

How to Cite:

Samanta, S., Banerjee, A., Mukherjee, S., & Kannabathula, A. B. (2022). Anatomical and radiological variations of the circle of Willis and its clinical correlations. *International Journal of Health Sciences*, 6(S4), 9151–9171.
<https://doi.org/10.53730/ijhs.v6nS4.11925>

Anatomical and radiological variations of the circle of Willis and its clinical correlations

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Abstract---Aim: To study of Circle of Willis both morphologically and radiologically and its variations in the branching pattern of the Circle of Willis and to correlate it clinically. Introduction: The circle of Willis (CoW) is an anastomotic arterial network on the base of the brain. Its major role is to provide efficient collateral circulation to cerebral and cerebellar tissue to prevent ischemia, and subsequent transient ischemic attack or stroke. The circle of Willis (CoW) is a vascular network formed at the base of skull in the interpeduncular fossa. Its anterior part is formed by the anterior cerebral artery, from either side. Anterior communicating artery connects the right and left anterior cerebral arteries. Posteriorly, the basilar artery divides into right and left posterior cerebral arteries and each join to ipsilateral internal carotid artery through a posterior communicating artery. Anterior communicating artery and posterior communicating arteries are important component of circle of Willis, acts as collateral channel to stabilize blood flow. In the present study, anatomical variations in the circle of Willis were noted and correlated those with clinically. Methods: 50 apparently normal formalin fixed brain specimens were collected from human cadavers. 50 Magnetic Resonance Angiography images were obtained and studied by dissection

method and radiological method. The Circles of Willis arteries were then, photographed, and numbered the abnormalities, if any, were noted. Results: Out of 50 specimens, 29 specimens (58%) were found to have complete normal symmetrical configuration, normal caliber and polygonal shape. Other 21(42%) specimens were abnormal either incomplete or asymmetrical or hypoplastic. Abnormalities in the vertebral and basilar artery were not taken into consideration in this study. Conclusions: Knowledge on of variations in the formation of Circle of Willis, all surgical interventions should be preceded by angiography. Awareness of these anatomical variations is important in the neurovascular procedures.

Keywords---anterior communicating artery, anterior cerebral artery, middle cerebral artery, posterior communicating artery, posterior cerebral artery.

Introduction

The circle of Willis (CoW) is an anastomotic arterial network on the base of the brain. Its major role is to provide efficient collateral circulation to cerebral and cerebellar tissue to prevent ischemia, and subsequent transient ischemic attack or stroke (Karatas, Coban, Cinar, Oran, & Uz, 2015; Karatas, Yilmaz, Coban, Koker, & Uz, 2016; KlimekPiotrowska et al., 2016)(1-3). Stroke is a major cause of disability and the second leading cause of death worldwide [4]. Seventy-five percent of all stroke deaths and 81% of the total disability adjusted life years lost due to stroke occur in developing countries [5, 6]. First described in Thomas Willis' landmark work "Cerebri Anatome" (Willis, 1664),(7) the CoW is classically described as a symmetrical polygon, derived from anastomoses between

Stroke risk factors include age, sex, race, hypertension, diabetes, hyperlipidemia, diet, smoking, and alcohol [8]. Arteriogenesis is a complex embryologic process and can lead to numerous anatomical variations [9,10]. In case of a major cerebral arterial occlusion, collateral vessels play an important role in maintaining essential blood flow. Circle of Willis is the most important collateral system in the brain with multiple potential anatomical variations [11–13]. Some of the most common variations in the circle of Willis include hypoplasia or aplasia of one or both posterior communicating arteries (PCoA) (34 to 68%), hypoplasia or aplasia of the A1 segment of anterior cerebral artery (ACA) (4 to 10%), absence or fenestration of anterior communicating artery (ACoA) (12 to 21%), persistent fetal origin of posterior cerebral artery (fPCA) (4% to 26%), and infundibular dilatation or widening of PCoA (7% to 15%) [14–20]. Although there are numerous studies on anatomical variations of the circle of Willis, presence of any association between anatomical variations of circle of Willis and incidence of ischemic stroke is still unclear [21–27]. The blood supply to the brain was achieved from two sources, Internal carotid artery and vertebral artery.

Internal carotid artery

After piercing the duramatter ~~turns~~ back below the optic nerve and gives off superior hypophyseal artery, runs between the optic nerve and the oculomotor nerve. It reaches the anterior perforated substance and it terminates by dividing into anterior, middle cerebral arteries and ophthalmic artery.

