Original Research Article

Evaluation of normal variants of circle of Willis at MRI

Peyush Pattayil Keeranghat, Jagadeesan D.*, Prakash M. L., Radha Gupta

Department of Radiodiagnosis, MGMCRI, Pillayarkuppam, Pondicherry, Tamil Nadu, India

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*Correspondence:
Dr. Jagadeesan D.,
E-mail: sonyjickey@gmail.com

ABSTRACT

Background: Anatomy of circle of Willis (COW) shows extensive variations in different individuals and signifies the causation and presentation of clinical disease. The present study aims to evaluate the different anatomical variations of the Circle of Willis (COW) in general population, using magnetic resonance (MR) 3D-time of flight angiography and to correlate the observations with age and gender characteristics.

Methods: This observational clinical study was conducted January 2013 to March 2014 in 503patients who were referred for MRI – Brain. MRI (Philips 1.5 Tesla magnet) with routine brain sequences along with 3D –TOF MRA was done in all patients. The anatomical variants of the anterior and posterior components of the COW were studied. The complete COW was assessed and the diameters of all the components were measured. The correlation between the vessel diameters in relations to age and gender were evaluated.

Results: The mean age group of study participants was 42 years. Male dominance was seen among participants (57.1%). The complete configuration of the circle was seen in 31.6% of population. Most common anterior variant is type A (normal anterior configuration) with a prevalence of 52.9% and posterior variant is type K with a prevalence of 32.9%. Average diameters of the proximal vessels supplying the COW were larger in the older age subjects (centripetal vessels, the right and left ICA s and BA). Statistically significant differences between the mean vessel diameters between males and females were seen in the ICA-RT, ICA-LT, and PCOA-LT.

Conclusions: The present study showed great variability of the anatomy of the COW in asymptomatic person. Various variants of COW can be picked up by MRA which is safer and non-invasive when compared with CTA / DSA. Knowledge of these variations would help in planning surgical procedures as well as preventing unwanted interventions.

Keywords: Anatomical variations, Circle of Willis, Magnetic resonance 3D-time of flight angiography, Vessel diameters

INTRODUCTION

The brain represents only 2% of the total body weight, but it receives 1/5th of the resting cardiac output. This blood supply is carried by the two internal carotid arteries and the two vertebral arteries that anastomose at the base of the brain to form the "Circle of Willis" (COW).[1] The COW is divided into two anterior and posterior portions depending upon the blood supply to the part of the brain. Carotid arteries and their branches contribute the anterior circulation and the vertebro-basilar system contributes to the posterior circulation.[2] Approximately 42% of general population has complete COW, and over 50% of population shows anatomical variations of COW.[3] They include changes in vessel diameters, hypoplasia, addition of certain branches and agenesis.[4] Significant variations in the COW are strongly correlated with the relative contributions of the flow rates of proximal arteries.[5] These anatomic variations in COW may affect the outcomes particularly in patients with carotid artery diseases.

Many studies reported the anatomical variations of the COW.[6,7] These variations can be effectively studied by transcranial Doppler ultrasound, digital contrast enhanced angiography or magnetic resonance angiography (MRA).[8,9] Among them three-dimensional time-of-flight (3D-TOF) MRA is a sensitive, noninvasive imaging modality suitable for detecting the variations in the anatomy of the COW in both healthy volunteers and patients with carotid artery disease, even though risks related to patient's exposure to radiation use of contrast agents are involved.[10,11]

The aim of this study is to evaluate the different anatomical variations of the Circle of Willis (COW) in local population, using magnetic resonance (MR) 3D-time of flight angiography. In addition to this, the objective of the study was to determine the average vessel diameter in different anatomic variations and to evaluate the age and gender related differences according to configurations.

METHODS

This was an observational clinical study conducted in the department of radio diagnosis, at Mahatma Gandhi medical college and research institute, Pondicherry, India over a time period of one year and five months from January 2013 to March 2014. The study included 503 patients after meeting the requirements of inclusion criteria. After getting approval from institutional ethics committee and written informed consent from the patients or guardians, all the patients were subjected to 3D- time of flight (TOF) MR angiograms (MRA) of the circle of Willis (COW) by using a 1.5 Tesla MRI machine.

Scanning was done with following parameters: TR-20 to 30 ms, TE-6 to 10 ms, FA-20 to 25 degree, ST- 0.7 mm, FOV-160, Voxel size-0.8 to 0.8, 0.8 to 1.0 mm, and with an average scan time of 5 to 6 minutes. All the images were analysed by senior consultant, then findings were reported independently. Images that satisfy the inclusion criteria were isolated.

