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PREVALENCE AND PATTERN OF CIRCLE OF WILLIS AND ITS ANATOMICAL VARIANTS ON 3D MRA IN POPULATION OF MEWAR AND MARWAR REGION OF RAJASTHAN

Anatomy

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ABSTRACT

Background: The Circle of Willis represents the most important collateral circulation system in the brain. Assessing its integrity and identifying hypoplastic or absent segments are critical objectives of neuroimaging. Such evaluations help explain an individual's predisposition to ischemic stroke, provide insights into the underlying causes of cerebrovascular events, and serve as essential guidance prior to vascular surgeries or endovascular interventions. Understanding anatomical completeness and variations of the Circle of Willis not only aids in risk stratification but also optimizes treatment planning and improves clinical outcomes. **Aims & Objectives:** This study was utilizing 3D TOF-MRA to evaluate the prevalence and patterns of anatomical variations in the Circle of Willis among individuals from the Mewar and Marwar regions of Rajasthan and examines their relationship with vascular risk factors. **Methodology:** This study was a prospective observational study conducted in the Department of Anatomy in collaboration with Department of Radiodiagnosis at R.N.T. Medical College, Udaipur, and Department of Radiodiagnosis at Dr. S.N. Medical College, Jodhpur, Rajasthan, India. Participants meeting the inclusion criteria were consecutively enrolled during the study period to minimize selection bias. This study was conducted on 550 patients using a Philips 1.5 Tesla Achieva MRI scanner. Non-contrast three-dimensional time-of-flight (3D-TOF) sequences with transaxial acquisition were employed to evaluate the Circle of Willis. All images were processed and reviewed on the Philips IntelliSpace Portal workstation to ensure high-quality visualization and accurate interpretation. **Results:** This study examines the prevalence and patterns of Circle of Willis configurations in 550 individuals, with a focus on anatomical variants and their association with demographic and vascular characteristics. The age distribution of the study cohort (n = 550) demonstrated a predominance of older participants. Analysis of Circle of Willis (CoW) configurations in the study cohort revealed that only 71 of the 550 participants (12.91%) demonstrated a complete arterial ring, whereas the vast majority, 479 participants (87.09%), exhibited an incomplete configuration. In present study, out of 550 subjects, 257 (46.73%) had a complete anterior circulation, while 293 (53.27%) presented with an incomplete configuration. Similarly, 550 individuals studied, only 101 (18.36%) had a complete posterior circulation, whereas a substantial 449 (81.64%) were incomplete. Posterior circle variations were significantly higher than anterior circle ($p<0.0001$). **Conclusion:** The present study provides a comprehensive evaluation of anatomical variations in the Circle of Willis among 550 individuals using high-resolution 3D-TOF MRA. We found that only a small proportion of the study population demonstrated a complete Circle of Willis, while the majority exhibited varying degrees of incompleteness in both the anterior and posterior circulations. Such information may assist in pre-operative planning, improve the interpretation of neuroimaging, and guide preventive strategies for cerebrovascular disorders.

KEYWORDS

Circle of Willi, Magnetic Resonance Angiography, Anatomical Variations, 3D TOF MRA

INTRODUCTION

The circulatory system of the brain is an intricate network designed to provide uninterrupted delivery of oxygen and nutrients to neural tissue, thereby maintaining normal cerebral function. At the base of the brain lies the Circle of Willis (CoW), a polygonal arterial anastomosis first described by Thomas Willis in 1664. The CoW is formed by the confluence of the internal carotid arteries (ICAs) and the basilar artery (BA), interconnected by the anterior communicating artery (AComA), posterior communicating arteries (PComAs), and the proximal segments of the anterior cerebral arteries (ACA) and posterior cerebral arteries (PCA). This arterial ring serves as an essential collateral pathway, ensuring stable cerebral perfusion in the event of arterial stenosis, occlusion, or embolism. [1,2]

