Evaluation of normal variants of the circle of Willis using MRI-MR angiography

Dr. Shruthi Medam[1], Dr. Kanishka S Patil[2], Dr. S. Sowmya[3]

[1]*Junior Resident, Department of Radiodiagnosis, Vinayaka Mission's Medical College and Hospital, Vinayaka Mission's, Research Foundation (Deemed to be University), Karaikal, Pondicherry, India*

[2]*Associate professor, Department of Radiodiagnosis, Vinayaka Mission's Medical College and Hospital, Vinayaka, Mission's Research Foundation (Deemed to be University), Karaikal, Pondicherry, India*

[3]*Junior resident, Department of Radiodiagnosis, Vinayaka Mission's Medical College and Hospital, Vinayaka, Mission's Research Foundation (Deemed to be University), Karaikal, Pondicherry, India*

***Corresponding Author:** Dr. Shruthi Medam

Junior Resident, Department of Radiodiagnosis, Vinayaka Mission's Medical College and Hospital, Vinayaka Mission's, Research Foundation (Deemed to be University), Karaikal, Pondicherry, India

KEYWORDS

Circle of Willis, Magnetic Resonance Angiography, Normal Variants, 3D TOF MRA, Cerebrovascular Anatomy, Vascular Imaging.

ABSTRACT:

Background: The Circle of Willis (CoW) is a critical arterial structure supplying blood to the brain. Variations in its configuration can influence cerebrovascular pathology and ischemic stroke risk. Magnetic Resonance Angiography (MRA) is a non-invasive imaging modality that provides detailed visualization of these variations.

Objective: To evaluate normal variants of the Circle of Willis using MRI-MR Angiography and assess their prevalence among different age groups and genders.

Materials and Methods: This hospital-based observational study was conducted at Vinayaka Mission's medical College and hospital,karaikal, over two years (November 2022–November 2024). A total of 50 patients referred for MRI Brain underwent 3D Time-of-Flight (TOF) MR Angiography. Variations in the anterior and posterior components of the CoW were analyzed using SYNGO VIA USER software. Statistical analysis was performed using SPSS version 20, with a p-value <0.05 considered statistically significant.

Results: Among the 50 participants, 56% were male and 44% were female, with a mean age of 47.26 (±18.48) years. The most common variation in the anterior circulation was Pattern A (82%), while the posterior circulation was predominantly Pattern K (54%). A complete CoW was observed in 52% of cases, whereas 44% had a partial configuration, and 4% exhibited an incomplete pattern. There was no significant association between CoW variations and age or gender ($p > 0.05$).

Conclusion: Normal variants of the Circle of Willis are prevalent, with a balanced configuration observed in most cases. MRA serves as an effective imaging modality for assessing these variations, aiding in the early identification of individuals at risk for cerebrovascular events.

INTRODUCTION

The Circle of Willis (CoW) is a critical arterial anastomotic system at the base of the brain, ensuring collateral circulation in cases of vascular occlusion or stenosis [1]. It is composed of the anterior cerebral arteries (ACA), anterior communicating artery (AComA), internal carotid arteries (ICA), posterior cerebral arteries (PCA), and posterior communicating arteries (PComA) [2]. Anatomical variations in CoW are common and can influence cerebral hemodynamics, potentially contributing to cerebrovascular diseases such as stroke, aneurysms, and transient ischemic attacks (TIA) [3].

MRI with MR Angiography (MRA) has emerged as a non-invasive imaging modality for assessing the anatomical configuration and variations of CoW, providing high-resolution 3D visualization without exposure to ionizing radiation or contrast agents [4]. The 3D Time-of-Flight (3D TOF) MRA technique is particularly useful in detecting hypoplastic, absent, or anomalous vessels in CoW [5].

Several studies have reported significant variations in CoW morphology, with only a small percentage of the population exhibiting a classical, complete CoW structure [6]. The prevalence of complete CoW has been estimated to range between 20–50%, with the remaining cases exhibiting hypoplasia or absence of one or more arterial segments [7]. Understanding these variations is essential for clinicians and neurosurgeons in planning

surgical interventions, endovascular procedures, and assessing stroke risk [8].
This study aims to evaluate the normal anatomical variants of the Circle of Willis in patients undergoing MRI Brain with MRA at Vinayaka Mission's medical College and Hospital, Karaikal. The findings will contribute to a better understanding of the prevalence and clinical implications of these variations in the Indian population.

MATERIALS AND METHODS

Study Design

This hospital-based observational study was conducted to evaluate normal variants of the Circle of Willis (CoW) using MRI-MR Angiography (MRA).

Study Population

The study included patients referred to the Department of Radiodiagnosis for an MRI Brain at Vinayaka Mission's medical College and hospital, karaikal.