Anterior cerebral artery

The anterior cerebral artery is the smaller of the two terminal branches of the internal carotid arteries. It is divided into 3 parts, A1-from the termination of internal carotid artery to the junction with the anterior communicating artery; A2-from the junction with the anterior communicating artery to the origin of callosomarginal artery; A3-distal to the origin of callosomarginal artery(28).

- The cortical branches supply the frontal lobe and supply the olfactory cortex, gyrus rectus and medial orbital gyrus. They also supply the motor and somatosensory areas that represent the lower limb.
- Frontal branches supply the corpus callosum, cingulate gyrus and paracentral lobule.
- Parietal branches supply the precuneus and the surrounding areas.
- Central branches supply the rostrum of corpus callosum, the septum pellucidum, anterior part of the putamen, head of the caudate nucleus and adjacent parts of the internal capsule (29).

Middle cerebral artery

The middle cerebral artery is the larger terminal branch of the internal carotid artery. It divides into four parts.

- M1-from the termination of the internal carotid artery to its bifurcation. This is known as sphenoidal segment.
- M2 segment - running in the lateral (sylvian) fissure, also known as the insular or sylvian segment.
- M3 segment- extends laterally from insula towards the cortex and is known as opercular part.
- M4 terminal or-cortical portions.

The middle cerebral artery runs at first in the lateral fissure, then posterosuperiorly on the insula and divides into branches. (30) Middle cerebral artery gives off cortical and central branches.

Vertebral artery

The right and left vertebral arteries are derived from the first part of respective subclavian arteries, ascend through the neck in the foramina transversoria of the upper six cervical vertebrae and enter the cranial cavity through the foramen

magnum close to the anterolateral aspect of the medulla. They converge medially and unite to form the basilar artery at the pontomedullary junction.

Basilar artery

Basilar artery is a large median vessel formed by the union of the right and left vertebral arteries at the mid medullary level. It lies in the pontine cistern and follows the shallow median groove on the ventral pontine surface, extending to the upper border of the pons. It ends by dividing into right and left posterior cerebral arteries at a variable level behind the dorsum sellae, usually in the interpeduncular cistern (31).

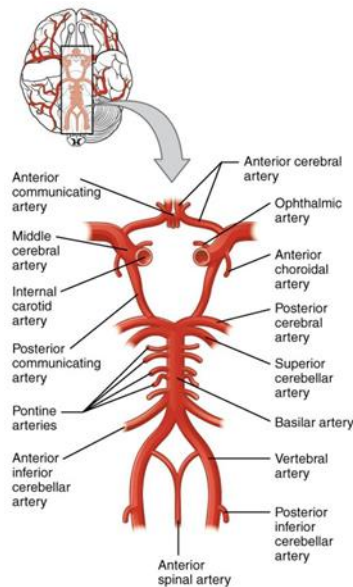


Fig 1: Showing the vertebral and basilar network

Posterior cerebral artery

The posterior cerebral artery is a terminal branch of the basilar artery. Surgical nomenclature divides into 3 parts (32).

- P1-from the basilar bifurcation to the junction with the posterior communicating artery.
- P2-from the junction with the posterior communicating artery to the portion in the perimesencephalic cistern.
- P3-the portion that runs in the calcarine fissure. The cortical branches supply the temporal, parieto-occipital lobes of the brain, the central branches supply the subcortical structures.

Anterior communicating artery

Anterior communicating artery is about 4mm in length and it connects the two anterior cerebral arteries.

Posterior communicating artery

The posterior communicating arteries are usually very small, arising from the internal carotid artery at the junction where it divides into anterior and middle cerebral arteries. Sometimes it is so large that the posterior cerebral artery was supplied via the posterior communicating artery rather than from the basilar artery (fetal posterior communicating artery)(33)

Embryological consideration

The vascular system develops in two stages: Vasculogenesis and Angiogenesis. The embryological development of the circulatory system supplying blood to the brain begins with the formation of the six pairs of primitive branchial arteries at the 1.3mm embryonic stage (34) . The brain vascular system arises from the perineural vascular plexus which sprout radially into the neuroepithelium. They subsequently branch off laterally in the subventricular zone, the subventricular plexus.

Materials and Methods

Materials of study

1. 50 embalmed adult human brain specimens were obtained and studied.
2. 50 Magnetic Resonance Angiography images were obtained and studied.

Method of study

- A. DISSECTION METHOD.
- B. RADIOLOGICAL METHOD.

Dissection method

This study was done in the Department of Anatomy, Santhiaram Medical College, Nandyal, Andhra Pradesh. An 50 preserved human cadavers irrespective of their sex and age. The brain specimens were dissected and studied between the years 2015-2017. The guidelines of Cunningham's manual of practical Anatomy were followed (fig2). AcoA- Anterior communicating artery. ACA-Anterior cerebral artery. MCA- Middle cerebral artery. PcoA- Posterior communicating artery. PCA- Posterior cerebral artery.

