Section: Radiodiagnosis

Original Research Article

ANATOMICAL VARIATIONS OF CIRCLE OF WILLIS: A COMPARATIVE STUDY OF 16 SLICE CT ANGIOGRAPHY AND MAGNETIC RESONANCE ANGIOGRAPHY

Sumana Bingi[1], Chakradhar S[2], Mahender Reddy G[3], Sneha Sudha[4]

[1]*Assistant Professor: Department of Radiodiagnosis, Mediciti Institute of Medical Sciences: Medchal Mandal, Ghanpur, Telangana, India*
[2]*Assistant Professor: Department of Radiodiagnosis, Selaiyur, Chennai, Tamil Nadu, India*
[3]*Professor: Department of Radiodiagnosis, Mediciti Institute of Medical Sciences: Medchal Mandal, Ghanpur, Telangana, India*
[4]*Senior Resident: Department of Radiodiagnosis, Kakinada, Andhra Pradesh, India*

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Corresponding Author:
Dr. Sneha Sudha,
Senior Resident: Department of Radiodiagnosis, Kakinada, Andhra Pradesh, India.
Email: drsnehasudhamdradio11@gmail.com

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ABSTRACT

Background: Digital subtraction angiography (DSA), Computed tomography angiography (CTA), Magnetic Resonance angiography –Time of flight (MRA-TOF) are useful tools in image acquisition. However, DSA remains the standard for the detection of any intracranial anomalies. The aim is to compare the efficacy of three-dimensional Computed Tomography and Magnetic Resonance Angiography.

Materials and Methods: This is a prospective observational study conducted over 18 months in Radiodiagnosis on Evaluation of cerebral vasculature by prospective analysis of both 101 CT angiography and MR Angiography examinations, selected in the same individual who are referred to the department of radiology, GEMS with a wide range of symptoms like headache, stroke, evaluation of atheromatous disease with age ranging from 10 to 70 years age distribution.

Results: The anterior and posterior communicating arteries showed a sensitivity of 100% and a specificity of 53.33% for anterior communicating artery and 100%,56.72% for the posterior communicating artery, respectively. It is observed that for a relatively larger vessel like the P1 segment of PCA showed a sensitivity, specificity, PPV, and NPV of 100%.

Conclusion: Relatively larger vessels like P1 segments of the posterior cerebral artery showed a sensitivity, specificity, PPV, and NPV of 100%. There was a good kappa correlation between the CTA and MRA, which was statistically significant.

Keywords: Circle of Willis, Proximal Segment Of The Anterior Cerebral Artery, Distal Segment Of The Anterior Cerebral Artery, Middle cerebral artery, Arteriovenous malformation.

INTRODUCTION

The brain is a richly vascularized organ which consumes 15% of the output from the heart. The main cerebral arteries form a polygonal ring at the base of the brain called Circle of Willis (CoW). The circle of Willis received its named after Thomas Willis (1621-1675), an English neuroanatomist, who presented a detailed description regarding the COW and its importance. The CoW is composed of Internal carotid artery (ICA), Anterior cerebral artery (ACA), Anterior communicating artery (ACOM), Posterior communicating artery (PCOM) and, Posterior cerebral artery (PCA). It connects the anterior circulation of either side and with posterior distribution forming an anastomosis between the Internal carotid and vertebral arteries. It serves as a significant source of collateral flow and adapts to any changes in the blood flow in sudden arterial occlusion. CoW exhibits variations, not only in geometry but also in topography where few vessels could be hypoplastic, duplicated, or completely absent.

The most common anatomical variants of the CoW encountered include, the fenestrations, duplications, a persistent carotid- basilar anastomoses, and other vascular anomalies identified at the base of the skull. Approximately 40-50% of the population showed a complete and symmetrical circulation. These topological variations affect in maintaining a normal cerebral blood flow increasing, the risk of strokes and, transient ischaemic attacks. Thorough knowledge of these variants and their clinical relevance is essential as it helps in diagnosis, management of acute stroke, and subarachnoid hemorrhage(SAH). It also helps in the planning of surgeries to avoid life- complications.

Digital subtraction angiography (DSA), Computed tomography angiography (CTA), Magnetic Resonance angiography –Time of flight (MRA-TOF) are useful tools in image acquisition. However, DSA remains the standard for the detection of any intracranial anomalies. CTA and MRA are noninvasive techniques used in detecting the variants in the CoW. MDCT angiography showed a sensitivity and specificity of 81%–90% and 93%, respectively.[1] The high spatial resolution of Three-dimensional (3D) MDCT angiography is beneficial in understanding the anatomic relations between bone and blood vessels. These 3D images, maximum intensity projection (MIP) images, and axial images of the skull base that are obtained using bone window settings provide comprehensive details of the intracranial and extracranial circulation. This study helps to ensure that most abnormalities and normal variants identified.

