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CIRCLE OF WILLIS & ITS VARIATIONS – EVALUATION WITH MAGNETIC RESONANCE ANGIOGRAPHY.

Radiodiagnosis

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ABSTRACT

Background: Circle of Willis (COW) shows wide variation in different population groups. This study evaluates the anatomical variations in mixed Indian population in tertiary hospital in Mumbai using three-dimensional time-of-flight (3D-TOF) magnetic resonance angiography (MRA).
Materials & Methods: Total 923 patients (471 men & 452 women; mean age, 52.3 years) underwent 3D-TOF MRA over a period of 18 months using a 3.0 T MR scanner with review of images done using maximum intensity projection (MIP) and 3D volume rendered images.
Results: A complete COW was seen in 247 patients (135 females and 112 males). An incomplete anterior and posterior COW was found in 166 cases (17.98 %). The remaining 510 (55.25 %) subjects had partially complete COW configuration. The most common type of COW in a single subject was anterior variant type A and posterior variant type E.
Conclusion: Our study provides an important reference source for COW variations in the regional population as a single center study and confirms that configuration of the COW varies largely in general population. The anterior COW was complete in 79.95 % cases while the posterior COW was incomplete in 70.53% cases. Complete COW was seen in 26.76 %. The prevalence of complete configuration of COW was slightly higher in females than males.

KEYWORDS

Anatomical variations, Circle of Willis, 3D-TOF MR angiography, Cerebral circulation.

Introduction:
The Circle of Willis (COW) is an important polygonal collateral network located at the base of the brain which unites the internal carotid and vertebrobasilar system and plays an important role in maintaining cerebral circulation. Its ability to redistribute blood flow depends on its morphology, the presence and size of the component vessels. The potential of the circle of Willis to develop collateral flow in the case of impaired blood supply has been known since Sir Thomas Willis first described the collateral function of the arterial anastomosis in his book Cerebri Anatome in 1664 [1].

Aims & Objectives:
The purpose of this study is to evaluate and describe the prevalence and pattern of COW, arterial variants (aplasia, hypoplasia) in 3D-TOF-MRA in mixed Indian population in tertiary hospital in Mumbai. Additionally, the purpose of this study was to investigate whether any sex-related differences could be found in circle morphology.

Materials and Methods:
In this observational study, analysis of cerebral magnetic resonance angiography (MRA) images of 923 patients referred for neuroimaging study to our tertiary center in Mumbai for various indications was performed over a period of 18 months from June 2016 to November 2017.

In this study, total 471 men and 452 women; mean age, 52.3 years underwent 3D-TOF MRA of the COW using a 3.0-tesla MR scanner (Philips Achieva 3.0 T, Philips Medical Systems, Netherlands).

Scanning technique: Patients were imaged in supine position with a dedicated head coil. Dedicated, optimized high-resolution 3D-TOF MRA protocol with average slices of 120 having slice thickness- 1.4 mm & slice overlap- 0.7 mm with field of view - 200 mm with repetition time (TR) - 23 ms, echo time (TE) - 3.5 ms and flip angle - 18° was used. The average imaging time for 3D TOF MRA sequence required approximately 4 min 10 s.

Images were reviewed for anatomical configuration of the COW using maximum intensity projection (MIP) and 3D volume rendered images by experienced radiologists. On few occasions, the unwanted branching vessel on the images was cutoff in order to better depict the target vessels and assess correct diameter. Vessels 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 & arteries seen as non-continuous segments were considered as absent. Vascular variations in the anterior and posterior parts of the circle were evaluated and classified according to the scheme. The prevalence of each anatomic variant was documented.

Results:
Classification presented in the work of *Chen et al.,* [10] is used for analysis purpose because of its simplicity. There are 10 types of variations (A–J) in anterior and posterior circle which are illustrated in the figures 1 and 2 respectively.

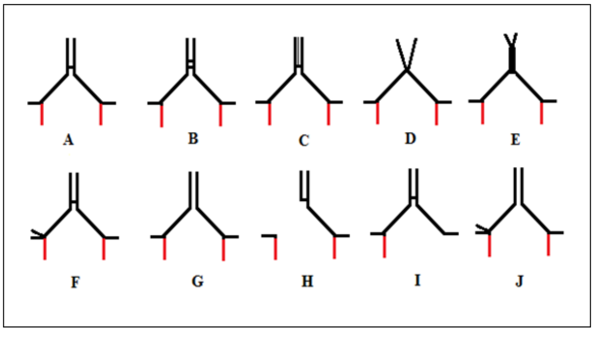

Figure 1: Schematic diagram of variations in anterior COW (Modified from Chen et al.), red line (ICA). Types-A: Single Acom B: Two or more Acoms C: Median artery of corpus callosum arises from Acom D: Fusion of ACAs over short distance E: ACA form a common trunk & split distally into two postcommunicating segments F: MCA originates from the ICA as two trunks G: Hypoplasia/absence of Acom H: One precommunicating segment of an ACA is hypoplastic/absent I: Hypoplasia/absence of an ICA Both ACAs & MCAs are supplied by a single ICA J: Hypoplasia/absence of Acom & MCA arises as two trunks

