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MRA-based evaluation of anatomical variation of circle of Willis in adult Pakistanis

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RESEARCH ARTICLE

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Abstract

Objective: To determine the frequency and patterns of normal anatomical variation of Circle of Willis on magnetic resonance angiogram in adults without cerebrovascular disease.

Methods: This descriptive cross-sectional study was conducted at the Radiology Department of Dow University of Health Sciences / Civil Hospital, Karachi, from January to December 2016, and comprised patients referred for magnetic resonance imaging of the brain and magnetic resonance angiogram without any clinical or radiological manifestation of cerebrovascular disease, primarily including those with suspected demyelination, infection, epilepsy or metastases. Three-dimensional time-of-flight magnetic resonance angiography was performed. The Circle of Willis was assessed for its completeness along with anatomical variations of anterior and posterior components of the circle.

Results: Of the 135 subjects, 70(51.8%) were males and 65(48.2%) were females with an overall mean age of 49.26±9.2 years. Among all the subjects, 30(22.2%) showed a complete circle, while 82 (60.7%) and 23(17.1%) had partially complete and incomplete circles respectively. The anterior part of the circle was completed in 108 (80%) subjects, showing type 'a' as the most common variant in 93(68.9%). The posterior part of the circle was completed in 30 (22.2%) subjects with type 'e' variant in 52(38.5%).

Conclusion: There was a wide variability in the anatomy of the Circle of Willis in Pakistani adults asymptomatic for cerebrovascular disease.

Keywords: Anatomical variation, Cerebral arteries, Circle of Willis, 3D-TOF MR Angiography, Complete circle, Anterior circulation, Posterior circulation. (JPMA 68: 187; 2018)

Introduction

The Circle of Willis (COW) is a ring of interconnecting arteries present at the base of brain that supplies blood to the brain and neighbouring structures. It consists of anterior cerebral, anterior communicating, internal carotid, posterior cerebral and posterior communicating arteries intercommunicating in a ring-like formation.[1,2] It was described along with its physiological significance by Thomas Willis in 1664.[3] This arterial circle is essential for the maintenance of a stable and constant blood flow to the brain, and also for preventing or minimising ischaemic infarctions and maintaining the perfusion during surgeries, especially the cardiac surgery, so any changes in its morphology may lead to the appearance of variable symptoms of vascular insufficiency.[4,5]

Considerable anatomic variation exists in the arteries of COW in their formation, development and size. Different abnormalities such as absence, hypoplastic and accessory vessels have been observed.[2,6] Studies have shown that these variations play an important role in the development of cerebrovascular disorders, such as aneurysms, infarcts and other vascular anomalies.[6,7] So identification of such variations in a specified population is important in the evaluation of cerebral vascular morbidity for adequate treatment. A thorough knowledge of the variations of vessels is also useful to neurosurgeons in planning the shunt operations and in determining the adequacy of the brain circulation for cerebral aneurysms surgery.[8]

Previously, most of the studies about COW were based primarily on autopsy findings that did not reflect the normal physiological status. Magnetic resonance angiography (MRA) provides an opportunity for imaging the vessels in the living. It is widely used in clinical practices and research due to its non-invasive, non-contrast and non-radiation imaging quality, which has enabled remarkable progress in the imaging of the intracranial vasculature for its morphology and variation.[4] Three-dimensional time-of-flight (3D-TOF) MRA is a sensitive imaging technique providing the morphological as well as haemodynamic information concerning blood flow direction in individual vessels accurately. It not only shows the distribution of COW variation, but provides the anatomical basis for future prognosis as well as treatment of cerebrovascular diseases and in planning neurosurgical procedures.[9,10]

There is limited information about the normal cerebral

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vascular anatomical variations in Pakistani population. One may take a variation for stenosis and pathology so knowledge of population-specific variations is important. The current study was planned to determine the morphology and congenital anatomical variations of COW on MRA in adult Pakistanis without cerebrovascular pathology.