Study Duration

The study was conducted over two years (November 2022 to November 2024).

Sample Size

A total of 50 patients were included in the study. The sample size was determined based on previous studies and the estimated availability of cases fulfilling the inclusion and exclusion criteria within the study duration.

Inclusion Criteria

Patients referred for MRI Brain who met the following criteria were included:

1. Patients of all age groups and both genders.
2. Patients referred for MRI Brain to evaluate vascular anatomy.

Exclusion Criteria

Patients with the following conditions were excluded:

1. Presence of a cardiac pacemaker.
2. MRI-incompatible stents or implants.
3. Claustrophobia leading to an inability to complete the scan.
4. Poor image quality due to artifacts or distortion.
5. Presence of atherosclerosis or narrowed vessels causing turbulent or low flow, leading to inadequate visualization of the Circle of Willis.

Methodology

All included patients underwent routine MRI Brain with MR Angiography (MRA) using standard imaging parameters.

MRI Protocol

The imaging was performed using 3D Time-of-Flight (3D TOF) MR Angiography, with the following scan parameters:

- Repetition Time (TR): 25 ms
- Flip Angle: 25°
- Slice Thickness (ST): 0.70 mm
- Field of View (FOV): 180 mm
- Voxel Size: 0.7 × 0.7 × 0.7 mm
- Scan Time: 5–6 minutes

Data Acquisition and Analysis

1. The acquired MRA images were processed using SYNGO VIA USER software at the workstation.
2. Maximum Intensity Projection (MIP) and source images were used to evaluate variations in the Circle of Willis.
3. Measurements of individual transverse 3D TOF sections of all vessels within the CoW were performed.
4. Vessels with a diameter of ≤1 mm were classified as hypoplastic.
5. The findings were recorded in a pre-designed questionnaire and tabulated.
6. The 3D TOF MRA and MIP images of the MRS sequence were analyzed to identify common and uncommon variations in the Circle of Willis.

Statistical Analysis

- Data was compiled using Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) version 20.
- Categorical data was presented as frequencies and percentages and analyzed using the Chi-square test.
- Quantitative data was analyzed using measures of central tendency (mean, median) and dispersion (standard deviation).
- Independent sample T-test and Analysis of Variance (ANOVA) were applied to determine statistical significance.
- A p-value < 0.05 was considered statistically significant.

Ethical Considerations

- The Institutional Ethical Committee of Vinayaka Mission's Medical College and Hospital, Karaikal, approved the study.
- Informed consent was obtained from all patients before inclusion in the study.

RESULTS AND OBSERVATIONS

A total of 50 patients were included in this observational study based on the inclusion criteria.

Table 1: Gender distribution of patients studied

Gender	Frequency	Percent
Male	28	56.0
Female	22	44.0
Total	50	100.0

Table 2: Age distribution of patients studied

Age group	Frequency	Percent
1 – 10 years	2	4.0
11 - 20 years	1	2.0
21 – 30 years	4	8.0
31 – 40 years	17	34.0
41 – 50 years	3	6.0
51 – 60 years	11	22.0
61 – 70 years	7	14.0
More than 70 years	5	10.0
Total	50	100.0

The mean (± SD) age of the study group was 47.26 (± 18.48) years ranging from 8 to 85 years. About 34% of the study subjects in this study belonged to 31 – 40 years followed by 51 – 60 years (22%), 61 – 70 years (14%), more than 70 years (10%), 21 – 30 years (8%), 41 – 50 years (6%), 1 – 10 years (4%) and 11 – 20 years (2%).

Table 3: Percentage of total variations of COW

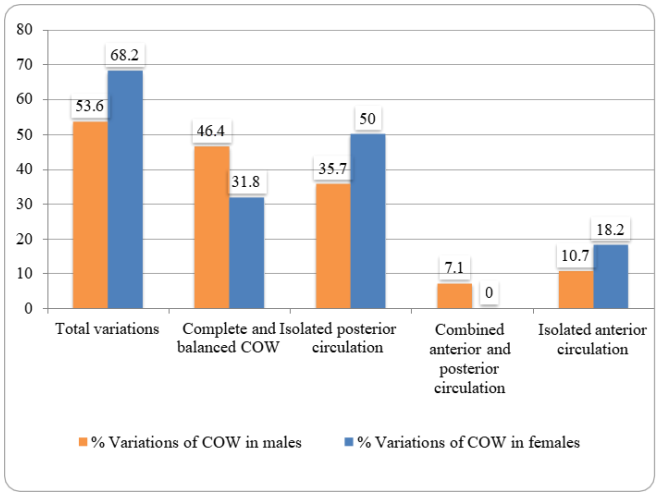
Variations	Complete n (%)	Incomplete n (%)	Partial n (%)
Anterior	0	0	7 (31.8)
Balanced	18 (69.2)	0	0
Combined	0	2 (100.0)	0
Posterior	6 (23.1)	0	15 (68.2)
Others	2 (7.7)	0	0
Total	26 (100.0)	2 (100.0)	22 (100.0)

About 31.8% of the patients had an anterior and partial circle of Willis, 69.2% had complete and balanced COW, 100% had combined and incomplete COW, 23.1% had complete and posterior COW, 68.2% had incomplete posterior COW and 7.7% had other variations.

