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# CIRCLE OF WILLIS AND ITS VARIATIONS ON MDCT

**Radio-Diagnosis**

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|---|---|
| **Dr Namita Shukla** | JR |
| **Dr Kaleem Ahmad** | Professor |
| **Dr Ved Prakash Shukla*** | Associate Professor *Corresponding Author |
| **Dr Sujeet Kumar Singh** | Assistant Professor |
| **Dr Amit Goel** | Assistant Professor |
| **Dr Ajay Kumar** | Professor |


## ABSTRACT

**INTRODUCTION:** The Circle of Willis (CoW) is the principal arterial anastomotic network at the base of the brain and plays a crucial role in maintaining cerebral perfusion through collateral circulation. Anatomical variations such as hypoplasia, aplasia, duplication and fenestration are common and may influence cerebral hemodynamics, susceptibility to ischemic events and aneurysm formation. **OBJECTIVES:** To study anatomical variations and anomalies of the Circle of Willis using computed tomographic angiography, identify the most common variation and estimate the prevalence of other variations.**METHODS:** This cross-sectional study was conducted over 18 months (2024-2025) among 100 patients aged >=20 years undergoing CT angiography for various clinical indications. Only scans reported as normal were included. Imaging was performed using a 64-slice MDCT scanner with contrast-enhanced angiography. Data were analyzed using SPSS version 26.0 and expressed in frequencies and proportions. **RESULTS:** The study included 100 participants, with male predominance [56 (56.0%)] and the largest proportion in the 30-39 years age group. Incomplete Circle of Willis was observed in 62 (62.0%) participants, while complete configuration was seen in 38 (38.0%). Asymmetrical configuration was present in 56 (56.0%) and symmetrical configuration in 44 (44.0%). PCOM hypoplasia was the most common variant [34 (34.0%)], followed by fetal PCA [20 (20.0%)], ACom hypoplasia [14 (14.0%)] and PCA P1 hypoplasia [10 (10.0%)]. PCOM hypoplasia was significantly associated with incomplete Circle of Willis (p=0.001) and headache (p=0.001). On multivariate analysis, PCOM hypoplasia showed the strongest association with incomplete Circle of Willis (adjusted OR 4.10; 95% CI 1.85-9.09), and the combined predictive model had the highest AUC (0.82).**CONCLUSION:** Anatomical variations of the Circle of Willis were highly prevalent in this MDCT angiography-based study. Incomplete and asymmetrical configurations were more common than the classical complete pattern, and PCOM hypoplasia was the most frequent and statistically important variant. Systematic MDCT assessment of CoW anatomy may improve reporting accuracy and support neurovascular decision-making.

## KEYWORDS

Circle Of Willis, Multidetector Computed Tomography, CT Angiography, Anatomical Variation, Posterior Communicating Artery Hypoplasia, Fetal Posterior Cerebral Artery, Cerebrovascular Imaging.

## INTRODUCTION

The Circle of Willis represents the principal arterial anastomotic network at the base of the brain, providing collateral communication between the anterior and posterior cerebral circulations. Its functional significance depends on the continuity, symmetry and caliber of its constituent arterial segments, including the anterior cerebral arteries, anterior communicating artery, internal carotid arteries, posterior communicating arteries and posterior cerebral arteries. Although a complete and symmetrical Circle of Willis is classically described, anatomical variations are frequently encountered in clinical imaging practice.

These variations include hypoplasia, aplasia or absence, duplication, fenestration and persistent embryonic configurations. Such vascular patterns are clinically relevant because they may alter intracranial hemodynamics, collateral recruitment and the ability of the brain to tolerate arterial narrowing or occlusion. Incomplete or asymmetric configurations may become particularly important in the setting of carotid atherosclerosis, ischemic cerebrovascular disease, aneurysmal pathology or planned neurovascular intervention.

Computed tomography angiography has become a widely available, rapid and non-invasive imaging modality for evaluating intracranial arterial anatomy. Multidetector CT angiography allows high-resolution visualization of the cerebral arterial circle with multiplanar and three-dimensional volume-rendered reconstructions. These advantages make MDCT angiography suitable not only for detecting vascular pathology but also for systematic documentation of normal variants and anatomical deviations.

