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Original Article

Study of anomalies in the circle of Willis using magnetic resonance angiography in north eastern India

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ABSTRACT

Introduction: The circle of Willis is a large arterial anastomotic ring present at the basal cistern of the brain, uniting the internal carotid and the vertebrobasilar system. Branches from this arterial ring are distributed to supply the brain. In the year 1664, Sir Thomas Willis was the first to describe the importance of the circle in maintaining collateral flow. It was observed that there is very little mixing of blood between the collateral branches of the circle. These collaterals may however open up during occlusive episodes of the proximal feeding vessels. The anatomy of the circle is known to vary considerably and functionally a complete circle is a rare finding. This type of incomplete or variant forms off the circle may diminish its role as a collateral route.

Methods: The morphological pattern of circle of Willis of 70 healthy individuals from northeast India was studied retrospectively using Time of Flight-Magnetic resonance angiography (TOF-MRA).

Results: Only 17 (24.28%) MRA's presented with a complete (classic) circle of Willis. Most common variant observed in our study was unilateral hypoplastic posterior communicating artery (20%). Most common variant observed in the anterior circulation was unilateral hypoplastic A1 segment of anterior cerebral artery (11.42%).

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Discussion: Most of the variant forms observed were comparable with earlier established findings. This variability (rare patterns) can be distinguished from an anomalous architecture if correlated phylogenically and embryologically.

1. Introduction

The outcome of a neurovascular injury depends on the presence or absence of an adequate collateral flow during occlusive episodes of the feeding arteries. The availability of these collaterals or alternate routes further depends on the morphological pattern of an arterial circle supplying the brain known as the circle of Willis. The circle of Willis is formed by anastomosis between the internal carotid, pre-communicating part (A1) of anterior cerebral, anterior communicating; pre-communicating part (P1) of posterior cerebral and posterior communicating arteries (Fig. 1). The morphological pattern of this arterial circle supplying the brain is again known to vary. Usually the mean variability (largest population) of these vessels represents the mainstream of evolution. This variability is again limited by extreme variants, still compatible with a function, and although still "normal", they represent an increase rigidity of the system at its edges. The "anomaly" usually represents too much convergence or divergence. A minimal additional constrain will reveal its limited flexibility; thereafter, the anomaly becomes "abnormal" and symptomatic.[1] Therefore, it is seen that under normal circumstances embryological events like territorial transfer and sharing of territories between the adjacent developing vessels may results in normal circulation even in variant forms of the circle of Willis.[1] The situation becomes complicated only during occluding episodes of the feeders. The common variations encountered may be a result of developmental arrest during embryonic life as most of the branches are derived from the internal carotid, formed progressively from the third arch artery. Review of phylogeny and embryology usually gives the clues and helps to establish the limits of variability.[1] A few variations will be difficult to recognize unless one is familiar with prior disposition of the vascular tree in animals.[1] Without proper acquaintance of these variations diagnostic and neurosurgical procedure may become complicated. Knowledge of these anomalies enables distinction between hypoplasia and spasm and angiographic filling pattern can also be determined.[2] In our study, the various morphological patterns of the circle of Willis were observed and classified retrospectively using Magnetic resonance angiography (MRA) in healthy living individuals. MRA has enabled evaluation of the intracranial vessels without the need for invasive procedures like catheter angiography, avoiding small but definite risk of clinically silent embolism[3] complications like pseudoaneurysms, contrast associated reactions and vascular dissections are possibilities of catheter angiography. MRA can not reveal any arteries invisible in conventional angiography, but provides a specificity of 100%. The sensitivity of MRA was 89.2% for the anterior and 81.3% for the posterior communicating arteries and 100% for the anterior, middle and posterior cerebral arteries.[4] In view of such high specificity and sensitivity we undertake this retrospective study on the various morphological variations of the circle of Willis. Four methods for performing MRA are available which includes Time of Flight (TOF), phase contrast (PC), Black blood Imaging and contrast enhanced MRA or CE-MRA. We used TOF-MRA in the present study.

