Original Article

Age-Related Variations in the Circle of Willis Among North Indian Adults: A Magnetic Resonance Angiographic Study

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Abstract

Background: The Circle of Willis (CoW) is the principal collateral arterial network of the brain. Variations in its configuration may influence cerebral blood flow, susceptibility to ischemic stroke, and outcomes of neurovascular interventions. The present study aimed to evaluate age-related variations of the Circle of Willis among North Indian adults using Magnetic Resonance Angiography (MRA). **Material and Methods:** This hospital-based observational cross-sectional study included 169 adult subjects undergoing brain MRA. Three-dimensional Time-of-Flight (3D TOF) MRA was performed using a 1.5 Tesla MRI system. Participants were categorized into four age groups (17–30, 31–50, 51–70, and 71–85 years). Images were assessed for basilar artery lateralization, hypoplasia, and absence of arterial segments of the Circle of Willis. Statistical analysis was performed using SPSS version 30.0. **Results:** The largest proportion of subjects belonged to the 51–70 years age group (43.2%). Basilar artery lateralization was observed in 30 cases, with the highest frequency in the 51–70 years age group (53.3%). Hypoplasia was the most common variation (120 cases), while arterial absence was identified in 23 cases. Posterior circulation involvement (75.8%) was more frequent than anterior circulation involvement (24.2%). A complete Circle of Willis was present in only 15.4% of subjects, whereas 84.6% demonstrated an incomplete configuration. Left-sided hypoplastic variations predominated and were statistically significant ($p = 0.003$). **Conclusion:** Anatomical variations of the Circle of Willis are highly prevalent among North Indian adults and occur predominantly in the posterior circulation. The high frequency of variations in older age groups highlights the influence of age-related vascular remodeling. Recognition of these variants is important for anatomical understanding, neurovascular imaging, cerebrovascular risk assessment, and surgical planning.

Keywords: Circle of Willis; Magnetic Resonance Angiography; Age-related variations; Hypoplasia; Posterior circulation; Cerebral collateral circulation.

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Introduction

The Circle of Willis (CoW) is an arterial anastomotic network located at the base of the brain that provides communication between the carotid and vertebra - basilar circulations. First described by Thomas Willis in Cerebri Anatome in 1664, it plays a crucial role in maintaining cerebral perfusion by acting as a collateral pathway during arterial stenosis or occlusion.[1,2]

The classical Circle of Willis is formed by the anterior communicating artery, bilateral anterior cerebral arteries, terminal segments of the internal carotid arteries, bilateral posterior communicating arteries, and bilateral posterior cerebral arteries.[3]

The functional integrity of the Circle of Willis is essential for preserving cerebral blood flow under pathological conditions. In cases of vascular narrowing or occlusion, collateral circulation through the communicating arteries helps maintain adequate perfusion and reduces the risk of cerebral ischemia.[4] Consequently, anatomical variations of the Circle of Willis have significant clinical implications, particularly in ischemic stroke, transient ischemic attacks, intracranial aneurysms, and cerebrovascular insufficiency.[5]

Numerous anatomical and radiological studies have shown that a classical complete Circle of Willis is present in less than half of the population. Variations such as hypoplasia, aplasia, asymmetry, and absent arterial segments are common and may significantly impair collateral cerebral circulation.[6] These anatomical variants can increase vulnerability to ischemic stroke, influence clinical outcomes following arterial occlusion, and affect the success of neurovascular interventions. Therefore, understanding their prevalence and distribution is essential for accurate cerebrovascular risk assessment and surgical planning.[7]

Magnetic Resonance Angiography (MRA), particularly three-dimensional Time-of-Flight (3D TOF) MRA, has emerged as a reliable and non-invasive modality for evaluating the intracranial

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arterial system. It enables accurate visualization of the Circle of Willis, facilitating identification of vascular variations that may influence collateral cerebral circulation.[8] Early recognition of these variations is clinically important for stroke risk assessment, treatment planning, and optimizing outcomes of neurosurgical and endovascular interventions. Furthermore, MRA provides a valuable tool for studying age-related vascular remodeling and its impact on cerebrovascular health.[9]

Stroke is a major global health concern, with approximately 12.2 million new cases reported annually worldwide, making it one of the leading causes of death and long-term disability.[10] As the burden of cerebrovascular disease continues to rise, understanding factors that influence cerebral collateral circulation, such as anatomical variations of the Circle of Willis, has become increasingly important for improving risk assessment and clinical outcomes.

