Original Article

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A Study of Circle of Willis and Normal Cerebral Circulation Variants on CT and MR Angiography

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Abstract

Background: The Circle of Willis is a polygon constituting the anastomosis of the internal carotid and vertebral systems that permits cerebral arterial circulation. The main objective of this study was to assess the role of angiography in the evaluation of variant anatomy of Circle of Willis and to determine its relation with various associated vascular pathologies. **Subjects and Methods**: This Hospital-based prospective study was carried out over 2 years from July 2019 to August 2021 at the Department of Radiodiagnosis, Narayana medical college, Nellore. The study population included 200 patients- 130 cases were imaged on a 3 Tesla MRI scanner and the rest 70 on a 128- slice CT scanner. MIP and 3D-reformatted images were scrutinized to ascertain the ultimate configuration of the CW and the presence of vascular pathology. **Results**: Out of the two hundred cases, Complete and balanced CoW was appreciated in 27.9% of them. Posterior circulation variations were eyed in 43.8% and anterior circulation variations in 19.6%. Combined anterior and posterior circulation variations were noticed in 8.7 %. Hypoplastic/ aplastic Posterior communicating arteries were the most familiar in segmental variations. No immediate or prompt correlation was established between the attained results and associated vascular pathologies. **Conclusion**: The study results demonstrate slight differences in the CW configuration. A significant proportion of complete anterior CW was espied in female patients. Posterior circulation variants were the commonest among both men and women. No remarkable association was revealed between CW configuration and the occurrence of aneurysms/AVMs in this analysis. Normal variants of the cerebral circulation are customary, and most such anomalies can be identified at CT and MR angiography.

Keywords: Computed tomography, Magnetic Resonance angiography, Circle of Willis, Time of Flight MRA, Tau sign

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Introduction

The Circle of Willis (CW) is a crucial anastomotic arterial polygon at the base of the brain that bridges the carotid and vertebrobasilar systems.[1–3] It is named after Thomas Willis, an English physician. It is imperative for cerebral perfusion and a crucial route for collateral blood supply to the brain in a state of occlusion in either system.[4,5]

The CW consists of bilateral internal carotid arteries(ICA) in conjunction with the posterior communicating arteries (PCoA) of either side, symmetrical proximal posterior cerebral arteries (PCA), the proximal portion of bilateral anterior cerebral arteries (ACA), and the anterior communicating artery(ACoA).

The middle cerebral artery (MCA) is not a direct contribution of the circle.

Anatomical variations in the Circle of Willis are common and most of them are incidentally discovered during imaging**.** The variants include- absent or hypoplastic vessels, accessory vessels, persistent primitive vessels, and anomalous origin. The ring-shaped arrangement of the arteries facilitates the redistribution of blood in the setting of reduced arterial flow in or upstream of the CW.

This collateral capability of the CW provides a surplus blood supply to the brain.[6–10]

The extended role of cross-sectional imaging and the advanced features of Computed tomography (CT) and Magnetic resonance imaging (MRI) angiographic techniques make it obligatory for radiologists to be conversant of variants of cerebral arteries as they are often observed incidentally. Additionally, the CW variants are of significant clinical value for diagnosis and decision-making in certain surgical procedures.[11]

Subjects and Methods

A two-year Hospital-based prospective study was carried out at Narayana Medical College and Hospital from July 2019 to August 2021 after taking informed consent.

The study included 200 patients aged between 19-80 years, irrespective of sex, referred to the department of radiodiagnosis for cerebral angiography. Pregnant women, patients having cardiac pacemakers and metallic foreign bodies, history of claustrophobia, and patients below 18 years of age were considered as the exclusion criteria of the present study.

Prior to the imaging, patients underwent a circumstantial clinical evaluation by the radiologists.

For the cases referred for MRA- To begin with, the patient was positioned in the MR gantry and a head coil was placed. 3 dimensional Time of Flight MR angiography (3D TOF MRA) imaging of the Circle of Willis was done using a 3.0 Tesla GE MRI scanner (DISCOVERY MR 750w). Later, the anatomy of circle of Willis was evaluated on the 3D TOF MRA volume dataset and MIP reconstruction images on the GE workstation. However, cases with poor quality of TOF MRA/MIP images and motion artifacts were excluded from the final analysis.

