"A MORPHOLOGICAL STUDY OF CIRCLE OF WILLIS AND ITS VARIATIONS IN ADULT HUMAN CADAVERS OF NORTH KARNATAKA"

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Under the Guidance of

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Date: Dr. Raghavendra. K

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LIST OF ABBREVIATIONS

- Ab - Absent.
- ACA - Anterior Cerebral Artery.
- ACoA - Anterior Communicating Artery.
- A1 - Pre-communicating part of Anterior Cerebral Artery.
- A2 - Post-communicating part of Anteriror Cerebral Artery.
- BA - Basilar Artery.
- Dup - Duplication.
- Hyp - Hypoplastic.
- ICA - Internal Carotid Artery.
- L - Left.
- MCA - Middle Cerebal Artery.
- MRA - Magnetic Resonance Angiography.
- MRI - Magnetic Resonance Imaging.
- N - Normal.
- PCA - Posterior Cerebral Artery.
- PCoA - Posterior Communicating Artery.
- P1 - Pre-communicating part of Posterior Cerebral Artery.
- P2 - Post-communicating part of Posterior Cerebral Artery.
- R - Right.
- VA - Vertebral Artery.

ABSTRACT

Background and Objectives:

Circle of Willis plays a vital role in collateral circulation and redistribution of blood to all areas of the brain. Variation in circle of Willis is known to cause grave disorders like cerebrovascular disorders, subarachnoid hemorrhage, cerebral aneurysm and schizophrenia.

The objectives of the present study are to study the formation and branching pattern of circle of Willis and also to study the distribution of variations.

Methods:

The study was conducted on 50 adult brain specimens. Each brain was removed in one piece by dissection and the circle of Willis was observed for its formation, pattern and variations.

Results:

Among the 50 specimens studied, 28 cases (56%) had a normal pattern of circle of Willis and variations were observed in the remaining 22 cases (44%). More number of variations was observed on the right side than on the left side. The most common variation observed was hypoplastic posterior communicating artery (7 cases, 31.8%). Posterior communicating artery was found to be the most variable vessel while middle cerebral artery was the least variable vessel.

Interpretation and Conclusion:

The results with respect to the circle of Willis and all its component arteries were consistent with the results in the available literature. The only exception was the increased incidence of absence of both the anterior and posterior communicating arteries. This finding is of clinical significance to neurologists and neurosurgeons in this geographical location of north Karnataka. A higher incidence of variations in the communicating arteries is likely to manifest as a higher incidence in disorders like migraine, schizophrenia and cerebrovascular disorders due to compromised collateral circulation and poor redistribution of blood.

Keywords:

Circle of Willis; Circulus Arteriosus; Anterior Cerebral Artery; Middle Cerebral Artery; Posterior Cerebral Artery; Anterior Communicating Artery; Posterior Communicating Artery.

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INTRODUCTION

Circle of Willis is the arterial anastomosis at the base of the brain which is also referred as "Circulus Arteriosus cerebri". The pattern of arterial arrangement & communication forms a unique arterial network connecting the principle arteries supplying the brain.[1]

Circle of Willis was named after a popular British Anatomist-Physician Thomas Willis (1621-1673) who was the first to describe it completely.[2] Though called a circle, it is precisely a nonagon or a nine sided polygon.[3]

Formation, Location & Relations:

The circle of Willis is a large arterial anastomosis which unites the internal carotid and vertebro-basilar systems. It lies in the subarachnoid space within the interpeduncular cistern, and surrounds the optic chiasma and infundibulum. Anteriorly, the anterior cerebral arteries, derived from the internal carotid arteries, are linked by the small anterior communicating artery. Posteriorly, the two posterior cerebral arteries, formed by the bifurcation of the basilar artery, are joined to the ipsilateral internal carotid artery by a posterior communicating artery.[4, 5]

There is considerable individual variation in the pattern and caliber of vessels that make up the circulus arteriosus. Although a complete circular channel almost always exists, one vessel is usually sufficiently narrowed to reduce its role as a collateral route and the circle is rarely functionally complete. The haemodynamics of the circle are influenced by variations in the caliber of communicating arteries and in the segments of the anterior and posterior cerebral arteries which lie between their origins and their junctions with the corresponding communicating arteries. The greatest variation in caliber between individuals occurs in the posterior communicating artery, which is normally very small, so that only limited flow is possible between the anterior and posterior circulations.[1]

Collateral circulation in circle of Willis

The circle of Willis performs the balancing act of redistributing blood and equalizing blood pressure between the blood vessels of all areas of the brain in case of any vascular compromise. It also provides alternate channels in case of reduced blood supply to the brain during many functional activities or disorders.

Brain depends on continuous and uninterrupted supply of blood as its source for oxygen, glucose and other nutrients for its normal functioning. The rapidity of unconsciousness in common syncope, more traumatically induced but mercifully swift in judicial hanging, are dramatic reminders of the precarious aerobic balance in which the parenchyma of the brain survives.[6]

The total cerebral blood flow amounts to 50-55ml/min/100g of brain tissue.

The cerebral circulation is “auto-regulatory” where circulation persists until the blood pressure is reduced to 60mm of Hg which conversely increases the cerebral blood flow. It is influenced predominantly by physical and neural factors.[7]

Under normal circumstances the collateral circulation is minimal as only a fractional amount of blood is exchanged or mixed. In case of obstruction to one of the carotids (ICA or CCA) due to any disorders, the collateral circulation is significantly increased via the established anastomotic networks.