Anatomical variations in the CoW are common and include hypoplasia, aplasia, fenestration, or asymmetry of its component vessels. Studies have reported that only a minority of individuals (less than 50%) possess a complete CoW configuration, and this prevalence varies across ethnic and geographic populations.[3] Such variations may alter cerebral hemodynamic and are implicated in the pathogenesis of ischemic stroke, intracranial aneurysm formation, transient ischemic attacks, and poor outcomes following vascular compromise.[4,5]

Recent advances in non-invasive neuroimaging have facilitated the detailed evaluation of CoW morphology in vivo. Three-dimensional time-of-flight magnetic resonance angiography (3D TOF-MRA) is now widely used to delineate intracranial arteries without contrast injection or ionizing radiation, offering excellent spatial resolution for detecting anatomical variations.[6,7] Despite extensive international research on CoW configurations, regional data from Indian populations-particularly those of Rajasthan's Mewar and Marwar regions-remain scarce.

Therefore, this study utilizes 3D TOF-MRA to evaluate the prevalence and patterns of anatomical variations in the Circle of Willis among individuals from the Mewar and Marwar regions of Rajasthan and examines their relationship with vascular risk factors.

MATERIAL AND METHODS

This study was a prospective observational study conducted in the Department of Anatomy in collaboration with Department of Radiodiagnosis at R.N.T. Medical College, Udaipur, and Department of Radiodiagnosis at Dr. S.N. Medical College, Jodhpur, Rajasthan, India. Both are tertiary care teaching hospitals that cater to a wide catchment area representing the diverse populations of the Mewar and Marwar regions. Participants meeting the inclusion criteria were consecutively enrolled during the study period to minimize selection bias.

The study protocol was reviewed and approved by the Institutional Ethics Committees of both participating institutions. Written informed consent was obtained from all participants prior to enrolment. Imaging procedures were non-invasive, carried minimal risk, and were performed in compliance with the Declaration of Helsinki and applicable local regulations. Participant confidentiality was safeguarded by anonymizing all imaging and clinical data and storing it on password-protected systems with access restricted to study investigators.

Participants in this prospective observational study included adults aged 18 to 89 years who underwent MRI examinations for non-vascular indications such as headache, vertigo, or general screening, as well as for non-brain-related clinical evaluations including musculoskeletal, abdominal, or spinal imaging. To ensure adequate statistical power and broad age representation, the study targeted a minimum sample size of 550 individuals. Patients with any history, symptoms, or imaging evidence of cerebrovascular disease were excluded to maintain the accuracy of anatomical evaluation of the Circle of Willis. All eligible individuals provided written informed consent to undergo additional three-dimensional time-of-flight (3D-TOF) magnetic resonance angiography of the Circle of Willis. Patients with a history of stroke, transient ischemic attack, or intracranial

arterial stenosis, previous neurosurgical or brain interventions, or the presence of MRI-incompatible implants or metallic foreign bodies were excluded. Individuals unable to tolerate MRI due to severe anxiety or claustrophobia, or those who refused to consent or cooperate during imaging, were also not included in the study.

Magnetic resonance imaging was performed on a Philips 1.5 Tesla Achieva scanner using a dedicated head coil. Non-contrast three-dimensional time-of-flight magnetic resonance angiography (3D-TOF MRA) sequences were acquired to evaluate the Circle of Willis with high spatial resolution. Imaging parameters were optimized to maximize signal-to-noise ratio and ensure accurate visualization of small arterial segments, allowing reliable assessment of arterial anatomy and variations. Imaging was performed on a Siemens MAGNETOM Vida 3-Tesla MRI system equipped with a wide-bore gantry, detachable patient table, and 64-channel head/neck coil. The unit integrates advanced gradient hardware, quiet technology, and ambient lighting to enhance patient comfort while delivering high-resolution 3D time-of-flight angiographic sequences for Circle-of-Willis's evaluation, consistent protocols.