CT image acquisition was done by GE OPTIMA 128 SERIAL SLICE CT scanner.

Non-enhanced scans were acquired precedently to demonstrate hemorrhage or calcification.80- 100 ml of LOCM via pump injector at an injection rate of 5ml/sec through an antecubital vein cannula with 20 seconds delay time was used for the image acquisition in adults. The scans were assessed on a console display for variations in the CW.

All the vessels comprising Circle of Willis were analyzed under the following parameters in radiological images-complete or incomplete formation, the normal or abnormal caliber of vessels.

The arterial polygon was evaluated for absent/ hypoplastic vessels, accessory vessels and attenuation, duplication/ triplication, abnormal origin, and persistent fetal circulation. An attempt has been made to study the incidence of variation of individual vessels involving the anterior and posterior parts of the Circle of Willis. Additionally, the association of the Circle of Willis variants with vascular anomalies was assessed.

Results

Amongst 200 cases, six cases were excluded from our study considering the poor quality of images. Two hundred cases of this study, 70 cases were imaged by CT Angiography and 130 cases by MR Angiography.

Out of the two hundred cases, normal variants were predominant over complete CW. Complete and balanced CW was appreciated in 27.9% (54 cases) whereas incomplete in 72.1% (140 cases). Posterior circulation variations were eyed in 85 cases and anterior circulation variations in 38 cases. Combined anterior and posterior circulation variations were noticed in 17 cases.

The peer age group of this study was within 38 to 65 years, with only 8 cases of the age below 25 years and the mean being 48 to 50 years. In addition, an increased prevalence of variants was observed in males (102 cases).

It was observed that the isolated posterior circulation variations 43.8% (85/194 cases) were the most common followed by isolated anterior circulation variations 19.6% (38/194 cases) and combined anterior and posterior circulation variations 8.7% (17/194 cases).

Variations in morphology such as hypoplasia, hyperplasia, early bifurcation, and fenestration were more common in our study 51.4% (72/140 cases) on comparison with variations in origin 25% (35/140 cases), number 22.8% (32/140 cases) and variation in pathway 0.71% (1/140 cases).

Hypoplastic/ aplastic Posterior communicating arteries were the most familiar in segmental variations followed by posterior cerebral arteries.

Fetal PCA was the most common type in variants of vessel origin 16.42% (23/140 cases).

Amid all 194 cases imaged by angiography, we observed one case (0.5%) of persistent carotid-vertebrobasilar anastomosis - persistent primitive trigeminal artery.

Aneurysms were appreciated in 6 cases, with ACoM aneurysms being the commonest (4cases) followed by the junction of ACA and ACoM (1 case) and bilateral ICA aneurysms (1 case).

Out of two hundred cases, which we analyzed, there was one case of AV malformation in the parafalcine region of the right frontal lobe with feeding artery from the A2 segment of right ACA and draining vein into the right internal cerebral vein posteriorly.

However, no immediate or prompt correlation was established between the attained results and associated vascular pathologies like aneurysms and arteriovenous malformations.

Discussion

The Circle of Willis is a great arterial anastomosis between the supraclinoid part of the bilateral internal carotid arteries and vertebral arteries in the suprasellar cistern with a vital role in cerebral perfusion.[7]

The paired internal carotid arteries contribute 80% of the cerebral blood supply while the dual vertebral arteries contribute 20% of the blood supply.[8] Each internal carotid