Materials and Methods

This hospital based observational cross-sectional study was conducted in the Department of Radiology, Swaroop Rani Nehru Hospital, associated with Motilal Nehru Medical College, Prayagraj, Uttar Pradesh, India, over a period of 15 months from January 2025 to March 2026.

Ethical approval was obtained from the Institutional Ethics Committee, and written informed consent was obtained from all participants prior to inclusion in the study.

A total of 169 adult subjects undergoing Magnetic Resonance Angiography (MRA) of the brain for various clinical indications were included. The sample size was calculated using the formula $N = Z^2(PQ)/d^2$.

Subjects with a history of previous neurosurgical intervention, major intracranial vascular malformations, gross intracranial space occupying lesions, traumatic brain injury, psychiatric illness, or poor quality angiographic images were excluded from the study.

For assessment of age - related variations, participants were categorized into four age groups:

1. 17 - 30 years
2. 31 - 50 years
3. 51 - 70 years
4. 71 - 85years

Magnetic Resonance Angiography was performed using a non - contrast three dimensional Time of Flight (3D TOF) technique on a 1.5 Tesla Magnetic Resonance Imaging system. All examinations were carried out using a standardized trans - axial imaging protocol with the subject in the supine position. The acquired datasets were processed using multiplanar reconstruction techniques to obtain detailed visualization of the Circle of Willis and its constituent arteries. Images were analyzed using Digital Imaging and Communications in Medicine (DICOM) compatible software on a dedicated workstation. The Circle of Willis was evaluated for anatomical configuration and vascular variations. All radiological findings were independently reviewed and confirmed by two experienced radiologists, each with more than 5 years of experience

Radiological parameters assessed included:

1. Basilar artery lateralization
2. Hypoplasia or absence of the right anterior cerebral artery
3. Hypoplasia or absence of the left anterior cerebral artery
4. Hypoplasia or absence of the anterior communicating artery
5. Hypoplasia or absence of the right posterior cerebral artery
6. Hypoplasia or absence of the left posterior cerebral artery
7. Hypoplasia or absence of the right posterior communicating artery
8. Hypoplasia or absence of the left posterior communicating artery

An arterial segment was considered hypoplastic when its luminal diameter measured less than 1.0 mm on 3D Time-of-Flight Magnetic Resonance Angiography. Arterial absence was defined as non-visualization of the vessel segment on MRA.

Data were compiled and analyzed using Statistical Package for the Social Sciences (SPSS) version 30.0. Categorical variables were expressed as frequencies and percentages. Comparative analyses were performed to evaluate age-related differences in vascular variations, and a p value of <0.05 was considered statistically significant.

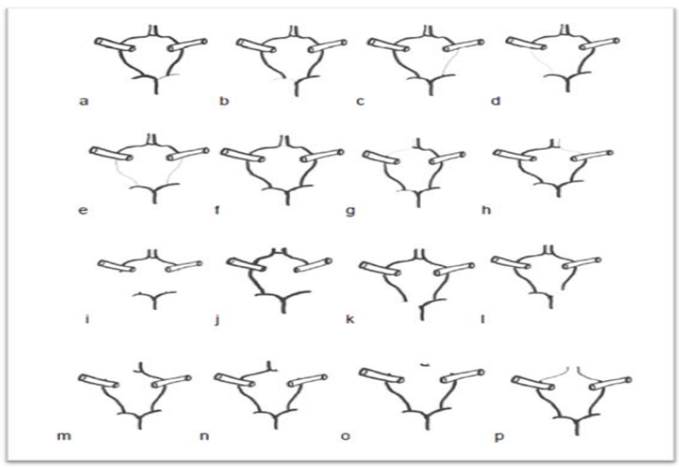

Figure 1: Schematic representation of the observed Circle of Willis variations: (a) left posterior cerebral artery (PCA) hypoplasia, (b) right PCA hypoplasia, (c) left posterior communicating artery (PComA) hypoplasia, (d) right PComA hypoplasia, (e) bilateral PComA hypoplasia, (f) anterior communicating artery (AComA) hypoplasia, (g) right anterior cerebral artery (ACA) hypoplasia, (h) left ACA hypoplasia, (i) bilateral absence of PComA, (j) absence of left PComA, (k) absence of right PCA, (l) absence of left PCA, (m) absence of right ACA, (n) absence of left ACA, (o) bilateral absence of ACA, and (p) absence of AComA.

