Anatomical Variations of the Circle of Willis: A Time-of-Flight MRI Morphological Analysis

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Abstract: ***The Circle of Willis, a crucial anatomical structure in the cerebrovascular system, plays a vital role in maintaining cerebral blood flow through its intricate network of communicating arteries. This prospective observational study utilized 1.5 T Time-of-Flight Magnetic Resonance Angiography (TOF-MRA) to investigate the morphological variations in the Circle of Willis among 30 participants aged 18–80 years. The findings revealed that 63.3% of participants exhibited variations in the Circle of Willis, with the posterior circulation showing the highest frequency of abnormalities. The most common variation was hypoplasia of the posterior communicating artery (23.3%). The study highlights significant individual differences in cerebral arterial configurations, emphasizing their potential impact on cerebrovascular health and collateral circulation. These findings call for personalized approaches in assessing cerebrovascular risks, while also acknowledging the study's limitations, including its small sample size and single-center design.***

Keywords: Circle of Willis, cerebral blood flow, TOF-MRA, cerebrovascular variations, neurovascular anatomy

1. Introduction

The Circle of Willis represents a remarkable architectural marvel of human neuroanatomy, serving as a critical hemodynamic interface that ensures optimal cerebral blood circulation through its intricate network of communicating arteries. This complex vascular configuration functions as a sophisticated natural bypass system, providing remarkable resilience and adaptability to the cerebrovascular network.[1]

Historically, the Circle of Willis has intrigued anatomists and neurologists since its first comprehensive description by Thomas Willis in the 17th century. Initially conceptualized as a uniform arterial ring, contemporary research has progressively revealed the extensive morphological diversity inherent in this neurovascular structure. Each individual's Circle of Willis emerges as a unique topographical landscape, characterized by subtle yet significant variations that can profoundly impact cerebral hemodynamics.[2]

The advent of advanced neuroimaging techniques, particularly Time-of-Flight Magnetic Resonance Angiography (TOF-MRI), has revolutionized our understanding of cerebrovascular anatomy. This non-invasive imaging modality provides unprecedented insights into the intricate morphological landscape of the Circle of Willis, enabling comprehensive visualization of arterial configurations with remarkable spatial resolution.[3]

2. Methodology

This prospective observational radiological study aimed to investigate the morphological characteristics of cerebral arterial configurations using 1.5 T Time-of-Flight Magnetic Resonance Angiography. The study included 30 participants, recruited over a period of 6 months, who underwent imaging evaluation. The imaging protocol involved acquiring high-resolution images with a slice thickness of 1.2 mm, field of view of 240 × 240 mm, and spatial resolution of 0.6 × 0.6 mm.[4]

The study population consisted of individuals aged 18-80 years, with no prior cerebrovascular interventions or significant neurological disorders. Participants with contraindications to MRI, incomplete or low-quality imaging studies, or a history of intracranial surgical procedures were excluded.[5]

To ensure accurate assessments, vessel diameter measurements were taken from original slices rather than Maximum Intensity Projection (MIP) images, overcoming the limitations of MIP. Distinguishing Posterior Communicating Arteries (PComAs) from anterior choroidal arteries was crucial, and this was achieved by sequentially scrolling through slices and evaluating artery trajectories in a dynamic display.[6]

The anterior and posterior parts of each circle were assessed separately in terms of morphology and classified accordingly. A complete arterial circle required all segments to be visible, continuous, and at least 0.8mm in diameter. Incomplete arterial circles featured defective segments, such as absence, in both configurations, whereas complete circles had complete anterior or posterior segments. A detailed morphological analysis revealed a distribution of complete and partial incomplete configurations, with significant inter-segment variation observed.[7]