Surgical significance of circle of Willis

- It is a well established fact that the adequacy and compliance of collateral circulation plays a vital role in the course and severity of a cerebrovascular disorder.
- Analysis and establishing the pattern of circle of Willis is one of the most important prerequisites of various diagnostic & therapeutic neurovascular procedures.
- In case of complete unilateral vascular occlusion or thrombosis, expansion of anastomotic channels and collateral circulation in circle of Willis is life saving.[8]
- Aneurysms are balloon-like swellings which occur on as a result of defects in the arterial wall. They are most commonly found on the vessels of the circle of Willis particularly at or near the junctions of vessels.
- Bleeding into the subarachnoid compartment, subarachnoid hemorrhage is the most common pathology that involves the subarachnoid space. The commonest cause is rupture of an aneurysm of the intracranial vessels that run within the subarachnoid space. The patient complains of a very sudden onset of headache that is frequently described as being their ‘worst ever headache’ or ‘like being hit on the head with a hammer’.
- A complete circle of Willis with a well formed arterial network is of primary concern to the operating neurosurgeon and critical for survival of the patient in the above mentioned cerebrovascular disorders.
- A high incidence of anomalies of circle of Willis has been reported in patients of migraine and schizophrenia.[9] Incomplete posterior part of circle of Willis

has been found to be a risk factor for migraine.[10] The same has also been reported in criminals and people with anti-social behavior.

- Variations in configuration of circle of Willis can remain asymptomatic or present with symptoms like sudden onset headache, blurring of vision, transient ischemic attacks. It may also predispose to cerebral ischemia in young adults.[11]
- Variations in the pattern of circle of Willis are increasingly being detected during systemic screening and evaluation of patients presenting with different forms of headache like sudden onset headache, migraine, unilateral headache and cluster headache. Increased circulatory stress due to altered hemodynamics is thought to be the reason for the headache.[11]

Relevance of the present study

The normal pattern of circle of Willis is relatively uncommon. Various studies in the past have revealed that a significant lack of consistency exists in the pattern and branching of circle of Willis.

Circle of Willis shows a considerable degree of individual variation which may justify the fact that, its functional efficiency differs widely in different individuals.

All these facts put together makes this present study all the more interesting and important. The present study is an effort to gather a substantial knowledge and information about the variations in circle of Willis in population of North Karnataka.

OBJECTIVES

1. To study the formation and branching pattern of circle of Willis.
2. To gather information about variations and anomalies encountered, if any which may prove valuable in clinical and neurosurgical procedures.
3. To study the incidence and distribution of variations in the circle of Willis.
4. To observe, compare and correlate the study findings with similar studies done in the past around the world.

REVIEW OF LITERATURE

History of circle of Willis:

A complete description of circle of Willis has eluded many a great anatomists in history. Descriptions of an arterial circle at the base of the brain has featured in the greatest works of various authors, anatomists and surgeons over a period of several centuries as listed below.

- Gabriel Fallopius (1561-62) - *Anatomical Observations.*
- Guilio Casserio (1627) - *De Humani Corporis Fabrica.*
- Vesling (1647) - *Syntagma Anatomicum.*
- Thomas Willis (1664) - *Cerebri Anatome.*
- Von Haller (late 18th century) - *First to refer to the arterial circle as circle of Willis.*

Thomas Willis is thought by many to be the first to illustrate the arterial circle at the base of the brain that has his name. This attribution is an error. Gabriel Fallopius in 1561-62 in his *Anatomical Observations* described an almost complete circle except for the posterior communicating artery, which he thought was only indirectly connected with the internal carotid artery through a network of small arteries. Delving further back into history we encounter Guilio Casserio (1545–1605), who in his elegant atlas published posthumously in 1627 illustrated an almost complete arterial circle in a book *De Humani Corporis Fabrica* published by Adrianus Spigelius. Thus the correct recognition of the arterial ramifications at the base of the brain had a long and gradual evolution, and it appears that many anatomists had a hand in describing and illustrating the complete structure of the circle. While Willis might not have been the first to recognize the presence of an arterial circle at the base of the brain, it is his independence of thought and creativity in understanding the significance of the circle that has produced the scientific work of lasting value and recognition. This alone provides sufficient historical justification for calling the structure the circle of Willis.[2.]

THOMAS WILLIS.[12]

History of collateral circulation:

A thorough search in literature reveals that John Hunter (1785) was among the first few to study collateral circulation. He demonstrated collateral circulation by ligating the main artery supplying the rapidly growing antler of a stag. He anticipated cessation of growth of the antler but the outcome was far from what was expected. Superficial vessels rapidly enlarged and bypassed the obstruction by carrying blood to the distal growing segments. He explained this phenomenon on the principle that “the blood flows where it is needed”. He applied the same principle to treat a patient having a popliteal artery aneurysm. He applied a ligature to the femoral artery and demonstrated that the distal segment remained viable. Hunter was the first to refer to the branching and arterial communication with one another as anastomosis. [13]

Several investigations served as evidence to support the concept that the circle of Willis is a potential source of collateral circulation. Kramer (1912) injected methylene blue into the carotid and vertebral arteries of experimental animals and demonstrated that the dye does not pass from one arterial system into the other unless there is an obstruction and reduced pressure on the contralateral side of the circle.[14]

Evolution of circle of Willis:

A few interesting facts about the evolution of circle of Willis from fish to primates have been cited here. These facts provide a comparative picture as to how the circle of Willis has changed and evolved to the present stage.

