Original Article

Anatomical variations in circle of willis in a random study group

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Abstract

Objectives: To evaluate and to describe the prevalence and pattern of Circle of Willis (CW), arterial variants and associated anomalies in noncontrast 3D-TOF-MRA in a random study group and to investigate whether any sex- or age-related differences could be found in circle morphology. **Materials and Methods:** In a descriptive study, 180participants (108 men and72 women); mean age, 68 years referred for neuroischemic study protocol from June 2015 to June 2016 were included in the study. Images were obtained with the sequence of spoiled gradient-recalled acquisition (SPGR) using a 1.5-tesla MR scanner (Achieve; Philips Medical Systems). Images were reviewed for CW anatomy and configuration. **Observations and results:** The prevalence of complete configuration of the circle was50 % in younger than 40 years and 45% in older than 40 years and is slightly higher in females than males. Complete anterior CW is more common with incidence of 75% in < 40 years and 65% in > 40 years individuals. The most common anterior circle variant is type A with a prevalence of 40-45% and the least common is type C. The most common posterior circle variant was type E with incidence of 24% in less than 40 years and 17% in >40 years. Overall, CW variants are slightly more common among the women in comparison to men. **Conclusion:** The morphological variations demonstrated by TOF-MRA in our study provide an important reference source for CW variations in the regional population. Incidence of associated anomalies, like aneurysm is comparable to that described in literature.

Keywords: Circle of Willis, variants, neuroischaemic, aneurysm.

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Received Date: 10/06/2016 Revised Date: 15/07/2016 Accepted Date: 18/08/2016

Access this article online	
Quick Response Code:	Website: www.statperson.com
	DOI: 20 August 2016

INTRODUCTION

The circle of Willis (CW) is an intracranial collateral circulation system importantin patients with cerebrovascular diseases. CW by means of its potential blood redistribution can maintain adequate blood flow and decrease damage of lesion areas through function.[1,2] This compensation depends on the anatomical morphology of CW. The variation of CW can modify cerebral hemodynamics, resulting in various cerebrovascular diseases[3]. Several studies in particular, have correlated the formation of cerebral aneurysm with the morphology of CW.[4] Moreover, due to the large variations of CW on the normal population, diverse consequences of clinical disease prognoses are obtained. Earlier research of CW was mainly based on autopsy and did not reflect the normal physiological status. With the development of medical imaging, methods like magnetic resonance angiography (MRA) it enables great progress in the study of the morphology and variation of CW.[5]MRA as a noninvasive method provides a possible survey on massive healthy population. By conducting a retrospective analysis on the morphology and variation of CW from individuals with normal cerebral MRI, it may confirm the distribution of variations of CW, which will provide anatomical basis for future prognosis of cerebrovascular diseases.

MATERIALS AND METHODS

In a descriptive study, 180participants (108 men and 72 women); mean age, 68 years referred for neuroischemic study protocol from June 2015 to June 2016 were included in the study. Informed consent from the patient

How to site this article: Aarthi Parthasarathy, Sachin G Shatagar. Anatomical variations in circle of willis in a random study group. *International Journal of Recent Trends in Science and Technology* August 2016; 20(1): 140-145 http://www.statperson.com (accessed 22 August 2016).

or guardian was obtained before scanning. All patients (108 men and 72women; mean age, 68 years) underwent 3D-TOF MR angiograms of the CW. Images were obtained with the sequence of spoiled gradient-recalled acquisition (SPGR) using a 1.5-tesla MR scanner (Achieva; Philips Medical Systems). Images were reviewed for CW anatomy and configuration.

Inclusion Criteria

180 patients who were referred forneuroischemic study to Father Mullers Medical College, Mangalore during June 2015 to June 2016

Exclusion Criteria

1. Patients with pacemaker, ferromagnetic intracerebral aneurysm clips, or other metallic implants and patients with claustrophobia were excluded.
2. Uncooperative, ill patients who were not able to remain stable for study duration were also excluded