The skull cap was removed after making a pencil mark on the skull. Using chisel and hammer, vault of the skull was opened along the marked line and the skull cap is removed. The meninges are reflected and the brain is removed carefully by cutting the cranial nerves near their exit along the various foramina and spinal cord is detached from it below the level of medulla oblongata. The vertebral

arteries, basilar artery and internal carotid arteries are traced. Then the Circle of Willis is exposed by opening the interpeduncular cisterns at the base of the brain was preserved in 10% formalin (Cunninghams manual 15th edit). The Circle of Willis and its major branches were carefully dissected. The photos of Circle of Willis and their variations were taken and documented. The Circle of Willis is a major collateral blood flow and principal anastomotic trunk to the brain connecting the vertebrobasilar and the internal carotid arteries. A caliper graduated to measure up to 0.02mm was used to measure the diameter of the vessels. The arteries less than 1mm in diameter for cerebral vessels and less than 0.5mm for communicating arteries were considered as hypoplastic.

Radiological method

The radiological study was conducted in the Department of Radiology, Santhiaram Medical College, Nandyal, Andhra Pradesh from 2015-2017. This cross-sectional study was conducted on consecutive patients who underwent brain MRI and MRA for suspected cerebrovascular accident. The frequency of anatomical variations including persistent fetal origin of Anterior cerebral artery, posterior cerebral artery (fPCA) and hypoplastic/aplastic Anterior communicating artery (ACoA) and posterior communicating artery (PCoA) and their association with infarction in different intracranial vascular territories was assessed. A total of 50 Magnetic Resonance Angiogram images were taken for the study with the proper informed consent from each individual. Clearance from the Institutional Ethical Committee was obtained before the start of study.

The technique used was three Dimensional Time of Flight Magnetic Resonance Angiography (3D-TOF-MRA) using 1.5Tesla MRI scanner. Only the arteries forming the Circle of Willis were taken into study. Following imaging parameters were used repetition time/echo time 23/7.0, flip angle 25 degrees, slice thickness 0.7mm, number of slice 44/slab, number of slabs 4, slice overlap 25%, flow direction feet to head with 40mm saturation at the head end, field of view 180x158 and 256 matrix size. For the purpose of identification, the Circle of Willis is divided into anterior and posterior configuration.

The following parameters of Circle of Willis were noted in this study from both Dissection and Radiological methods.

1. Complete or incomplete formation.
2. Shape of the Circle of Willis.
3. Normal or abnormal caliber.
4. Symmetrical or asymmetrical pattern.
5. Morphological variations like absent vessels, attenuation, duplication / triplication and abnormal origin were studied.

Observations

Morphological study

Among the 50 brain specimens, the morphology is considered under four parameters.

1. Complete form.
2. Symmetrical.
3. Normal caliber.
4. Polygonal in shape.

Out of 50 specimens, 29 specimens (58%) were found to have complete normal symmetrical configuration, normal caliber and polygonal shape. Other 21(42%) specimens were abnormal either incomplete or asymmetrical or hypoplastic. Abnormalities in the vertebral and basilar artery were not taken into consideration in this study(Fig-2)

Anomalous circle

The present study was shows 21(42%) anomalous circle and described below.

Incidence of absence vessels

The least common anomaly seen in the variation of the Circle of Willis was the absence or aplasia of either the cerebral or the communicating arteries. Found there was aplasia of the posterior communicating artery in one specimen. Aplasia of anterior communicating artery was not found in this study(Fig – 3).

Incidence of hypoplastic vessels

The most common variation found was the hypoplasia of one or other components of the Circle of Willis. Posterior communicating artery was found to be more frequent among hypoplastic vessels followed by posterior cerebral artery. The incidence of hypoplasia is depicted in (Table 1). The posterior communicating artery shows high percentage of hypoplasia (38.09%) among all the vessels taken for the study (fig -4).

Incidence of accessory vessels

The accessory vessels were present in the form of duplication or triplication of one of the component of Circle of Willis. Duplication of component vessels was seen while triplicate vessels were not found in any specimens. Out of 21 variations seen, 5 specimens showed accessory vessels in the form of duplication (fig 5, 6). The anterior communicating artery was found to be more among all the vessels (19.04%). No duplication or triplications were seen in posterior part of Circle of Willis (Table 2) .