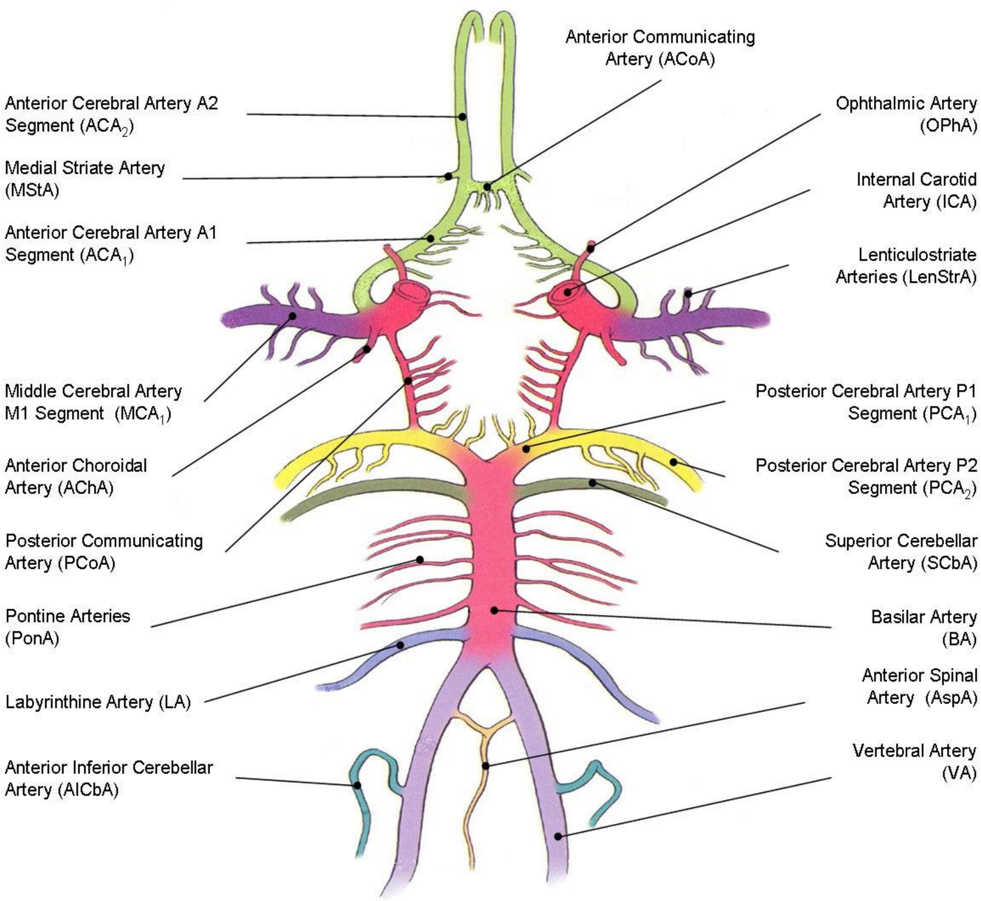
- Frogs and reptiles do not have a circle of Willis.
- In fish, amphibians and reptiles, the internal carotid artery is the sole blood supplier to the cerebrum.
- In birds, the cerebral circulation has two halves which do not communicate with each other.

- In browsing animals like cattle (cow, goat and sheep) the circle of Willis is well developed. The anterior communicating artery is represented by a mesh like network of fine vessels.
- In monkeys, the circle is similar to that of man. In chimpanzees, the anterior cerebral arteries united to form a single median artery that runs in the longitudinal fissure and then splits into two at the level of rostrum of corpus callosum. Hence the anterior communicating artery is absent. In black spider monkey, the vertebral arteries do not fuse to form a basilar artery but remain as two separate parallel branches.
- The circle of Willis is a characteristic feature of mammalian circulation. [15]

James Watts (1934) studied the circle of Willis in the monkeys and primates in comparison with that of humans. The pattern of cerebral arteries in the gorilla and orangutan closely resembled that of man. Chimpanzee has only a single anterior cerebral artery, while the black faced spider monkey has a double basilar artery which hints at persistence of an early embryonic condition. The relative importance of carotid and vertebral arteries greatly differs across species. In the lemur, the vertebral artery supplies almost the whole of the brain and the carotid arteries are rudimentary. In humans, the carotid and vertebral arteries are of nearly the same importance in view of their contribution to anterior and posterior circulation respectively.[16]

Formation of circle of Willis

The circle of Willis is a large arterial anastomosis which unites the internal carotid and vertebro-basilar systems. Anteriorly, the anterior cerebral arteries, derived from the internal carotid arteries, are linked by the small anterior communicating artery. Posteriorly, the two posterior cerebral arteries, formed by the division of the basilar artery, are joined to the ipsilateral internal carotid artery by a posterior communicating artery.[1, 4, 5]



CIRCLE OF WILLIS.[7]

The Internal Carotid Arteries (ICA):

The common carotid & internal carotid arteries perform the crucial role of carrying blood vertically upwards & against the force of gravity towards the brain. The internal carotid artery begins at the bifurcation of the common carotid artery in the neck, ascends towards the brain and enters the cranial cavity through the carotid canal of the temporal bone. It then runs forward within the cavernous sinus. The cerebral portion of the artery, after perforating the duramater at the medial side of anterior clinoid process turns backwards through the duramater forming the carotid siphon. Before reaching the brain, it turns below the optic nerve and divides into the anterior and middle cerebral arteries. The terminal parts of the two internal carotids and anterior cerebral arteries form a part of the circle of Willis while the middle cerebral arteries do not. [1, 4, 5]

A) The anterior cerebral artery (ACA):

The anterior cerebral artery is one of the terminal branches of the internal carotid artery and starts at the medial end of the lateral cerebral sulcus. It passes forwards and medially above the optic nerve to the commencement of the longitudinal fissure. Here it is joined to the homologous artery of the opposite side by the anterior communicating artery, a short transverse trunk.

The part of the anterior cerebral artery before the communication is called the A1 segment (pre-communicating), while the part of the anterior cerebral artery after this communication is called the A2 segment (post-communicating).

