RESEARCH ARTICLE

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Evaluation of Circle of Willis Variations Using 1.5 Tesla Time-of-flight Magnetic Resonance Angiography

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Abstract

Objectives: The circle of Willis (COW) is an arterial ring located at the base of the brain that connects the internal carotid and vertebral arteries through anastomotic branches. This circle includes two anterior cerebral arteries (ACA) connected by the anterior communicating artery (AComA) in the anterior part; two posterior cerebral arteries (PCA) linked to the carotid system via the posterior communicating arteries (PCom), along with the basilar artery in the posterior part. Collateral circulation in the COW is important in maintaining adequate cerebral blood flow in cases of obstructive arterial diseases. This study aimed to reveal the frequency of each COW variation detected on magnetic resonance imaging (MRI) time-of-flight images.

Methods: This retrospective study included of 410 adult patients who underwent brain MRI due to symptoms such as headache, dizziness, ormemoryloss. Anterior and posterior segments of the COW (A1, AComA, PCom, P1) were evaluated separately. Vessel segments with a diameter smaller than 1 mm were considered hypoplastic. Vascular diameters of the COW were measured through the axial plane, perpendicularly to the elongation of the artery and 3 mm from the vessel origin. When the vascular segment is too short, the middle part of the artery is measured.

Results: Of the 410 individuals, 176 were male and 234 female, with a mean age of 41.2±12.7 years. A complete, symmetric COW was observed in 118 cases (28.8%). The most common variations were: - PCom hypoplasia: right 23.1%, left 18.6% - PCom aplasia: right 9.7%, left 7.6% - fetal PCA: unilateral 11.2%, bilateral 4.6% - azygos ACA: 0.7% - basilar artery fenestration: 0.7% - persistent trigeminal artery: 0.2%. There were no statistically significant differences in the prevalence of variation between sexes ($p>0.05$).

Conclusion: COW exhibits significant anatomical variability between individuals. Awareness of these anatomical patterns is important in clinical decision-making, influencing treatment strategies and risk assessment.

Keywords: Manyetic resonance imaging, manyetic resonance angiography anatomical variation, Willis polygon

Introduction

The circle of Willis (COW) (circulus arteriosus cerebri) is an arterial ring located at the base of the brain that connects the internal carotid and vertebral arteries through anastomotic branches (Figure 1). This circle includes two anterior cerebral arteries (ACA) connected by the anterior communicating artery (AComA) in the anterior part, and two posterior cerebral arteries (PCA) linked to the circle via the posterior communicating arteries (PCom), along with the basilar artery in the posterior part.[1] In normal anatomy, a complete and symmetric configuration-called the "typical" COW-is rare; a functionally complete arterial ring is not commonly observed in the general population.[2] In autopsy series, only about 21% of cases exhibit a fully symmetric and complete circle.[3] Most individuals have at least one segmental variation such as hypoplasia or aplasia. These normal anatomical variations are considered the result of differences during embryological development and are commonly encountered even in healthy individuals.[4,5]

The clinical relevance of COW variations is significant. A complete circle supports collateral flow in cases of carotid or vertebrobasilar artery occlusion. An incomplete or anomalous circle may lead to inadequate perfusion of brain regions, increasing the risk of ischemic stroke.[6] For, example, PCom aplasia may reduce vertebrobasilar contribution to the PCA territory, leading to vertebrobasilar insufficiency.[7] Conversely, the presence of a fetal PCA indicates PCA perfusion from the internal carotid system, which may increase the risk of infarction in the PCA territory in cases of unilateral carotid stenosis.[8] Similarly, the absence of AComA or ACA A1 segments limits collateral flow and may compromise anterior cerebral circulation.[9]

Understanding these variations is vital for clinical procedures such as endovascular interventions, aneurysm clipping, carotid artery stenting, and stroke management. For example, in the surgical treatment of AComA aneurysms, knowledge of cross-flow patterns through the circle is critical.[10] Thus, the configuration of the COW is essential in planning cerebrovascular interventions.