Incidence of anomalous origin

The fetal origin of posterior cerebral artery from the internal carotid artery is common variant in the posterior part of the circle. Here the posterior cerebral artery is small, hypoplastic or even absent and in order to compensate for the posterior circulation, the posterior cerebral artery is connected by a small communicating type of vessel. In this study, fetal origin of Posterior cerebral

artery was found in 2 specimens (9.52%). (Fig 7). The other vessels did not show any abnormality (Table 3)

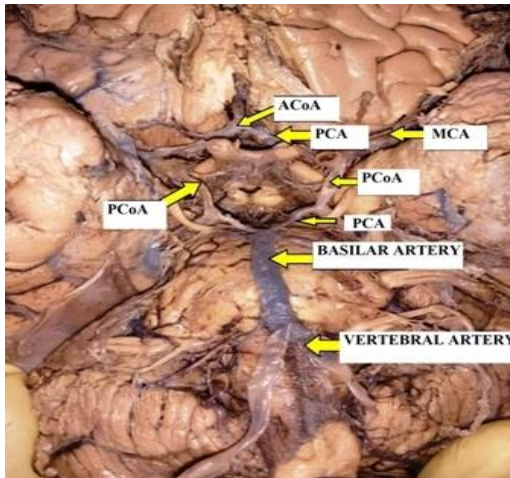


Fig 2: Showing normal circle of willis

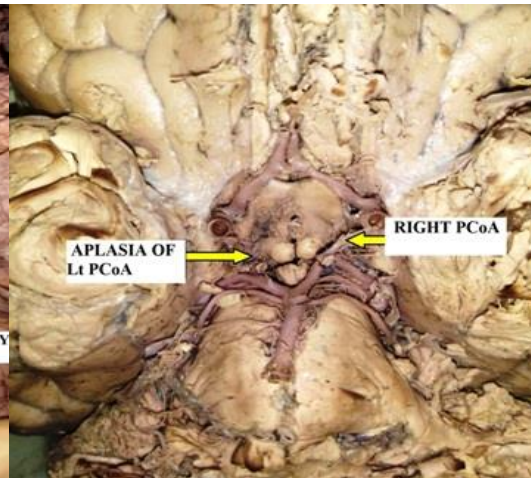


Fig 3: Showing aplasia of left PcoA.

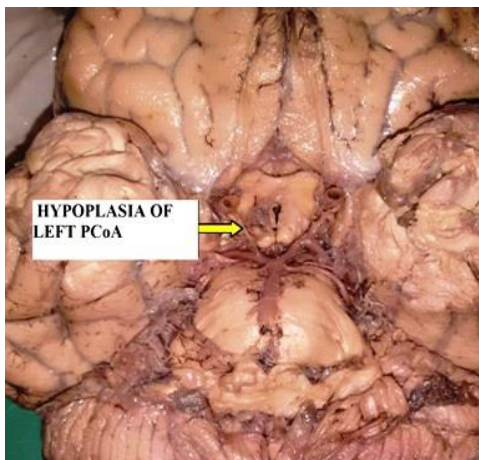


Fig 4: Showing Hypoplasia of left PcoA.

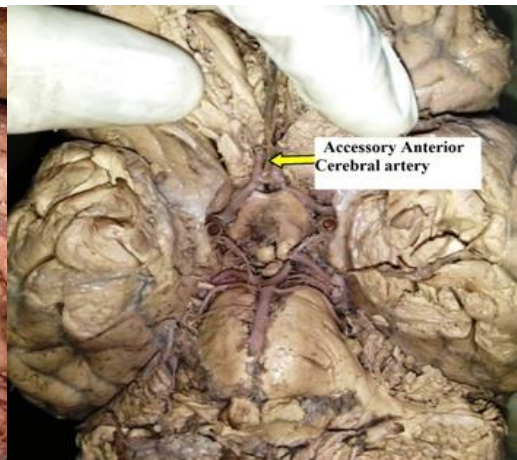


Fig 5: showing Accessory ACA

Incidence of variation in anterior and posterior part of the circle

Variations in anterior part of the circle was found in 7 specimens (33.33%) and the variations in the posterior part of circle was found in 14 specimens showing percentage of 66.67%.

Variation in individual vessels

The overall variation of the anterior part of the circle is 33.33% while the posterior part of the circle is 66.67%. Among all the variations, hypoplasias of the posterior communicating artery were found to be common followed by hypoplasia of the posterior cerebral artery(Table -3) .

TABLE – 1 : depicting the incidence of hypoplasia among cerebral and Communicating vessels out of 21 specimens.