Regional documentation of Circle of Willis variations is important because the frequency of complete and incomplete configurations may differ across populations, clinical settings and imaging protocols. In an Indian tertiary-care radiodiagnosis setting, structured assessment of these variants can provide clinically useful baseline data and improve consistency in neurovascular reporting.

The present study was therefore undertaken to evaluate the anatomical variations and anomalies of the Circle of Willis using computed tomographic angiography, identify the most common variation and estimate the prevalence of other variants.

## MATERIALS & METHODS

**Study design:** Cross-sectional study.

**Study setting:** Department of Radiodiagnosis, B.R.D. Medical College, Gorakhpur.

**Study period and sample size:** The study was conducted over 18 months during 2024-2025 and included 100 patients.

**Study population:** Patients aged >=20 years undergoing CT angiography for various clinical indications were evaluated. Only brain CT scans reported as normal were included for assessment of Circle of Willis anatomy.

**Inclusion criteria:** Consenting patients aged >=20 years whose brain CT scan was labelled as normal.

**Exclusion criteria:** Patients with congenital brain anomalies, skull base tumours, aneurysm, arteriovenous malformation, arteriovenous fistula, acute ischemic stroke, hemorrhagic stroke, pregnancy, severe renal failure and known contrast allergy were excluded.

**MDCT angiography protocol:** Imaging was performed using a 64 detector-row CT scanner (GE Healthcare Optima 64-slice). Contrast-enhanced CT angiography was performed using 80-120 ml of non-ionic iodinated contrast with iodine concentration of 300/350 mg iodine/ml injected at 3-4 ml/sec. Bolus tracking was used. Selective analysis and three-dimensional volume rendering assessment of the Circle of Willis

were carried out by reconstructing data above the foramen magnum with 0.625 mm thickness, 0.3 mm intervals and a field of view of 9.6 cm.

**Outcome definitions:** Fenestration was defined as division of an arterial lumen into distinct lumens with distal convergence. Duplication was defined as two distinct arteries with separate origins and no distal convergence. Absence and hypoplasia denoted absent and small-caliber vessels, respectively. Fetal origin of the posterior cerebral artery was defined when the posterior communicating artery was prominent with ipsilateral PCA of the same size or with hypoplastic/absent P1 segment. Accessory MCA, ACA trifurcation, bihemispheric ACA, azygos ACA, hyperplastic anterior choroidal artery and infundibulum were classified according to the predefined study criteria.

**Data collection and statistical analysis:** Data were collected using a semi-structured proforma and entered in MS Excel. Statistical analysis was performed using SPSS version 26.0. Outcomes were expressed in frequencies and proportions. Normality of continuous variables was assessed by the Kolmogorov-Smirnov test. Categorical variables were compared using Chi-square test, and $p<0.05$ was considered statistically significant.

**Ethical considerations:** Institutional ethics committee approval was obtained before commencement of the study. Written informed consent was obtained from all participants before enrolment.

## RESULTS

The present cross-sectional study included 100 participants who underwent MDCT angiography for evaluation of intracranial vascular anatomy. The study population showed male predominance, and the largest proportion of participants belonged to the 30-39 years age group. The result section primarily focuses on the morphological configuration of the Circle of Willis and distribution of its anatomical variants in accordance with the study objectives.

**Figure 1: Morphological configuration of the Circle of Willis**

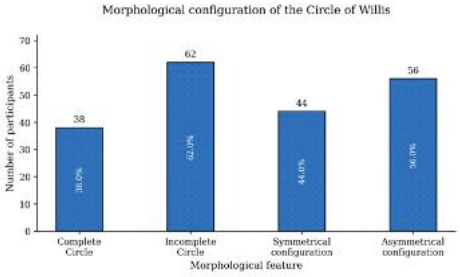


Figure 1 demonstrates that incomplete and asymmetrical configurations were more common than the classical complete and symmetrical Circle of Willis. This indicates that anatomical variation was more frequent than the conventional complete arterial circle in the present study population.