Distal to the anterior communicating artery, the two anterior cerebral arteries run parallel to each other in the longitudinal fissure, curving around the genu of corpus callosum and turning backwards along its superior surface. Here it terminates by anastomosing with branches of the posterior cerebral artery. The anterior cerebral artery gives off two types of branches namely central & cortical branches. [4, 5]

B) The Anterior Communicating Artery (ACoA):

The anterior communicating artery is a small vessel that connects the A1 segments of the anterior cerebral arteries of both the sides in the midline across the commencement of the longitudinal fissure. Sometimes it is double, fenestrated or multi-channeled. This anastomosis forms the ACA-ACoA complex. This arrangement facilitates the potential cross circulation between the two carotids of either side via the circle of Willis.

C) The Posterior Communicating Artery (PCoA):

The posterior communicating arteries are two in number and arise from the internal carotid arteries on either side. They run backwards, above the oculomotor nerves and anastomose with the posterior cerebral artery of their respective side to close the arterial circle and form the circle of Willis.

The Vertebro-Basilar system:

After passing through the foramen magnum in the base of the skull, the two vertebral arteries join to form a single median vessel called the basilar artery. This vessel terminates by bifurcating into the right and left posterior cerebral arteries.

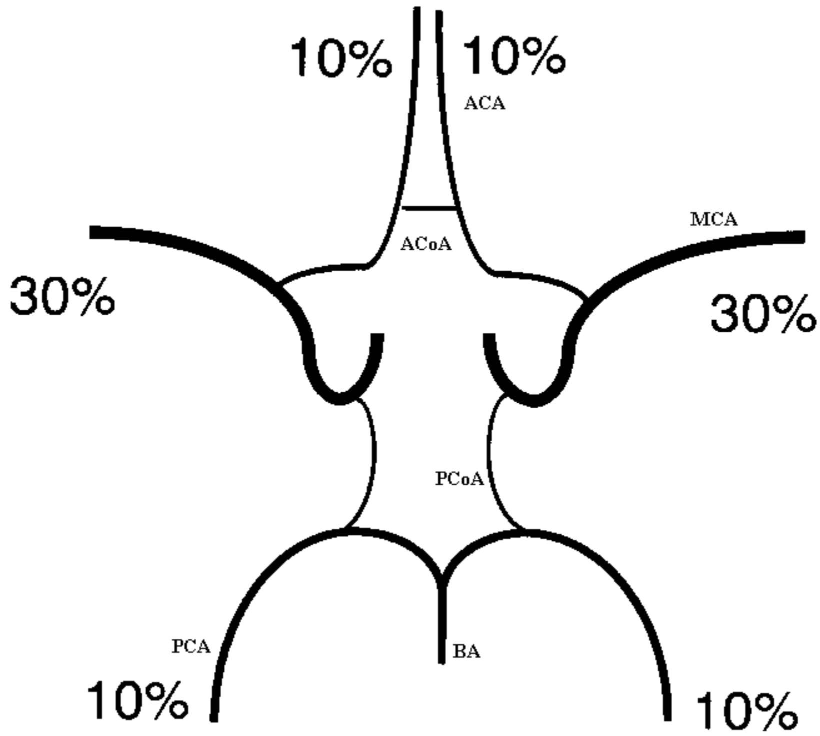
A) The Basilar Artery (BA):

The basilar artery is a large midline vessel that is formed by the confluence of the two vertebral arteries. It extends superiorly from its origin near the ponto-medullary junction to its terminal bifurcation into a pair of posterior cerebral arteries. It occupies a shallow median groove on the anterior surface of pons called the basilar sulcus.

B) The Posterior Cerebral Artery (PCA):

The posterior cerebral artery passes laterally on both sides. It receives the posterior communicating branch of the internal carotid artery. The part of the posterior cerebral artery proximal to this communication is called the P1 segment (pre-communicating) and the part distal to this communication is called the P2 segment (post-communicating. Then the artery winds around the cerebral peduncle and reaches the tentorial surface of the cerebrum to terminate into the branches that supply the temporal and occipital lobe. The posterior cerebral artery is similar to the anterior cerebral artery in giving off central and cortical branches.

Thus a complete circle of Willis consists of two internal carotid arteries, two anterior cerebral arteries, an anterior communicating artery, two posterior communicating arteries, two posterior cerebral arteries and a basilar artery. [1, 4, 5]



Estimated volume flow of the anterior, middle and posterior cerebral arteries (The numbers have been approximated to multiples of 10%). [17]

EMBRYOGENESIS

Each cerebral artery is formed from a primitive vascular network surrounding the brain. New channels have evolved and enlarged from this network in response to variable demands of different parts of the brain.

Development of Anterior Circulation:

At 4mm stage of human development, the internal carotid artery is the major cerebral vessel. The internal carotid arteries develop from the third aortic arches, the dorsal aorta and a plexiform primordial vascular network that surrounds the forebrain and the midbrain.

The primitive internal carotids divide into the cranial and the caudal divisions. The caudal divisions initially terminate as the primary olfactory arteries and then give rise to the definitive anterior cerebral arteries as well as to the anterior choroidal and middle cerebral arteries. The anterior communicating artery is formed from a plexiform vascular network that coalesces in the midline and connects the two developing anterior cerebral arteries. The adult pattern, except for the differential growth is established by 40mm stage of development.[1, 18]

Development of Posterior circulation:

The division of caudal internal carotid artery anastomoses with the dorsal longitudinal neural arteries. The caudal divisions then normally regress and become posterior communicating arteries. The caudal division of internal carotid arteries forms the pre-communicating segments of the posterior cerebral arteries. The paired dorsal longitudinal neural arteries fuse in the midline and form the basilar artery as the definitive vertebro-basilar circulation matures in addition to the posterior connections as the anterior circulation partially involutes. Hence the posterior cerebral artery, initially a branch of internal carotid artery, in the late developmental stages becomes derived primarily from the vertebro-basilar system.[1, 18]

The following are excerpts and results from various studies conducted on the circle of Willis on a platform and background similar to the present study.