The neuroradiologists reviewed the images blinded to the demographics of the participants. The presence of elements of Circle of Willis, anterior cerebral arteries (ACA) and their continuity, anterior communicating artery (ACoA) and their continuity, internal carotid arteries (ICA) and their continuity, posterior communicating arteries (PCoA) and their continuity, posterior cerebral arteries (PCA) and its continuity, diameter of arteries were only measured. Instruments [greater than] or [greater than or equal to] 0.8 mm were found to be present and < 0.8 mm were considered to be hypoplastic. Anatomical differences given were hypoplasia, aplasia, duplication and fenestration, which were noted and classified.

The scanning sequences applied on MRI were DWI, and GR/T2*WI. MRA was adopted using the 3D-TOF MRA in axial plane with the following parameters: TR 25ms, TE 6.9ms, Relative SNR 1.00, NSA 1, FOV 20 cm × 20 cm × 12.6 cm, matrix 495 × 284 × 180 and slice thickness 0 mm. 180 images were obtained. Images were reported using source images as well as 2D & 3D maximum intensity projections (MIP) and volume rendering (VR) on the Philips Intelli space portal workstation.

Statistical Analysis:

Data were analysed using Microsoft Excel (Microsoft Office 2021) and SPSS version 20.0. Descriptive statistics, including frequencies and percentages, were used to report the prevalence and patterns of Circle of Willis variants. SPSS version 20 was used to conduct the chi square test, two sample Z test and unpaired t test and statistical significance was considered using the alpha level of 0.05.

RESULTS

The Circle of Willis (CoW) is a critical arterial ring located at the base of the brain that provides redundancy in cerebral perfusion and serves as an important safeguard against ischemic injury. Formed by the anastomosis of the internal carotid arteries, the basilar artery, and their communicating branches, the CoW maintains collateral flow when primary vessels are compromised. This study examines the prevalence and patterns of Circle of Willis configurations in 550 individuals, with a focus on anatomical variants and their association with demographic and vascular characteristics. The age distribution of the study cohort (n = 550) demonstrated a predominance of older participants. The largest proportion of respondents belonged to the 61–80 years age group, representing 38.73% of the sample, followed by those aged 41–60 years at 34.55%. Participants aged 21–40 years comprised 16.91%, whereas the youngest (≤ 20 years) and oldest (> 80 years) age categories each accounted for only 4.91% of the population. Overall, the findings indicate that the study sample was skewed toward middle-aged and elderly individuals, with relatively few participants at the extreme ends of the age spectrum. (Table 1) In our study, the study cohort exhibited a male predominance, with 64% (n=352) of participants identified as male, while females accounted for 36.0% (n=198). This sex-based distribution may reflect underlying epidemiological patterns, sociocultural healthcare access disparities, or disease-specific prevalence in the sampled population. (Table 2) Analysis of Circle of Willis (CoW) configurations in the study cohort revealed that only 71 of the 550 participants (12.91%) demonstrated a complete arterial ring, whereas the vast majority, 479 participants (87.09%), exhibited an incomplete configuration. This finding underscores the predominance of anatomical variations within the CoW in this population, aligning with previous reports that complete configurations are relatively uncommon in the general population. The high frequency of incomplete patterns may have clinical implications, as such variants can influence the adequacy of collateral circulation during cerebrovascular events. (Figure 1) In present study, out of 550 subjects, 257 (46.73%) had a complete anterior circulation, while 293 (53.27%) presented with an incomplete configuration. This slight majority of incomplete cases suggests a common anatomical variation, which could influence clinical assessments involving cerebral blood flow and anterior circulation integrity. Similarly, 550 individuals studied, only 101 (18.36%) had a complete posterior circulation, whereas a substantial 449 (81.64%) were incomplete. This high prevalence of incomplete configurations highlights the anatomical variation in posterior circulation and could have implications for posterior cerebral perfusion and stroke risk. (Table 3) The distribution of anterior circulation configurations of the Circle of Willis (CoW) among 550 participants demonstrates notable anatomical variability. Type 1, considered the typical or classical pattern, was observed in 46.36% of cases, suggesting it represents the predominant arterial arrangement within this cohort. In contrast, Types 2 through 6 were progressively less frequent, highlighting a spectrum of developmental variants. Type 3 was identified as the rarest configuration, occurring in only 2.0% of participants. These findings reinforce prior evidence that the anterior circulation exhibits significant heterogeneity in the general population. (Table 4) In this study, distribution of 14 posterior circulation types among 550 subjects. Type D is the most prevalent, representing 39.64% of cases, followed by Types A (18.0%) and E (15.27%). The remaining types occur less frequently, with several appearing in under 5% of cases. This diversity illustrates substantial anatomical variability in posterior cerebral circulation patterns. (Table 5)