Subjects and Methods

The descriptive cross-sectional hospital-based study was conducted at the Computed Tomography (CT) and Magnetic Resonance Imagig (MRI) Centre, Dow University of Health Sciences/Civil Hospital, Karachi, from January to December 2016. It comprised patients of either gender between 20 and 70 years of age without prior history of cerebrovascular accident (CVA) or vascular disease. Primarily included were those referred for suspected demyelination, infection, epilepsy or metastases. Patients who had claustrophobia, CVA, known arteriovenous malformation (AVM), AV fistula, aneurysm primary intracranial tumour, any peripheral vascular disease, diabetes or hypertension were excluded.

The sample size was calculated by Openepi Version 3, taking 66% type 'a' anterior circulation among patients without prior history of CVA or vascular disease,[11] 8% error margin width and 95% confidence interval (CI) level. Written informed consent was obtained from each subject. As it was a completely descriptive, non-interventional study, institutional ethical approval was not sought.

3D-TOF MRAs of COW were obtained using spoiled gradient-recalled acquisition (SPGR) sequence on a 1.5-Tesla MR scanner (GE Health Care Signa H D). These images were post-processed by the maximum-intensity projection (MIP) algorithm. All component vessels of the COW were accessed on MIP as well as TOF source images on workstation (Victrea®). Vessels visualised as continuous segments of at least 0.8mm in diametre were considered present and less than 0.8 mm in diameter were considered hypoplastic.[11,12] Vessels visualised as non-continuous segments were considered absent.[11,12] The anterior and posterior parts of COW were evaluated separately and classified according to the scheme proposed in literature.[13] The frequency of each anatomic variant was calculated. Foetal type posterior communicating artery (FTPcomA) was considered when the posterior cerebral artery (PCA) originated from the ipsilateral internal carotid artery (ICA) instead of the basilar artery with diameter greater than the ipsilateral pre-communicating segment (P1) of the PCA.[12] Vessel arising from ICA with equal or smaller diameter than the ipsilateral P1 of the PCA were classified as PcomAs.[12] COW was then classified as complete, partially complete and incomplete configuration. The frequency of each class was assessed. Complete configuration of the circle was considered when both anterior and posterior parts of the arterial circle formed a complete circle, while partially complete configuration meant either anterior or posterior parts of the arterial circle formed a complete circle.[12] Incomplete configuration meant that neither anterior nor posterior part of the circle formed a complete circle.[12]

Data collected was analysed by SSPS 20. Measures of central tendency and dispersion were calculated as mean, standard deviation and range along with frequency and percentages.

Results

Of the 135 subjects, 70(51.8%) were males and 65(48.2%) were females with a overall mean age of 49.26±9.2 years

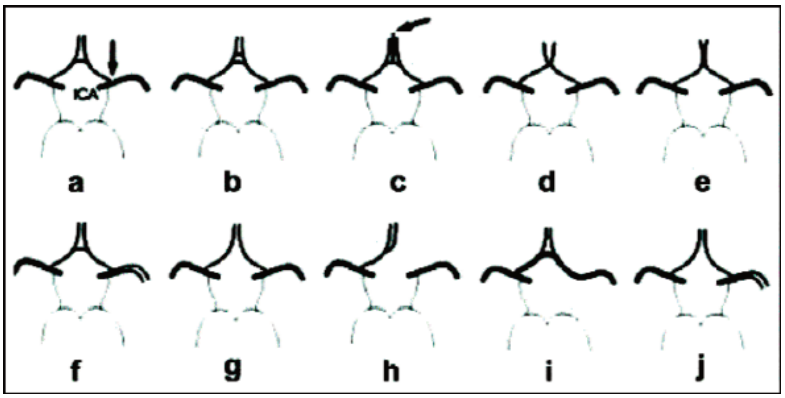

Figure-1: Schematic diagrams of anatomical variations of the anterior part of the Circle of Willis.

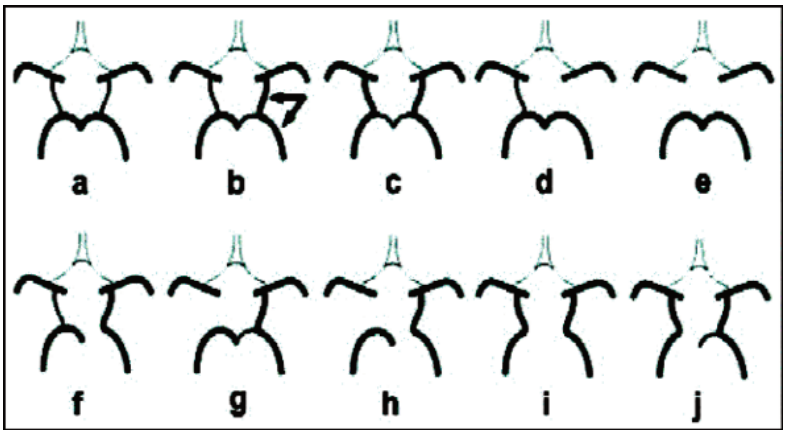

Figure-2: Schematic diagrams of anatomical variations of the posterior part of the circle of Willis.