MATERIALS AND METHODS

This is a prospective observational study conducted over 18 months from Dec 2017 to June 2019 done in Department of Radiodiagnosis at Great Eastern Medical School and Hospital, Srikakulam on Evaluation of cerebral vasculature by prospective analysis of both 101 CT angiography and MR Angiography examinations, selected in the same individual who are referred to the department of radiology, GEMS with a wide range of symptoms like headache, stroke, evaluation of atheromatous disease with age ranging from 10 to 70 years age distribution. The sample size is comparable with the previous studies like Patrux B et al,[2] (1994) who compared MRA of the circle of Willis with conventional transfemoral four-vessel angiography in 54 subjects and Stock K W et al,[3] (1996) who examined the reliability of the source images and the maximum intensity projection images of MR angiography in showing the arterial segments of the circle of Willis Intra-arterial DigitalS ubtraction angiographically in 62 patients. Few authors compared CTA and MRA using sample size slightly larger than the present study.

However, studies with the aim of anatomical variations using a particular technique used a larger sample than the present study. Few patient populations showing severe stenosis of the intracranial segment of the carotid artery, complete occlusion of a single or bilateral internal carotid arteries, aneurysms, and post aneurismal clipping were not suitable for the present study. Hence, the current sample size was determined based on the hospital workload. The arteries were analyzed with source images as well as MIP (Maximum Intensity Projection) and VR (Volume Rendering). Statistical significance was determined with the chi-square, cohen kappa test to look for the anatomical variations of the anterior and posterior arterial circulation of the brain, taking into account the age and sex of patients.

Inclusion criteria

Patients for the study were chosen from the patient population referred for computed tomography and magnetic resonance imaging of the brain to the Department of Radiology, Great Eastern Medical School and Hospital, Srikakulam.

Exclusion criteria

- Postoperative cases
- Internal carotid artery occlusion or severe stenosis
- Patient having aneurysms and history of aneurysmal clipping/ coiling.
- Poor quality CT angiographic images.
- Patients having motion artifacts that interfere with an optimal assessment of the image.
- Subjects having cardiac pacemakers, prosthetic heart valves, cochlear implants, or any metallic implants.
- Patients having a history of claustrophobia.
- Patients are not willing to be a part of the study.

All CT angiographic studies were carried out by using a 16 Slice –detector row volumetric CT scanner (GE), and a standardized protocol was used. First, a nonenhanced CT scan is done, followed by an angiographic study.

Imaging parameters for nonenhanced CT

Pitch	1.34
Source thickness	0.625mm
Source collimation	0.625mm
Reconstruction interval	1mm
Matrix	512x512
Field of view	180-220mm
Tube voltage	120kv
Tube current	200mAs

Imaging parameters for CT angiography

Gantry rotation speed	0.98sec
Source thickness	0.625mm
Image reconstruction interval	0.625..
Matrix	512x512
Field of view	180-220mm
Tube voltage	120kv
Tube current	200mAs
Scan delay time	Automatic
Scan direction	Craniocaudal

Intravenous nonionic contrast (Omnipaque) was calculated as per 1.5ml/Kg body weight and is administered accordingly at a flow rate of 4-5 mL per second injected in the peripheral vein through the power injector. The scanning coverage - The bottom of the anterior arch of the C1 cervical vertebrae to the top of the cranial vault.

All CT angiographic data are transferred to a workstation for post-processing. The source images are reformatted as maximum intensity projection (MIP) and volume- rendered images. Maximum intensity projection (MIP) images achieved by displaying only the highest attenuation value from the data encountered in a given volume. Usually, 5mm and 10mm thickness slab MIP images were used. However, more or fewer thickness slabs are used as necessary. As MIP images are 2D images, the depth information is lost, so corresponding source images are used for localization.

Selection of several groups of voxels according to their attenuation in Hounsfield units and to assign them a color and a so-called opacity. The voxels with attenuation between 100 and 300 HU containing information about contrast-enhanced vascular structures are assigned a red color. These voxels of high attenuation providing information about bony structures are assigned a white color. Any level of opacity between 0% and 100% are used as required. Automatic segmentation to remove the skull bones used. If automatic skull removal is not accurate, manual removal was done.

MR Angiography MR non-contrast angiographic studies were performed by using a 1.5T (GE Company). A standardized protocol was used.