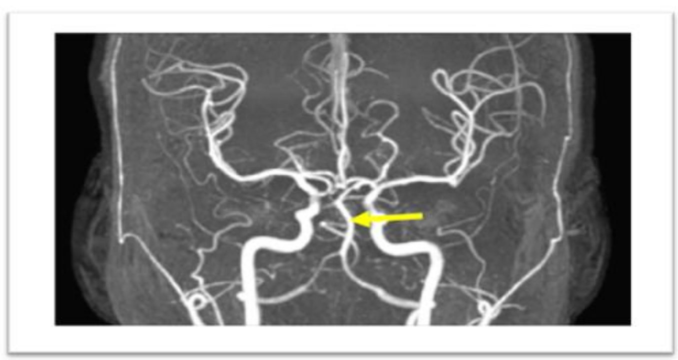

Figure 2: Photograph of MRA of circle of Willis showing basilar artery lateralisation (yellow arrow)

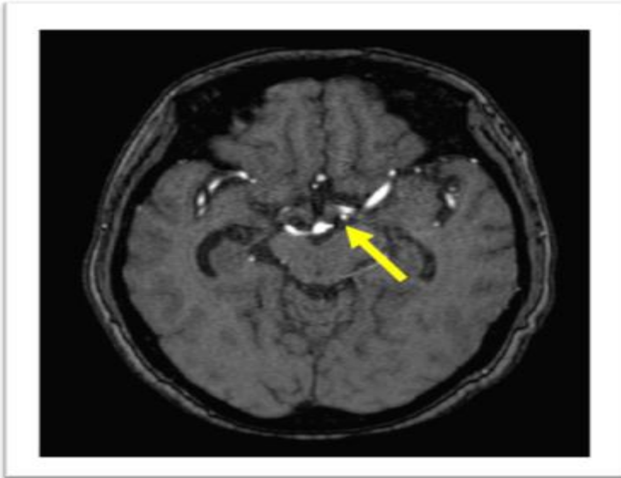

Figure 3: Photograph of MRA of circle of Willis showing left posterior cerebral artery hypoplasia (yellow arrow)

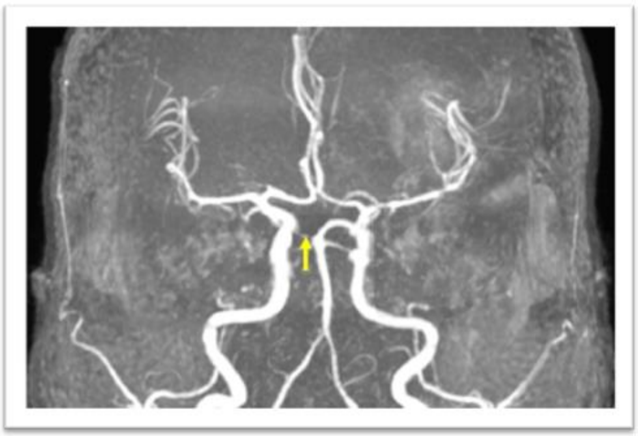

Figure 4: Photograph of MRA of circle of Willis showing right posterior cerebral artery hypoplasia (yellow arrow)

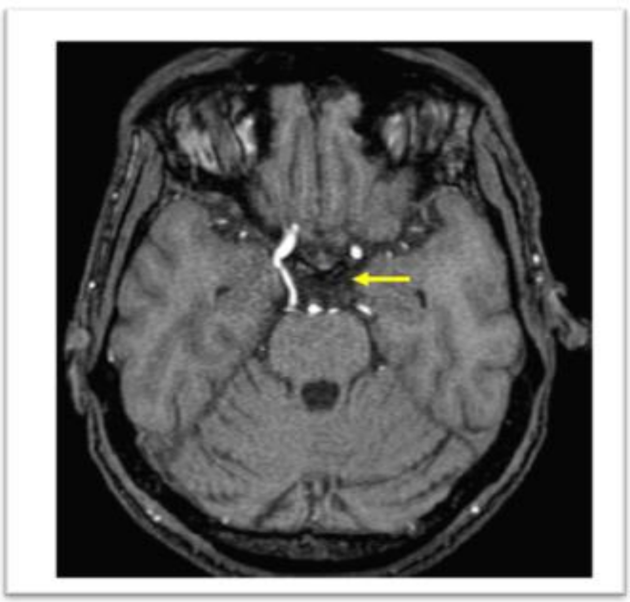

Figure 5: Photograph of MRA of circle of Willis showing left posterior communicating artery hypoplasia (yellow arrow)