**Table 1: Distribution of Circle of Willis variants on MDCT angiography**

| Circulation segment | Variant | n (%) |
|---|---|---|
| Anterior circulation | ACA A1 hypoplasia | 8 (8.0%) |
| | ACom hypoplasia | 14 (14.0%) |
| | ACom absence | 6 (6.0%) |
| | Azygos ACA | 1 (1.0%) |
| | Bihemispheric ACA | 2 (2.0%) |
| | ACA trifurcation | 3 (3.0%) |
| | Accessory MCA | 3 (3.0%) |
| Posterior circulation | PCOM hypoplasia | 34 (34.0%) |
| | PCOM absence | 8 (8.0%) |
| | Fetal PCA | 20 (20.0%) |
| | PCA P1 hypoplasia | 10 (10.0%) |
| Other vascular variants | Fenestration | 3 (3.0%) |
| | Duplication | 2 (2.0%) |
| | Hyperplastic anterior choroidal artery | 4 (4.0%) |
| | Infundibulum | 5 (5.0%) |

Table 1 shows that posterior circulation variants formed the dominant pattern of Circle of Willis variation. PCOM hypoplasia was the most common overall variant, followed by fetal PCA, while ACom hypoplasia was the most frequent anterior circulation variant. Rare variants such as azygos ACA, bihemispheric ACA, accessory MCA, fenestration and duplication were also observed at lower frequencies.

**Figure 2: Laterality distribution of major posterior circulation variants**

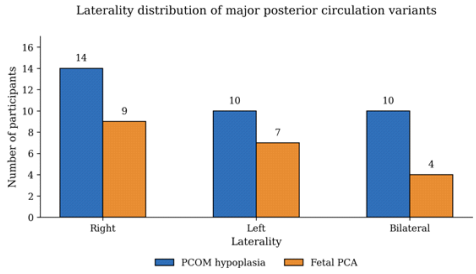


Figure 2 shows that PCOM hypoplasia and fetal PCA were more frequently right-sided than left-sided or bilateral. This laterality pattern supports the presence of asymmetric posterior circulation development in a subset of participants.

**Table 2: Association and predictive analysis for incomplete Circle of Willis**

| Analysis | Variable / predictor | Result | p-value |
|---|---|---|---|
| Age group and completeness | 20-39 years | Complete: 22 (48.9%); Incomplete: 23 (51.1%) | 0.034 |
| | 40-59 years | Complete: 10 (25.0%); Incomplete: 30 (75.0%) | |
| | >=60 years | Complete: 6 (40.0%); Incomplete: 9 (60.0%) | |
| PCOM hypoplasia and completeness | PCOM hypoplasia present | Complete: 6 (17.6%); Incomplete: 28 (82.4%) | 0.001 |
| | PCOM hypoplasia absent | Complete: 32 (48.5%); Incomplete: 34 (51.5%) | |
| Variant and headache | PCOM hypoplasia | Headache present: 26 (76.5%); Headache absent: 8 (23.5%) | 0.001 |
| | Fetal PCA | Headache present: 12 (60.0%); Headache absent: 8 (40.0%) | 0.34 |
| | ACom absence | Headache present: 4 (66.7%); Headache absent: 2 (33.3%) | 0.35 |
| Multivariate analysis | Age >40 years | Adjusted OR 1.45; 95% CI 1.10-1.92 | - |
| | Hypertension | Adjusted OR 1.35; 95% CI 0.48-3.78 | - |
| | PCOM hypoplasia | Adjusted OR 4.10; 95% CI 1.85-9.09 | - |
| ROC analysis | PCOM hypoplasia | AUC 0.78 | - |
| | Age | AUC 0.63 | - |
| | Combined model | AUC 0.82 | - |

Table 2 shows that age group had a statistically significant association with completeness of the Circle of Willis. PCOM hypoplasia was significantly associated with incomplete Circle of Willis and also showed a significant association with headache. On multivariate analysis, PCOM hypoplasia had the strongest association with incomplete Circle of Willis. ROC analysis showed that the combined model had the highest predictive performance, followed by PCOM hypoplasia alone.

Overall, the results demonstrate that incomplete Circle of Willis configuration was more common than the complete classical pattern. Posterior circulation variants formed the major burden of anatomical variation, with PCOM hypoplasia emerging as the most common and statistically important variant. The association and predictive analysis further showed that PCOM hypoplasia was strongly linked with incomplete Circle of Willis, supporting its clinical relevance in MDCT angiographic evaluation.