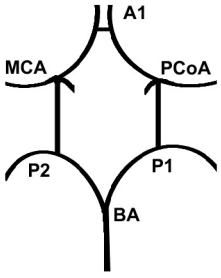

Fig. 1 – Schematic representation (vessels forming the circle of Willis) of the anterior part of the circle formed by the pre-communicating segments (A1) of the right and left anterior cerebral arteries (ACA) and an anterior communicating artery (ACoA) between them. The posterior part of the circle formed by the pre-communicating segments (P1) of the right and left posterior cerebral arteries (PCA), together with the right and left posterior communicating arteries (PCoA). The right and left PCoA's originate from the right and left internal carotid arteries (ICAs) The A2 and P2 segments are the post -communicating portions of the anterior and posterior cerebral arteries respectively. BA: basilar artery, MCA: middle cerebral artery.

2. Materials and method

In the present study the circle of Willis was studied in 70 living individuals retrospectively by using Time of Flight-Magnetic resonance angiography. The study includes subjects of all age groups and both sexes belonging to different communities in the northeast region of India. The study was conducted in the Department of Radiology, NEIGRIHMS, Shillong, Meghalaya, India, for a period from 10th April 2012 to 22nd November 2012. All the patients went under 3D TOF-MR Angiography using 1.5 T machine (Avanto, Siemens, Germany). Following imaging parameters were used repetition time/echo time 23/7.0, flip angle 25 °, slice thickness 0.7 mm, number of slice 44/slab,

number of slabs 4, slice overlap 25%, flow direction feet to head with 40 mm saturation at the head end, field of view 180 x 158 and 256 matrix size. Reconstructions were done in Syngo MR Workplace using 3D maximum intensity projection (MIP) and volume rendering technique (VRT). The anterior cerebral arteries were studied under: A1 segment – from its origin at the internal carotid till the junction with the anterior communicating artery and A2 segment – the course distal to junction with the anterior communicating artery and the posterior cerebral arteries were studied under: P1 segment – from the basilar bifurcation, to the junction with the posterior communicating artery and P2 segment – from the junction with the posterior communicating artery, to the portion in the perimesencephalic cistern.

3. Observation and result

In the present study, the circle of Willis was studied by Magnetic resonance angiography (MRA) retrospectively. In order to be consistent with the previous works, hypoplastic vessels were defined to be those with diameters less than one millimeter (1 mm). Out of the total 70 cases, only 17 cases (24.28%) presented with a complete (classic) circle of Willis (Fig. 2). For a comprehensive understanding of the different patterns of the variations observed during our study, a schematic representation for the variant forms of circle of circle of Willis in anterior and posterior part is shown in Fig. 3 and Fig. 4 respectively. These labeled representations of the variant forms were used for classifying and numbering the variations shown in Table 1 and Table 2.

3.1. *Variations in the anterior part of circle of Willis*

The variant forms of vessels in the anterior part of the circle of Willis (anterior cerebral artery & anterior communicating artery) observed was 34 (48.57%), (Table 1). Variation in the anterior cerebral artery (ACA) was found in 17 (24.28%) cases whereas, anterior communicating artery (ACoA) presented with variant forms in 16 (22.85%) cases. The most common variant found in anterior circulation was hypoplastic A1 segment observed in 8 cases (11.42%).

3.2. *Variations in the posterior part of circle of Willis*

Twenty five cases (35.712%) in presented with variant forms of posterior cerebral artery (PCA). 14 cases, presented with fetal PCoA with hypoplastic P1 whereas, 11 cases presented with aplastic P1 with complete fetal PCoA. The variations in the posterior communicating artery (PCoA) were found in 28 (40%) cases. Hypoplastic PCoA was found in 22 cases, with unilateral 14 and bilateral 8 cases. Absent PCoA (unilateral and bilateral) was seen in 6 MRA cases. Unilateral hypoplastic PCoA was found to be the most common variant, with 14 observations out of 70 cases as shown in Table 2.

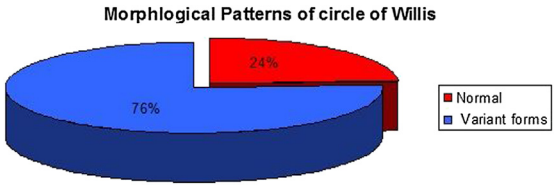

Fig. 2 – Pie diagram showing variation observed in the circle of Willis by both methods.