Name of the vessel	No. of Hypoplastic vessel	Percentage %
ACA	1	4.7%
AcoA	1	4.7%
PCA(P1)	3	14.28%
PcoA	8	38.09%

TABLE- 2: Showing incidence of Accessory Vessels out of 21 specimens

Name of the vessel	No. of Accessory vessel	Percentage %
ACA	1	4.7%
AcoA	4	19.4%
PCA(P1)	3	14.28%
PcoA	8	38.09%



Fig 6: Showing Duplication of the AcoA.



Fig 7: Anomalous origin of Posterior cerebral artery

The most common variation noted is the hypoplasia of the cerebral and communicating vessels with a percentage of 61.90%. The next common variation is presence of accessory vessels with 23.80%. Among all the four vessels, Posterior communicating artery was found to have more variations (42.85%).

Hypoplasia of posterior communicating artery with vessel diameter less than 0.5mm is 38.09%. Followed by posterior cerebral artery with 14.2 %.

Name of the Vessel	Aplasia	Hypoplasia	Accessory Vessel	Anomalous Origin	%
ACA	-	1	1	-	9.82
AcoA	-	1	4	-	23.80
PCA	-	3	-	2	23.80
PcoA	1	8	-	-	42.86

Table 3: showing overall incidence of variation of individual vessels

Radiological study

Out of 50 cases, 34 cases were found normal, symmetrical and complete form of circle. The remaining 16 cases were found variations and showing one or more variations in the morphological patterns (Fig – 8).

Anomalous circle

The sixteen specimens with anomalous circle were taken into consideration.

Incidence of absent vessels

In the present study found no case of aplasia of either ACA or PcoA were reported.

Incidence of hypoplastic vessels

The hypoplasia was found to be common in anterior cerebral artery in 7 cases with a percentage of 43.75%(fig 9,10). The posterior cerebral artery was hypoplastic in 4 cases with a percentage of 25% and posterior communicating artery with one case with a percentage of 6.25%. The anterior communicating artery does not show any hypoplastic changes in this study.

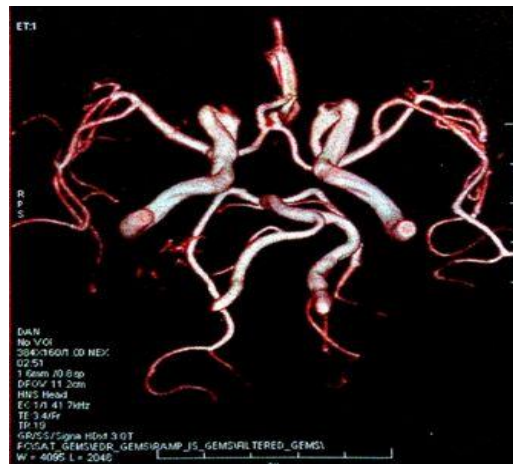


Fig 8 : : Showing normal Circle of Willis



Fig 9: Hypoplasia of left anterior cerebral artery

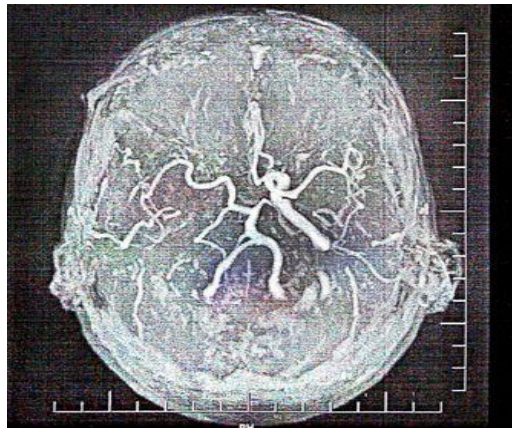


Fig 10: Hypoplasia of right anterior cerebral artery

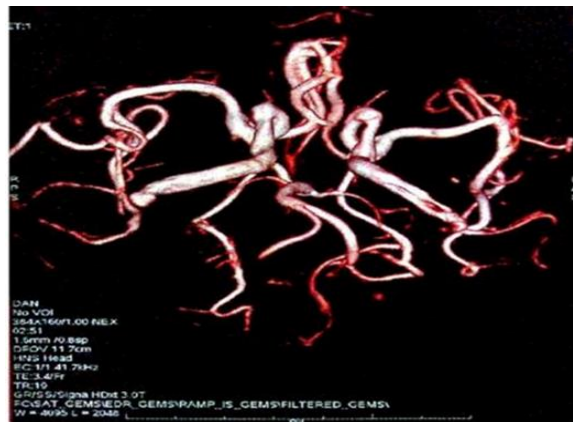


Fig11: Hypoplasia of left Posterior cerebral artery.

Incidence of accessory vessels

In the present study, no case of absent vessels was reported.