MRA 3D-Time of flight protocol(1.5T)

TR/TE/FA	Out of phase/28/20o
Field of view	22
Slice thickness	1.4mm
Bandwidth	16.67

RESULTS

The study group was consisting of 47 females (46.5%) and 54 males (53.4%) and the mean age as 42.22 years (SD 15.358). The age distribution was ranging from 10yr to 70 years. The total sample studied was divided into two groups according to age. Those aged < 40 years (n = 48) and those aged more than or equal to 40years (n = 53). If any artery of the CoW was invisible, it considered incomplete. All of the arteries forming the circle that was complete CoW, found in 50 samples (49.5%). Incomplete CoW found in 51 samples (50.5%). The anatomical variations of anterior as well as posterior parts of the CoW were determined. On CT angiograms, 87 (86.1%) subjects demonstrated a complete anterior part of the CoW, 47 (46.5%) showed an entire posterior circulation of the CoW, and as we know, 50(49.5%) demonstrated an entirely perfect CoW. The values were 79(78.2%), 47(46.5%) and, 36(35.6%) on MR angiographic findings, respectively.

Table 1: Number and percentage of patients complete and incomplete COW in CTA and MRA.

	Complete Circle	Complete Anterior Circle	Complete Posterior Circle
CTA	47(46.5%)	87(86.1%)	47(46.5%)
MRA	36(35.6%)	79(78.2%)	47(46.5%)

Variations found more in the posterior part of the circulation. The presence of an entire, complete circle of Willis is seen slightly higher in subjects more than or equal to forty years. However, it does not show any statistical significance.

Table 2: Number and percentage of the complete status of CoW according to the age.

CTA	Number	Complete Circle	Incomplete Circle
Age <40	48	24(23.7%)	24(23.7%)
Age >=40	53	26(25.7%)	27(26.7%)
TOTAL	101	50(49.5%)	51(50.4%)

The absolute absence of the anterior communicating artery has been found in 7.9%, 14.8% of the study population in CTA, MRA, respectively. The anterior communicating artery often was not depicted at MR angiography, but this did not necessarily mean that the artery was absent. Because out of 21 aplastic Acom cases on MRA, only 15 cases were absent on CTA.

Table 3: Anatomical variations of the anterior communicating artery.

Technique	ACOM Aplasia	ACOM Hypoplastic
CTA	8(7.9%)	12(11.8%)
MRA	15(14.8%)	21(20.7%)

Regarding the absence of the A1 segment of the ACA, this study showed an absent A1 segment of the right ACA in 1.9 % of patients in both techniques. However, the overall absence of the A1 segment was 3.9% (4patients) with MR angiogram, with CTA 3.9%(4patients). CTA demonstrated a hypoplastic vessel in the remaining 8.9%(9 patients) [Figure 6]. Fenestration of the A1 and A2 segment of ACA is a rare finding seen in 0-4%0-4% and 2% in the autopsy, respectively.[6] One case of A1 fenestration was observed in this study.

The Fetal origin of PCA was noted in 14.8%(15 cases) and 14.8% (15 cases) on CTA and MRA, respectively. 8.9% (9 cases) seen on the right side, and 5.9% (6 cases) were noted on the left side, respectively

Anatomical variations were more commonly observed in the posterior CoW. Only 46.5% of the subjects shows the complete CoW. The findings were summarized and plotted in Fig: 8. In our study, three (2.9%) of the cases showed trifurcation of the ACA distal segment, one case showed (0.9%) bifid MCA. Bihemispheric A2 of ACA vessel (0.9%), fenestration of the left A1 division (0.9%) were noted in different subjects, as mentioned.

CT angiography in young patients showed a larger diameter in almost all vessels except for left PCOM. This observation was even more statistically significant for the left P1 segment(p<0.005).

Table 4: Number of patients with COW vessel diameter changes according to age

CTA	AGE	No.	Mean	Standard Deviation	p-value
RT PCOM	<40	42	0.995	0.600	0.7909 NS
	>=40	41	0.956	0.731	
RT PCA P1	<40	45	2.062	0.672	0.1035 NS
	>=40	47	1.816	0.757	
RT ICA	<40	48	3.785	0.529	0.9778 NS
	>=40	53	3.788	0.551	
RT A2	<40	46	1.610	0.072	0.7917 NS
	>=40	53	1.615	0.109	
RT A1	<40	47	2.129	0.564	0.1318 NS
	>=40	52	1.956	0.567	
ACOM	<40	43	1.120	0.523	0.1383 NS
	>=40	48	0.915	0.399	
LEFT A1	<40	47	2.195	0.651	0.1819 NS
	>=40	53	2.037	0.523	
LEFT A2	<40	46	2.175	0.684	0.1892 NS
	>=40	53	2.009	0.565	
LEFT 1CA	<40	48	3.852	0.625	0.2876 NS
	>=40	53	3.733	0.491	
LEFT PCA P1	<40	45	2.210	0.439	0.0094*
	>=40	47	1.864	0.762	
LEFT PCOM	<40	34	0.762	0.448	0.2708NS
	>=40	43	0.915	0.698	