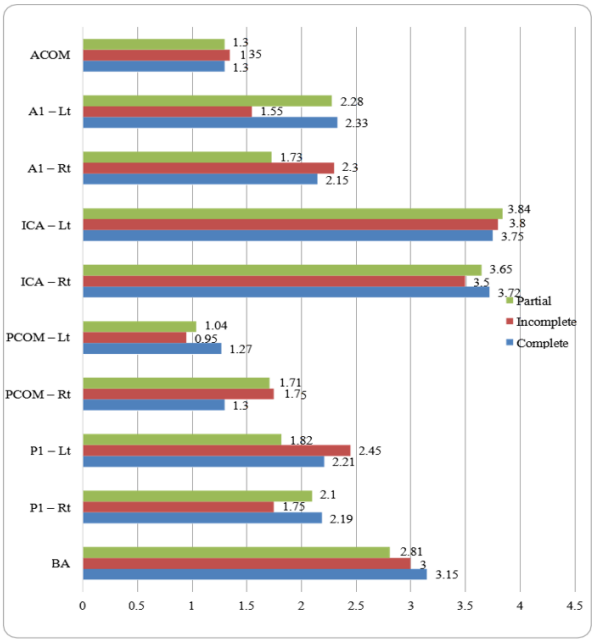
Table 4; Distribution of Study Group According to Variations in the Circle of Willis (CoW)

Variation Pattern	Anterior Part (Frequency, %)	Posterior Part (Frequency, %)
A	41 (82.0%)	-
A, H	7 (14.0%)	-
E	1 (2.0%)	-
H, I	1 (2.0%)	-
K	-	27 (54.0%)
L	-	8 (16.0%)
M	-	0 (0%)
N	-	8 (16.0%)
O	-	1 (2.0%)
P	-	2 (4.0%)
Q	-	0 (0%)
R	-	0 (0%)
S	-	4 (8.0%)
T	-	0 (0%)
Total	50 (100.0%)	50 (100.0%)

- Anterior Part Variations: The most common was the A pattern (82%), followed by A, H (14%), while the E and H, I patterns (2% each) were rare.
- Posterior Part Variations: The K pattern (54%) was the most frequent, followed by L and N patterns (16% each), while S (8%), P (4%), and O (2%) were less common. Some patterns (M, Q, R, T) were not observed.



Graph 1: Column diagram for comparison of variations of COW between males and females



Graph 2: Bar diagram for distribution of study group according to mean diameter of arteries forming

COW and configuration of variations

Table 5: Distribution of the study group according to mean diameter of arteries forming COW and age group & gender

Variables	Total number of patients	Configuration of COW			P value
		Complete (n=26)	Incomplete (n=2)	Partial (n=22)	
Age in years					
≤ 40 years	24	10 (38.5)	1 (50.0)	13 (59.1)	
>40 years	26	16 (61.5)	1 (50.0)	9 (40.9)	0.361, NS
Gender					
Female	22	9 (34.6)	0	13 (59.1)	
Male	28	17 (65.4)	2 (100.0)	9 (40.9)	0.104, NS

The completed configuration of the circle of Willis was found in most of the study subjects aged more than 40 years, the partial configuration was equal in both the study subjects aged more and less than 40 years, and incomplete configuration was mainly found in the study subjects aged less than 40 years. This difference in configuration was not statistically significant with age.
The configuration of the circle of Willis was complete in males compared to females, partial in 40.9% of the male cases, and incomplete in two males. There was no statistically significant difference in the configuration.