Incidence of anomalous origin

The fetal origin of posterior cerebral artery from internal carotid artery was found in 4 cases with a percentage of 25%. The other arteries do not show any abnormal origin.

Incidence of variation in anterior and posterior part of the circle of Willis

showing percentage of variation in anterior and posterior part of circle. Showing variations in 7 cases with 43.75% in the anterior part of circle of willis. In 9 cases with 56.25% showing variations in posterior part of circle of willis.

Variation in individual vessels

The overall variation in the anterior part of the circle is 43.75% and of the posterior circle is 56.35%. The common variation seen radiologically is hypoplasia of anterior cerebral artery followed by posterior cerebral artery. The anomalous origin of fetal posterior cerebral artery arising from internal carotid artery was seen in 4 cases with a percentage of 25%. (table 4) The most common variation among vessels forming the Circle of Willis is the hypoplasia with a percentage of 75%. The next common variation is presence of anomalous origin in 25% of specimens. Among all the four vessels, posterior cerebral artery showed more variations (50%). Hypoplasia of anterior cerebral artery is 43.75%. Followed by posterior cerebral artery with 25% and posterior communicating artery with 6.25%.

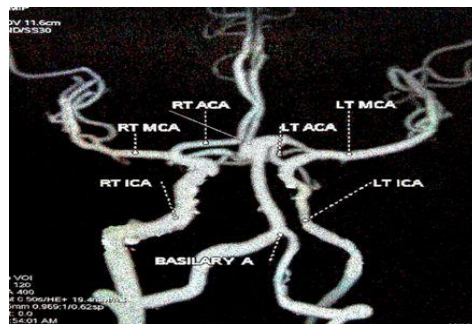


Fig 12: Left fetal origin of posterior cerebral artery

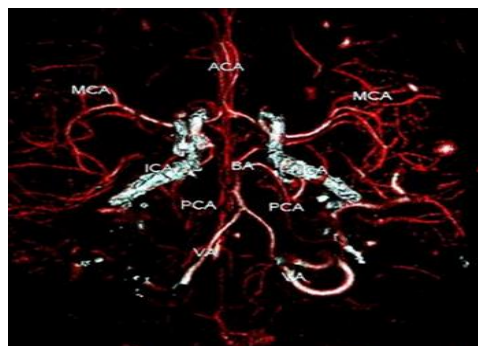


Fig 13: Right sided Fetal origin of posterior cerebral artery

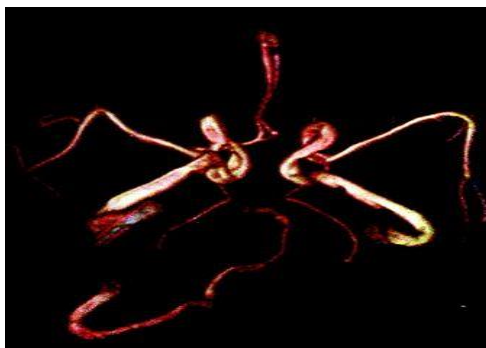


Fig15: Radiological image showing bilateral fetal type of Posterior cerebral artery

Name of the vessels	Aplasia	Hypoplasia	Accessory vessels	Anomalous origin	Percentage (%) (50 specimens)
ACA	-	7	-	-	43.75
AcoA	-	-	-	-	-
PCA	-	4	-	4	50
PcoA	-	1	-	-	6.25

Table 4: showing overall incidence of variation of individual vessels

Discussion

The Circle of Willis and its branches are subjected to numerous variations. The variations not only differ from person to person but also on the right and left side of the same individual. The role of arterial circle is to equalize the pressure and under normal condition, little interchange of blood takes place along the anastomotic channel due to equality of blood pressure. In case of occlusion, the arterial circle tends to equalize the pressure, thereby maintaining the circulation. The prevalence of the typical circle that is “normal text book type” polygon ranges from 5% to 72% (S.Iqbal) ⁴³. The wide range of variation is due to diversity in defining the criteria used to define hypoplastic vessels. The normal pattern and the variation are tabulated (4).

Author name	Normal Pattern (%)	Variations (%)
Alpers et al	52.3%	47.7%
Raja Reddy et al	53.3%	46.7%
Kamath S	56%	44%
Stephen and John	52%	48%
Macchi et al	41%	59%
Raghavendra et al	56%	44%
Hartkamp et al	42%	58%
Present study	58%	42%

Table 5: Comparing the normal and variation percentage with present and other studies

Raghavendra et al studied about Morphometric variation in the Circle of Willis in 50 adult brain specimens. Among the 50 specimens, 28 cases (56%) had a normal pattern of Circle of Willis while the remaining 22 cases(44%) showed variations. The common variation reported is the hypoplastic posterior communicating artery with a percentage of 31.8%. Of the 22 cases, 7 variations were seen in the anterior circulation and 15 variations were seen in the posterior circulation. In this study, variations in anterior circle was found in 7 cases and 14 cases showed variations in posterior circle. Thus the finding of the present study is comparable with that of Raghavendra et al ⁽³⁶⁾ .

