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PATTERN OF CIRCLE OF WILLIS ARTERIAL VARIANTS AND ANOMALIES IN NON-CONTRASTED THREE-DIMENSIONAL TIME-OF-FLIGHT MR ANGIOGRAPHY

K.M.Navas[1*] and Gurusiddhanagouda[2]

[1]Associate Professor, Department of Radiology, KMCT Medical College, Manassery post, Mukkam, Kozhikode, Kerala, India.

[2]Assistant Professor, Department of Radiology, Kerala Medical College, Mangode, Cherupulassery, Palakkad, Kerala, India.

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ABSTRACT

Considerable anatomic variation exists in the Circle of Willis. There are ten types of variation (A to J) in anterior and posterior circle. In one study, common variation the proximal part of the posterior cerebral artery is narrow and its ipsilateral posterior communicating artery is large, so the internal carotid artery supplies the posterior cerebrum. In another variation the anterior communicating artery is a large vessel, such that a single internal carotid supplies both anterior cerebral arteries. A total of 300 healthy participants (198 men, 102 women; mean age, 55 years) who underwent three-dimensional time-of-flight (3D-TOF) MR angiograms of the circle of Willis (CoW) were obtained with the sequence of spoiled gradient-recalled acquisition (SPGR) using a 1.5-tesla MR scanner (Achieva; Philips Medical Systems) at the Department of Radio diagnosis. Among the subjects studied, commonest variant is type e. It is commonest among male (34.8%). Type i is not found in the study population. Among the subjects studied, commonest variant is type e. It is commonest below 50 yrs [61 of 113 (54%)]. Type i is not found in the study population. The most common posterior circle variant is type E.

INTRODUCTION

The circle of Willis is a vascular structure that is capable of rerouting blood flow at the level of the skull base from the posterior to anterior circulation via the posterior communicating artery (PComA) or vice versa, or from one hemisphere to the other hemisphere via the anterior communicating artery (AComA). The circle of Willis is considered a highly effective collateral pathway to maintain adequate cerebral perfusion in case of diminished arterial perfusion pressure in the ICAs and VBA in case of severe stenosis or occlusion. The arrangement of the brain's arteries into the Circle of Willis creates redundancies or collaterals in the cerebral circulation.

Corresponding Author

K.M.Navas
Email: - ramspsm@gmail.com

If one part of the circle becomes blocked or narrowed (stenosed) or one of the arteries supplying the circle is blocked or narrowed, blood flow from the other blood vessels can often preserve the cerebral perfusion well enough to avoid the symptoms of ischemia

Considerable anatomic variation exists in the Circle of Willis. There are ten types of variation (A to J) in anterior and posterior circle. In one study, common variation the proximal part of the posterior cerebral artery is narrow and its ipsilateral posterior communicating artery is large, so the internal carotid artery supplies the posterior cerebrum. In another variation the anterior communicating artery is a large vessel, such that a single internal carotid supplies both anterior cerebral arteries.

The variations of the CoW are clinically important as the CoW plays an important role in cerebral hemodynamic as a collateral anastomotic network and patients with effective collateral circulations have a lower

risk of transient ischemic attack and stroke than those with ineffective collaterals [1,2]. Fetal configuration where the diameter of the ipsilateral pre-communicating (P1) segment of the posterior cerebral artery (PCA) is less than the diameter of PcomA, so that the blood supply to the occipital lobe is mainly via the internal carotid artery (ICA)] were found in autopsy brains with infarcts [1,2]. Studies have shown that there also exists a correlation between cerebral aneurysms and certain variations of the CoW [3-5].

In most, one of the vessels is sufficiently narrowed to impair its role as a collateral route. The development of such pathways depends on the individual morphological and hemodynamic factors. The collateral potential of the CoW is believed to be dependent on the presence and size of its component vessels [6-8].The anatomical variations of the circle of Willis have been reported in previous studies [9,10]. Volume flow rates in the feeding arteries of the brain, such as the internal carotid artery and the basilar artery, have been used to evaluate blood flow dynamics in vascular disease [11,12]. The anatomic variations in the circle of Willis presumably affect the volume flow rates in the feeding arteries. Toru Horiroshi et al have reported that asymptomatic aneurysms were found in 2.8% of patients who underwent MRA [13]. Anomalies of the "Circle of Willis" may play a role in the development of aneurysms by producing haemodynamic changes in blood flow and inducing strain on the weak point of the arteries at bifurcation. In this regard, we might say that MRA is a quite sensitive diagnostic modality to detect cerebral arterial pathological lesions or normal variants. In this study our aim and to determine whether there is sex related or age-related difference in our study results.