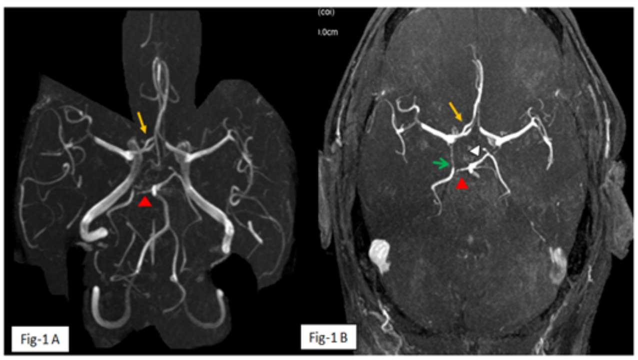

Figure 1: A, 3D time-of-flight MRA MIP image and Fig-1 B, Axial time-of-flight MRA image demonstrate dual channels arising from the middle of the right A1 segment (yellow arrow)- Fenestrated right Anterior cerebral artery. Red arrowheads show right superior cerebellar artery and absent P1 segment of the right posterior cerebral artery with prominent right PCoM (green arrow) - right Fetal Posterior cerebral artery. Note the normal left posterior cerebral artery (white arrowhead).

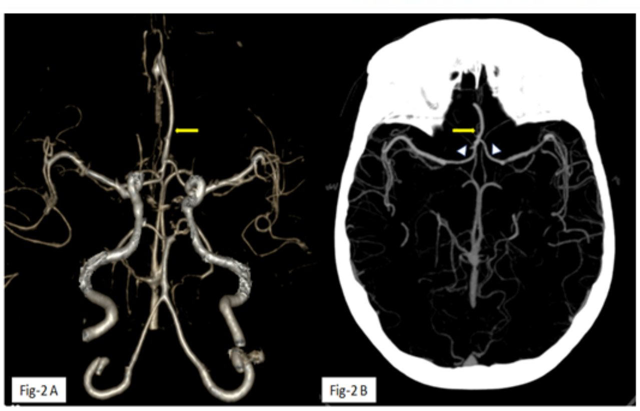

Figure 2: A, 3D cerebral CTA image and Fig-2 B, Axial cerebral CTA image showing the convergence of the bilateral A1 segments (white arrowheads) to form a single midline A2 trunk (yellow arrows) - Azygos anterior cerebral artery. It represents the persistence of the embryonic median artery of the corpus callosum.

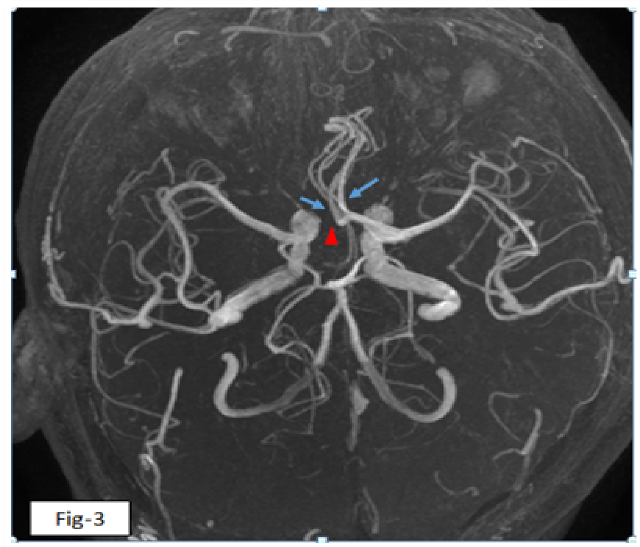

Figure 3: Axial time-of-flight MRA image illustrates the absence of A1 segment of the right anterior cerebral artery (red arrowhead). The origin of both A2 segments (blue arrows) is from a single, unilateral left A1 segment.