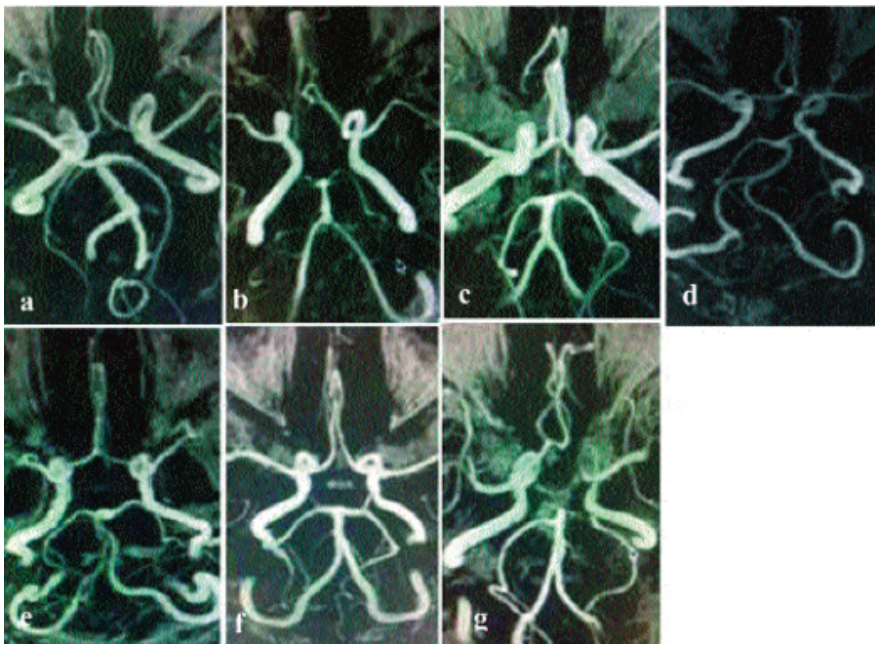

Figure-3: Magnetic resonance angiogram (MRA) images of the circle of Willis (COW) showing anatomic variations in the anterior part of the circle. a) A single anterior communicating artery (AcomA) with normal A1 segment of the anterior cerebral artery (ACA) and the middle cerebral artery (MCA). b) Two AcomAs. c) Collsomarginal artery arising from the AcomA. d) Fusion of the ACAs over a short distance. e) ACA forms a common trunk and split distally into two A2 segments. f) Absent AcomA. g) Absent left A1-segment of the ACA, the other A1-segment gives rise to both A2 segments of the ACAs.