The purpose of this study is to evaluate and to describe the prevalence and pattern of circle of Willis (CoW) arterial variants (aplasia, hypoplasia) and anomalies {arteriovenous malformations (AVMs), and aneurysms} in non-contrasted three-dimensional time-of-flight MR angiography (3D-TOF-MRA) in general population

METHODOLOGY

A total of 300 healthy participants (198 men, 102 women; mean age, 55 years) who underwent three-dimensional time-of-flight (3D-TOF) MR angiograms of the circle of Willis (CoW) were obtained with the sequence of spoiled gradient-recalled acquisition (SPGR) using a 1.5-tesla MR scanner (Achieva; Philips Medical Systems) at the Department of Radiodiagnosis.

The following patients were excluded

- Patients with pacemaker, intracerebral aneurysmal clips or other metallic implants.
- Patients with severe claustrophobia.
- Severely ill, uncooperative patients who are not able to remain stable for study duration time

Scanning technique

Patient Preparation

Informed consent from the patient / attender (children/ unconsciousness) was obtained before each scanning. Patients were imaged either in natural sleep or, where necessary, after sedation with midazolam 0.07 to 0.08 mg/kg IM (approximately 5 mg IM) administered upto 1 hour before the study for uncooperative patients, to prevent image degradation from motion artifacts. Each patient was positioned supine, and the head was immobilized by head coil. Additional ear protection was used for each patient. Monitoring of patients vital signs was performed throughout the scanning.

MR Imaging Data Acquisition

All patients were scanned by using a 1.5T scanner (Achieva; Philips Medical Systems) with a dedicated high-resolution 3D time-of-flight (TOF) MRA protocol with TR/TE/flip angle of 19/5.7ms/16°, respectively, and true isotropic resolution of 0.6 x 0.6 x 0.6 mm^3. This protocol has been specifically optimized for use in a patient population. Standard anatomic T1- and T2-weighted images were also acquired; more specifically T1-weighted volume scans and T2-weighted multisection fast-field echo anatomic scans were obtained for the detection of brain abnormalities.

Magnetic resonance angiography

Due to its non-invasive nature, magnetic resonance angiography (MRA) has enabled in vivo investigation of the circle of Willis in normal individuals, as well as in patients, by obviating the risks related to conventional contrast angiography (CXA), such as athero-embolic or thromboembolic processes resulting from intra-arterial catheter manipulation, puncture site hematoma formation, and adverse reactions to contrast medium. Especially conventional angiography of the cerebral vessels carries a risk of embolism resulting in cerebral ischemia. Recently, Moreover, MRA also reduces the costs of cerebral angiography by obviating admission to hospital for post-angiographic observation, as is required with conventional cerebral angiography. MRA can display the functional morphology of the arterial circle as well as provide a means for hemodynamic assessment of blood flow and direction through its components with quantitative phase contrast MRA techniques.

MRA techniques

Intracranial MRA has been shown to be an accurate and effective technique for detection of arterial circle morphology and determination of its diameters. In addition, MRA can accurately assess blood flow direction through the component vessels of the arterial circle, and can reliably quantify blood flow through its supplying vessels. MRA is used for a variety of clinical applications such as for the diagnosis of intracranial aneurysms and arteriovenous malformations, for the assessment of Moya

moya disease, to distinguish the anatomical variants of the anterior communicating artery from aneurysms, and to detect an unexpected course of arterial circle component vessels preoperatively. In general, there are three non contrast MRA methods: time-of flight (TOF), phase contrast (PC), and black blood imaging. In our investigation we used the time-of flight (TOF) method, however first two methods are dealt with briefly below.

Time-of-flight

In time-of-flight (TOF) MRA, repetitive radiofrequency (RF) pulses are applied to an imaging slice using an extremely short repetition time to prevent T1 relaxation (i.e. to prevent the longitudinal magnetization from being regained between two successive RF pulses). Thus, the stationary tissue within an imaging slice is saturated with RF pulses, leading to a steady-state situation in which only a minimal amount of longitudinal magnetization is available. The stationary tissue is therefore unable to generate any substantial signal on subsequent pulses. However, fresh spins flowing in to the imaging slice through blood vessels have full (longitudinal) magnetization, and will generate high signal when exposed to the RF pulses directed at that slice. Thus, in TOF MRA, high contrast is achieved between the high signal of the flowing spins in the blood vessels relative to the low signal of the surrounding saturated stationary tissue.