4. Discussion

In the present study the anatomical variants of the circle of Willis (COW) were studied by TOF-MRA technique. The different patterns of the COW observed were classified and compared with the earlier established finding. The individual variant forms observed can be correlated to their phylogeny and embryology. These variations encountered in the COW may be a result of triggers. Triggers are phenomena that may alter the vascular construction programmed at any stage without necessarily producing an immediately detectable morphological abnormality. The trigger alters the program or its execution either in a transient or in a permanent way. If it does not stimulate repair or apoptosis; then the program alteration can be transmitted to the next cell generation.[1] The normal classical pattern of COW as observed by different authors has wide range of variations ranging from 42%[5] to 7.89%[6] (Table 3). In our study of 70 subjects, only 17 (24.18%) were of normal pattern which is more or less similar to the observations made by Riggs & Rupp et al and P.N. Jain et al.[7,8]

A functional vessel (collateral channel) may prevent or amplify a neurological damage during an occlusive cerebrovascular episode.[15–17] The congenital disposition of these vessels represents the earlier natural adaptation of the territories to their arterial supply. Territories and arteries grow together in harmony because of constant interaction. The effects of a given vascular insult vary according to the preexisting congenital arrangement. An acquired constrain factor upsetting hemodynamic balance of a given area will lead to a hemodynamically unstable situation leading to a clinically expressed disorder.[1] In the present study the role of these arteries as a collateral route in normal (classic) COW or as a risk factor in case of variant forms cannot be established and remains a mere speculation. However, vascular aplasia remains a definite risk factor to develop a neurological insult.

Complete fusion of both anterior cerebral arteries (ACA) distal to commencement of the median longitudinal fissure has been described earlier.[9] This type of fusion may give rise to a single ACA or azygous ACA which is seen commonly associated with anomalies like holoprosencephaly.[18] Fusion of vessels may be a result of an event (or trigger) which will testify to the partial or transient interruption of the maturation phase during vasculogenesis[1] or it may be correlated phylogenetically, as similar pattern of a united A2 segment is normal in monkeys (Macaca mulatta).[19] In the present study complete fusion of the ACA was not observed, however, a focal fusion of both ACA's forming a single arterial trunk which re-divides into right and left branches was observed, in one case. This type of focal fusion of the ACA's also has been reported previously.[6]

The anterior communicating artery (AcoA) is recognized as the most important collateral channel during severe internal