*p value <0.05 statistically significant NS- Not significant

CTA In males, a significant number of the vessels show increased diameter except for the left PCOM whereas, in females, larger vessel diameter is noted in the left PCOM. However, the change in diameter of the vessel according to sex appears statistically significant for left ICA, left P1, and left PCOM(P<0.005). [Table 8].

Table 6: Number of patients with COW vessel diameter changes according to sex

CTA	SEX	No.	Mean	Standard Deviation	p-VALUE
RT PCOM	M	44	0.972	0.735	0.9677 NS
	F	39	0.978	0.591	
RT PCA	M	48	1.979	0.811	0.5145 NS
P1					
	F	44	1.880	0.617	
RT ICA	M	54	3.827	0.537	0.4203 NS
	F	47	3.740	0.541	
RT A2	M	52	1.614	0.108	0.833 NS
	F	45	1.610	0.072	
RIGHT A1	M	53	2.042	0.632	0.9449 NS
	F	46	2.034	0.496	
ACOM	M	51	1.083	0.429	0.3968 NS
	F	41	1.000	0.506	
LEFT A1	M	54	2.20	0.525	0.1120 NS
	F	46	2.012	0.647	
LEFT A2	M	54	2.175	0.584	0.1376 NS
	F	45	1.987	0.665	
LEFT ICA	M	54	3.790	0.559	0.0001*
	F	47	0.378	0.626	
LEFT PCA P1	M	53	2.151	0.527	0.0467*
	F	42	1.887	0.748	
LEFT PCOM	M	40	0.725	0.531	0.0587*
	F	41	0.976	0.640	

*p value <0.05 statistically significant NS- Not significant

MRA demonstrated a mild increase in diameter in almost all vessels except for left PCOM in young people. This observation was even more statistically significant for the left P1 segment(p<0.005). [Table 9].

Table 7: The number of patients with COW vessel diameter changes according to age.

MRA	AGE	N	Mean	Standard Deviation	p- VALUE
RT PCOM	<40	35	0.779	0.645	0.9806 NS
	>=40	33	0.775	0.706	
RT PCA P1	<40	45	1.914	0.632	0.0961 NS
	>=40	47	1.677	0.715	
RT ICA	<40	48	3.629	0.531	0.6877 NS
	>=40	53	3.586	0.539	
RT A1	<40	45	2.002	0.649	0.2473 NS
	>=40	53	1.856	0.592	
RT A2	<40	48	1.95	0.555	0.2347 NS
	>=40	52	1.820	0.532	
ACOM	<40	41	0.943	0.526	0.1085 NS
	>=40	41	0.773	0.416	
LEFT A2	<40	46	2.047	0.627	0.0862 NS
	>=40	53	1.849	0.509	
LEFT A1	<40	46	2.158	0.738	0.1109 NS
	>=40	53	1.943	0.591	
LEFT 1CA	<40	48	3.666	0.622	0.2709 NS
	>=40	53	3.543	0.492	
LEFT PCA P1	<40	48	2.058	0.438	0.0080*
	>=40	46	1.726	0.721	
LEFT PCOM	<40	39	0.552	0.471	0.1412 NS
	>=40	37	0.747	0.661	

*p value <0.05 statistically significant NS- Not significant

MRA In males, a significant number of the vessels showed an increase in the diameter, whereas, in females, a slight increase in vessel diameter is noted in the left PCOM. The change in diameter of P1, according to sex, showed statistical significance for left A1 and P1 segments (p<0.005).

Table 8: The number of patients with COW vessel diameter changes according to sex.