Phase contrast

Phase-contrast MRA uses a different principle to image moving blood within vessels. In this method, a magnetic field gradient is applied along an orthogonal imaging axis (i.e. the x, y, or z axis), which is followed by a complementary gradient of the same magnitude in the opposite direction along the same axis. Phase differences initially induced by the first gradient according to location are cancelled out by an equal and opposite phase shift specific to location effected by the second gradient. Stationary tissue thus has all phase shifts cancelled out. However, moving spins do not experience an equal and opposite gradient during the second gradient switch, since they have changed location, resulting in an acquired phase shift. The resulting phase shift acquired by movement generates a signal for these moving spins. The complementary gradient switches are applied in all three orthogonal directions. The method therefore requires much longer acquisition times. An advantage of this technique is that, besides the magnitude of movement (speed), T1-weighted images are generated simultaneously, and the direction of movement can also be determined. The direction of flow along each of the three axes is determined by performing phase reconstructions of the dataset along each axis separately (i.e. left-to-right flow is detected along the x axis, antero-posterior flow is determined along the y axis, and caudo-cranial flow is detected along the z axis). Every phase reconstruction for sensitivity along each of the axes requires an additional full reconstruction time for the appropriate (two-dimensional or three-dimensional) Fourier transformation, which renders the technique extremely time-consuming when performed in three-dimensional mode.

Scanning parameters

Include

- Slice thickness 1.2 mm.
- 0.6 mm slice overlap (i.e. a gap of –0.6 mm).
- Field of view of 100 x 100 mm.
- Matrix - 0.6 x 0.6 x 0.6 mm^3.
- Repetition time - 19 ms.
- Echo time - 5.7ms.
- Flip angle - 16^0.
- Total number of slices – 50.

Covering a volume of 30 mm in the caudocranial direction (50 x 0.6 mm effective slice thickness).

The total imaging time, including acquisition of the survey image and positioning, was approximately 15-20 minutes, of which the 3D TOF MRA sequence required 3 minutes 24 seconds.

Image Analysis

These axial source images were post-processed by the maximum-intensity projection (MIP) algorithm to produce eight projections rotating about the section axis and one axial image (projection images). All component vessels of the CoW were assessed by measuring the diameter on the individual MIP images. Whenever there is a doubt in determining the diameter of one vessel due to overlapping vessels in the MIP images, the TOF source images are then reviewed on the advanced workstation (Philips ADW 4.0 workstation). Occasionally, it may be necessary to cut off the unwanted branching vessel on the images to better depict the target vessels and assess correct diameter. Vessels, which were visualized as continuous segments of at least 0.8 mm in diameter, were considered present. Those smaller than 0.8 mm in diameter were considered as hypoplastic. The images are seen in volume rendering technique to see overlapping vessels and also seen in all the angles. Vessels, which were visualized as non-continuous segments, were considered as absent and their diameters were regarded as zero when we determine the mean diameter for each specific segment. The anterior and posterior parts of CoW were evaluated separately and classified according to the scheme .The prevalence of each anatomic variant was calculated.

The aim of the image assessment was to confirm the completeness or incompleteness of the CoW and to identify and record the prevalence of different anatomic variations (absence/hypoplasia of the posterior communicating artery [PcomA], anterior communicating artery [AcomA], proximal A1 and P1 segments of the anterior cerebral artery [ACA], and posterior cerebral artery [PCA] respectively; and fetal-, transitional-, or adult-type origin of the PCA). Both maximum intensity

projections (MIPs) in all imaging planes and source images were used to confirm the findings.

Completeness of the CoW and anatomic variations were classified on the basis of the arterial configurations described in previous adult studies. Segments of the communicating arteries visualized only in the source images but not in the MIP images were reported as hypoplastic; segments visualized in neither the source nor the MIP images were reported as absent. Both hypoplastic and absent segments were considered not present when determining the completeness or incompleteness of the CoW because visibility was used as a surrogate measure of the functionality of the vasculature; therefore, absent or hypoplastic vessels were considered not functional.

Care was taken to differentiate the PcomAs from the anterior choroidal and overlapping pericallosal branches of the ACA on the axial MIP .This was achieved by scrolling through the sections and judging the courses of the arteries in sequential display. The communication of the PcomA with the PCA had to be visualized to determine the identity of the vessel. The same method was used to help differentiate the PCAs from the superior cerebellar segments and the anatomic variants of enlarged anterior choroidal branches.

