution of Variations

Region of Variation	Number	Percentage (%)
Anterior circulation	9	30.0
Posterior circulation	15	50.0
Both regions	6	20.0

Posterior circulation was most frequently involved.

Table 3: Mean Diameter of Arteries

Artery	Mean Diameter (mm) ± SD
Anterior cerebral artery	2.2 ± 0.4
Anterior communicating artery	1.1 ± 0.3
Posterior communicating artery	1.0 ± 0.3
Posterior cerebral artery	2.4 ± 0.5

Hypoplastic vessels (<1 mm) were most commonly seen in the posterior communicating artery.

Discussion

In present study, a complete Circle of Willis was observed in 40% of cases, while 60% showed variations, which is consistent with the widely reported high prevalence of anatomical deviations in the general population.

A recent meta-analysis by Jones et al. (2021) reported that approximately 68% of individuals exhibit some variation in the Circle of Willis, supporting our findings of a predominance of incomplete or variant configurations. [6] This suggests that the classical "textbook" configuration is less common than previously believed.

The most frequent variation observed in our study was hypoplasia of the posterior communicating artery (PCoA). Similar findings have been reported in recent literature, where unilateral PCoA hypoplasia has been documented in approximately 19–25% of cases, and bilateral involvement in nearly 20%. [6,7] This highlights the posterior segment as the most variable and vulnerable component of the CoW. The clinical implication is significant, as hypoplastic PCoA may compromise collateral flow during vertebrobasilar insufficiency.

We also observed aplastic segments and incomplete circles in a considerable proportion of specimens (20%), which is in agreement with recent systematic reviews reporting incomplete circles in around 6–30% of individuals, depending on population and methodology. [8] Such incomplete configurations are associated with a higher risk of ischemic events due to reduced compensatory capacity.

Anterior circulation variations, including anomalies of the anterior communicating artery (ACoA) and anterior cerebral artery (ACA), were less frequent in our study compared to posterior variations. However, duplications and hypoplasia of ACoA have been reported in about 8–12% of cases in recent studies [8]. These variations are clinically important as the ACoA region is a common site for intracranial aneurysms. Recent evidence has further established a strong association between Circle of Willis variations and intracranial aneurysm formation. Feng et al. (2022) demonstrated that variations, particularly involving the ACoA and PCoA, are frequently observed in patients with aneurysms, suggesting altered hemodynamics as a contributing factor. [9] This aligns with our observations where structurally altered arterial segments may predispose to turbulent blood flow and vascular wall stress.

Additionally, studies using modern imaging techniques and computational modeling have shown that collateral flow patterns are significantly influenced by anatomical variations, with anterior communicating artery acting as an early compensatory channel, followed by posterior communicating arteries under pathological conditions. [10] This supports the functional importance of even small communicating vessels in maintaining cerebral perfusion.

Recommendations

- Preoperative vascular imaging (CTA/MRA) should be routinely performed in patients undergoing neurosurgical or endovascular procedures to identify variations in the Circle of Willis.
- Clinicians should consider CoW variations while assessing patients with stroke, transient ischemic attacks, and aneurysms, as these variations influence collateral circulation.

Limitations

- The study had a relatively small sample size (n = 30), which may limit generalizability of the findings and being a cadaveric study, it does not account for dynamic blood flow and functional hemodynamics.
- Demographic details such as age, comorbidities, and cause of death were not always available, limiting correlation with clinical conditions.

Conclusion

The present study demonstrates that anatomical variations of the Circle of Willis are common, with incomplete configurations observed more frequently than complete ones.

Posterior circulation, particularly the posterior communicating artery, showed the highest variability. Hypoplasia was the predominant variation.

These findings highlight the importance of understanding cerebral vascular anatomy for accurate diagnosis and effective management of cerebrovascular disorders, especially in planning neurosurgical and endovascular interventions.

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