Statistics

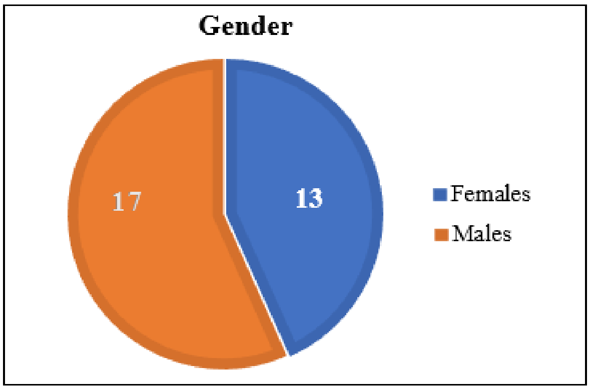
The statistical analysis was performed using SPSS software (version 25). The frequency and percentage of each variation were calculated. Descriptive statistics were used to summarize the demographic characteristics of the patients. The mean age of the patients was calculated, and the standard deviation was used to measure the variability of the age distribution.

3. Results and observations

1) Gender distribution

Table 1: Gender wise distribution of Cases

Gender	Number of individuals	Percentage of individuals	Ratio (Male: Female)
Male	17	56.6%	1.31: 1
Female	13	43.3%	



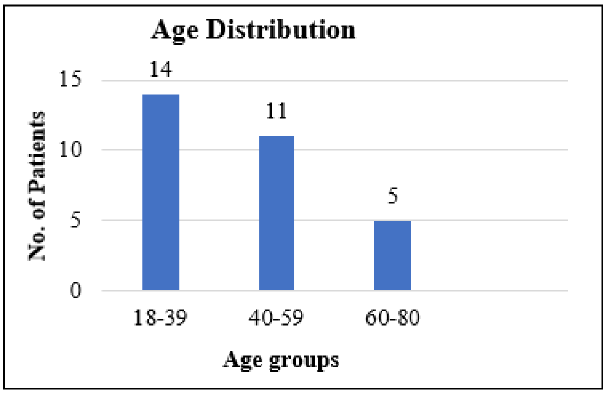
Graph 1: Pie chart showing gender distribution of the study population

2) Age distribution

Table 2: Distribution of study population according to age

Age group	Number of individuals	Percentage of individuals
18-39	14	46.6
40-59	11	36.6
60-80	5	16.6

Mean= 39.75

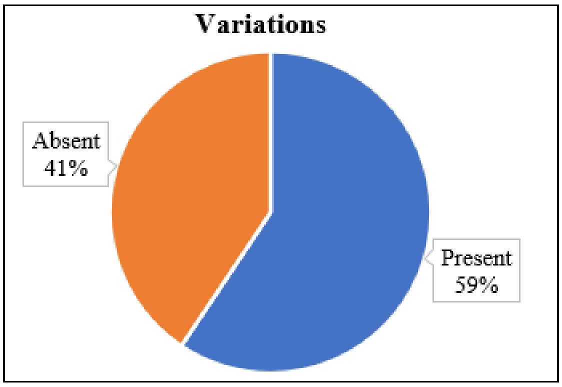


Graph 2: Bar graph showing the age distribution of the study population.

3) Distribution of variations of Circle of Willis

Table 3: Table showing the distribution of variations of Circle of Willis in the study population

	No of Circles	Percentage of Circle (%)
Presence of Variations	19	63.3
Absence of Variations	11	36.6

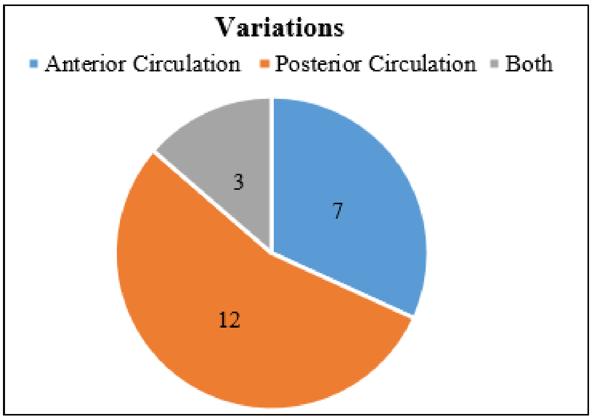


Graph 3: Table showing the distribution of Variant circles in the anterior and posterior Circulations