Isolated MRA data were assessed on a workstation with NOVA PACS software, by using MIP as well as source images. The variations in COW among gender were noted. All the component vessels of the COW were assessed by measuring the diameter on the individual transverse 3D TOF sections. Vessels that showed at least 1 mm in diameter were considered as hypo plastic. The anterior and posterior parts of CW were evaluated separately and classified according to the scheme. The prevalence of each anatomic variant was documented.

Statistical analysis

Descriptive and inferential statistical analysis has been carried out in the present study. Results on continuous measurements are presented on Mean±SD (Min-Max) and results on categorical measurements are presented in number (%). Analysis of variance (ANOVA) has been used to find the significance of study parameters between three or more groups of patients, Student t test (two tailed, independent) has been used to find the significance of study parameters on continuous scale between two groups (Inter group analysis) on metric parameters. Chi-square/Fisher Exact test has been used to find the significance of study parameters on categorical scale between two or more groups. All the p values <0.05 considered as statistically significant.

RESULTS

This observational radiological study included 503 patients. Among them majority were in the age group of 51-60 (18.1%), 41-50 (17.3%) and least was among >70 years (6.4%). The mean age was 42.03±19.08 years. Male predominance (57.1%) was seen in the study. On analyzing the total samples of COW, partial type of configuration (53.5%) was seen in majority of the patients compared to complete and incomplete configurations (Table 1).

Table 1: Demographic and configuration characteristics of study participants.

Characteristics	No. of patients (n=503)	Percentage (%)
Age in years		
1-10	40	8.0
11-20	43	8.5
21-30	76	15.1
31-40	77	15.3
41-50	87	17.3
51-60	91	18.1
61-70	57	11.3
>70	32	6.4
Gender		
Male	287	57.1
Female	216	42.9
Configuration of COW		
Complete	159	31.6
Partial	269	53.5
Incomplete	75	14.9

The prevalence of variants of the anterior and posterior COW was given in Table 2. The commonest variation involving the anterior part of the COW was type-A, and the commonest variation involving the posterior part of the COW was type-K which is slightly more when compared with type-O (32.8% versus 31.6%).

Among other variants of COW which represents only 6.2% of the total sample studied, fenestration was seen among 2.2% of study population. The PTA SLTZ–2 was the most common and most cephalic of the persistent carotid-vertebrobasilar anastomoses (Table 3).

Table 2: Prevalence of variants involving the anterior and posterior part of COW.

Anterior	No. of patients (n=503)	(%)	Posterior	No. of patients (n=503)	(%)
A	266	52.9	K	165	32.8
B	51	10.1	L	12	2.4
C	14	2.8	M	4	0.8
D	45	8.9	N	81	16.1
E	50	9.9	O	159	31.6
F	0	0.0	P	44	8.7
G	29	5.8	Q	9	1.8
H	64	12.7	R	9	1.8
I	0	0.0	S	14	2.8
J	3	0.6	T	4	0.8

Table 3: Prevalence of other variants involving the COW.

Other variants	No. of patients (n=503)	%
Nil	472	93.8
Yes	31	6.2
Azygos ACA	2	0.4
Bi hemispheric ACA	5	1.0
Dolichoectasia - LVA & BA	1	0.2
Duplication	7	1.4
Fenestration	11	2.2
PHA	2	0.4
PTA SLTZ -2	3	0.6

ACA- Anterior cerebral artery, LVA- Left vertebral artery, BA- Basilar artery, PHA- Persistent hypoglossal artery, PTA SLTZ–2- Persistent trigeminal artery-Saltzman type 2.

Age and gender related differences and their statistical significance in vessel diameters are demonstrated in Table 4. Average diameters of the proximal vessels supplying the COW were larger in the older age subjects (centripetal vessels, the right and left ICA s and BA). However, the distal branches of the circle which supply the brain (centrifugal vessel) demonstrate similar diameters to that of the older subjects.

These age related differences proved to be statistically significant for the P1-RT, and PCOA-RT, in this study. There were statistically significant differences between the mean vessel diameters between males and females in the ICA-RT, ICA-LT, and PCOA-LT.

Table 5 presents the distribution of vessel diameter (in mm) according to configuration. Statistically significant differences between the mean vessel diameters and configurations were seen in P1-RT, PCOA-RT, PXOA-LT, ICA-RT, A1-RT, A1-LT.

The findings tabulated in Table 6 showed significant correlation between different configurations with age and gender. Significant correlation was seen among different configurations with age and gender. Higher percentage of complete configuration was noticed in younger patients (39.4%) and in females (36.1%).