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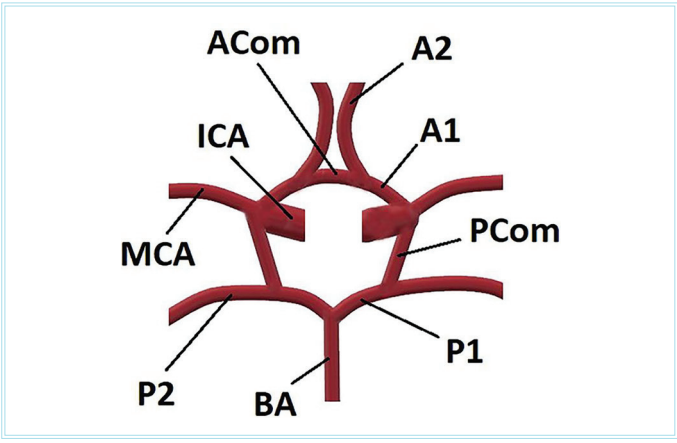

Figure 1. A schema will be used to present the different types of COW and to indicate the differences between the variances better

Acom: Anterior communicating artery, PCom: Posterior communicating artery, P1: pre communicating segment of posterior cerebral artery, P2: Post communicating segment of posterior cerebral artery, ICA: İnternal carotid artery, A1: Pre communicating segment of anterior cerebral artery, A2: Post communicating segment of posterior cerebral artery, MCA: Middle cerebral artery

This study aimed to reveal the frequency of each COW variation detected using TOF images of MRI in a population that had no previous cerebrovascular pathology.

Methods

The study was conducted with approval from the Erzincan Binali Yıldırım University Non-Interventional Clinical Research Ethics Committee (decision no: 2025-14/05, date: 24.07.2025). This retrospective study included time-of-flight (TOF) magnetic resonance angiography (MRA). The study analyzes images of 410 adult patients who underwent brain MRI between January 2022 and March 2024 due to symptoms such as headache, dizziness, or memory loss.

To avoid the possible effects of other vascular diseases on vessel calibers of the COW, the medical records of these patients have been scanned. Four patients with left ICA occlusion, one patient with basilar artery aneurysm, one patient with significant (>50%) right ICA stenosis, one patient with ACom aneurysm, one patient with vascular malformation, one patient with subdural effusion, and one patient with sizeable cerebral hematoma were also excluded from the study. MR angiography images with artifacts hindering interpretation due to motion (cannot remain stable during the examination or patients with dyskinesia) and other imaging artifacts (due to ferromagnetic intracerebral aneurysm clips, etc.) were excluded from the study (n=8).

All imaging was performed without contrast using a 1.5 Tesla scanner (Siemens Magnetom Aera, Germany).

A 16-channel standard head coil was used in each patient. The 3D-TOF images were handled with technical parameters as follows: repetition time: 24 ms, echo time: 7.15 ms, flip angle: 25°, slice thickness: 0.6 mm, field of view: 243×256 mm, and matrix size: 0.4×0.4×0.6 mm^3. The imaging time was approximately 7 min 18 s.

Anterior and posterior segments of the COW (A1, AComA, PCom, P1) were evaluated separately. Hypoplasia was defined as a vessel diameter of less than 1 mm.

Statistical Analysis

Analyses were made using IBM Statistical Package for the Social Sciences 25 statistical software. The normal distribution of continuous variables was checked with Shapiro-Wilk and Kolmogorov-Smirnov tests. In comparisons between two independent groups of male and female participants, the independent samples t-test was used when normal distribution was met, and the Mann-Whitney U test was used otherwise. In 2x2 categorical variable comparisons (frequency >5), Pearson chi-square test was used; if the expected value was between 3 and 5, Yates' corrected chi-square test was used; and if the expected value was less than 3, Fisher's exact test was used. The level of statistical significance was accepted as $p<0.05$.

Results

Of the 410 individuals, 176 were male and 234 female, with a mean age of 41.2±12.7 years. A complete, symmetric COW was observed in 118 cases (28.8%). The most common variations were: - PComhypoplasia: right 23.1% (n=94), left 18.6% (n=76) - PComaplasia: right 9.7% (n=39), left 7.6% (n=31) - fetal PCA: unilateral 11.2% (n=45), bilateral 4.6% (n=18) -AComAaplasia: 2.1% (n=8) - ACA A1 hypoplasia: right 4.1% (n=16), left 2.8% (n=11) - ACA A1 aplasia: 3.4% (n=13) - ACA trifurcation: 2.4% (n=9) - azygos ACA: 0.7% (n=3) -basilar artery fenestration: 0.7% (n=3) – persistent trigeminal artery: 0.2% (n=1). (Tables 1, 2) (Figures 2, 3)

There were no statistically significant differences in variation prevalence between sexes ($p>0.05$).