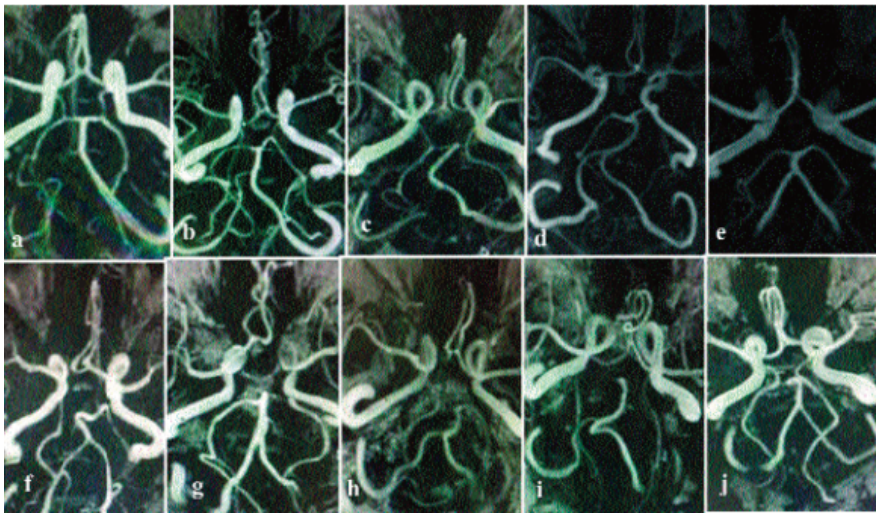

Figure-4: Magnetic resonance angiogram (MRA) images of the circle of Willis (COW) showing anatomical variations of the posterior part of the circle. a) Bilateral posterior communicating arteries (PcomAs) are present. b) Right posterior cerebral artery (PCA) originates predominantly from the internal carotid artery (ICA) (unilateral foetal type PCA); the PcomA on the other side is patent. c) Bilateral foetal type PCAs with both P1-segments of the PCAs patent. d) Right PcomA (unilateral) present. e) Absent PcomAs bilaterally and isolation of the anterior and posterior parts of the circle at this level. f) Right-sided foetal type PCA (unilateral) with ipsilateral absent P1-segment of the PCA. g). Left-sided foetal type PCA and absent right PcomA. h) Right-sided foetal type PCA with ipsilateral absent pre-communicating (P1) segment of the PCA and hypoplastic left PcomA. i) Bilateral foetal type PCAs with hypoplastic both P1-segments of the PCAs. j) Bilateral foetal type PCAs with hypoplastic P1-segment of right PCA.

(range: 20-70 years).

Overall, 30(22.2%) circles were normal and complete in anatomical configuration and 105(77.8%) were anomalous either due to asymmetrical paired vessels, unilaterally or bilaterally absent and hypoplastic PcomAs, absent or double AcomAs.

The anterior circle was complete in 108(80%) subjects with a normal configuration (type a) in 93(68.9%). The anterior circle was incomplete in 27(20%) subjects with compromised anterior collateral flow due to absent AcomA in 20(14.8%) subjects and hypoplastic/absent A1 in 7(5.2%). Out of these 7 patients, A1 was absent in 4(57.4%) and hypoplastic in 3(42.6%) patients. Double AcomA was found in 2(1.5%) and collasomarginal artery in 3(2.2%) patients. Double middle cerebral artery (MCA) or absent ICA were not found in any case.

The posterior circle was complete in 30(22.2%) patients and incomplete in 105(77.8%). The unilateral FTPcomA-type b, f, g and h was seen in 30(22.2%) and bilateral FTPcomA (type c, i and j) in 11(8.15%) of patients. More anatomical variation and incomplete collaterals were seen in posterior part of circle compared to the anterior part. A FTP-COW was seen in 41(30.4%) patients. Of them, 28(68%) were classified as having partial FTP due to the presence of hypoplastic P1 segment and 10(24%) as full FTP due to absent P1 segment. The most common posterior configuration was type-e seen in 52(38.5%) patients Morphological variants of anterior part of COW (Figures 1-2) as well as those of posterior part (Figures 3-4) were studied to identify types and their frequencies (Table).

The most common anomaly of COW was hypoplasia/absence of one or other components of the circle. The hypoplastic/absent vessels were encountered either alone or in

Table: Frequency of variants of the anterior and posterior part of the circle of Willis.

Anterior circulation		Posterior circulation	
Variants	**Frequency**	**Variants**	**Frequency**
a	93 (68.9%)	a	22 (16.3%)
b	2 (1.5%)	b	4 (3.0%)
c	3 (2.2%)	c	4 (3.0%)
d	7 (5.2%)	d	20 (14.8%)
e	3 (2.2%)	e	52 (38.5%)
f	0	f	5 (3.7%)
g	20 (14.8%)	g	7 (5.2%)
h	7 (5.2%)	h	14 (10.3%)
i	0	i	4 (3.0%)
j	0	j	3 (2.2%)
Complete circulation	108 (80%)	Complete circulation	30 (22.2%)

combination with other anomalies in 105(77.8%) circles. Of these vessels, the PcomA was the most frequently hypoplastic/absent in 93(68.9%), followed by P-1 segment of the PCA in 26(19.2%), AcomA in 20(14.8%) and A-1 segment of the ACA in 7(5.2%) subjects.