Fawcett and Blachford (1905) studied 700 specimens of circle of Willis. Their findings were reported as follows.

- Circle of Willis was completely formed in 673 specimens (96.1%) and incomplete in the remaining 27 cases (3.9%). The circle was symmetrical in 514 cases (73.4%).
- Variations of anterior cerebral arteries were rare. In 2 cases doubling was seen and in both cases it was on the right side.
- Variations of anterior communicating arteries were classified as double (51 cases), plexiform or treble (3 cases) and absent (1 case).
- Absence of posterior communicating artery was seen in 23 cases unilaterally and in 3 cases bilaterally.
- Asymmetry in the pattern of circle of Willis was seen in 10 cases due to abnormal origin of posterior cerebral artery from internal carotid artery. In 6 cases this asymmetry was on the right side and in 4 cases on the left side.[19]

Blackburn (1907) studied 207 brain specimens and reported that only 29.5% specimens had a normal pattern. He reported double anterior communicating artery in 14 cases and its absence in 2 cases. In only one case, he noted a unilateral absence of posterior communicating artery. In his subsequent studies with Hinze and Wybrow he found that, 44-55% of criminals and schizophrenics showed anomalies in circle of Willis. [9]

Stopford (1915) studied 150 specimens and reported that doubling of anterior communicating artery was the most frequent variation accounting for 10% (15 cases) of the variations. Trebling or plexiform anterior communicating artery was seen in 2 cases. Unilateral absence of posterior communicating artery was seen in 11 cases.[20]

Saphir (1935), Fetterman and Moran (1941) observed cerebral infarction in patients with atherosclerosis and heart diseases with no morphological evidence suggesting occlusion of cerebral arteries. Consequently, they attributed the cause of cerebral infarction to defective collateral circulation in posterior communicating arteries and concomitant cardiac failure. [21]

Rogers (1947) developed experimental models to demonstrate that adequate cerebral circulation could be maintained under normal circumstances even though blood flow through posterior communicating arteries was negligible. Rogers suggested that the value of circle of Willis in collateral circulation under normal circumstances was potential rather than actual because similar to all other anastomosis, it was capable of opening up and providing a bypass if one of the main supplying channel is blocked.[22]

Wilson G, Riggs H and Rupp C (1952) conducted a pathological study on 143 cases of subarachnoid hemorrhage to assess the factors affecting successful surgical intervention in ruptured military aneurysms. 118 cases were associated with anomalies of circle of Willis. They observed that two factors were critical in deciding the outcome. One was identifying the exact location of aneurysm and the other was presence of associated anomalies of the circle of Willis. They conclusively said that in every case of aneurysm, circle of Willis anomalies should be looked for before any surgical intervention is undertaken, as it affects the adequacy of collateral circulation post surgically. [23]

Sir Russell Brain (1957) suggested that the biological function of circle of Willis is to protect the brain from ischemic conditions, whatever the position of the head relative to the trunk might be. He further suggested that the blood supply to the brain depends directly upon the systemic blood pressure and inversely on the resistance offered by the walls of cerebral blood vessels. To maintain optimum blood flow to the brain these two factors were balanced by various factors. His view was supported by another study by Tool and Tucker (1960) who demonstrated the variations in blood flow in the carotid and vertebral arteries that occurred with changing positions of the head relative to the cervical spine.[24]

Alpers (1959) reported the normal pattern of circle of Willis in 52% cases among the 350 specimens they studied. Their observations of variations are as follows.

- Absence of anterior communicating artery in 2% of cases.
- Absence of posterior communicating artery in 0.6% of cases.
- Doubling of anterior communicating artery in 9% of cases.
- Doubling of posterior communicating artery in 1% of cases.
- Anomalous origin of posterior cerebral artery in 15% of cases.[25]

Sedzimir (1959) studied collateral circulation through anterior segment of circle of Willis in 712 subjects using angiography. Contrast medium was injected into one internal carotid while the opposite internal carotid artery was being compressed physically in the neck. Results showed that nearly one third of the subjects had defective collateral circulation through the anterior segment.[26]

W B Stehbens (1963) studied pathological features of 252 cases of cerebral aneurysm at autopsy. He found no evidence to prove the belief that variations of circle of Willis were more prevalent with aneurysms than in general population. He suggested that certain variations of circle of Willis may be commonly seen with aneurysms of anterior communicating artery due to hemodynamic factors. But an association of aneurysms with an overall raise in incidence of variations in the circle could not be proven.[27]

Riggs (1963) conducted a study on 994 specimens and found variations in 81% of the cases. He classified the different variations encountered as follows.

- Type 1 (Normal): 19%.
- Type 2 (Thin but fully formed posterior communicating artery): 6%.
- Type 3 (Unilateral hypoplasia of anterior cerebral artery): 25%.
- Type 4 (Unilateral hypoplasia of P1 segment of posterior cerebral artery with posterior cerebral artery developing partially or fully from internal carotid artery): 16%.
- Type 5 (Bilateral hypoplasia of P1 segment of posterior cerebral arteries with partial or complete origin of both posterior cerebral arteries from the internal carotid arteries): 11%.
- Type 6 (Combination of type 3 and type 4 on the same side): 8%.
- Type 7 (Combination of type 3 and type 4 on the contralateral side): 8% and
- Type 8 (combination of type 3 and type 5): 8%.[28]

Vare A M (1964) observed 50 specimens of circle of Willis and found variations in 84%. Their findings are as follows.

- Duplication of anterior communicating artery in 5 cases.