MRA	SEX	N	Mean	Standard Deviation	p-VALUE
RT PCOM	M	37	0.972	0.735	0.2001 NS
	F	31	0.757	0.613	
RT PCA P1	M	53	1.979	0.811	0.891 NS
	F	44	1.729	0.574	
RT ICA	M	54	3.655	0.483	0.3302 NS
	F	47	3.551	0.585	
RT A1	M	51	1.953	0.684	0.6340 NS
	F	47	1.893	0.545	
RT A2	M	53	1.916	0.584	0.5056 NS
	F	45	1.842	0.498	
ACOM	M	49	0.900	0.443	0.3450 NS
	F	37	0.802	0.512	
LEFT A2	M	53	2.038	0.521	0.0800 NS
	F	46	1.836	0.615	
LEFT A1	M	54	2.188	0.522	0.0209*
	F	46	1.880	0.781	
LEFT 1CA	M	54	3.612	0.495	0.8375 NS
	F	47	3.589	0.628	
LEFT PCA P1	M	51	2.151	0.527	0.0022*
	F	43	1.746	0.715	
LEFT PCOM	M	35	0.725	0.531	0.8466 NS
	F	31	0.753	0.644	

*p value <0.05 statistically significant NS- Not significant

Table 9: Display of arterial segments both tests

		CTA			MRA		
Vessel	No.	Visible	Hypo Plastic	Aplastic	Visible	Hypo Plastic	Aplastic
A1	202	189	9	4	.185	12	5
A2	202	197	3	2	.189	9	3
ACOM	101	81	12	8	65	21	15
P1	202	183	2	17	182	3	17
PCOM	202	125	39	38	90	45	68
Total	909	775	65	69	711	90	108

We calculated sensitivities and specificities for the MR angiographic source images, taking CTA as the standard reference. Partially visible arterial segments were considered as present. CT angiography depicted 840 vessel segments as present and 69 segments as absent. The MRA images showed 801 out of 909 as visible. Zero cases showed vessel segments that were not visualized on CTA.

Table 10: Correlation between CTA and MRA

			CTA		Total
			Positive	Negative	
MRA	Positive	Count	801	0	801
	Negative	Count	39	69	108
Total		Count	840	69	909

	k-value	Asymptomatic Standard Error	Approx. Tb
Measure of agreement kappa	0.724*	0.40	22.465

Kappa test was applied to the above values in this study, and variability yielded a k of 0.724 for the measure of agreement between both techniques.

*k value 0.61-0.80- Good agreement

Kappa = 0.724 (The Strength of Agreement is considered to be "GOOD")

Similarly, subgroup analysis of each vessel was performed separately. The anterior and posterior communicating arteries showed a sensitivity of 100% and a specificity of 53.33% for anterior communicating artery and 100%,56.72% for the posterior communicating artery, respectively. It is observed that for a relatively larger vessel like the P1 segment of PCA showed a sensitivity, specificity, PPV, and NPV of 100%.

Table 11: Subgroup analysis of the COW arterial segments

Vessel	No.	CTA			MRA			
		Visible	Hypo Plastic	Aplastic	Sensitivity	Specificity	PPV	NPV
A1	202	189	9	4	100	80	99.49	100
A2	202	197	3	2	100	50	99	100
ACOM	101	81	12	8	100	53.33	92.47	100
P1	202	183	2	17	100	100	100	100
PCOM	202	125	39	38	100	56.72	82.32	57

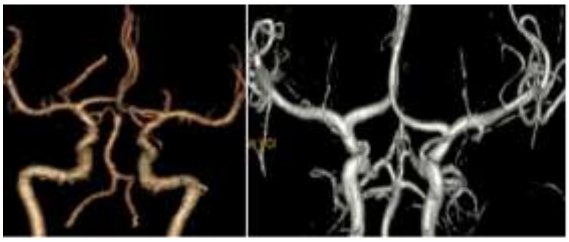

Figure A and B: CTA VR and MR MIP images in the same subject showing aplastic anterior and posterior communicating arteries on the right and left sides.

Figure C and D: CTA VR and MR MIP images in the same subject showing aplastic posterior communicating arteries on the right and left sides.

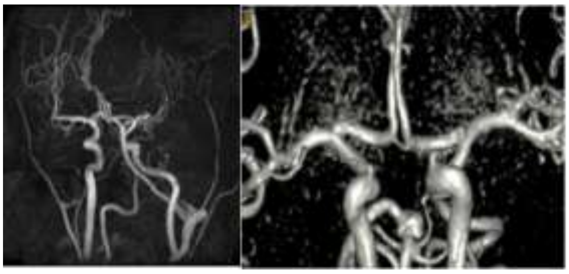

Figure E: MR MIP image showing trifurcation of the A2. Figure F: MR MIP image showing absent right Pcom.