DISCUSSION
The Circle of Willis (CoW) is a crucial arterial network that provides collateral circulation to the brain. Anatomical variations in its configuration can have clinical implications, particularly in cerebrovascular diseases. This study aimed to evaluate normal variants of the CoW using MRI-MR Angiography (MRA) and analyze their distribution among different age groups and genders.
Prevalence of Variants
Our study found that 69.2% of cases exhibited a complete and balanced CoW, while 31.8% showed anterior and partial variations. Additionally, posterior incomplete configurations were observed in 68.2% of cases, highlighting the prevalence of anatomical diversity in the CoW. These findings are consistent with previous studies that have reported a significant proportion of incomplete CoW formations in the general population [1,2].
Anterior vs. Posterior Variations
The most common anterior variation observed was the A pattern (82%), followed by A, H (14%). In contrast, the posterior segment showed a predominance of the K pattern (54%), followed by L and N patterns (16% each). The presence of posterior variations is particularly relevant, as studies suggest that an incomplete posterior CoW may increase susceptibility to ischemic strokes due to inadequate collateral circulation [3,4].
Gender and Age Correlation
Gender-based analysis revealed no statistically significant differences in CoW variations. However, the complete configuration was more frequently observed in males (65.4%) than in females (34.6%). In contrast, the partial configuration was equally distributed among males and females. Similar trends have been documented in other MRA-based studies [5].
Age-wise, a complete CoW was more prevalent in individuals above 40 years (61.5%), whereas younger individuals showed a higher tendency toward partial configurations (59.1%). This could be attributed to developmental anatomical changes that may progress with age [6,7].
Clinical Implications
Understanding CoW variations is critical in neurovascular procedures and stroke risk assessments. Studies have demonstrated that individuals with an incomplete CoW have a higher likelihood of suffering from transient ischemic attacks and cerebral infarctions due to compromised compensatory circulation [8,9]. Therefore, MRA-based assessments can aid in preemptive identification of at-risk individuals.
Comparison with Previous Studies
Comparing our findings with global studies, a meta-analysis by Krabbe-Hartkamp et al. (1998) reported that only 42% of subjects had a complete CoW, indicating significant inter-population differences [10]. Additionally, similar studies in Indian populations have shown a slightly higher prevalence of complete CoW configurations, likely due to genetic and environmental factors [11,12].

Limitations and Future Directions
The primary limitation of this study is the relatively small sample size (n=50), which may not fully represent population-wide variations. Furthermore, the study did not include pathological conditions that could influence CoW morphology. Future research with larger cohorts and multi-center data would provide a more comprehensive understanding of CoW variants.

CONCLUSION

This study reinforces the anatomical diversity of the CoW and its potential clinical implications. The high prevalence of incomplete posterior CoW configurations highlights the need for routine cerebrovascular screening, especially in patients with risk factors for ischemic events. Further research in this area could improve our understanding of cerebrovascular pathophysiology and guide therapeutic interventions.

REFERENCES

1. Van Overbeeke JJ, Hillen B, Tulleken CA. "A comparative study of the circle of Willis in fetal and adult life." Stroke. 1991;22(8):1143-1151.
2. Kapoor K, Singh B, Dewan LI. "Variations in the configuration of the circle of Willis." Anat Sci Int. 2008;83(2):96-106.
3. Alpers BJ, Berry RG, Paddison RM. "Anatomical studies of the circle of Willis in normal brain." AMA Arch Neurol Psychiatry. 1959;81(4):409-418.
4. Riggs HE, Rupp C. "Variation in form of circle of Willis." Arch Neurol. 1963;8(1):8-14.
5. Fawcett E, Blachford JV. "The circle of Willis: An examination of 700 specimens." J Anat Physiol. 1905;40(1):63-70.
6. Mchedlishvili G, Nikolaishvili A. "Variations of the circle of Willis: A study of 160 cases." Stroke. 1986;17(1):73-78.
7. Lazorthes G, Gouaze A, Santini JJ, Lazorthes Y, Burdin P. "The arterial circle of the brain (circulus arteriosus cerebri)." Anat Clin. 1979;1(3):241-257.
8. Hoksbergen AW, Legemate DA, Ubbink DT, Jacobs MJ. "Collateral function of the circle of Willis: Transcranial color-coded duplex ultrasonography in patients with unilateral internal carotid artery occlusion." Stroke. 2000;31(7):1016-1021.
9. Hartkamp NS, Van der Grond J, Van Everdingen KJ, Hillen B, Mali WP. "Circle of Willis collateral flow investigated by magnetic resonance angiography." Stroke. 1999;30(12):2671-2678.
10. Krabbe-Hartkamp MJ, Van der Grond J, De Leeuw FE, et al. "Circle of Willis: Morphologic variation on three-dimensional time-of-flight MR angiograms." Radiology. 1998;207(1):103-111.
11. Saikia KC, Chandran A, Bhuyan SK. "Anatomic variations of the circle of Willis: A study in an Indian population." J Neurol Sci. 2015;355(1-2):75-81.
12. Nayak SR, Singh G, Krishnamurthy A, et al. "Morphological variations of the circle of Willis in a cadaveric study of an Indian population." J Clin Diagn Res. 2016;10(3):AC01-AC04.