Table 4: Vessel diameter (in mm) according to age and gender.

Vessel diameter (in mm)	Age in years		P value	Gender		P value
	≤40 years	>40 years		Male	Female	
A. BA	3.19±0.26	3.22±0.37	0.402	3.22±0.36	3.19±0.27	0.234
B. P1-RT	2.11±0.38	1.99±0.53	0.005**	2.04±0.49	2.05±0.45	0.868
C. P1-LT	2.08±0.38	2.09±0.41	0.863	2.07±0.42	2.12±0.35	0.174
D. PCOA-RT	1.35±0.36	1.51±0.51	0.001**	1.46±0.47	1.40±0.42	0.243
E. PCOA-LT	1.33±0.33	1.39±0.41	0.151	1.40±0.39	1.31±0.33	0.027*
F. ICA-RT	3.94±0.25	3.98±0.32	0.154	3.98±0.31	3.93±0.26	0.039*
G. ICA-LT	4.08±0.29	4.12±0.33	0.143	4.14±0.33	4.06±0.27	0.007**
H. A1-RT	2.08±0.41	2.1±0.42	0.617	2.10±0.43	2.09±0.40	0.731
I. A1-LT	2.18±0.31	2.18±0.29	0.951	2.18±0.29	2.17±0.30	0.751
J. ACOA	1.23±0.11	1.23±0.12	0.700	1.23±0.11	1.23±0.12	0.822

BA- Basilar artery, P1- Posterior cerebral artery– first segment, PCOA- Posterior communicating artery, ICA- Internal carotid artery, A1- Anterior cerebral artery– first segment, RT- Right, LT- Left, ACOA- Anterior communicating artery.*= Moderately significant (P value: $0.01 < P \leq 0.05$); **= Strongly significant (P value: $P \leq 0.01$).

DISCUSSION

This observational clinical study included 503 humans of both the gender who were referred to our department for MRI-BRAIN with various clinical diagnoses following the inclusion criteria. The 3D-TOF MRA findings of normal and congenital variants in COW were illustrated with the use of individual source and MIP images to determine the average vessel diameter, and gender related differences.

The knowledge of the presence and clinical relevance of normal variants plays a crucial role in the diagnosis, management and in surgical planning of the patient.[12]

As mentioned in the previous literatures the main finding is that the variations in the COW are common and demonstrated that 3D-TOF MRA is a sensitive, non-invasive imaging modality suitable for evaluation of the COW, similar to our study. Moreover, the other risks related to CXA and CTA, mainly due to the adverse reactions to contrast medium and radiation exposure had made MRA superior though its time consuming.[10,11]

Table 5: Vessel diameter (in mm) according to configuration.

Vessel diameter (in mm)	Configuration			P value
	Complete	Partial	Incomplete	
A. BA	3.18±0.29	3.21±0.31	3.25±0.42	0.256
B. P1-RT	2.17±0.22	2.01±0.51	1.88±0.63	<0.001**
C. P1-LT	2.17±0.22	2.05±0.44	2.05±0.49	0.273
D. PCOA-RT	1.28±0.22	1.52±0.53	1.77±0.55	<0.001**
E. PXOA-LT	1.27±0.16	1.43±0.47	1.47±0.48	<0.001**
F. ICA-RT	3.92±0.30	3.95±0.26	4.07±0.33	0.001**
G. ICA-LT	4.08±0.32	4.10±0.31	4.15±0.32	0.280
H. A1-RT	2.17±0.27	2.12±0.39	1.79±0.64	<0.001**
I. A1-LT	2.20±0.22	2.19±0.27	2.08±0.48	0.014*
J. ACOA	1.23±0.12	1.23±0.11	1.21±0.12	0.501

BA- Basilar artery, P1- Posterior cerebral artery– first segment, PCOA- Posterior communicating artery, ICA- Internal carotid artery, A1- Anterior cerebral artery– first segment, RT- Right, LT- Left, ACOA- Anterior communicating artery.*= Moderately significant (P value: $0.01 < P \leq 0.05$); **= Strongly significant (P value: $P \leq 0.01$).

Table 6: Age and gender distribution according to configuration.