The findings of the present study were also comparable with the study done by Alpers et al, Raja Reddy et al, Kamath S, Stephen and John et al etc (37 , 38) S.Iqbal studied about the Anatomical variation of the Circle of Willis in adult Human brain. The parameters included were the morphological variations of the arteries forming the Circle of Willis. In their study, majority of the circle showed variations(52%). Hypoplasia was the most common variation and was found in 24% of the brain specimens. Accessory vessels in the form of duplication or triplication of anterior communicating artery were seen in 12% of the circle. In this study, 42% of the brain specimens showed variation. The parameters include completeness of the circle, symmetrical, normal caliber and polygonal in shape. In the present study, hypoplasia was a common variation seen in 26%, which is comparable to the previous study done by S.Iqbal. ⁽³⁶⁾The other variations are tabulated.

Variations	S.Iqbal et al (in %)	Present study (in %)
Aplasia	6%	2%
Hypoplasia	24%	26%
Accessory vessels	12%	10%
Abnormal origin	10%	4%

Table 5: Comparing percentage of variations in both studies

Name of the author	PCOA	PCA (P1 segment)	ACOA	ACA(A1 segment)
Alpers et al	22%	-	3%	2%
Rigs &Rupp	53%	27.7%	9.25 %	11.97%
Kamath	10%	-	2%	2%
Present study	38.09%	14.2%	4.7%	4.7%

Table 6: Comparing the incidence of hypoplasia among different vessels.

Hypoplasia or attenuation of either the cerebral or the communicating vessel were found to be common among the variations. Hypoplasia were found in 26% of the present study and were common among all other variation. ^(37,38)Alpers et al reported an incidence of 27%, Kamath with an incidence of 24% and ⁽³⁹⁾Fetterman and Moran with an incidence of 23%. The following table compare the incidence of hypoplasia of the present study with the other studies. The wide range of variation is due to the different criteria used to measure hypoplastic vessels.

Hypoplasia were more prominent in the posterior portions of the Circle of Willis. This finding in the present study is comparable with other studies.

Accessory vessels in the form of duplication or triplication were found in the Circle of Willis. Among the accessory vessels, the incidence of duplication of Anterior communicating artery were 19.04% and the anterior cerebral artery were 4.7% in a total of five cases. The accessory vessels were not seen in posterior circulation. Apart from two normal anterior cerebral artery, it is also accompanied by a midline third anterior cerebral artery. This finding were comparable with S.Iqbal et al ⁽³⁵⁾.

The embryonic origin of the posterior cerebral artery from the internal carotid artery were found in 9.52% of the circle. Such a vessel is connected to the basilar artery by a small communicating artery. The anomalous origin were seen in 2 cases (9.52%). This study was comparable with S.Iqbal⁽³⁵⁾, Alpers et al ⁽³⁷⁾.

Table 7: Comparing the incidence of anomalous origin.

Name of the author	Incidence of embryonic origin of PCA from ICA(%)
S.Iqbal	10%
Riggs & Rupp	22%
Alpers et al	15%
Milenkovic et al	21%
Present study	9.52%

The least common anomaly of the Circle of Willis was the absence of one of the cerebral or the communicating vessels. In the present study, absence of posterior communicating artery were seen in one case with a percentage of 4.7%. The reported incidence of absent vessels in the Circle of Willis in normal brain ranges from 0.6% (Alpers) to 17%(Windle BCA⁽⁴⁰⁾). The absent vessel is not seen in anterior part of the circle. Fawcett and Blachford reported an incidence of 3.8% of absent vessels of posterior communicating arteries ⁽⁴¹⁾.

Cerebrovascular diseases such as stroke, thromboembolism, aneurysms together with their signs and symptoms depend upon the variations of the anatomical pattern of the Circle of Willis. The main collateral blood flow is through the communicating arteries and obstruction of the collateral pathway determines the severity of hemodynamic impairment(Yu-Ming Chuang)⁽⁴²⁾. The state of circle becomes important in determining the adequacy of the brain circulation.

For the radiological study, Magnetic Resonance Angiography has been used. The total number of images taken for the study is 50. 34 cases were found to be normal and the remaining 16 cases showed abnormal type of Circle of Willis. The abnormal circle either showed asymmetrical pattern, incomplete, or abnormal caliber.