- Unilateral absence of posterior communicating artery in 6 cases.
- Posterior cerebral artery arose from internal carotid artery in 13 cases.
- Middle anterior cerebral artery in 1 case.[29]

Gunter (1964) studied 98 fetal circles of Willis specimens and found that only 21 specimens had a complete and symmetrical circle of Willis. He also found that in comparison to adult circles more significant variations were found in the posterior parts of the fetal circles. In one case he found the intracranial part of the right internal carotid artery to be smaller than the left which was associated with multiple anomalies of the circle of Willis. [30]

Augusto Baptista (1966) studied numerous circles of Willis over a period of time and arrived at a conclusion that circle of Willis is primarily designed to provide symmetrical blood flow for symmetrical growth of the two halves of the forebrain. He also pointed out that variations, if present are more common on the non dominant side of the brain.[31]

Battacharji (1967) studied 137 specimens in which 49 specimens affected with cerebral infarction were compared with 88 normal specimens used as controls. With the help of models and experiments they demonstrated that posterior communicating arteries played a crucial role in maintaining the adequacy of collateral circulation when extracranial blood vessels are occluded. Thinning or absence of posterior communicating artery was the commonest anomaly in their study followed by anomalous origin of posterior cerebral artery from internal carotid artery.[32]

Vare A M and Bansal P C (1970) studied 175 brain specimens for their vascular supply. Only 47 specimens had a normal pattern and symmetry of circle of Willis. The variations were classified and subclassified as follows.

- Variations of anterior cerebral arteries were subclassified into straight course (5.1%), splitting (3.4%), unequal size (11.4%), anomalous origin (2.3%), median anterior cerebral artery (1.7%). Berry's aneurysms were present in 6.9% cases in anterior cerebral artery.
- Anterior communicating artery variations were subclassified into duplication (10.3%), triplication (2.3%), string like vessel (1%), variation in direction (7%), absent (1%).
- Posterior communicating arteries presented with a large number of variations. It was absent in 10.2% of cases and in 11.7% cases it was found to be unequally sized in comparison with its counterpart on the opposite side.
- The commonest anomaly in their study was abnormal origin of posterior cerebral artery from internal carotid artery in 25% cases.
- Basilar artery was found to be smaller in dimensions in 10 cases. In 34 cases the basilar artery continued as a single posterior cerebral artery. [33]

Raja Reddy (1972) studied 357 medicolegally autopsied brain specimens. They found normal pattern and symmetry of circle of Willis in 53.3% (190) cases. Interestingly no aneurysms were found in any of the cases. Marked asymmetry in the sizes of component vessels was found to be the most common anomaly. Some of their other findings are as follows.

- Absence of anterior communicating artery in 0.5% cases.
- Absence of posterior communicating artery in 1.6% cases.
- Duplication of anterior communicating artery in 7% cases.[34]

Orts P A, Gomez M N and Padeco (1975) studied 62 specimens of circle of Willis from patients who died of various causes. They studied and compared individual cerebral and communicating arteries for variations. They arranged the findings of constituent vessels in an ascending order with reference to number of variations.

- The middle cerebral artery was the most constant vessel and least affected by variations.
- This was followed by anterior cerebral artery the reason being that, hypoplasia of any one anterior cerebral artery was compensated by hypertrophy of anterior communicating artery. Thus calibers of anterior cerebral artery and anterior communicating artery were inversely proportional to each other.
- Variations in anterior communicating artery were relatively high (35.4%). They stated that common anomalies of duplication, triplication and partial duplication are nothing but persistence of embryological stages.
- Highest number of variations were seen in posterior communicating arteries (65.3%) the most frequent anomaly noted being its hypoplasia (51.6%). They also noted that caliber of posterior communicating artery had no relation to that of posterior cerebral artery. This is in contrast to anterior circulation where an inverse relation existed between calibers of anterior cerebral artery and anterior communicating artery.
- Posterior cerebral arteries were affected more often by hypoplasia than anterior cerebral arteries.

Overall variation in pattern was seen in 87% cases. On correlating clinical history and postmortem data with the findings, it was concluded that the circle of Willis was a physiological unit and any variations in it does not affect the normal functions of the brain.[35]

Ozaki et.al (1977) classified variations in circle of Willis into 10 categories.

- Type 1: Fenestration of anterior communicating artery including ‘V’, ‘H’, ‘Y’ and ‘N’ forms, double, triple and plexiform types.
- Type 2: Fusion of anterior cerebral artery at one point (‘X’ shaped).
- Type 3: Median anterior cerebral artery.
- Type 4: Asymmetrical proximal segments (A1) of anterior cerebral artery.
- Type 5: Accessory middle cerebral artery.
- Type 6: Early duplication of middle cerebral artery.
- Type 7: String like posterior communicating artery.
- Type 8: Asymmetry of posterior communicating arteries.
- Type 9: Primitive type of posterior communicating arteries.
- Type 10: Asymmetry of vertebral arteries.[36]

N Jayasree and G Sadasivan (1981) studied 100 specimens of circle of Willis. They found the classical description of circle of Willis in 18 cases only. The variations they observed in each constituent vessel are grouped as follows.

Anterior cerebral artery:

- The two A1 segments forming the anterior part of the circle were of unequal sizes in 14% cases.
- Buttonhole formation or Island formation (splitting of A1 segment of anterior cerebral artery to rejoin again) was seen in 6% cases.

- Fusion of both A2 segments to form a single median trunk was seen in 2% cases.
- The presence of recurrent artery of Heubner was classified as a variation. It was seen in 40% cases.

Anterior communicating artery:

- String like anterior communicating artery (diameter less than 1mm) was seen in 3% cases.
- Duplication and triplication, considered together were seen in14% cases.
- Horizontal 'Y' artery was seen in 6% cases.
- Complete absence of anterior communicating artery was seen in 6% cases.

Internal carotid artery:

- Trifurcation of internal carotid artery at its termination was seen in 28% cases.

Middle cerebral artery:

- No variations were seen in middle cerebral artery. It was found to be the most constant and least variable vessel in circle of Willis.