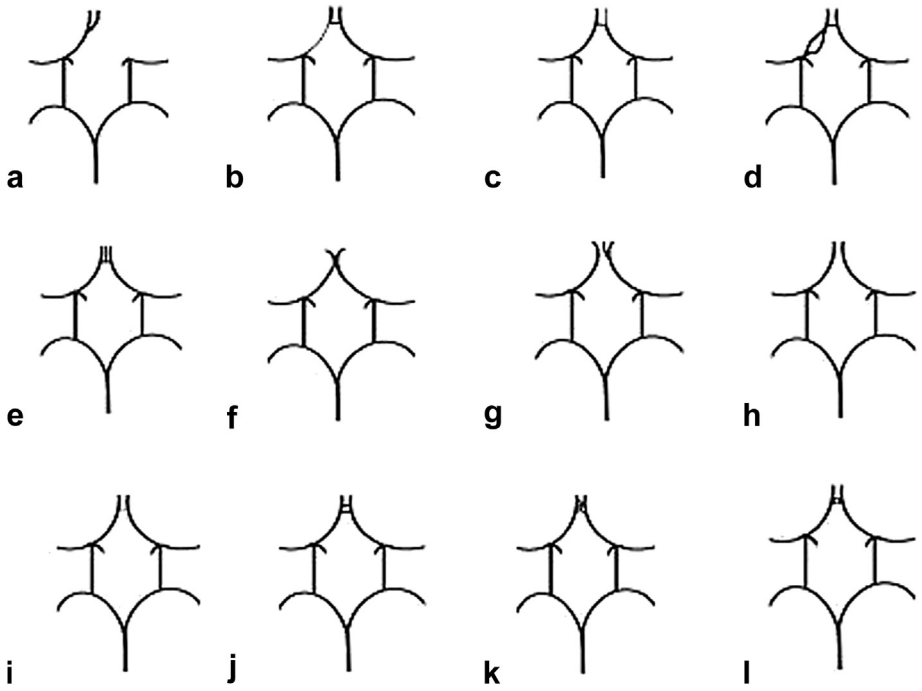

Fig. 3 – Schematic diagram to show the variations in the circle of Willis in the anterior circulation, i.e. anterior cerebral artery (ACA) & anterior communicating artery (ACoA): a) absent A1 segment with both ACA arising from the opposite ICA. b) Hypoplastic A1, c) Hypoplastic A2. d) Fenestration of A1. e) Median artery of corpus callosum. f) Fused ACA with absent ACoA. g) Absent ACoA with early origin of the callosomarginal branch. h) Absent ACoA. i) Hypoplastic ACoA. j) Double ACoA. k) Plexiform ACoA. l) Fenestrated ACoA. ICA: internal carotid artery.

carotid artery (ICA) stenosis.[20–22] Aplasia of the A1 with both ACA's arising from internal carotid of one side was seen earlier in many studies.[7,9] It was observed that if both ACA's fill only from one side, usually it is from the left side.[23] This observation was confirmed later on by the arteriographic study which also showed that the left carotid was eight times more likely to be the site of origin of both ACA's.[24] In our study, aplasia of the A1 was found in 3 cases, 2 on the right and one on the left side (Fig. 5). String like or hypoplastic A1 segment as reported earlier[12–14] were seen in 8 cases, 3 on the right and 5 on the left side. Presence of the median ACA was earlier reported by Windle, P.N. Jain et al and Krabbe-Hartkamp in 4.5%, 3.47%

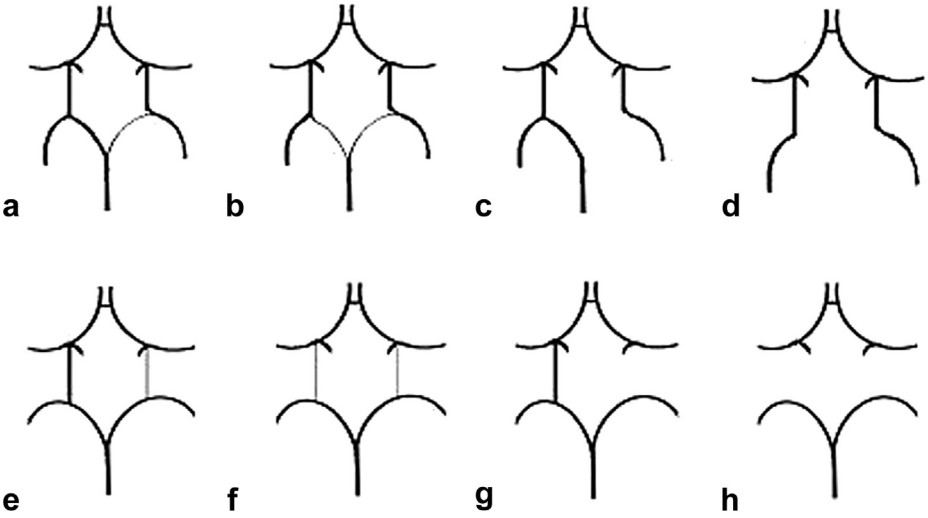

Fig. 4 – Schematic diagram to show the variation in the posterior portion of the "circle of Willis" i.e., posterior cerebral artery (PCA) & posterior communicating artery (PCoA): a) Hypoplastic P1 (U/L) with partial fetal PCoA b) Hypoplastic P1 (B/L) with partial fetal PCoA. c) Absent P1 (U/L) with complete fetal PCoA d) Absent P1 (B/L) with complete fetal PCoA. e) Hypoplastic PCoA (U/L) f) Hypoplastic PCoA (B/L) g) Aplastic PCoA (U/L) h) Aplastic PCoA (B/L).

Table 1 – Frequency of different variations in anterior part of the "circle of Willis" according to the type (classification) shown in Fig. 3.