Fetal type posterior communicating artery (FTPcomA) indicates that cases in which the major stem of the posterior cerebral artery arises from the ipsilateral internal carotid artery instead of the basilar artery.

The vessel stems from ICA, which have greater diameter than the ipsilateral pre-communicating segments of the PCA and that continued distally as the posterior cerebral artery was classified as FTPcomA whereas vessel stems from ICA which have equal or smaller diameter that the ipsilateral pre-communicating segments of the PCA were classified as posterior communicating arteries (PcomAs).

The CoW was then classified as complete, partially complete and incomplete configuration. The prevalence of each class was assessed.

Complete configuration of the circle means both anterior and posterior parts of the circle of Willis form a complete circle.

Partially complete configuration means either anterior or posterior parts of the circle of Willis form a complete circle.

Incomplete configuration means neither anterior nor posterior part of the circle form a complete circle.

Mean diameter for each component of CoW was measured for age related neuroparenchymal loss in the form of prominent sulci, ventricles and basal cisterns group, and both sexes. Hypoplastic or absent vessels were counted as zero in diameter. Age- and sex-related difference of the prevalence of the anatomic variants of the CoW was evaluated. A P1 segment of the PCA larger than the ipsilateral PcomA as visualized on the MIP was classified as adult-type origin of the PCA, a P1 segment with the same size as the PcomA was classified as a transitional-type origin of the PCA, and a P1 with a smaller size than the PcomA (or totally absent) was classified as fetal-type origin of the PCA.

RESULTS

Table 1. Gender distribution of anterior circle of Willis variants

Gender	a	b	C	d	e	f	g	h	i	j
Male	127	1	3	12	5	0	27	22	0	0
Female	71	1	3	6	3	0	12	6	0	0
Total	198	2	6	18	8	0	35	28	0	0

Gender distribution of subjects of anterior circulation variants were studied: Among the subjects studied, commonest variant is type a. It is commonest among female (69.6%). Type f, i and j are not found in the study population.

Table 2. Age distribution of anterior circle of Willis variants

Age	a	b	C	d	e	f	g	h	i	j
< 50 yr	78	1	3	5	3	0	15	4	0	0
> 50 yr	120	1	3	13	5	0	24	24	0	0
Total	198	2	6	18	8	0	35	28	0	0

Age distribution (above and below 50 yrs) of subjects of anterior circulation variants were studied: Among the subjects studied, commonest variant is type a. It is commonest among below 50 yrs (71.8%). Type f, i and j are not found in the study population.

Table 3. Gender distribution of posterior circle of Willis variants

Gender	a	b	C	d	e	f	g	h	i	j
Male	22	11	7	22	69	2	19	5	0	7
Female	29	3	6	5	29	1	2	5	0	1
Total	51	14	13	27	98	3	21	10	0	8

Gender distribution of subjects of posterior circulation variants were studied: Among the subjects studied, commonest variant is type e. It is commonest among male (34.8%). Type i is not found in the study population.

Table 4. Age distribution of posterior circle of Willis variants

Age	a	b	C	d	e	f	g	h	i	j
< 50 yr	37	7	6	7	38	0	2	2	0	2
> 50 yr	14	7	7	20	60	3	19	8	0	6
Total	51	14	13	27	98	3	21	10	0	8

Age distribution (above and below 50 yrs) of subjects of posterior circulation variants were studied: Among the subjects studied, commonest variant is type e. It is commonest below 50 yrs [61 of 113 (54%)]. Type i is not found in the study population.

DISCUSSION

Variations in the segments of the circle of Willis have been reported. The aetiology of these variations has been the subject of many theories e.g. the possibility of genetic factors [14] and postnatal development of the brain following occlusive diseases [15]. From the evolutionary standpoint, it is noteworthy that variations of the cerebral arteries seem to be equally common in humans as well as animals [16].

In Abubakr HM study, aplasia of the AComA occurred in 2.1% of cases a percentage which is similar to that reported by Piganiol et al [17]. In Hsin Wen Chen, type A variant is the most common type of anterior part of the CoW in all age and both sex groups.

In Kanchan Kapoor and coworker study, the anterior cerebral artery was absent in 0.4%; hypoplastic in 1.7%; duplicated in 2.6%; triple in 2.3% and single in 0.9%. The anterior communicating artery was absent in 1.8%, duplicate in 10%, triplicate in 1.2% and plexiform in 0.4%.