Discussion

COW is one of the most important arterial anastomotic systems in the human body and its morphology as well as function has been studied widely. However, majority of previous studies were done on autopsies that showed limitations in relationship between COW's morphology and physiological changes of haemodynamic system, but MRA has quite high sensitivity in demonstrating and providing the haemodynamic information of the intracranial arteries.[4]

The present study focussed on the anatomical variants of the arteries of COW, including the AcomA, the pre-communicating segment (A1) of the ACA, the pre-communicating segment (P1) of the PCA, the PcomA, and ICA on MRA. These arterial variations have a major role in management of cerebrovascular accident and planning the surgery. Whenever there is significantly reduced flow either in the ICA or basilar artery due to any reason, the cerebral perfusion is maintained by the collateral vessels like AcomAs and PcomAs.[12] A study[14] showed increased risk of stroke in cases of ICA occlusion with absent/hypoplastic PcomA.

The mean age of the patients was 49.26 ± 9.2 years in this study which showed complete COW in 22.2%, partially complete circle in 60.7% and incomplete circle in 17.1%. These findings were comparable with a study[4] that demonstrated the prevalence of 21.30%, 61.14% and 17.55%, another[10] showing 12.24%, 70.17% and 17.59% and one other[11] showing 16.6%, 61.3% and 22% respectively. This study was also comparable with another study[9] in terms of complete configuration of COW.

The anterior COW was completed in 80% of cases in this study. This result closely matches that of other studies.[4,9,11,15] In this study, the commonest anterior variation was the presence of complete arteries with single AcomA (type a) seen in 68.9%. This was in agreement with earlier studies.[4,9,11] The next commonest anterior variation was absent AcomA (type g) that was seen in 14.8% cases. This was comparable with literature.[8,9] While another study[16] found only one case of absent AcomA in 102 patients.

The complete posterior COW was seen in 22.2% cases. Chen et al. found 25.44%, Kondori et al. found 20.95% and Qui et al. found 16.07% for the same.[4,9,11] In the present study, the commonest posterior variation was the absence of bilateral PcomAs (type e) seen in 38.5%. This is less than those by Chen et al. (42.8%) and Kondori et al. (44.7%) and higher than those by Naveen et al. (32.66%).[4,9,11] The next common posterior circle variation was the presence of pcomAs bilaterally (type a) that was seen in 16.3% of cases. This was consistent with finding by Chen et al.[4] and Kondori et al.[9] FTP-COW was detected in 30.4% of cases, further categorised by unilateral FTP (type b, f, g and h) in 22.2% and bilateral FTP (type c, i and j) in 8.2% of patients. Similar results were also seen in studies by Chen et al. and Naveen et al.[4,11] Various studies have been done to explain the reason of development of FT-PCA. Van Overbeeke et al. categorised the various configuration of COW in foetus.[17] There is a transitional type in early foetal life, in which diameters of P1 segment of PCA and PComA are equal; with the growth of the foetus this would either transform into adult type in which P1 diameter is larger than the PComA diameter or into foetal type in which diameter of the P1 is smaller than diameter of PcomA.[12] Van Overbeeke et al. and Milenkovic et al. concluded that rapid development of occipital lobes occurs during foetal life that increases the demand for vasculature which significantly affects the final form of COW, particularly in the posterior circle and can lead to development of either adult or foetal configuration from transitional configuration.[17,18]

The sensitivity of MRA is high in evaluating the normal variants and providing the haemodynamic information of the intracranial arteries but there are also some limitations as well like the vessels with turbulent or slow flow are not visualised on TOF-MRA images despite being patent.[4,12]

This study demonstrated the wide range of variations in COW in adult Pakistanis as seen in other studies. This wide variation may be either due to a different type of study

population, different methods as well as techniques of studies or variation in age and gender of study population.

Conclusion

The present study showed a marked variability of the morphology of COW in adult Pakistanis, particularly in the posterior part of COW. These anatomical variations provide an important reference source for the regional population and should be reported in the MRA findings because these can increase the risk of stroke, aneurysm, and vascular anomalies. The wide range in the morphology of COW among various races warrants further research on larger population to confirm the influence of genetic, regional, environmental and haemodynamic factors or the combination of these factors.

Disclaimer: None.

Conflict of Interest: None.

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