Posterior communicating artery:

- It was absent unilaterally in 2% cases.
- It was string like (diameter less than 1mm) in 9% cases.
- Abnormal dilation of this artery was seen in 24 cases.

Posterior cerebral artery:

- P1 segments were narrower than P2 segments in 24% cases. In all these cases posterior communicating arteries continued as P2 segments of posterior cerebral arteries. In these cases posterior cerebral artery is actually a branch of internal carotid artery. A narrow P1 segment is seen but a prominent posterior communicating artery joins this and continues as P2 segment. This is called **Embryonic or Fetal origin of posterior cerebral artery.**

Basilar artery:

- Basilar artery was formed at a lower level in 14% cases and at a higher level in 5% cases.
- Bifurcation into two unequal posterior cerebral arteries was seen in 21% cases.[37]

Kamath S (1981) studied 100 brain specimens to analyze the pattern of formation and measurements of circle of Willis in south Indian subjects. 44% cases showed variations, most affected being the communicating arteries. Anterior communicating arteries were found to be more anomalous in length while posterior communicating arteries were more anomalous in diameter. Anomalies were noted more on the right side. Average diameters were more on the left side than on the right side indicating the blood supply to the left dominant hemisphere was more. [38]

Prakash H B (1981) studied 80 specimens of circle of Willis in south Indian subjects. Variations were seen in 60% cases. In the posterior circulation hypoplasia of posterior communicating artery accounted for majority of the anomalies (30%). Fetal origin of posterior cerebral artery from internal carotid artery was the second most frequent anomaly reported (17.5%). In anterior circulation, presence of median artery of corpus callosum was observed in 3.73% cases. Absence of anterior communicating artery compensated by partial fusion of anterior cerebral arteries for a short length was seen in 1.25% cases.[39]

Yasargil (1984) studied posterior circulation in 400 specimens. He reported that the size of posterior communicating artery was smaller than the corresponding posterior cerebral artery in 67.5% cases and in the remaining 32.5% cases it was equal or larger than the posterior cerebral artery.[40]

Lippert (1985) classified the collateral circulation around the brain into primary and secondary collateral pathways. Circulation in circle of Willis was considered as primary pathway whereas circulation through ophthalmic artery and leptomeningeal vessels were considered as secondary pathway. The blood flow across anterior communicating artery and A1 segment of anterior cerebral arteries was responsible for anterior collateral circulation. The posterior communicating arteries served as a communication between anterior and posterior circulations. Lippert observed that asymmetry in the arterial circle is very frequent and an ideal pattern was seen in very few cases. Absence of anterior communicating artery (1%), absence or hypoplasia of A1 segment (10%) and absence or hypoplasia of posterior communicating artery unilaterally or bilaterally (30%) were the most commonly seen anomalies.[41]

Orlandini (1985) studied 100 brain specimens in Italy and arrived at the following conclusions.

- Arteries of the left side were comparatively larger than those on the right side (corresponding to the dominance of left cerebral hemisphere).
- Increase in the perimeter of the arterial polygon corresponds to a uniform increase in length of all its constituent sides (constituent arteries).
- Anterior and posterior communicating arteries were the most common arteries to be affected by variations.
- There was a lack of correlation between dimensions of anterior and posterior communicating arteries. No clear correlation or pattern existed between variations in these arteries.

- A significant difference in dimensions of vessels was observed between males and females.[42]

Hillen B (1986) studied the relationship between diameters of various segments of circle of Willis in 100 specimens. His observations were as follows.

- The diameter of internal carotid artery and ipsilateral posterior communicating artery were inversely related.
- The diameters of basilar artery and P1 segment of posterior cerebral artery were inversely proportional to the ipsilateral posterior communicating artery diameter.

He conclusively reported that the variations in circle of Willis were related to the individual variations of blood flow in the arterial network.[43]

Pedroza (1987) studied the posterior communication arteries in 50 specimens. His observations were as follows.

- Hypoplastic posterior communicating arteries were seen in 34% cases.
- Fetal origin of posterior cerebral artery was seen in 22% cases. It was bilateral in 16% cases and unilateral in the remaining 6% cases.
- Normal posterior communicating arteries on both sides were seen only in 16% cases.[44]

Jain P N, Kumar V, Thomas R J and Longia G S (1990) conducted a study with a sample size of 144 brain specimens and reported variations in 80.55% cases. The variations were broadly categorized into anterior half variations (29.16%) and posterior half variations (51.38%). Anomalies were further classified under these two categories.

Anterior half variations:

- Anterior communicating artery variations accounted for majority of the variations seen (25%). These were duplications (5.5%), triplications (0.7%), horizontal ‘Y’ shaped anterior communicating artery (13.2%) and median artery of corpus callosum (3.5%). Median artery of corpus callosum is a third anterior cerebral artery arising from anterior communicating artery. It is also called arteria termatica of Wilder.
- Absence of anterior communicating artery was seen in 2.1% cases.
- A median anterior cerebral artery formed by fusion of the two anterior cerebral arteries was seen in 1 case.

Posterior half variations:

- Posterior communicating artery variations accounted for majority of the variations in the posterior half (50%). They were classified as string like (18.05%) and absent (13.88%) posterior communicating arteries. Unilateral absence is seen in 17 cases and bilateral absence in 3 cases. Duplication of posterior communicating artery was seen in 1.38% cases.
- Embryonic origin of the posterior cerebral artery was reported in 16% cases.
- In one specimen (0.7%) both posterior communicating arteries joined the basilar artery at its point of bifurcation. This had not been reported in literature in the past.[45]

Van overbeeke (1991) studied 100 specimens of circle of Willis with an aim of classifying posterior communicating arteries. On the basis of origin of posterior communicating arteries, they classified the configurations as follows.