In K. Ranil D. De Silva study, variations in the AcomA were classified into 12 types based on Ozaki et al, 1977. 193 (86%) showed "hypoplasia", of which 127 (56.4%) were with multiple anomalies, unilaterally in 14 (4%), and AcomA was hypoplastic in 91 (25%). The precommunicating segment of the anterior cerebral arteries (A1) was hypoplastic unilaterally in 17 (5%). Types of variations in the AcomA were: single 145 (65%), fusion 52 (23%), double 22 (10%) [V shape, Y shape, H shape, N shape], triplication 1 (0.44%), presence of median anterior cerebral artery 5 (2%), and aneurysm 1 (0.44%).

In Suemoto and co-worker study, the most common anomaly was fusion of the anterior communicating artery (ACA) for a longer distance than expected (33.03%), followed by the various forms of duplication of this artery (15.38%). In another study, ACA's duplication was more frequent. In the present study type A, which is the normal complete anterior circle is common anterior circulation variant with 66% (n=198). Anterior circle variant types F (MCA originates from the ICA as two separate trunks), I {Hypoplasia or absence of an ICA. The contralateral precommunicating segment of the ACA gives rise to both post-communicating segments and supplies retrograde flow to the ipsilateral precommunicating segment, which, in turn, gives rise to the ipsilateral MCA (both ACAs and both MCAs are supplied by a single ICA)}, and J (Hypoplasia or absence of an anterior communication. The MCA arise as two separate trunks) are not found in study group. Duplicated anterior communicating artery (AcomA), although rare (0.7%), is important to be recognized not as an anterior communicating artery (AcomA) aneurysm, which should be a blind-end sac instead of a tubular continuity between both ACAs. Unilateral hypoplastic A1 segment, with the incidence of 9.3%, may cause hemodynamic overload in the contralateral proximal ACA and in the AcomA complex, and may possibly promote the formation of aneurysm, according to previous studies by others [13]. Therefore, it is always crucial to review the source images on a dedicated workstation for the image analysis and measurement of major arterial components of circle of Willis. Accessory middle cerebral artery (AMCA), which arises from either the ICA proximal to its bifurcation or from the A1 segment of ACA then meandering through Sylvian fissure and dividing to supply the adjacent cerebral cortex in the middle cerebral artery territory [18,19], was not found in our 300 subjects. This may be due to that the population of our series is not big enough. According to literature [19], the prevalence is 0.31% in the study of 6000 angiograms, larger group may be needed to demonstrate the precise prevalence.

In Hsin Wen Chen, the prevalence of unilateral FTPcomA (posterior part variants B, F, G and H) was 20.71% and bilateral FTPcomA (posterior part variants C, I and J) was found in 10.06%.

In Abubakr HM, aplasia of the PcomA ranging from 2.2% to 4.5% on the right side and from 0.85% to 6.5% on the left side.

In Qi Li and co-worker study, A fetal-type posterior circle of Willis was seen in 15 (9.4%) patients.

In Kanchan Kapoor and coworker study, multiplication of posterior cerebral artery was observed in 2.4% cases while it was hypoplastic in 10.6% brains. Posterior communicating artery was absent in 1% and hypoplastic in 13.2%. Seventy-four brains (7.4%) had multiple variations.

In K. Ranil D. De Silva and coworker study, posterior communicating artery (PComA) was hypoplastic bilaterally in 93 (51%) and unilaterally in 49 (13%). Precommunicating segment of the posterior cerebral arteries (P1) was hypoplastic bilaterally in 3 (2%), unilaterally in 14 (4%), and AcomA was hypoplastic in 91 (25%).

In Suemoto and co-worker study, the posterior circulation was considered normal in 20.36%. Presence of both small posterior communicating arteries (PCAs) was the most common alteration (39.37%). Absent PCA at both sides occurred in 8.6%. PCA preserves a large pattern when its diameter is the same of posterior cerebral artery. Similar anomaly was found in 22.62% of cases. Hypoplasia of PCA was the most reported variation. Persistence of fetal pattern of PCA had the same prevalence from previous studies. The most commonest posterior circle variant is type E (Hypoplasia or absence of both PcomAs and isolation of the anterior and posterior parts of the circle at this level) with 37.6% (n=113). The type I (Bilateral fetal type posterior cerebral arteries with hypoplasia or absence of both precommunicating segments of the PCAs) is not found in the study group. Various figures have been published regarding aplasia of the PcomA ranging from 2.2% to 4.5% on the right side and from 0.85% to 6.5% on the left side. This is in agreement with some reported literature where aplasia of

the PcomA occurred more on the left side. In the present study, aplasia was observed in 9% & 10.3% on the left and right side respectively. The FTP is an important variant in the posterior circle of Willis. The prevalence of FTP varies greatly in the literature. In early autopsy studies of normal brains, 15% of participants were found to have FTP.