Variables	Total number of patients	Configuration			P value
		Complete (n=159)	Partial (n=269)	Incomplete (n=75)	
Age in years					
≤40 years	226	89 (39.4%)	116 (51.3%)	21 (9.3%)	<0.001**
>40 years	277	70 (25.3%)	153 (55.2%)	54 (19.5%)	
Gender					
Male	287	81 (28.2%)	154 (53.7%)	52 (18.1%)	0.030*
Female	216	78 (36.1%)	115 (53.2%)	23 (10.6%)	

Our study included 503 participants (males-286, females-216) and all age groups with a vast difference ranging (1 month to 82 years of age), with a mean age of 42 years. Sample size was similar to that of Chen et al, study with a similar configuration machine on 507 patients using 3D TOF-MRA, his study included 241 males and 266 females, aged from 18 to 89 years.[10]

In our study, the morphology of COW shows complete type of configuration in 31.6%, partially complete in 53.5%, and incomplete in 14.9% all these findings were similar to that of, and in a study by Hafez et al, the complete configuration was higher than partially complete type 38.3% versus 45%, however the sample size is different in each study.[13]

Our study showed 8 variants in anterior part of COW, among which type A is more common with 52.9%, there was no evidence of type F, and type I which is similar to that of Hafez et al were 4 variants types- C, F, I, J was not demonstrated.[13] In a study conducted by Chen et al, all 10 variants was seen.[10] The next common variant in the present study was type H, it was seen in 12.7%. Similar result was reported by prior studies Hafez et al, it was 15% in males and 20% in females.[13] In contrary Maaly et al, it was type B which was common in age group less than 40 years of age, and type G in ages more than 40.[14]

In our study the posterior part of COW showed all the 10 correlated variants, among which type K and type O were common with 32.8% and 31.6% respectively, which is similar to that of Hafez et al, were type K was found in 30% males and 26.6% females followed by type N.[13] The next common variant in the present study was type N, which was seen in 16.1%. Similar result was reported by prior studies Hafez et al, it was 20% in both males and females.[13] Type-M and T was found least about 0.8% in the present study, type-T was not seen in a study by Hafez et al.[13] And there was a significant difference among author's in predicting a comparable uncommon variant of posterior circle. However, in the current work,

separate list for variations among males and females or age groups in the anterior and posterior part of the circle were not made.

Prevalence of other variants involving COW was found only in 6.2% among which the fenestration was common found in 2.2% of the whole sample studied. PTA was seen at 0.6% of study population all were of type-2, other two types was not seen in our study. In a study by Dimmick et al by using CTA he demonstrated several other variants however the statistical analyses were lacking.[12]

In present study the average transverse diameter of vessels forming the COW that showed at least or less than 1 mm in diameter were considered as hypoplastic which was similar to that of Hafez et al.[13] On analysing the mean vessel diameter by gender mean diameters of the male vessels was larger than the female vessels, and there was significant P value for ICAs and left PCOA which were all increased in calliper among males when compared to that of females. However the calliper of left P1 segment was found more in females when compared to males, which is contradict to the study by Hafez et al, were his study demonstrates similar values except for the PCOA which in his study found to be larger by calliper in females.[13] Mean vessel diameter by age in our study showed similarities of past studies by Chen et al and Maaly et al.[10,14] In present study, there was a significant P-value for right PCOA which appeared larger in age groups more than 40 years of age when compared to younger age groups, which again contradicts with a study by Maaly et al, were the PCOA measured larger in younger age group, however the right and left side vessels was not assessed separately in their study.[14]

In the present study, the prevalence of entirely complete CW was 36.1%, higher in females than males (28.2 %) and young than older subjects (39.4 and 25.3%, respectively). Previous studies also shown higher incidence of complete circles in female patients and younger patients.[10,15]

Limitations of our study

The present study included only single observer for measurement of the vessel diameter, hence most of the measurement normally could vary from user to user or by the same user over time. Next would be the lack of measurement of length of a vessel included which was done in earlier studies, which too will be useful in surgical planning. Specific age groups either adult or paediatric population and clinical diagnosis pertaining to the symptoms of the patient could not dealt with this study. The studies are limited only on comparison with 3T MRI or higher which could be used for better signal to noise ratio and spatial resolution and, the vessels with a slow flow may not show a high signal intensity on 3D-TOF MRA due to saturation effect, in which case even a large artery cannot be visualized and may be wrongly classified as a hypoplastic artery, thus the correlation of

3D-TOF MRA with phase contrast MRA method is also demanding for flow rate measurements.

CONCLUSION

The findings of the study concluded that the morphological variations and diameter differences in the COW are common with gender or age. Configuration of the COW varies largely in general local population. The prevalence of complete configuration of the circle is higher in younger persons as well as in females. And some of the vessel diameters show statistically significant differences according to the age and gender. This normal anatomical variant identification plays an important role in surgery.

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