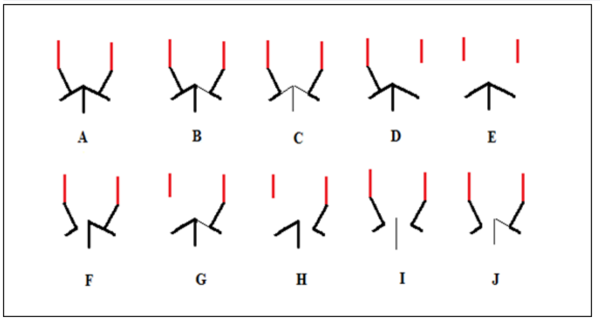

Figure 2: Schematic diagram of variations in posterior COW (Modified from Chen et al.), red line (ICA). Types-A: Bilateral patent Pcom B: Unilateral fetal PCA (fPCA); patent Pcom on other side C: Bilateral fPCAs with patent precommunicating segments (P1) of both PCAs D: Unilateral patent Pcom E: Hypoplasia/absence of both Pcoms F: Unilateral fPCA & absent ipsilateral P1 segment G: Unilateral fPCA & absent contralateral Pcom H: Unilateral fPCA & absent ipsilateral P1 segment & contralateral Pcom I: Bilateral fPCAs with absent both P1 segments J: Bilateral fPCAs with hypoplasia/ absence of P1 segment of either PCA

In this study, total 923 patients (471 men and 452 women) with a mean age of 52.3 years were included. Our findings are summarized in tables below.

Prevalence of variations in anterior COW is documented in Table 1.

Table 1: Variations in Anterior Circle of Willis

Type	Prevalence	Percentage of total
Type A	625	67.71
Type B	6	0.65
Type C	20	2.16
Type D	35	3.79
Type E	51	5.52
Type F	0	0
Type G	41	4.42
Type H	143	15.50
Type I	0	0
Type J	0	0
Unclassified	2	0.21
Total	923	100

Anterior COW variants:

The anterior COW was complete in 738 out of 923 participants (79.95 %). Most prevalent type among anterior COW variant was Type A (normal configuration) [Figure 3] seen in 625 patients (67.71 %). Next most prevalent variant with complete anterior COW was type E [Figure 5] seen in 51 patients (5.52 %) with common trunk of A1 segments. Type C with median artery of corpus callosum [Figure 8] arising from anterior communicating artery was noted in 20 patients (2.16 %). In 6 patients, two anterior communicating arteries (Type B) were observed. 1 patient had azygous ACA with absent A1 segment & duplicated MCA on right side [Figure 6], which is included in the unclassified category in the current scheme of classification.

The anterior circle was incomplete in 185 patients with absent anterior communicating artery [Figure 9] noted in 41 patients (Type G). Rest 143 patients had unilateral A1 segment hypoplasia/aplasia (Type H) [Figure 4] and 1 patient had agenesis of bilateral ACAs and anterior communicating artery, with MCA branches supplying ACA territory [Figure 7].

Prevalence of variations in posterior COW is documented in Table 2.

Table 2: Variations in Posterior circle of Willis

Type	Prevalence	Percentage of total
Type A	201	21.77
Type B	39	4.22
Type C	32	3.46
Type D	147	15.92
Type E	410	44.42
Type F	42	4.55
Type G	23	2.50
Type H	15	1.62
Type I	12	1.30
Type J	2	0.21
Unclassified	0	0
Total	923	100

Posterior COW variants:

The posterior COW was complete in 272 out of 923 participants (29.47 %). Most prevalent type among complete posterior COW variant was Type A [figure 3] seen in 201 patients (21.77 %). Next most prevalent variant with complete posterior COW was type B seen in 39 patients (4.22 %) with unilateral fetal PCA with patent contralateral posterior communicating artery. Type C with bilateral fetal PCA with patent pre-communicating segment of bilateral PCAs was noted in 32 patients (3.47 %).