Procedure

Scanning technique: Patients were imaged in supine position, wherever necessary, after sedation with midazolam 0.07-0.08 mg/kg intramuscular (IM; approximately 5 mg IM) administered up to 1 h before the study in uncooperative patients. Examination was done with a dedicated head coil. Monitoring of vital signs of patient was performed throughout the scanning. Dedicated, optimized high-resolution 3D-TOF MRA protocol with repetition time (TR)/echo time (TE)/flip angle of 19/5.7 ms/16°, respectively, with isotropic resolution of 0.6×0.6×0.6 mm3 was used. T1-weighted volume scans and T2-weighted multisection fast-field echo anatomic scans were obtained for the detection of brain abnormalities. Scanning parameters included; slice thickness 1.2 mm, 0.6 mm slice overlap, field of view of 100×100 mm, and matrix 0.6×0.6×0.6 mm3 andTR-19 ms, TE - 5.7ms, and flip angle-16°. Totally 50 slices covering a volume of 30 mm (50×0.6 mm effective slice thickness) was obtained. The total imaging time was approximately 15 min, of which the 3D TOF MRA sequence required 3 min 24 s. These axial source images were post-processed by the maximumintensity projection (MIP) algorithm to produce eight projections rotating about the section axis. All component vessels of the CW were assessed by measuring the diameter on the individual MIP images. 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.[11,33] The images were also reviewed with volume rendering technique and evaluated in all the angles when needed. Arteries when seen as noncontinuous segments were considered as absent. The anterior and posterior parts of CW were evaluated separately and classified according to the scheme. The prevalence of each anatomic variant was documented.

Table 1: Parameters of 3D TOF MR angiography

	3D TOF
TR	30-40msc
TE	6-10 msc
FA	20-25
Slice thickness	0.8 mm
No. of partitions	96
Voxel Size (mm)	0.8x0,8x0.8-1.0

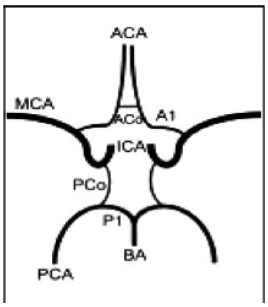

Figure 1: Schematic diagram of the vessels that form the circle of Willis the precommunicating segment (A1) of both anterior cerebral arteries (ACA) and anterior communicatingartery (ACo) between them forms the anterior part of the circle

The precommunicating segments (P1) of both posterior cerebralarteries (PCA) together with both posterior communicatingarteries (PCo) form the posterior part of the circle. MCA, middlecerebral artery; ICA, internal cerebral artery; BA, basilar artery.

RESULTS

Study group consisted of 180participants (108 men and72 women); mean age, 68 years. Distribution of males and females < 40 years and >40 years are described in Table 2.Common morphological types of CW variations and common types of anterior and posterior circulation are illustrated in Table 3 and 4. The illustrations for the variations in anterior circulation (Figure2) and in posterior circulation (Figure3). The prevalence of the variants of the anterior and posterior circle of Willis (CW) for different age groups of both sexes and for total subjects are also shown in tables 5 and 6. Mean vessels diameters with regard to age and sex with statistical significance is shown in Table 7.

Table 2: Distribution of males and females in the study population

Age	Male	Female	Total
<40y	35(63%)	23(37%)	58(33%)
>40y	73(58%)	49(42%)	122(67%)
Total	**108(60%)**	**72 (40%)**	**180**

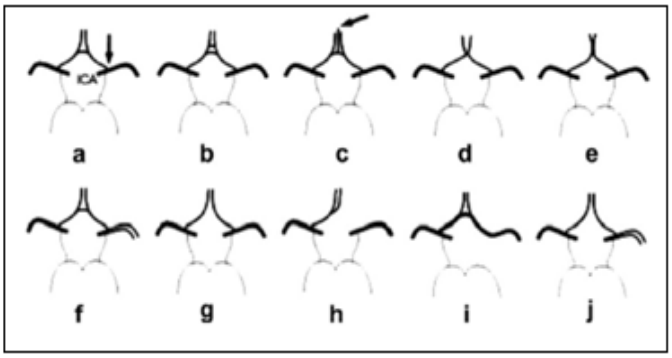

Figure 2: Schematic diagrams of anatomic variations in the anterior part of the COW.

(A) A single anterior communicating artery. The ICA bifurcates into the precommunicating segment of the anterior cerebral artery and the MCA. (B) Two or more AcomAs. (C) Medial artery of the corpus callosum arises from the AcomA. (D) Fusion of the ACAs occurs over a short distance. (E) ACA forms a common trunk and split distally into two postcommunicating segments. (F) MCA originates from the ICA as two separate trunks. (G) Hypoplasia or absence of an anterior communication. (H) One precommunicating segment of an ACA is hypoplastic or absent, the other precommunicating segment gives rise to both post-communicating segments of the ACAs. (I) Hypoplasia or absence of an ICA. The contralateral precommunicating segment of the ACA gives rise to both postcommunicating segments and supplies retrograde flow to theipsilateralprecommunicating segment, which, in turn, gives rise to the ipsilateral MCA (both ACAs and both MCAs are supplied by a single ICA). (J) Hypoplasia or absence of an anterior communication.