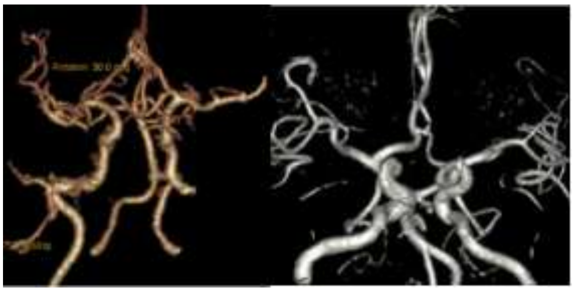

Figure G: CT VR image showing the complete circle of Willis. Figure H: MR MIP image showing hypoplastic left A1 segment

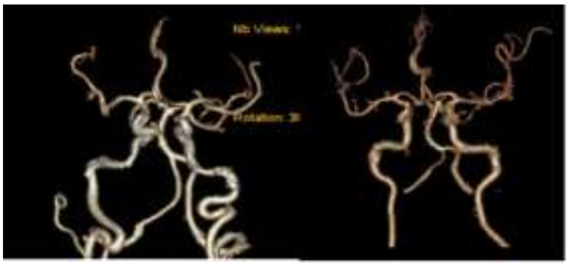

Figure I and J: CT VR image showing absent bilateral Pcom.

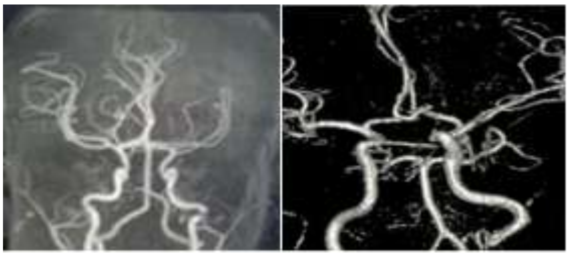

Figure K: MR MIP image showing duplicated left MCA. Figure L: MR MIP image showing bifurcation of left A2.

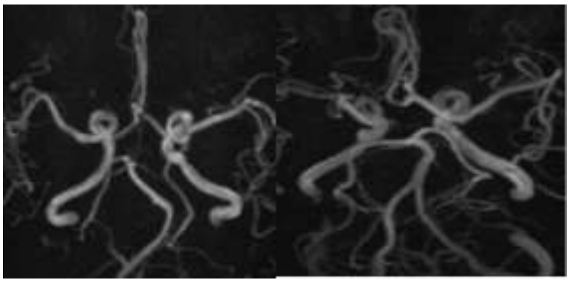

Figure M: MR MIP images showing the fetal origin of left PCA. Figure N: MR MIP images showing aplastic right A1 segment.

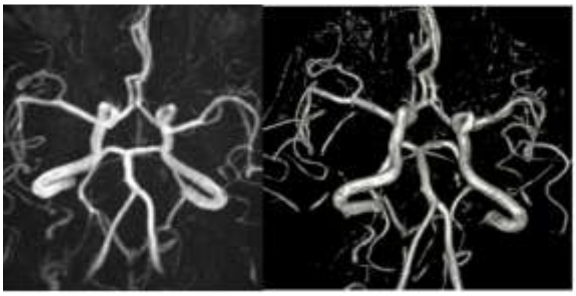

Figure O and P: MR MIP and VR images showing hypoplastic fenestration of the left A1 segment.

DISCUSSION

Most of the anatomical and clinical studies investigated the configuration of the circle of Willis. Only a few studies have investigated the configuration of CoW systematically in the general population. The Circle of Willis plays a significant role in the establishment of the collateral pathways in patients with a significant reduction in the blood flow in either an internal carotid artery or the basilar artery as a result of embolic or stenotic ischemic conditions. This collateral circulation maintains the cerebral perfusion in the territory of the vessels affected. The patent anterior and posterior communicating arteries are the primary collaterals, which respond quickly in the form of either with a reversal of flow direction or higher blood flow. The leptomeningeal anastomoses or ophthalmic artery are the secondary collaterals, which need more time to develop to contribute a significant blood supply. MR angiography can easily detect the configuration of the circle of Willis and its primary collaterals at the base of the brain. In the present study, the source images of a 3-D TOF MRA sequences are compared with CTA images findings, which was relatively the standard of reference. However, DSA angiography is the standard reference.

Our study focuses on the normal anatomical variants of the circle of Willis. Unlike the earlier studies, the following vessels forming the circle of Willis like the A1 portion of the anterior cerebral artery, anterior communicating artery, middle cerebral artery, P1 part of the posterior cerebral artery, and posterior communicating artery were evaluated. Proper knowledge of the normal cerebral variants like fenestrations, duplications, and the persistent fetal arteries and their clinical relevance is essential, as it plays a crucial role in the diagnosis and the management of critical conditions like acute stroke and subarachnoid hemorrhage and it also aids in surgical planning. On CT angiograms, 87(86.1%) subjects demonstrated a complete anterior part of the COW, 47(46.5%) subjects demonstrated a complete posterior part of COW whereas 50(49.5%) showed an entirely complete COW (complete anterior and posterior portions of the circle combined), 79(78.2%), 47(46.5%) and 36(35.6%) were the MR angiographic findings respectively.