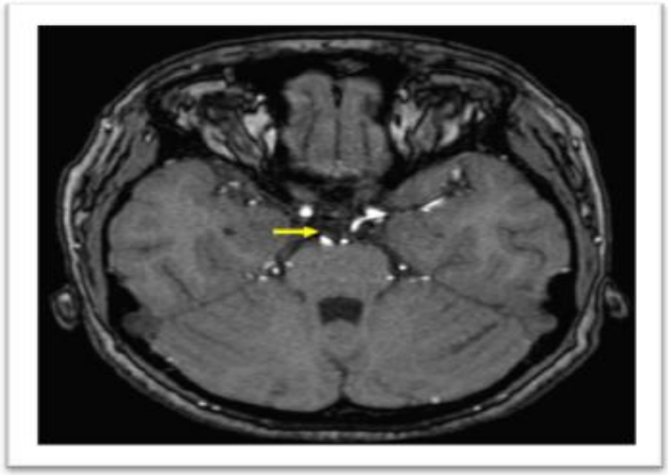

Figure 6: Photograph of MRA of circle of Willis showing right posterior communicating artery hypoplasia (yellow arrow)

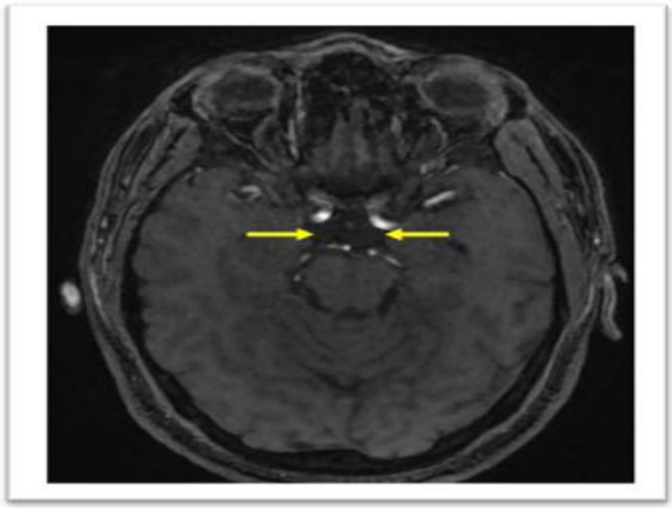

Figure 7: Photograph of MRA of circle of Willis showing bilateral absence (non-visualization) of posterior communicating arteries (yellow arrow)

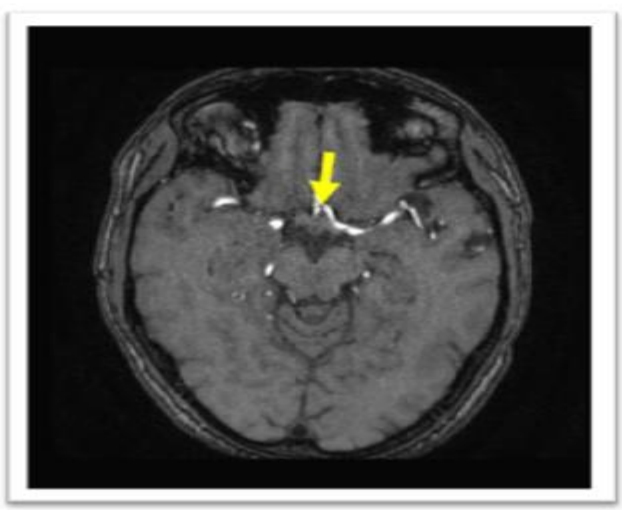

Figure 8: Photograph of MRA of circle of Willis showing anterior communicating artery hypoplasia (yellow arrow)