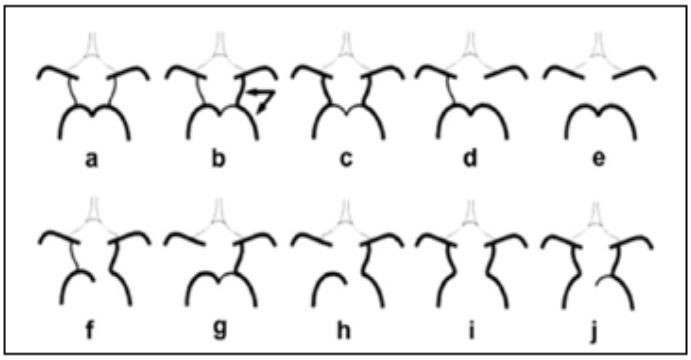

Figure 3: Schematic diagrams of the anatomical variations of the posterior part of the COW.

(A) Bilateral PcomAs are present. (B) PCA originates predominantly from the ICA. This variant is known as a unilateral fetal type posterior cerebral artery; the PcomA on the other side is patent. (C) Bilateral fetal type posterior cerebral arteries with both precommunicating segments of the PCAs patent. (D) Unilateral PcomA present. (E) Hypoplasia or absence of both PcomAs and isolation of the anterior and posterior parts of the circle at this level. (F)Unilateral fetal type posterior cerebral artery and hypoplasia or absence of the precommunicating segment of the posterior cerebral artery. (G) Unilateral fetal type posterior cerebral artery and hypoplasia or absence of contralateral PcomA. (H) Unilateral fetal type posterior cerebral artery and hypoplasia or absence of both precommunicating segments of the posterior cerebral artery and the PcomA.(I) Bilateral fetal type posterior cerebral arteries with hypoplasia or absence of both precommunicating segments of the PCAs. (J) Bilateral fetal type posterior cerebral arteries with hypoplasia.

Posterior circle variants

Table 3: Prevalence of variations in anterior part of circle of Willis

GROUP	A	B	C	D	E	F	G	H	I	J	Complete anterior configuration
<40 y	45	10	0	5	5	5	15	10	0	5	75%
>40 y	40	20	0.8	5	4.2	5	10	10	0	5	65%

Table 4: Prevalence of variants of the posterior part of circle of Willis

GROUP	A	B	C	D	E	F	G	H	I	J	Complete posterior configuration
<40 Y	5	10	5	10	25	5	5	20	10	5	40%
>40 Y	2.3	15	10.8	9.2	18.3	4.2	5	17.3	11.7	5	37.5%

Table 5: Prevalence of entirely complete, partially complete, incomplete configuration of COW according to sex

Group	Complete configuration (%)	Partial complete (%)	Incomplete configuration (%)
Male(n=108)	41.6	40.7	14.7
Female(n=72)	53.8	31.5	17.7
Total(180)	**46.7**	**37.2**	**16.1**

Table 6: Prevalence of entirely complete COW, partially complete and incomplete configuration of Circle of Willis according to age

Group	Complete configuration (%)	Partial configuration (%)	Incomplete configuration (%)
Age<40y(n=60)	50	38	12
Age>40 y (n=120)	45	36.5	18.5
Total(180)	**46.7**	**37.2**	**16.1**

Table 7: Mean vessels diameters with regard to age and sex and their statistical significance

Vessel	< 40 years	➢ 40 years	p value
ICA	3.51+0.16	3.86 +0.09	<0.001
BA	2.91+0.14	3.09 +0.12	<0.05
AI	2.15 +0.29	1.81 +0.09	<0.001
ACO	1.18 +0.07	1.14 +0.07	>0.05
PI	1.88 + 0.99	1.82 +0.09	>0.05
PCO	1.25 +0.99	1.16 +0.07	<0.01
Vessel	Mean diameter(males)	Mean diameter(females)	P value
ICA	3.72 + 0.20	3.71+0.22	<0.001
BA	3.06 + 0.16	2.94 +0.14	<0.001
AI	1.99 + 0.22	1.92 +0.22	<0.05
ACO	1.18 +0.07	1.12+0.47	<0.05
PI	1.89+0.07	1.79+0.99	>0.05
PCO	1.17+0.07	1.21 +0.09	>0.05