## DISCUSSION

The present study evaluated anatomical variations of the Circle of Willis using MDCT angiography in 100 participants. The main finding was that incomplete configuration was more common than the complete classical arterial circle, and asymmetrical configuration was also more frequent than symmetrical morphology. This supports the concept that anatomical variation of the Circle of Willis is common in routine neurovascular imaging and should not be regarded as an incidental or exceptional finding. The observed pattern is comparable with Dhakal et al. [2], who reported a high frequency of incomplete Circle of Willis on CT cerebral angiography, and with Şahin and Pekçevik [1], who also documented frequent anatomical variations on CTA.

Posterior circulation variants constituted the dominant burden of variation in this study. PCOM hypoplasia was the most common overall variant, observed in 34.0% of participants, followed by fetal PCA in 20.0%, PCA P1 hypoplasia in 10.0% and PCOM absence in 8.0%. These findings are clinically relevant because the posterior communicating arteries form an important collateral pathway between anterior and posterior circulations. A hypoplastic or absent PCOM may reduce collateral reserve during carotid or posterior circulation compromise. Similar emphasis on the clinical relevance of Circle of Willis configuration has been reported by Saba et al. [9], Li et al. [10] and Zhu et al. [11], who highlighted the relationship between CoW morphology, cerebral perfusion and vascular disease patterns.

Anterior circulation variants were less frequent than posterior circulation variants. ACom hypoplasia was the most common anterior variant, followed by ACA A1 hypoplasia and ACom absence. Rare variants including azygos ACA, bihemispheric ACA, ACA trifurcation and accessory MCA were also identified. Although less common, recognition of these variants is important because they may influence aneurysm location, surgical approach, catheter navigation and interpretation of collateral flow. Pachani et al. [14] reported the clinical relevance of azygos ACA in relation to aneurysm formation, supporting the importance of documenting even rare variants during angiographic assessment.

The present study also demonstrated that PCOM hypoplasia was strongly associated with incomplete Circle of Willis. Among participants with PCOM hypoplasia, 28 of 34 had incomplete configuration, and the association was statistically significant. On multivariate analysis, PCOM hypoplasia had the strongest association with incomplete Circle of Willis, with an adjusted OR of 4.10 and 95% CI of 1.85-9.09. ROC analysis further supported its predictive importance, with PCOM hypoplasia showing an AUC of 0.78 and the combined model showing an AUC of 0.82. These findings reinforce that posterior communicating artery development is a major determinant of overall Circle of Willis completeness.

Age group showed a statistically significant association with Circle of Willis completeness, while hypertension showed a weaker association in multivariate analysis. This may reflect interaction between anatomical configuration, vascular remodeling and vascular risk factors, although the cross-sectional design limits causal interpretation. The association of PCOM hypoplasia with headache was also significant, while fetal PCA and ACom absence did not show significant association. This suggests that not all anatomical variants have similar symptomatic relevance, and that hemodynamic implications may vary according to the segment involved.

The strength of this study lies in its MDCT angiography-based evaluation, predefined anatomical definitions and objective documentation of anterior, posterior and other vascular variants. The findings are relevant to radiologists and clinicians because systematic reporting of Circle of Willis morphology can improve diagnostic accuracy, risk stratification and pre-procedural planning. However, the study was single-centre and cross-sectional, with a sample size of 100 participants. Functional flow assessment and long-term clinical follow-up were not included. Future multicentric studies with quantitative vessel diameter and perfusion assessment may help define the prognostic significance of specific variants more precisely.

## CONCLUSION

Anatomical variations of the Circle of Willis were highly prevalent in this MDCT angiography-based cross-sectional study. Incomplete and asymmetrical configurations were more frequent than the classical complete circle. PCOM hypoplasia was the most common overall variation and showed the strongest association with incomplete Circle of Willis, while fetal PCA and ACom hypoplasia were other frequent variants. MDCT angiography provided reliable, non-invasive visualization of these vascular patterns and allowed systematic assessment of clinically relevant anterior and posterior circulation variants. Routine documentation of Circle of Willis morphology can improve diagnostic accuracy, support risk stratification and assist clinical decision-making in neurovascular practice.

## DECLARATIONS

**Conflict of Interest:** None.
**Funding:** None.
**Ethical Approval:** Obtained.
**Consent:** Written consent secured.

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