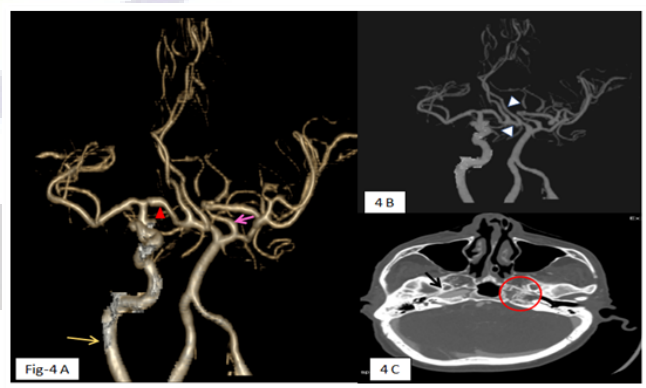

Figure 4: A and Fig-4 B, 3D cerebral CTA images show agenesis of the left internal carotid artery (ICA) whereas the right ICA is normal (yellow arrow). The collateral circulation is well established. The left middle cerebral artery is supplied by the posterior communicating artery (pink arrow), and the left anterior cerebral artery is supplied by the anterior communicating artery(white arrowheads). The left A1 segment (the first segment of the anterior cerebral artery) is absent. The right A1 segment is normal (red arrowhead). 4C, Axial CT bone window of the same patient showing an absent bony carotid canal (red circle) on the left side. The normal carotid canal on the right side is marked with a black arrow for comparison.

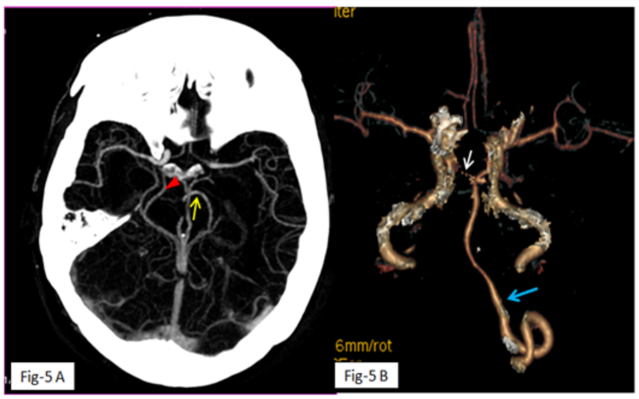

Figure 5: A, Axial cerebral CTA image and Fig-5 B, 3D cerebral CTA image showing the fetal origin of the right posterior cerebral artery (PCA): as the ipsilateral P1-segment (the first segment of PCA) is hypoplastic (white arrow) and the caliber of the posterior communicating artery (red arrow-head) is greater than that of the ipsilateral P1 segment. Note the normal left PCA (yellow arrow). The right vertebral artery is absent. Note the normal left vertebral artery (blue arrow).