Table 1: Age Distribution Of The Study Population

Age	Frequency	Percent
<20	27	4.91%
21-41	93	16.91%
41-61	190	34.55%
61-81	213	38.73%
>81	27	4.91%
Total	550	100.0%

Table 2: Sex Distribution Of The Study Population

Sex	Frequency	Percent
Female	198	36.00%
Male	352	64.00%
Total	550	100.00%

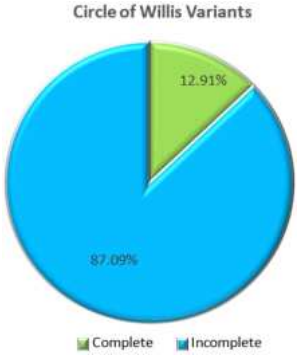

Figure 1: Distribution Of Circle Of Willis Variants In The Study Population

Table 3: Distribution Of Anterior And Posterior Circulation Completeness

Anterior Circulation	Frequency	Percent
Complete	257	46.73%
Incomplete	293	53.27%
Total	550	100.0%
Posterior Circulation	**Frequency**	**Percent**
Complete	101	18.36%
Incomplete	449	81.64%
Total	550	100.0%

Table 4: Classification Of Anterior Circulation Variants

Anterior Circulation	Frequency	Percent
1	255	46.36%
2	114	20.73%
3	11	2.00%
4	58	10.55%
5	60	10.91%
6	52	9.45%
Total	550	100.0%

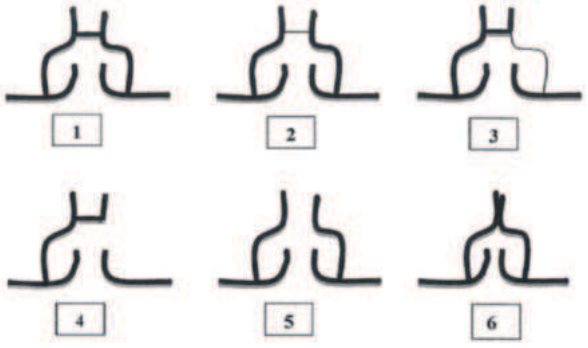

Image 1: Following Variation Patterns Were Noted In Anterior Circulation

1. Classical type – normal bilateral A1 segment with normal anterior communicating artery (ACOM).
2. Hypoplastic ACOM with normal bilateral A1.
3. Hypoplastic unilateral A1 with normal ACOM.
4. Absent unilateral A1.
5. Absent ACOM.
6. Bilateral A1 in close approximation with no separately distinguishable ACOM.

Table 5: Classification Of Posterior Circulation Variants

Posterior Circulation	Frequency	Percent
A	99	18.00%
B	21	3.82%
C	23	4.18%
D	218	39.64%
E	84	15.27%
F	19	3.45%
G	18	3.27%
H	1	0.18%
I	24	4.36%
J	8	1.45%
K	17	3.09%
L	3	0.55%
M	2	0.36%
N	7	1.27%
Total	550	100.0%