The posterior circle was incomplete in majority of cases- 651 patients (70.53%). The most prevalent variant in this group was type E [figure 4, figure 7], with aplasia of both posterior communicating arteries with separation of anterior and posterior circulation, seen in 410 patients (44.42%). Unilateral fetal type PCA and absence of the ipsilateral precommunicating segment of PCA type F [Figure 6] was noted in 42 patients (4.55%). Bilateral fetal origin of PCA with absent precommunicating segments and hypoplastic basilar artery -Type I [Figure 5] was seen in 12 cases (1.30%). Type J i.e bilateral fetal type PCA with hypoplasia or absence of the precommunicating segment of either PCA [figure 9] was seen in 2 cases (0.21%).

Entire circle of Willis:

In the combined analysis of entire circle of Willis, a complete COW [figure 3] was seen in 247 cases (26.76 %). Complete COW was seen in 135 females (54.65 %) as compared to 112 males (45.34%). An incomplete anterior and posterior COW was found in 166 cases (17.98 %). The remaining 510 (55.25 %) subjects had partially complete COW configuration. The most common type of COW in a single subject was anterior variant type A and posterior type variant E. Incidentally two patients had variants in anterior circulation which were unclassified according to current scheme of classification used. In two patients, unilateral persistent trigeminal arteries were noted on MR angiograms.

Discussion:

The variations of the COW are clinically important as it plays an important role in cerebral hemodynamic as a collateral polygonal anastomotic network and patients with effective collateral circulations have a lower risk of transient ischemic attack and stroke than those with ineffective collaterals [2]

Several anatomical studies [2,3,4,5] have reported a range of variations in the anatomy of the COW, but it is not clear whether the frequency of occurrence of the different variations of the COW are similar in the studies done in the Indian subcontinent as compared to studies done in other ethnic or racial populations. Also these anatomical studies have their limitations as they are based on the study of autopsies and fail to reflect physiological changes of hemodynamic stress on morphology of COW.

Study of embryonic development of the circle of Willis shows that hemodynamic changes during fetal life may play an important role in determining final COW. A study conducted on the formation of the circle of Willis in fetus showed that, in a 29-day-old embryo, the posterior communicating artery originated from ICA. In the early stages of growth, the vertebrobasilar system is supplied by the carotid through the trigeminal artery. Following the formation of the posterior cerebral artery, the circle closes and perfusion is established from the vertebrobasilar system to the carotid system. That study suggested that hemodynamic changes at this stage can cause different variations. [6]

With increase in number of procedures like aortic arch surgery, carotid end arterectomy and microsurgical clipping of anterior communicating artery aneurysms, detailed knowledge of the variations in cerebral arterial circle is essential [7,8]. In a clinical study, Chuang et al. (2008) found that the absence or hypoplasia of posterior communicating artery can increase the risk of stroke in cases of internal carotid artery occlusion. [9]

Our results in variation of the COW are comparable to other studies conducted till now as shown in table 3. [10, 11, 12, 13, 14]

Table 3: Comparison of our results with other similar studies conducted.

Study	Population	Method	Complete anterior circle	Complete posterior circle	Entire complete COW
Current study	Indian	TOF MRA	79.95%	29.47 %	26.76 %
Chen et al.[10]	Chinese	TOF MRA	78%	25%	21%
Krabbe Hartkamp et al. [11]	Netherlands	TOF MRA	74%	52 %	42 %
Mohamed AM et al. [12]	Egyptian	TOF MRA	68.3%	38.3%	46.7%
Naveen et al.[13]	Indian	TOF MRA	77.3%	33%	16.6%
Kondori et al.[14]	Tehran	TOF MRA	80.95%	20.95%	20.9%

Conclusion:

The morphological variations demonstrated by TOF-MRA in our study provide an important reference source for COW variations in the regional population. Our findings confirm the view that the configuration of the COW vary largely in our general population. Complete anterior COW is more common with incidence of 79.95 % of all cases. The most common anterior circle variant was type A (normal anterior configuration) with a prevalence of 67.71 %. The posterior circle was incomplete in 70.53% of cases. The most common posterior circle variant was type E, with aplasia of both posterior communicating arteries with separation of anterior and posterior circulation, seen in 44.42%. The prevalence of complete configuration of the circle was 26.76% and is slightly higher in females than males.