In our study, variations were seen more commonly in the posterior part of the circulation. The presence of an entirely complete COW was slightly higher in subjects more than or equal to forty. However, it did not show any significance statistically. The anterior communicating artery often was not depicted at MR angiography, but this did not necessarily mean that the artery was absent. Because out of 21 absent Acom cases on MRA, only 15 cases were absent on CTA. This study showed an absent A1 segment of the right ACA in 1.9 % of patients in both techniques. However, the overall absence of the A1 segment was 3.9% (4 patients) with MR angiogram, with CTA 3.9 % (4 patients). CT demonstrated a hypoplastic vessel in the remaining 8.9% (9 patients). Fenestration of the A1 segment of ACA is a rare finding (0-4%). Fenestration of the A2 portion of ACA is also a rare finding seen in 2% at autopsy.[4] One case of A1 fenestration was observed in this study. In our study, three (2.9%) of the cases showed A3 segments; one case showed (0.9%) bifid MCA. Bihemispheric A2 of the ACA vessel was seen in one subject(0.9%). MR Source images a good sensitivity and specificity (95.36% and 100% respectively) in depicting the circle of Willis. Sensitivity was lower for anterior and posterior communicating arteries (92.4% and 82.32%, respectively).

Some studies showed vessel segments in MRA, which were not visualized on CTA, such cases were considered as False positive. In our study, no such segments are identified. The false-positive findings on the source images might be due to the following: As the vessel should be followed through several images, there are high chances that it can be confused with another vessel nearby, the posterior communicating artery might be confused with the basal vein or the anterior choroidal artery. Secondly, a thrombosed artery showing high signal due to methemoglobin can be misinterpreted as a patent vessel. Lastly, the patent vessel is not visible on CT angiography due to inadequate contrast opacification of the vessel. When such an artery is seen with MR angiography, it is considered as a false-positive finding. The turbulence and saturation effects of slow-flowing blood or high in-plane flow results in false-negative outcomes. Partial volume effects lead to the loss of visibility of very small arteries due to the loss of their signal intensity. The MIP display images result in loss of clarity of small arteries and reduction of the vessel diameter with a low signal intensity because of occult blood near the vessel wall or as a result of the MIP algorithm itself. MR angiography can be obtained using a magnetization transfer saturation pulse, which provides an improved background suppression. Therefore, an angiographic sequence with a high-resolution is preferred.[5]

Fenestration of the A1 segment of ACA is a rare finding (0-4%) 10. Fenestration of the A2 portion of ACA is also a rare finding seen in 2% at autopsy.[4] One case of A1 fenestration was observed in this study(0.9%). Duplication of the ACOM was never found in this study. The reported prevalence of MCA duplication is 0.2%–2.9%. Only one case of duplicated MCA was identified in this study. However, duplicate middle cerebral arteries have no direct clinical significance. The prevalence of azygos anterior cerebral arteries is 0.2%–4.0%. The vessel diameter was measured on the source images, only those collateral vessels with a diameter of at least 1.0 mm are effective in preventing watershed infarction. Blood adjacent to the wall has slower velocity, and as a consequence, low signal intensity due to saturation may be expected. MIP images do not display this low signal intensity, which does not exceed the signal intensity of the background. Underestimation of the vessel diameter on the source images can be attributed to saturation and signal loss of slow-flowing blood, partial volume effect of pixels at the vessel wall, and turbulent flow signal loss. These effects are negated to a certain degree by pulsatile movements of the vessel.

Patrux B et al,[2] showed MR Angiography showed a sensitivity of 89.2% and 81.3% for the anterior and posterior communicating arteries respectively, and 100% for the anterior, middle, and posterior cerebral arteries. MR Angiography was shown to be a beneficial technique for assessing the patency of the circle of Willis. In our study, MRA showed an overall sensitivity of 95.36% and a specificity of 100%. The sensitivity for anterior and posterior communicating arteries was 92.4% and 82.32%, respectively, and 99.4%,100%, and 100% for the A1 segment of ACA, P1 segment of PCA and MCA respectively.