Type of variation												Total
Group	a	b	c	d	E	f	g	h	i	j	k	l	
MRA	3	8	1	3	1	1	1	6	5	3	0	2	34

Table 2 – Frequency of different variations, in posterior part of the "circle of Willis" according to the (classification) shown in Fig. 4.

Type of variation									Total
Group	a	b	c	d	e	f	g	h	
MRA	9	5	5	6	14	8	1	5	53

and 1.33% cases respectively.[8,9,13] Padget explains this artery to be formed from lower group arterial plexus, similar to the formation of ACA.[25] In our study we did not find any median ACA. Buttonhole formation or fenestrated ACA is characteristics of rats, which was described by Brown in his study of adult albino rats.[26] This type of incomplete fusion or fenestration may be result of an incomplete maturation process of arterial wall rather than fortuitous. The lack of cell selection that such patterns imply may preserve weaker endothelial cells which may later reveal arterial aneurysms. This area of COW represents an area of hemodynamic stress and immature situations which are vulnerable.[1] In our study 3 cases in MRA of buttonhole formation in ACA (A1) was observed (Fig. 6). This can be explained as an evolutionary course.

Studies conducted earlier have shown that the ACoA does not allow any mixing of blood between the two ACA's, however it does acts as a collateral channel if one of the ICA is occluded.[27] The frequency of duplication and triplication of the ACoA was reported to be racial.[28,29] Windle[9] found duplication of the ACoA in 22 out of 200 cases. It was later reported by almost all the authors examining the COW. Triplication of the ACA's was reported in one case by P.N. Jain et al[8] Absence of the ACoA's was reported earlier by several authors.[10,11] Plexiform ACoA was first reported by Windle[9] in 0.5% cases. Later on Puchades-Orts et al[12] found plexiform ACoA in 4.83% of his cases and explained it as persistence of the embryonic

Table 3 – Incidence of normal pattern of circle of Willis.

Study	Technique	Brains examined	Normal pattern (%)
Windle[9]	Gross dissection	200	38%
Blackburn[10]	Gross dissection	220	29.5%
Von Mitterwallner[11]	Gross dissection	360	27.2%
Riggs& Rupp[7]	Gross dissection	994	21%
A. Puchades-Orts, et al[12]	Gross dissection	62	13%
P.N. Jain et al[8]	Gross dissection	144	19.45%
Krabbe-Hartkamp et al[13]	MRI	150	42%
Parthapratim P. et al[6]	Gross specimen	76	7.89%
Haripriya & Melani[14]	MRI	50	32%
Our study	MRI	70	24.18%

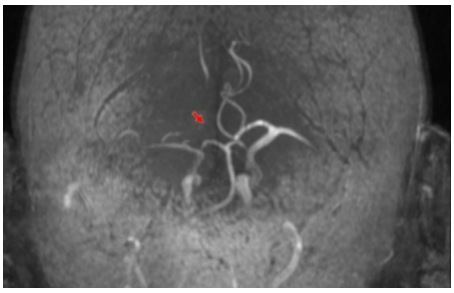

Fig. 5 – Photograph of MRA of circle of Willis showing absence of A1 segment of anterior cerebral artery of left side (arrow) with both the anterior cerebral artery arising from the right internal carotid artery.

form. Absent, multiple or plexiform vessels suggest incomplete cell selection and apoptosis during vasculogenesis.[1] If the trigger that lead to altered vasculogenesis is not corrected to stimulate repair or apoptosis, then the programme alteration can be transmitted which may appear to be a racial or regional pattern as described by previous authors. In our study duplication of ACoA were observed in 3 cases, fenestration in 2 cases and in 6 cases the ACoA was absent.

The most frequent variation observed in posterior cerebral artery (PCA) was the PCA originating from the ICA as a result of persistent primitive embryological pattern. The name fetal PCA came due to persistence of the embryological or fetal pattern.[23] The PCA has its embryonic origin from the ICA and only during the late embryonic and early post-fetal life does the distal part of the PCA begin to gain much of the blood flow from the basilar artery (BA) system through its junction with the distal branches of the BA (the mesencephalic arteries) commonly called P1 segment. Kaplan[30] suggested that the proximal portion of the so called PCA's, which arises from the BA, should be designated the mesencephalic artery and only the distal portion beyond the junction with the posterior communicating artery (PCoA) should be referred to as the PCA.