4) Distribution of the variations among circulations

Table 4: Table showing the distribution of Variant circles in the anterior and posterior Circulations

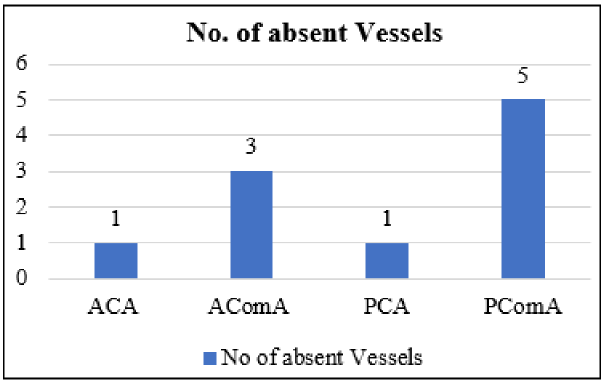
Circulation	No. of patients	Percentage (%)
Anterior	7	23.3
Posterior	12	40
Both	3	10



5) Distribution of absent vessels:

Table 5: Table showing distribution of absent vessels in the patients of the study

Name of the vessel	No. of absent vessels	Percentage (%)
ACA (A1)	1	3.33
AComA	3	10
PCA (P1)	1	3.33
PComA	5	16.6

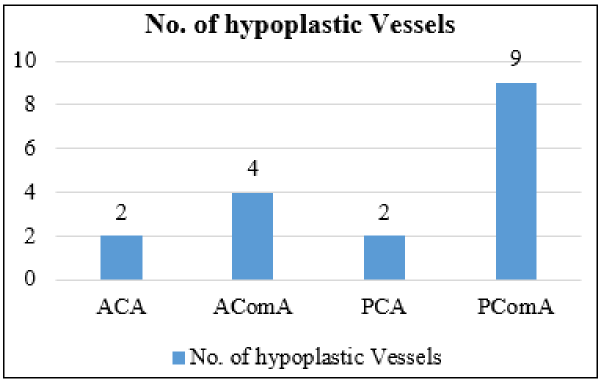


Graph 5: Table showing distribution of absent vessels in the patients of the study

6) Distribution of hypoplastic vessels:

Table 6: Table showing distribution of hypoplastic vessels

Name of the vessel	No. of hypoplastic vessel	Percentage (%)
ACA (A1)	2	6.6
AComA	4	13.3
PCA (P1)	2	6.6
PComA	7	23.3



Graph 6: Bar chart showing distribution of hypoplastic vessels

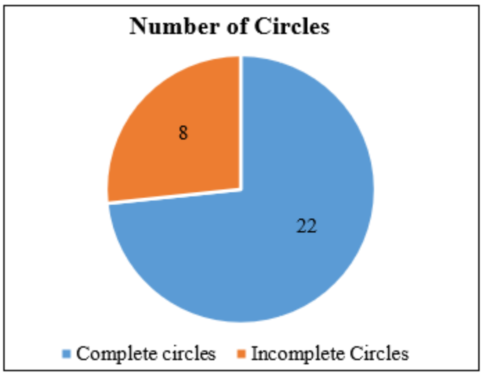
7) Distribution of other variations

In the present study, no other significant variations are noted

8) Distribution of completeness of Circle of Willis

Table 7: Table showing distribution of completeness of vessels

Completeness	No. of Circles	Percentage (%)
Complete	22	73.30%
Incomplete	8	26.60%



Graph 7: Table showing distribution of completeness of vessels

Representative Images

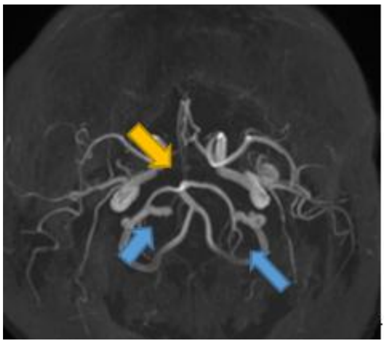


Figure 1: TOF image showing aplasia of bilateral Posterior Communicating Arteries (PComA) (**Blue Arrows**) and hypoplasia of Right A1 segment of Anterior Cerebral Artery (ACA) (**Yellow Arrow**)