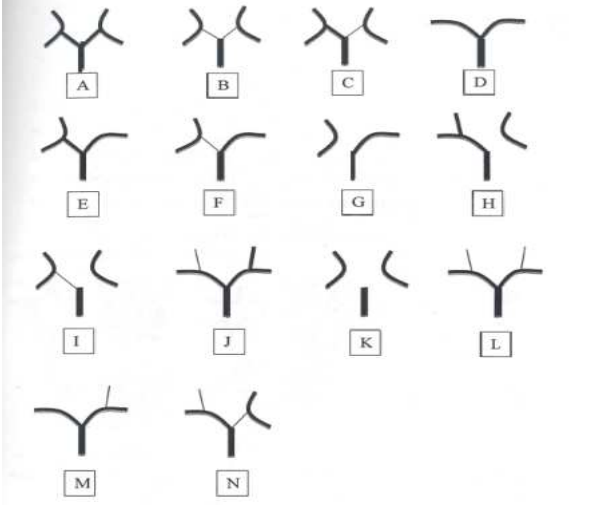

Image 2: Diagrams Of Posterior Circulation Variations

In our study, variation in posterior circulation were classified as:
A. Classical type, normal bilateral P1 segments with bilateral posterior communicating arteries (PCOM)
B. Bilateral partial fetal type posterior cerebral arteries with both P1 segments are patent
C. Unilateral partial fetal type PCA
D. Absent bilateral PCOM
E. Absent unilateral PCOM
F. Absent unilateral PCOM with contralateral partial fetal type PCA
G. Unilateral pure FTP with absent contralateral PCOM
H. Unilateral pure FTP
I. Unilateral pure FTP & contralateral partial fetal type PCA
J. Hypoplastic unilateral PCOM
K. Bilateral pure FTP
L. Hypoplastic bilateral PCOM
M. Unilateral hypoplastic PCOM
N. Unilateral hypoplastic PCOM with contralateral partial FTP

DISCUSSION

The Circle of Willis (CoW) plays a critical role in maintaining cerebral perfusion, particularly in situations of compromised blood flow such as arterial stenosis or occlusion. Its configuration directly affects the brain's ability to establish collateral circulation, thereby influencing clinical outcomes in ischemic cerebrovascular events. In the present study, the majority of participants exhibited an incomplete CoW (87.09%), with only 12.91% demonstrating the classical complete configuration. These findings are consistent with several angiographic and autopsy studies reporting a wide range of completeness, typically between 20% and 50%, depending on the imaging modality and population studied.

In our study of 550 participants, most were in the older age groups: 38.73% were aged 61–81 years and 34.55% were aged 41–61 years. Only a small number of participants were younger than 20 years (4.91%) or older than 81 years (4.91%). This age pattern is important because previous studies have shown that the Circle of Willis (CoW) becomes less complete as age increases.

Several studies have reported similar observations. Krabbe-Hartkamp et al. (1998) found that younger individuals had a higher chance of having a complete CoW, while older individuals were more likely to have missing or underdeveloped vessels.[8] A recent MRI-based study from Norway (Tromsø Study) also showed that only about 11–12% of adults had a complete CoW, and the frequency of incomplete variants increased with age.[9]

In another angiographic study, Papantchev et al. (2013) reported that the number of complete CoW cases decreased steadily in older age groups, supporting our finding that an elderly population tends to show more variations in this arterial network.[10]

Not all research agrees completely. Some recent studies—such as by Zhao et al. (2025)—found no significant statistical link between age and CoW variations, although they did note slight trends toward more incomplete patterns in older age groups.[11] Differences in imaging techniques (CT angiography vs. MR angiography vs. cadaveric studies) and in how CoW types are classified could explain why results are not always uniform.

In this study, we assessed the completeness of the anterior and posterior components of the Circle of Willis (CoW) in 550 individuals. We found that 46.73% had a complete anterior circulation, while a larger proportion—53.27%—presented with incomplete anterior circulation. In contrast, the posterior circulation demonstrated much lower completeness, with only 18.36% yielding a complete configuration and 81.64% exhibiting incompleteness.