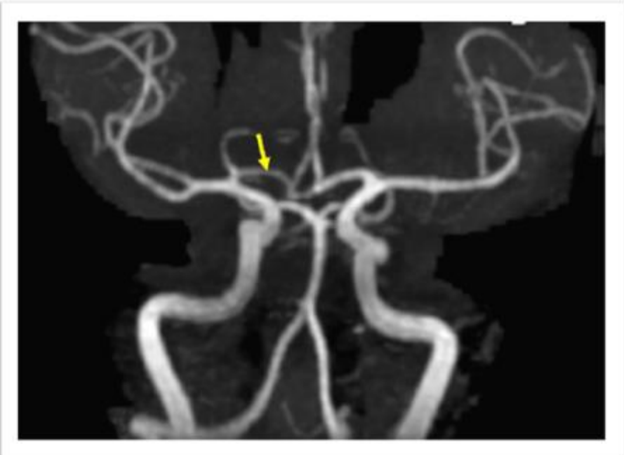

Figure 9: Photograph of MRA of circle of Willis showing right anterior cerebral artery hypoplasia (yellow arrow)

Figure 10: Photograph of MRA of circle of Willis showing left anterior cerebral artery hypoplasia (yellow arrow)

RESULTS

Table 1: Distribution of Study Population According to Age Group

Age Group (Years)	Number (n)	Percentage (%)
17–30	25	14.8
31–50	58	34.3
51–70	73	43.2
71–85	13	7.7
Total	169	100.0

Table 2: Age wise Distribution of Basilar Artery Lateralization

Age Group (Years)	Number (n)	Percentage (%)
17–30	5	16.7
31–50	8	26.7
51–70	16	53.3
71–85	1	3.3
Total	30	100.0

Table 3: Age wise Distribution of Hypoplastic Variations of the Circle of Willis

Age Group (Years)	Number (n)	Percentage (%)
17–30	26	21.7
31–50	41	34.2
51–70	50	41.7
71–85	3	2.5
Total	120	100.0

Table 4: Age wise Distribution of Arterial Absence in the Circle of Willis

Age Group (Years)	Number (n)	Percentage (%)
17–30	2	8.7
31–50	7	30.4
51–70	13	56.5
71–85	1	4.4
Total	23	100.0

Table 5: Distribution of Hypoplastic Variations According to Cerebral Circulation

Circulation Type	Number (n)	Percentage (%)
Anterior Circulation	29	24.2
Posterior Circulation	91	75.8
Total	120	100.0

Table 6: Side wise Distribution of Hypoplastic Variations

Side	Number (n)	Percentage (%)
Right Side	45	37.5
Left Side	51	42.5

Midline	20	16.7
Bilateral	4	3.3
Total	120	100.0

Table 7: Side wise Distribution of Arterial Absence

Side	Number (n)	Percentage (%)
Right Side	6	26.1
Left Side	7	30.4
Bilateral	9	39.1
Midline	1	4.4
Total	23	100.0

Table 8: Distribution of Complete and Incomplete Circle of Wills

Configuration	Number (n)	Percentage (%)
Complete Circle of Willis	26	15.4
Incomplete Circle of Willis	143	84.6
Total	169	100.0

Table 9: Statistical Analysis of Circle of Willis Variations on Magnetic Resonance Angiography

Variable	Test Used	Test Statistic	p-value	Interpretation
Side-wise Distribution of Hypoplastic Variations	Chi-square test	13.92	0.003	Statistically Significant
Side-wise Distribution of Arterial Absence	Chi-square test	—	0.10	Not Statistically Significant

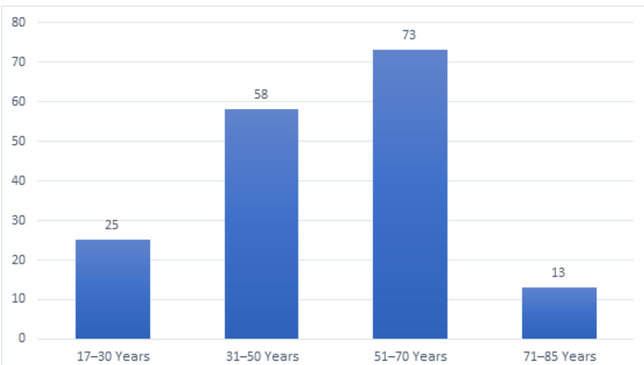

Chart 1: Distribution of Study Population According to Age Group (n = 169)