Krabbe-Hartkamp MJ et al,[6] showed statistically significant difference was found in vessel diameters between the younger and the older age groups. The authors determined typical reference values for morphologic variants and diameter measurements of the circle of Willis specific to three- dimensional time-of-flight MR angiography. In our study, the sample was divided into two groups: those aged less than forty(n=48), and those aged more than or equal to forty(n=53). In our study, variations were seen more commonly in the posterior part of the circulation. The presence of an entirely complete COW was slightly higher in subjects more than or equal to forty. However, it did not show any statistical significance.

Macchi C et al,[7] studied the variations of the circle of Willis in a cohort of 118

healthy older persons by magnetic resonance angiography. An Entirely complete configuration in seen 47% of the subjects, a complete configuration of its anterior part in 90% of the subjects, and a complete configuration of its posterior part in 48.5% of the subjects. In our study 87(86.1%) subjects demonstrated an entire anterior part of the COW, 47(46.5%) subjects demonstrated a complete posterior part of COW whereas 50(49.5%) showed an entirely complete COW (complete anterior and posterior portions of the circle combined) on CT angiograms, and 79(78.2%), 47(46.5%) and 36(35.6%) were the MR angiographic findings respectively.

Maaly et al,[8] observation was even more statistically significant for the P1 segment on the left side. MRA In males, showed an increase in diameter in most of the vessels, whereas, in females, a slight increase in vessel diameter is noted in the left PCOM.

The change in diameter of P1, according to sex, showed statistical significance for A1 and P1 segments on the left side.

De Silva KR et al,[9] study revealed the significant variations in the circle of Willis among Intra and inter- ethnic groups and warrants further studies with similar methods of measurements and the data assessment.

Regattieri et al,[10] study has shown that the anatomical variations of the branches of the Circle of Willis occur, regardless of age and sex. In the present study, 101 patients underwent CTA, followed by MRA with age ranging from 10 to 70 years. Most of the variants were seen in the posterior circulation on both CTA and MRA. Incomplete posterior circulation was viewed in 47 subjects on CT angiogram and MR angiogram.

Klimek-Piotrowsketal,[11] study shows that the prevalence of the normal CW constitutes a minority of cases in a healthy population (16.80%). Interestingly, 69.20% of the patients were noted to have an incomplete cerebral arterial circle that was unable to secure collateral blood supply. Female subjects and patients over 46 years of age were observed to have a higher occurrence of such deficient variants of the CW. Additionally, female subjects had a significantly higher proportion of an open anterior part of CW. Unfortunately, comparing studies proved to be challenging and was impeded by dissimilarities in the study population characteristics.

BahaddurEet al,[12] evaluated the prevalence and pattern of the circle of Willis

(CoW) arterial variants (like aplasia and hypoplasia) and other anomalies of Circle of Willis in the south Indian population by Using MRA in non-contrasted 3D-TOF. This study was performed in the Department of Radiodiagnosis, Narayana Hrudayalaya Institute of Medical Sciences, Bangalore. This study included 300 healthy participants, of whom198, were men and 102 were women. A complete configuration of the circle was seen in 16.6% with a slight female predominance than males and younger (below 50 yrs) than older subjects. The incidence of the associated anomalies, like an aneurysm or AVM, is comparable to those described in the literature. In the present study, an entire anterior circle of Willis is seen with 86.1% in CTA and 78% on MRA of all the subjects. Subjects having aneurysms and AVM were not included in the present study.

Naveen et al,[13] showed incidence of associated anomalies like an aneurysm or arteriovenous malformation (AVM) was comparable to that described in the literature. In our study, there were 54 males and 47 females, and the mean age was 45years. A complete circle of Willis was seen in 50 (49.5%) subjects, and the incomplete circle was noted in 51 (50.4%) subjects in CT angiogram. An incomplete circle was slightly more in subjects aged more than forty years.

CONCLUSION

The most common anatomical variant in the present study is the hypoplastic left posterior communicating artery followed by a hypoplastic anterior communicating artery. The fetal origin of the posterior cerebral artery was noted predominantly on the right side of the study population. The sensitivity, specificity, positive predictive value negative predictive value accuracy of MRA in detecting anatomical variations were 100%, 63.89%, 95.36%, and 100%, respectively. Subgroup analysis of the anterior and posterior communicating arteries showed a sensitivity of 100% and a specificity of 53.33% for anterior communicating artery and 100%, 56.7% for the posterior communicating artery, respectively. It was observed that for relatively larger vessels like P1 segments of the posterior cerebral artery showed a sensitivity, specificity, PPV, and NPV of 100%. There was a good kappa correlation between the CTA and MRA, which was statistically significant (<0.05).

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