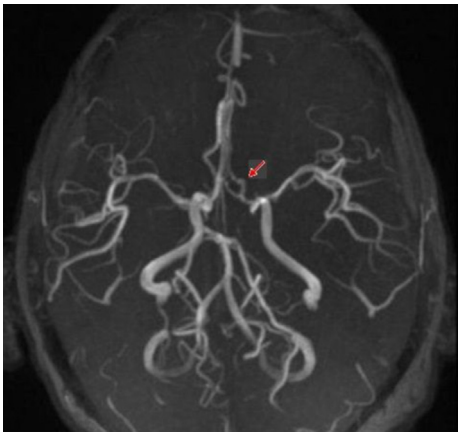

Fig. 6 – Photograph of MRA of circle of Willis showing fenestrated A1 segment of anterior cerebral artery (red arrow) with aplastic posterior communicating artery over the right side.

This terminology however merits consideration since it should help to simplify clinical description of patterns of blood flow. Krabbe-Hartkamp[13] and P.N. Jain[8] observed fetal type of PCA in 32% and 16.66% of their specimens respectively. It was also observed that patients with fetal-type PCA could be more prone to develop vascular insufficiency.[31] In our study complete fetal PCA was seen in 6 cases whereas, incomplete fetal PCA was seen 5 cases. PCA hypoplasia could be a contributory risk factor for ischemic stroke, even in absence of ICA occlusion.[32] In our study 14 MRA's presented with hypoplastic P1 with partial fetal PCA whereas, 11 MRA's presented with absent P1 with complete PCA arising from ICA. Anomalies of the PCoA have a great significance since it forms a link between two major arterial systems—the internal carotid and the vertebrobasilar circuit. Congenital hypoplastic vessels are a common finding which should be differentiated from an acquired one. When narrowing is segmental, congenital hypoplasia is unlikely. Congenital situations are usually harmonious and one should expect a congenital hypoplastic vessel to follow its ontogenetic branching.[1] A hypoplastic PCoA may be a risk factor for developing neurological deficit in patients with ICA occlusion.[16] Windle[9] found the PCoA's small in 2.33% and absent in 1.5% of specimens. He observed anomalies in 49% and described the origin of the PCA's from one or both ICA's as the most common variant. Mitchell[33] described 16 patients with anomalies in the PCoA's, with 9 of them absent. P.N. Jain et al[8] found 20 absent and 26 hypoplastic PCoA and Partopratim et al[6] found 44 hypoplastic forms of PCoA's. In our study out of 70 cases, the most common variant observed was unilateral hypoplastic PCoA which was seen in 14 (20%), MRA cases. This observation was similar with previous authors.[5,8,12] Bilateral hypoplastic PCoA was seen in 8 cases. Aplastic PCoA was seen unilaterally in one case and bilaterally in 5 MRA cases.

5. Conclusion

The present study is based on the analysis made from observing MRA's of healthy subjects. It was observed that the morphological variations are quite frequent in the circle of Willis (COW) in human beings. The foundation of COW lies in vessels which are formed in the early stages of fetal life some of which succumb to involution, while others are evolving to supply the developing structures. The fetal patterns of morphological variants are a result of agenesis or involution during embryonic development. Such an immense number of variability must be recognized as a prior outlook of the vascular tree in lower animals. Because of the variability, the clinical manifestation may vary considerably from one individual to another, and the effectiveness of collateral circulation may be greatly influenced. Whether this is a risk factor for stroke should be subject of further investigation. Our study comprising of MRA's of healthy subjects from northeast India gives an indirect opportunity to compare the variations of the COW in this region with the earlier published data worldwide. In TOF-MRA limitations include dependence on amount and direction of flow as well as the exact technique employed. Therefore smaller arteries with very little flow might not be detected and leading to interpretation as an aplastic artery instead of it being actually hypoplastic. Despite these limitations we were able to document several variations during this study. Further studies based on quantitative measurements of the luminal diameters and flow of the segments should be carried out for a more specific detail on the clinical manifestation of these variations.

Conflicts of interest

All authors have none to declare.

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