In a MRA study of 150 participants [20], FTP was found in 32% of subjects, and the prevalence of FTP was 30% in another study of 50 young subjects. In our study, we found the prevalence of FTP was 23%. Compared with previous reports, it is slightly less prevalent in our study. In most studies, "FTP" referred to a partial FTP in which a the P1 segment was smaller than the PcomA. However, in one study, "FTP" referred to a full FTP in which the P1 segment was invisible. The prevalence of full and partial FTP is 18.6% and 4.3 % respectively.

We also looked explicitly for transitional-type posterior circles in the population, which we observed in 4% of participants. Interestingly, we also observed posterior variant (posterior variant J) in the study population. We believe that, these variants reported here may greatly improve our understanding of the collateral circulation in a normal population.

In Macchi et al study, Magnetic Resonance angiography (MRA) study of 100 healthy subjects (50 men and 50 women) found no statistically significant difference between the two sexes. In Abubakr HM study, out of the 143 cases 73 were males and 70 were females. No statistically significant difference between the frequencies of variations between the two sexes was found.

In Hsin Wen Chen study, no sex-related difference in vessel diameter was found statistically. Majority of the subjects were men (n= 198, 66%). Female were 102 (34%). Complete anterior circulation is commonest among both genders with 74.7% and 82.3% in male and female respectively. Complete posterior circulation and complete both circulation is proportionately common in women with 17% and 16.6% respectively.

The most common variant in anterior circulation is type A, which is normal pattern in both the sexes. Type A variant in anterior circulation in common among women (n= 71, 69.6%) slight more compared to men (n= 127, 64.1%). Type E variant of posterior circulation is commonest in both the sexes. It is also common in men (n=69, 34.8%) slightly more compared to women (n=29, 28.4%). In A. W. J. Hoksbergen and co-worker study, in 76 patients with a mean age of 61 (35 to 89) years. In Hsin Wen Chen study, no statistically significant difference among each age group except that the older subjects has smaller caliber in left A1 segment than younger subjects. In Suemoto and co-worker study, 221 CoW were dissected and the mean age was 70.34±12.05 years old (50-102 years), 51.58% were male. Most of the subjects are between the age group of 40 to 70 yrs (n=198, 66%). The youngest subject is 9 yr and oldest subject is 90 yrs. The average age of the patients studied is 55 yrs. For the purpose of the study, the subjects are divided into above and below 50 yrs. The number of subjects below 50 yr is 109 and above 50 yrs is 191. All the anterior and posterior circulation Circle of Willis were divided according to gender and age groups.

Complete anterior circulation is common above 50 yrs of age (n=179, 93.7%). Complete posterior circulation is slightly more common below 50 yr of age (n=37, 33.9%). In this study, partially complete Circle of Willis is the commonest variant (n=184, 61.3%). Complete both anterior and posterior circulation is common below 50 yr (n=37, 33.9%). Partially complete Circle of Willis is common in above 50 yrs (n=131, 68.5%). Incomplete Circle of Willis is common in above 50 yrs (n=47, 24.6%).

Kanchan Kapoor and co-worker study, intracranial saccular aneurysm was present in 10 (1%). AVMs were found in 2 cases (1.4%) in the Posterior Cerebral Artery. The right middle cerebral artery (MCA), though not part of the circle, showed AVM in three cases (2.1%). In the present study aneurysms were detected in 3 cases (1%); in both the AComA and the left ACA. AVMs were found in 1 cases (0.33%) in the right parieto-occipital region though not part of the circle. One subject was having persistent left trigeminal artery (0.33%) on MR angiograms.

CONCLUSION

The commonest anterior circle variant is type A (normal anterior configuration) with a prevalence of 66%. The most common posterior circle variant is type E (Hypoplasia or absence of both PcomAs and isolation of the anterior and posterior parts of the circle at this level) with 32.6%. Overall, circle of Willis variants are slightly more common among the women in comparison to men. Incidence of associated anomalies, like aneurysm or AVM is comparable to that described in literature.

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CONFLICT OF INTEREST:

The authors declare that they have no conflict of interest.

STATEMENT OF HUMAN AND ANIMAL RIGHTS

All procedures performed in human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

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