Discussion

Hypoplasia was the most common variation observed in the present study, occurring in 120 subjects (71.0%), while complete absence of an arterial segment was identified in 23 subjects (13.6%). Both hypoplastic and absent vessels were most frequently seen in individuals aged 51–70 years.
Similar findings have been reported by Naveen et al,[11] and Kızılgöz et al,[12] who also observed that most Circle of Willis variations were related to narrowing of vessels rather than complete absence. These findings suggest that age-related changes in blood vessels may contribute to alterations in the normal configuration of the Circle of Willis.
Variations were more common in the posterior circulation (75.8%) than in the anterior circulation (24.2%). Similar observations were made by Diljohn et al,[6] Naveen et al,[11] and Kızılgöz et al,[12] who reported that abnormalities involving the posterior communicating and posterior cerebral arteries were among the most frequent vascular variants.
The higher occurrence of posterior circulation variations may be related to the more complex developmental pattern of the vertebrobasilar system during embryonic life, making this part of the Circle of Willis more prone to anatomical variation.
The present study demonstrated a slight predominance of hypoplastic vessels on the left side (42.5%) compared to the right side (37.5%), which was statistically significant (p = 0.003). Similar side-related asymmetry in Circle of Willis components has been reported by Kızılgöz et al,[12] who observed variation in arterial diameters between the two sides. These findings suggest that developmental and hemodynamic factors may contribute to side-specific vascular variation patterns.
A complete Circle of Willis was identified in only 15.4% of subjects, whereas 84.6% showed an incomplete configuration. These findings are comparable to those reported by Naveen et al,[11] who observed complete circles in 16.6% of subjects, and by Diljohn et al,[6] who reported complete configurations in 24.3% of cases.
The findings indicate that anatomical variations of the Circle of Willis are common in the general population, while the classical textbook pattern is relatively uncommon. Awareness of these variations is important because they may influence collateral cerebral blood flow and can have implications during neuroimaging, neurosurgical procedures, and the management of cerebrovascular diseases.

Table 10: Comparative Analysis of Circle of Willis Variations Between the Present Study and Previous Published Studies

Parameter	Present Study	Naveen SR et al. (2015)	Kızılgöz V et al. (2022)	Diljohn J et al. (2024)
Sample size	169	300	867	152
Age distribution	Highest frequency: 51–70 years (43.2%)	Mean age 55 years	Mean age 48 years	Mean age 46.4 ± 16.5 years
Hypoplastic variations	120 cases (71.0%)	Predominantly due to hypoplastic segments	Hypoplastic/absent segments major contributors	Posterior circulation variations predominant

Arterial absence	23 cases (13.6%)	Less frequent than hypoplasia	Included within vascular variations	Included within vascular variations
Posterior circulation involvement	75.8%	PCoA hypoplasia/absence 32.6%	PCoA absence 27.57%	64.5%
Anterior circulation involvement	24.2%	Less common than posterior circulation	ACoA 16.49%, A1 variation 2.88%	30.2%
Complete Circle of Willis	15.4%	16.6%	High prevalence of variants reported	24.3%
Incomplete/Variant Circle of Willis	84.6%	83.4%	58.71%	75.6%

Conclusion

The present study demonstrates that the Circle of Willis rarely conforms to the classical textbook description, with anatomical variations being observed in the majority of individuals. Hypoplasia was the most frequent variation, with posterior circulation vessels showing the greatest involvement, particularly among individuals aged 51–70 years.

These findings reinforce an important anatomical principle: the vascular anatomy of the human brain is not identical in every individual. Variations of the Circle of Willis are common rather than exceptional, and their recognition is essential for every medical professional. From a clinical perspective, such variations may influence collateral cerebral circulation, affect the severity and outcome of cerebrovascular events, and have important implications during neuroimaging, neurosurgical procedures, and endovascular interventions.

From an anatomical standpoint, this study highlights the need to appreciate normal human variability beyond textbook descriptions. A sound understanding of these variations not only strengthens anatomical knowledge but also bridges the gap between anatomy and clinical practice, emphasizing the continued relevance of anatomy in modern medicine.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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