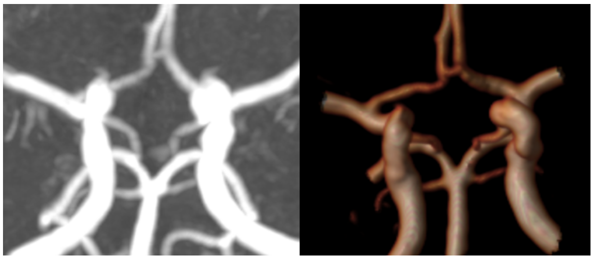

Figure 3: A. Maximum Intensity Projection (MIP) & B. 3-D volume rendered (VR) MRA of COW—Type A anterior circulation and Type A posterior circulation. Complete Circle of Willis.

Figure 4: A. Maximum Intensity Projection (MIP) & B. 3-D volume rendered (VR) MRA of COW—Type H anterior circulation and Type E posterior circulation.

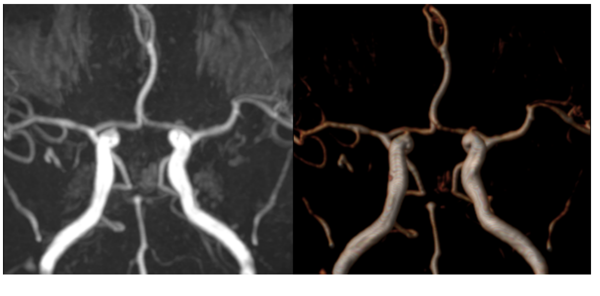

Figure 5: A. Maximum Intensity Projection (MIP) & B. 3-D volume rendered (VR) MRA of COW—Type E anterior circulation and Type I posterior circulation.

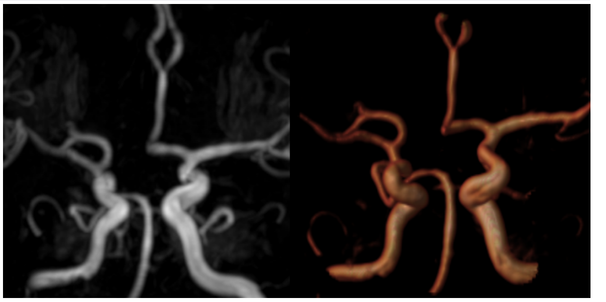

Figure 6: A. Maximum Intensity Projection (MIP) & B. 3-D volume rendered (VR) MRA of COW—Unclassified anterior circulation and Type F posterior circulation.

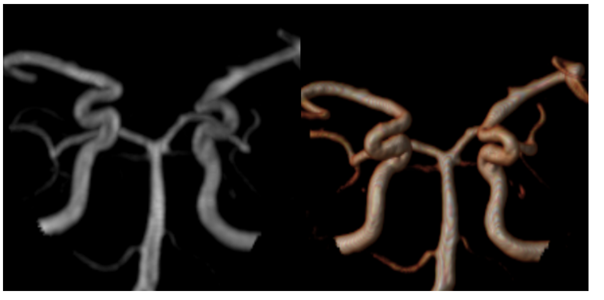

Figure 7: A. Maximum Intensity Projection (MIP) & B. 3-D volume rendered (VR) MRA of COW—Unclassifed anterior circulation with bilateral ACA agenesis and Type E posterior circulation.

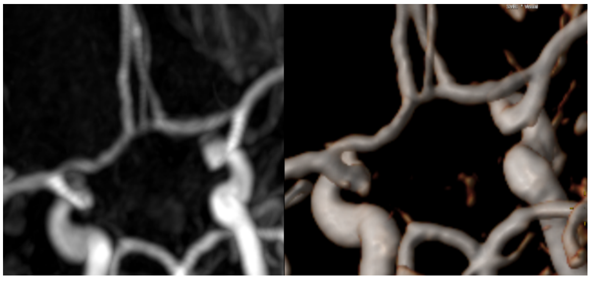

Figure 8: A. Maximum Intensity Projection (MIP) & B. 3-D volume rendered (VR) MRA of COW—Type C anterior circulation with median artery of corpus callosum arising from anterior communicating artery.

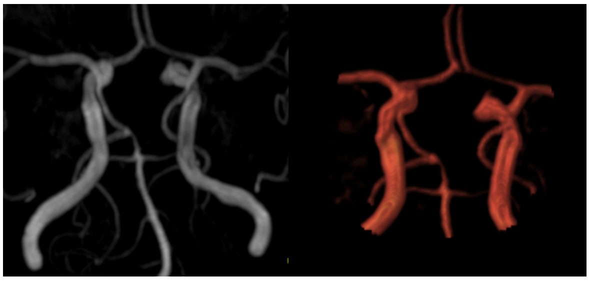

Figure 9: A. Maximum Intensity Projection (MIP) & B. 3-D volume rendered (VR) MRA of COW—Type G anterior circulation and Type J posterior circulation.

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