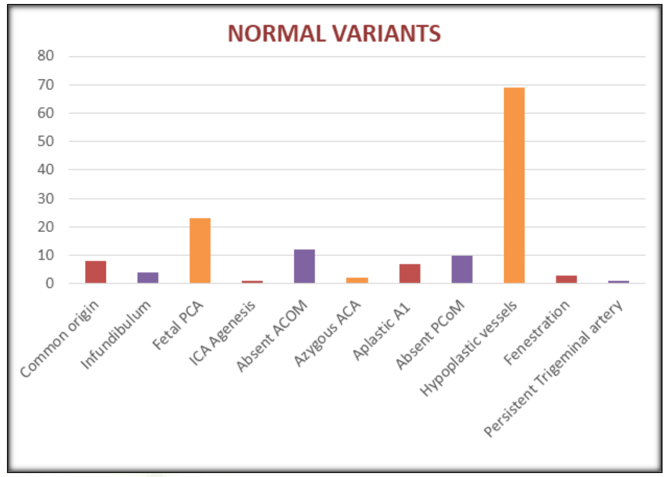

Chart 1: **Demonstrating the normal variants in our analysis.**

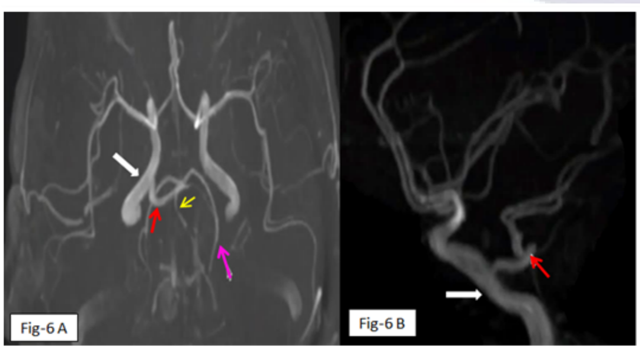

Figure 6: A, Axial time-of-flight MRA MIP image demonstrates the hypoplastic proximal basilar artery (yellow arrow). PTA (persistent trigeminal artery) – [red arrow] seen as a connection between the cavernous segment of the right ICA (white arrow) and basilar artery. Pink arrow shows the normal left PCA. Figure 6 B, Sagittal MRA TOF representing the "TAU" sign-greek letter τ. Anterior horizontal limb and vertical limbs (white arrow) are formed by the ICA and the posterior limb (red arrow) is formed by the proximal part of the right PTA.

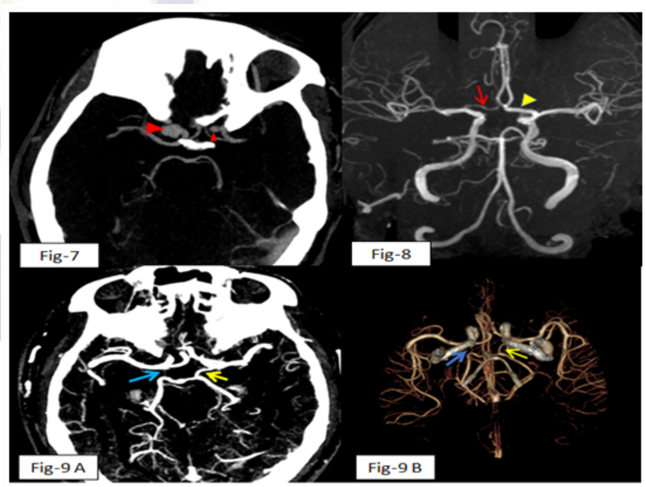

Figure 7: Axial cerebral CTA image showing aneurysms in the bilateral internal carotid arteries (red arrow-heads). Figure 8, Axial time-of-flight MRA image illustrates the hypoplastic A1 segment of the right anterior cerebral artery (red arrow). Note the normal left ACA (yellow arrowhead). Figure 9A, Axial cerebral CTA image and Figure 9B, 3D cerebral CTA image showing the hypoplastic right posterior communicating artery (blue arrow). The normal left posterior communicating artery is marked with yellow arrow for comparison.

Table 1: Percentage of variations - territorial distribution

Type	Percentage variations observed
1.Complete & balanced	27.9% (54/194)
2. Isolated posterior circulation variations	43.8% (85/194)
3. Combined anterior and posterior circulation variations	8.7% (17/194)
4. Isolated anterior circulation variations	19.6% (38/194)

artery branches into anterior and middle cerebral arteries respectively, which supply blood to the brain. The basilar artery, which in succession is formed by the union of the fourth part of bilateral vertebral arteries splits at the upper border of pons into posterior cerebral arteries on either side. The communicating arteries connect the anterior and posterior parts to complete the ring.[7]

The Circle of Willis is considered complete when no component is hypoplastic or absent.

An attempt has been made to study and report the prevalence of CoW variants based on 3T MR and CT angiography images. Additional findings taken into consideration include association with age and sex, anterior, posterior circulation and combined variants, their conditional frequencies, and coalition with vascular pathologies namely aneurysms and arteriovenous malformations.[12–14]

According to a study conducted by Battacharji SK et al,[12] in 1967**,** anatomical variations in the Circle of Willis were noticed in about 60% of cases.

As reported by Roy Munialo Machasio et.al,[15] in their study of the patients referred for cerebral CTA, complete CW was seen in 37.2% of the patients with no statistically significant difference between males and females.

In our study, incomplete CW was observed in 72.1% (140 cases) with slight male predominance (52%- 102 cases).