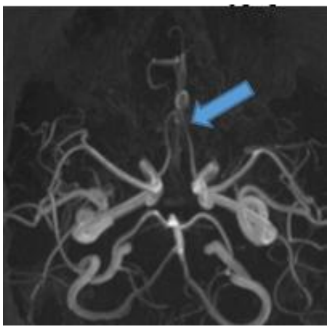


Figure 2: TOF image showing aplasia Anterior Communicating Artery (AComA) (**Blue Arrow**)

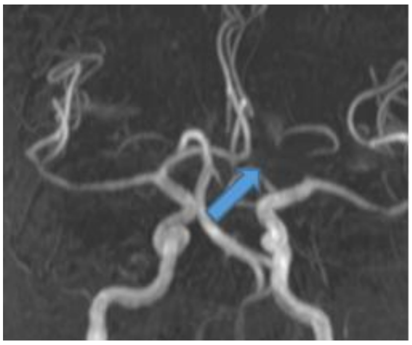


Figure 3: TOF image showing aplasia of A1 segment of left Anterior Cerebral Artery (ACA) (**Blue Arrow**)

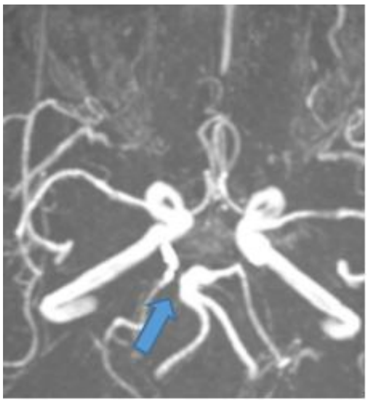


Figure 4: TOF image showing aplasia of P1 segment of right Posterior Cerebral Artery (PCA) (**Blue Arrow**)

4. Discussion

In the conducted study, out of 30 patients 17 (56.6%) were male and 13 (42%) were female.

The age distribution of the patients ranged from 18 to 80 years, with an average age of 39.75 years. The majority of the patients fell into the age groups of 18-39 years (46.6%).

The study revealed that 63.3% (19) of the patients exhibited some variation in their Circle of Willis. Among those with variations, 23.3% had variations exclusively involving in the anterior circulations, 40 % in the posterior circulations and 10% had anterior and posterior circulations. The most common variation noted was hypoplasia of PComA (23.3%).

Key Observations

Our study revealed a high prevalence of asymmetrical configurations in the Circle of Willis, highlighting the complexity of cerebral vascular anatomy. We also observed significant variability in the morphology of the communicating arteries, which could have important implications for understanding cerebral blood flow. Furthermore, our findings suggest that the variability in Circle of Willis configurations may have potential implications for collateral circulation mechanisms, which could be relevant for the diagnosis and treatment of cerebrovascular diseases.

Comparative Insights

Our findings align with emerging literature suggesting considerable individual variations in neurovascular architecture, challenging previous uniform conceptualizations of cerebral arterial networks.[2, 3, 4, 5, 6]

5. Limitations

This study has several limitations, including a relatively small sample size of 30 patients. Additionally, the study was conducted at a single center, which may limit the generalizability of the findings to other populations. The results may also be influenced by regional demographic factors, which could impact the applicability of the findings to other regions. Furthermore, the cross-sectional design of the study limits our ability to draw longitudinal insights or conclusions about the natural history of the variations in the Circle of Willis

6. Conclusion

Morphological variations in the Circle of Willis are more prevalent than traditionally understood. These findings underscore the importance of personalized neurovascular assessment and potential individualized approaches to cerebrovascular risk management.

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