DISCUSSION

The configuration of the CW has been reviewed in many anatomical and clinical studies.[3,4,5,6,7]However,there are only limited studies that have systematically investigated the configuration of the CW in the general population.[9,10] There is a great significance to CW variations clinically, allowing causation of intracranial ischemia in incomplete circles. Though well-accepted clinically, sensitivity of 3D time-of-flight (TOF) MRA depends on the blood flow velocity of the vessel, and the technique may have difficulties in visualizing small vessels in the CW with turbulent or slow flow.[34] In most studies, MRA 3D acquisitions were made with either steady state precession (FSSP) or spoiled gradient technique (SPGR) using 1.5-tesla systems. From these studies, it is demonstrated that the prevalence of entire complete circle of Willis was seen in 21–42%[9],These variations in the results are related to several factors. Primarily, the selected study populations differ as they were performed in patients with neurovascular disease. Secondly the methods and techniques used in phase contrast or TOF MR angiography is operator dependent. Third, the variations in the sex and age distributions in the study populations. The mean age in our study was 68 years. In a similar study by Hartkamp and Grond[19] the mean age of the control group was 66. In another recent study[26] the percentages of entire complete circle of Willis were seen in 45% while in our study it was detected in 46.7%.The anterior circle configurations were complete in 65%of cases in this study. The other studies are in agreement with our results showing 68–78%[18,19]. In our study, complete anterior circle of Willis was higher in younger than in older cases. The complete posterior circle configurations demonstrated in 38.3% of our study population and the results reported by other studies showed 25–52% of the cases[8,26]In our study, complete posterior circle of Willis was higher in younger than older cases. These results were seen in other studies[8,18]. The prevalence of the complete circle in our study was lower in males (42.6) than females (52.8) and in older (45%)than younger subjects (50%). These results cope with the results of published studies by Chen *et al*[18] and Hafez *et al*,[26]. All of these studies used 3D TOF MR angiography in examination of the circle of Willis. Although 3D TOF MR angiography has been known to have a high specificity and sensitivity for depicting the anatomy of the circle of Willis, it shows limitations in displaying small collateral channels because of the turbulent flow or slower velocity of blood adjacent to the wall due to laminar flow[28]. The sensitivity of 3D TOFMRA in detection of small communicating vessels improves when flow through these channels increases, since an increase in flow velocity improves signal intensity.[28] Non-visualization of vessels on a TOF MRA could be due to negligible flow within a patent vessel or due to the true absence of the vessel. The mean diameter of centrifugal vessels is lower than the centripetal vessels in older individuals.[8,29] Vessel diameters of the circle of Willis were measured in original slices and MIP images and vessels measuring 0.8 mm diameter were considered present, those smaller than 0.8 mm were considered hypoplastic. The mean vessel diameters measured in our study compared well with other studies[6,8,18.] The findings in our study indicated that mean vessel diameters were different according to sex and age. The diameters of the centripetal vessels are larger than the centrifugal vessels

in older individuals which was statistically significant, while those of centrifugal tend to be smaller. This might be explained by compensatory enlargement of the centripetal vessels in elderly persons due to decreased elasticity or atherosclerosis of which its prevalence increased by age[8,27] In our study there was general trend of increased vessel diameters in males than females except the PCO artery which was slightly larger in females than males. Some of these differences were statistically significant. Hartkamp *et al* showed similar results in his study. El Barhoun *et al*[30]in a similar study demonstrated that the basilar artery diameter showed significant association with age.

CONCLUSION

The morphological variations demonstrated by TOF-MRA in our study provide an important reference source for CW variations in the regional population. Our findings confirm the view that the configuration of the CW vary largely in our general population. The prevalence of complete configuration of the circle was50% in younger than 40 years and 45% in older than 40 years and is slightly higher in females than males. Complete anterior CW is more common with incidence of 75% in < 40 years and 65% in > 40 years individuals. The most common anterior circle variant is type A (normal anterior configuration) with a prevalence of 40-45% and the least common is type C and Type I. The most common posterior circle variant was type E (hypoplasia or absence of both Pcom As and isolation of the anterior and posterior parts of the circle at this level) with incidence of 24% in less than 40 years and 17% in >40 years. Overall, CW variants are slightly more common among the women in comparison to men. Some of the vessel diameters show statistically significant differences according to age and sex. Incidence of associated anomalies, like aneurysm is comparable to that described in literature.

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Source of Support: None Declared
Conflict of Interest: None Declared