Discussion

The findings of this study are largely consistent with previous literature. For example, Chen et al.[11] reported a 27% prevalence of complete circles in a Chinese population. The fetal PCA rate in our study was 15.8%, similar to Koshy et al.[12], that who reported 18.3%. ACA segment variations were relatively low (3-6%), suggesting preserved anterior collateral flow in most individuals.[13]

Table 1. Prevalance of anterior COW variants

Anterior variant type	Number of patients (n)	Percentage (%)
AcomAaplasia	8	2.1
ACA A1 hypooplasia right	16	4.1
ACA A1 hypooplasia left	11	2.8
ACA A1 aplasia	13	3.4
ACA trifurcation	9	2.4
Azygos ACA	3	0.7

COW: Circle of Willis, ACA: Anterior cerebral arteries, Acom: Anterior communicating artery

Table 2. Prevalance of posterior COW variants

Posterior variant type	Number of patients (n)	Percentage (%)
PcomAplasia right	39	9.7
PcomAplasia left	31	7.6
PcomHypoplasia right	94	23.1
PcomHypoplasia left	76	18.6
Fetal PCA ipsilateral	45	11.2
Fetal PCA bilateral	18	4.6

COW: Circle of Willis, PCA: Posterior cerebral arteries, Pcom: Posterior cerebral arteries

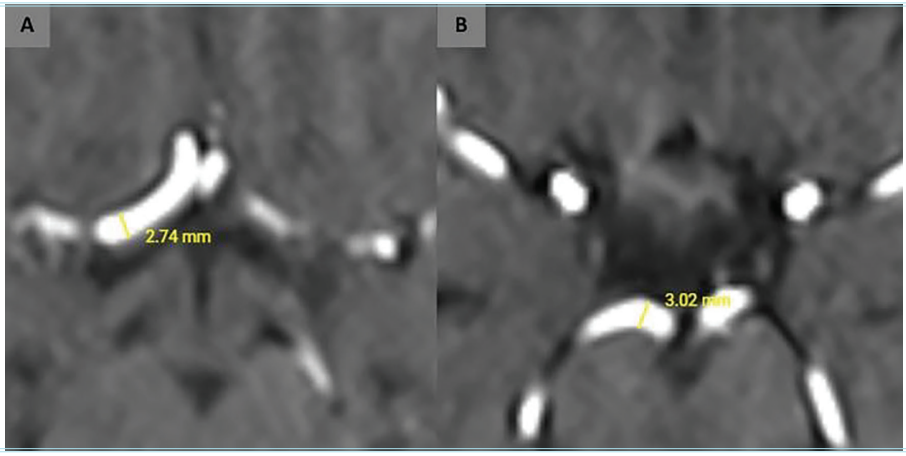

Figure 2. The measurements of vascular diameters of the right A1 segment (A) and right P1 segment (B) are presented. Axial MR images with ×400 magnification were used to measure the vessel calibers