Fig16: : Right side Vertebral artery hypoplasia along with hypoplasia of Right ACA.

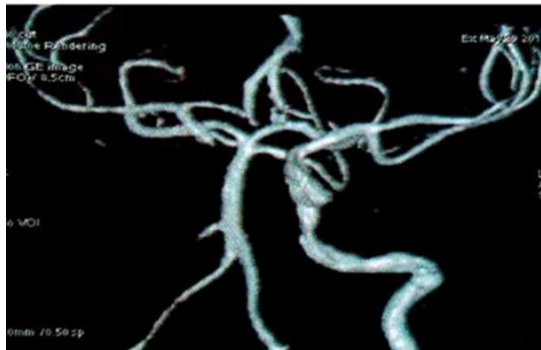


Fig 17: Stenosis of right internal carotid artery

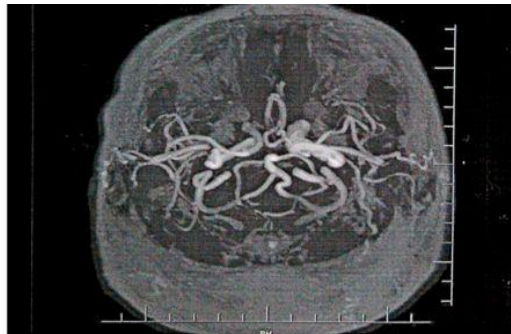


Fig 18: Showing ectasia of left internal carotid artery

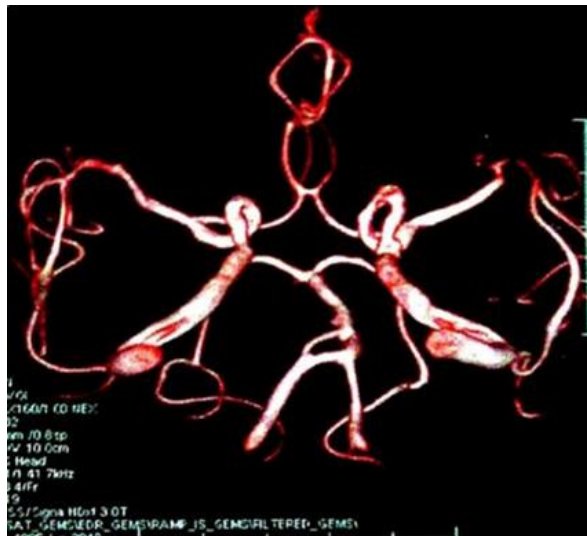


Fig 19: : Radiological image showing vertebrobasilar fenestrations

The variations pertaining only to the Circle of Willis were taken and was seen in 16 cases. There are other variations present in the study but were not taken owing to the objective of the study. Those variations include vertebral hypoplasia, stenosis /narrowing of internal carotid artery, ectasia of internal carotid artery and vertebrobasilar fenestrations.

The patients whose radiological images taken for the study were admitted with variety of neurological symptoms including stroke, focal muscular weakness, hemiparesis, hemiplegia etc. The outcome of the neurovascular injury depends on the presence or absence of collateral flow. The availability of these collaterals depends upon the normal pattern of Circle of Willis (Kalula N.T) ⁽⁴³⁾. Ability of the Circle of Willis to redistribute blood flow depends on its component vessels, (Miralles et al)⁽⁴⁴⁾.

The incidence of normal pattern of Circle of Willis radiologically shows wide variations among different studies. In the present study, out of 50 radiological images, 16 cases showed variation in the pattern of Circle of Willis with an percentage of 32%. The same parameters of the other study were compared. The prevalence of complete Circle of Willis was seen in 68% of the present study.

Conclusion

The arterial Circle of Willis was studied and analyzed as per the parameters the normal parameter like complete formation, shape, normal caliber of vessels and symmetrical Circle of Willis were found in more than 55% of cases. The variations in the Circle of Willis like absent vessels, hypoplasia of vessels and accessory vessels also found. The posterior parts of the circle were found to have more variation (66.67%) than the anterior part of the circle (33.34%) involving the posterior cerebral artery and posterior communicating artery. Among the variations found, hypoplasia was the most common variation and hypoplasia was seen more commonly in posterior communicating artery followed by posterior

cerebral artery. The other variations like anomalous origin of posterior cerebral artery were also found.

A thorough knowledge about the normal anatomy of Circle of Willis and its variations like hypoplasia, attenuation of vessels and anomalous origin is necessary for clinicians, neuro surgeons, vascular surgeons and radiologist. This will help them to diagnose the diseases and to plan for further management to perform correct interventional procedures.

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