Our results align closely with several recent imaging studies, in a population-based 3D-TOF MRA study from Tehran, the anterior circulation was complete in 80.95% of participants, whereas the posterior circulation was complete in only 20.95%—a striking resemblance to our observed pattern of anterior > posterior completeness.[12] In South Indian tertiary hospital imaging data, 77.3% had a complete anterior CoW, compared to 38.3% with complete posterior circulation; the full CoW was complete in 16.6% of individuals.[13]

Another one study, large retrospective MRA evaluation (n = 250)

reported anterior completeness at 68.3% and posterior completeness at 38.3%, with 46.7% of subjects having a complete overall CoW—again supporting the trend we observed.[14]

The more frequent completeness of the anterior circulation compared to the posterior is consistent across populations and imaging methods. Embryologically, anterior vessels such as the anterior communicating artery (AComA) and A1 segments develop earlier and are typically more robust than the posterior communicating arteries (PComAs) and P1 segments of the posterior circulation—a plausible reason for our findings.

The distribution of anterior circulation into six types demonstrates considerable anatomical variation in the studied population. Type 1 configuration was observed in 46.36% of cases, aligning with previous studies that reported this as the predominant pattern of the anterior part of the Circle of Willis. This high prevalence indicates that Type 1 may represent the classical or textbook anatomy frequently illustrated in neurovascular references.[15,16]

Other variants (Types 2–6) were seen in smaller proportions, with Type 3 being the rarest at only 2.0%. This agrees with reports by Krishnaswamy et al.[17] and De Silva et al.,[18] who also documented the rarity of such configurations in MR angiographic and cadaveric studies, respectively. The presence of these variations is clinically significant. An incomplete or atypical anterior circulation may impair collateral flow during cerebrovascular occlusion, increasing the risk of ischemic events. Conversely, a complete and well-developed anterior circle may provide better protection against ischemia by allowing redistribution of blood flow.

Our results are consistent with the work of Kapoor et al.[16], who found a predominance of the classical pattern, but differ slightly from Eftekhar et al.[15], who reported a lower frequency of complete anterior configurations in an Iranian population. These differences suggest that anatomical variability may be influenced by ethnic and genetic factors, highlighting the need for population-specific vascular studies.

This study demonstrates a wide spectrum of posterior circulation variants of the Circle of Willis in 550 cases. The most common variant was Type D (39.64%), followed by Type A (18.00%) and Type E (15.27%), while extremely rare variants such as Type H (0.18%), Type M (0.36%), and Type L (0.55%) were also observed. The predominance of Type D in our cohort is consistent with the findings of other study Kapoor et al.,[16] and De Silva et al.,[18] who also noted a high frequency of posterior circulation variants with hypoplastic or absent segments of the posterior communicating artery (PCoA).

However, our results differ from those of Eftekhar et al.,[15] who reported Type A (classical posterior configuration) as the most frequent pattern in an Iranian population. Similarly, Krishnaswamy et al.,[17] using MR angiography in a South Indian cohort, found a lower prevalence of Types D and E compared to our data, highlighting possible ethnic or regional differences in vascular anatomy.

CONCLUSION:

The present study provides a comprehensive evaluation of anatomical variations in the Circle of Willis among 550 individuals using high-resolution 3D-TOF MRA. We found that only a small proportion of the study population demonstrated a complete Circle of Willis, while the majority exhibited varying degrees of incompleteness in both the anterior and posterior circulations. In the anterior circulation, Type 1 configuration was most prevalent, whereas in the posterior circulation, Type D was the dominant pattern, with several other variants occurring at much lower frequencies.

These findings emphasize that anatomic variations of the Circle of Willis are common rather than exceptional, and their distribution patterns may have important clinical implications. An incomplete or variant Circle of Willis may compromise collateral blood flow during arterial occlusion or stenosis, thereby influencing the severity of cerebrovascular events such as ischemic stroke, aneurysm formation, or outcomes following neurosurgical and endovascular procedures.

By documenting the prevalence of these variants in a large Indian cohort, this study contributes valuable reference data for radiologists, neurologists, and neurosurgeons. Such information may assist in pre-operative planning, improve the interpretation of neuroimaging, and guide preventive strategies for cerebrovascular disorders. Further research correlating these anatomical patterns with clinical outcomes is recommended to better understand their prognostic significance.

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