MR: Magnetic resonance

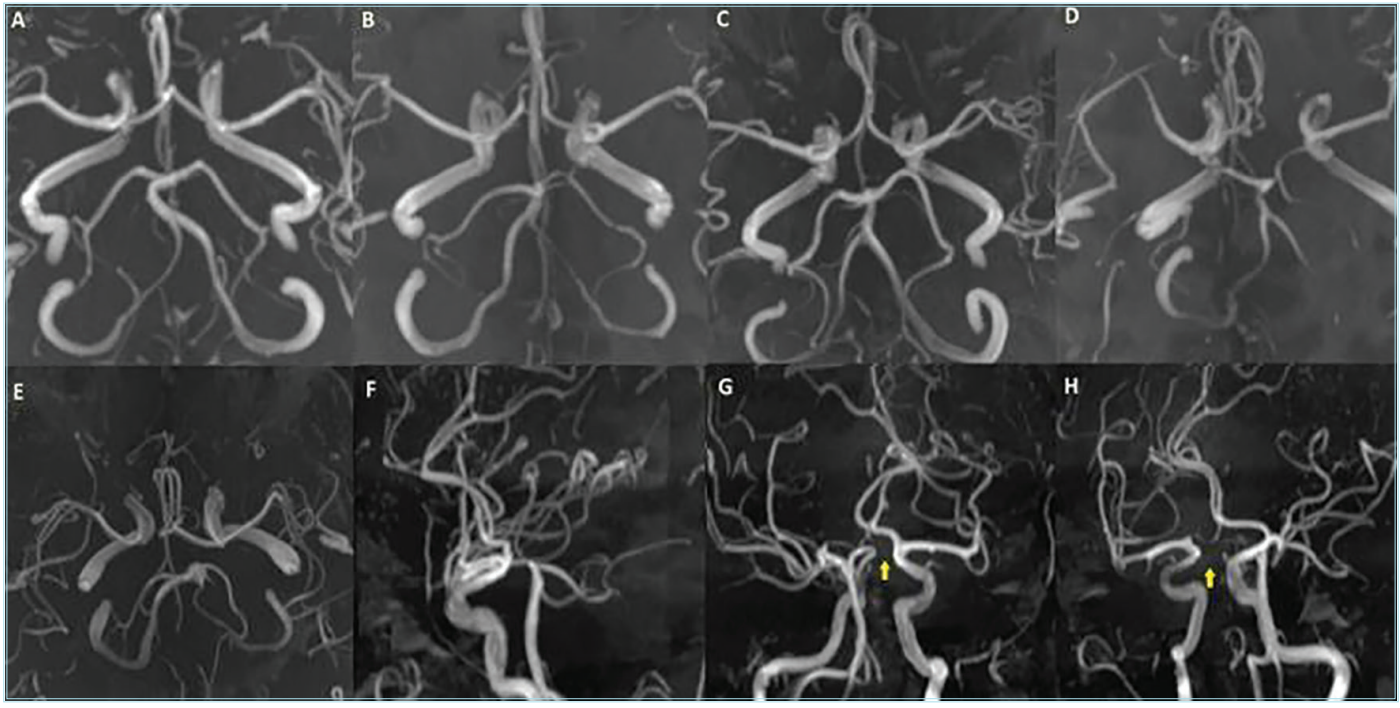

Figure 3. Some samples of MR angiography images from our patient population, classified as "partially incomplete" circle of Willis. The posterior circulation is characterized by the absence of both PComs (A). The posterior circulation is noted with the absence of the right PCom (B). Anterior circulation with anterior cerebral arteries originating from a common trunk (C). The anterior circulation is characterized by the absence of the left A1 segment (D). Another patient posterior circulation (E) and lateral (F), right oblique (G) and left oblique (H) images of the same patient indicate the absence of bilateral PComs (yellow arrows)

MR: Magnetic resonance, PCom: Posterior communicating artery

The high prevalence of PCom segment variations suggests greater embryological variability in the posterior circle.[14] These variations may reduce vertebrobasilar contributions to posterior circulation and help identify vulnerable regions in cerebrovascular events.[15]

Study Limitations

This study had limitations that should be noted. First, the 3D TOF sequence is not a perfect imaging technique for measuring vascular calibrations and analyzing them. Although this technique is widely used and very successful in imaging intracerebral circulation, it has some difficulties in imaging small vascular collateral channels because of turbulent flow, or slower velocity of blood adjacent to the vessel wall due to the laminar flow.

Conclusion

The COW exhibits significant anatomical variability between individuals. This study, using 1.5T TOF MRA, demonstrated that posterior segment

variations are particularly common. Awareness of these anatomical patterns is important in clinical decision-making, influencing treatment strategies and risk assessment.

Ethics

Ethics Committee Approval: The study was conducted with approval from the Erzincan Binali Yıldırım University Non-Interventional Clinical Research Ethics Committee (decision no: 2025-14/05, date: 24.07.2025).

Informed Consent: Since the study was a retrospective study, informed consent was not required by the ethics committee.

Footnotes

Authorship Contributions

Surgical and Medical Practices: K.B., Concept: K.B., M.S., Desing: K.B., Data Collection or Processing: K.B., M.S., Analysis or Interpretation: T.K., M.S., Literature Search: K.B., T.K., M.S., Writing: K.B., T.K., M.S.

Conflict of Interest: No conflict of interest was declared by the authors.

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