This study followed the morphological classification proposed by Arsany Hakim et.al for normal cerebral arterial variants: variation in vessel origin (Common origin, Infundibulum, Anomalous origin due to persistent embryological circulation), variation in the number of vessels (Increased or decreased number of vessels), variation in morphology (Hypoplasia, Hyperplasia, Early bifurcation, Fenestration), and variation in the pathway (Persistent carotid-vertebrobasilar and internal-external carotid anastomosis).[6]

In our analysis, variations in morphology were predominant (51.4%) with hypoplastic vessels being the most common (95%- 69/72 cases). The most frequently involved vessel was the PCoM (n=48, 66.6%), followed by A1 segment of ACA (n=16, 22.2%) and ICA (n=5, 6.9%). However, unilateral involvement of PCoM was repeatedly spotted in comparison to bilateral.

Our study is similar to the study conducted by Naveen SR et al. in 2015 and Nordon et.al on fifty cadavers of the Brazilian population in 2012, wherein PCoM was most common in variation.[13,14]

The present analysis had three cases of fenestrated A1 segment with a prevalence of 2.14%. The anatomic imaging studies by Ito J et.al,[16] and angiographic studies by Sanders WP et.al,[17] observed the prevalence of fenestration of the A1 segment between 0% - 4% and 0.058% respectively.

An azygos anterior cerebral artery signifies the persistence of the embryonic median artery of the corpus callosum.[18] A solitary midline A2 trunk supplies the anterior cerebral artery territories of either side. Various studies have reported the prevalence of azygos anterior cerebral arteries as 0.2%–4.0% in the general population.[19–21] *Asper* our study, azygous ACA was detected in only 1.4% of the cases.

The ICA agenesis, which is spotted in around 0.01%, will result in the absence of the carotid canal, which is the most empirical approach in recognizing this anomaly in medical practice. Generally, the ECA and the vertebrobasilar system have a well-established collateral circulation in patients with ICA agenesis making them asymptomatic.[22–24] Our study had one case of left ICA agenesis.

Persistent primitive carotid-vertebrobasilar anastomoses ensue as a result of the failure of regression of fetal trigeminal, otic, hypoglossal, and proatlantal intersegmental arteries in the course of normal embryological development. The most often appraised category amongst them is persistent primitive trigeminal artery with a prevalence rate of 0.1-0.6%.[25] The “Tau” sign- on sagittal MR images due to its resemblance with the Greek letter “Tau” is an epitome of PTA.[26,27] One Case of a persistent primitive trigeminal artery (0.5%) was noticed in this study arising from the right ICA and joining the basilar artery.

Among the 194 cases of our study, fetal PCA constitutes 11.3% and aneurysms constitute 3.09%, with ACoM aneurysm being the commonest (4cases) followed by the junction of ACA and ACoM (1 case) and bilateral ICA aneurysms (1 case). However, no association was noticed between aneurysms and CW variants.

Duplications, trifurcations, and early bifurcations were not observed in this study.

We observed that the normal variants of cerebral circulation are customary, and most such variations in the Circle of Willis can be identified at CT and MR angiography. The study results demonstrate slight differences in the CW configuration. A significant proportion of complete CW was espied in female patients. Posterior circulation variants were the commonest among both men and women. No remarkable association was revealed between CW configuration and the occurrence of aneurysms/AVMs in this analysis. This study concluded that CT and MR angiography are the supreme non-invasive modalities for assessment of collateral circulation and the anastomotic variants of the Circle of Willis with either of the modalities having limitations of radiation dose, iodinated contrast, artifacts by skull base, and prolonged scan time leading to frequent degradation of images by motion artifacts respectively.

Conclusion

Our analysis revealed that normal variants were predominant over complete and balanced CW with increased prevalence of variants in males. Hypoplastic PCoM was the most frequent variant of the sample. The current study reported no significant association between CW configuration and incidence of aneurysms/AVMs.

Comprehensive knowledge regarding the anatomy and possible variants of Circle of Willis are essential for clinicians, radiologists, and vascular surgeons. This assists in better understanding of most cerebrovascular diseases and aids in current diagnostic and therapeutic procedures as well as accurate interpretation on Computed Tomography and Magnetic Resonance Imaging.

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