- Type 1 (Adult configuration): Diameter of P1 segment of posterior cerebral artery is larger than that of posterior communicating artery (which is not hypoplastic). This was seen in 84% cases.

- Type 2 (Fetal or Embryonic configuration): Diameter of P1 segment of posterior cerebral artery is smaller than that of posterior communicating artery. The occipital lobes receive their blood supply predominantly from internal carotid artery. This was seen in 14% cases.
- Type 3 (Transitional configuration): Diameters of P1 segment and posterior communicating artery are almost the same and make approximately equal contribution to the P2 segment. This was seen only in 2% cases.[46]

Stephen P Lownie and John (1991) conducted a comparative study of circulation in which 194 infarcted brains were compared with 350 normal brains. Normal pattern of circle of Willis was seen in 52% of the normal brains but only 33% of the infracted brains had normal patterns.[47]

Michael L J (1993) studied numerous specimens of circle of Willis over a period of time and listed his findings as follows.

- Normal pattern of circle of Willis is seen in 20 to 50% cases.
- Among the anomalous patterns 75% cases show hypoplastic condition in one, two or three communicating arteries with asymmetry of anterior or posterior cerebral arteries.
- Variations developed as an adaptation to fetal head movements and also due to phylogenetic factors.
- He stated that the term “fetal type of posterior communicating artery” used to refer to a widely patent posterior communicating artery is a misnomer. It is presumably based on the observation that posterior communicating arteries of embryos are larger than P1 segments. He further stated that this variation is

not due to persistence of embryonic stage but a result of secondary vascular alterations in response to hemodynamic factors.

- He found an inverse relation between diameters of posterior communicating arteries and P1 segments.[48]

Schomer (1994) studied the anatomy of posterior communicating artery in ipsilateral watershed infarctions of brain using MRI and 3D contrast MRI angiograms in 32 hemispheres with internal carotid artery occlusion. They found that presence of posterior communicating arteries measuring at least 1mm in diameter (in 13 hemispheres) was not associated with any watershed infarctions. In cases with hypoplastic or absent posterior communicating arteries, watershed infarcts were frequently associated. 4 such infarcts were seen out of 6 cases with hypoplastic or absent posterior communicating arteries. 10 infarcts were seen in 13 hemispheres with no detectable blood flow in the ipsilateral posterior communicating arteries. Thus, it was concluded that absent or hypoplasic posterior communicating artery is a risk factor for ischemic cerebral infarction in internal carotid artery occlusion.[49]

Macchi C (1996) studied MR Angiographs of 100 healthy human subjects and found normal circle of Willis patterns in 41% cases. The anomalies they found were reported as follows.

- Absence of anterior communicating artery in 3% cases.
- Partially fused anterior cerebral arteries in 2% cases.
- Hypoplasia of posterior communicating arteries in 21% cases.
- Origin of posterior cerebral artery from internal carotid artery in 9% cases.
- Combined hypoplasia of anterior and posterior cerebral arteries in 2% cases.
- Unusual combination of other variations in 7% cases.

- Variations were seen more frequently on the left side than on the right side.[50]

Arthur G (1996) classified variations of circle of Willis into 5 categories after observing MR Angiograms of 104 patients.

- Type 1: Absence of A1 segment of anterior cerebral artery (10 cases).
- Type 2: Hypoplasia of A1 segment with diameter less than 1mm (10 cases).
- Type 3: Asymmetry of A1 segments when both vessels have diameter larger than 1mm (28 cases).
- Type 4: Posterior communicating artery larger than ipsilateral P1 segment of posterior cerebral artery also called as fetal posterior cerebral artery (9 cases).
- Type 5: Balanced circulation (47 cases).

The study also inferred that unilateral absence or hypoplasia of A1 segment of anterior cerebral artery was frequently associated with ipsilateral decrease in internal carotid artery caliber.[51]

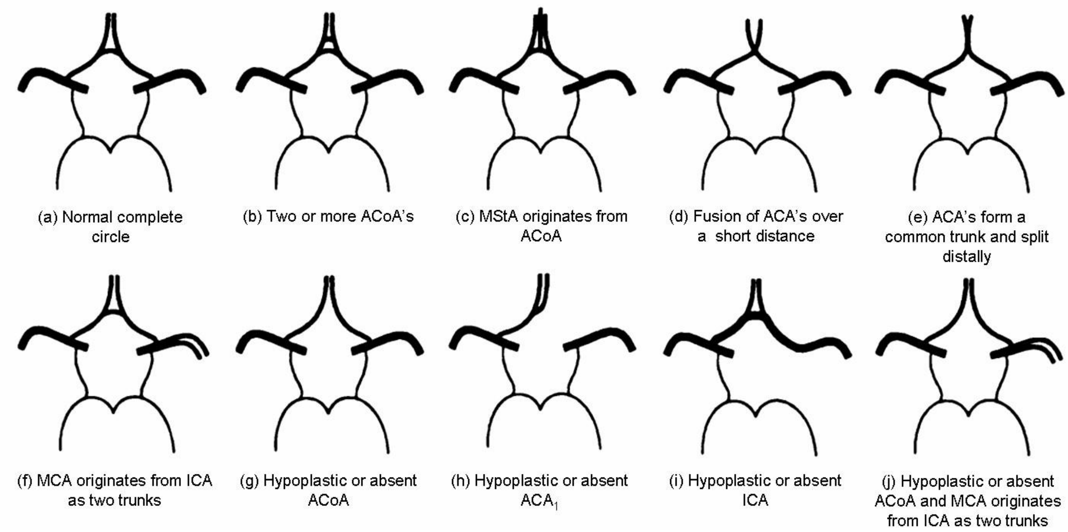
Hartkamp (1998) conducted an angiographic study of 150 cases and found complete pattern of circle of Willis in 42% cases.

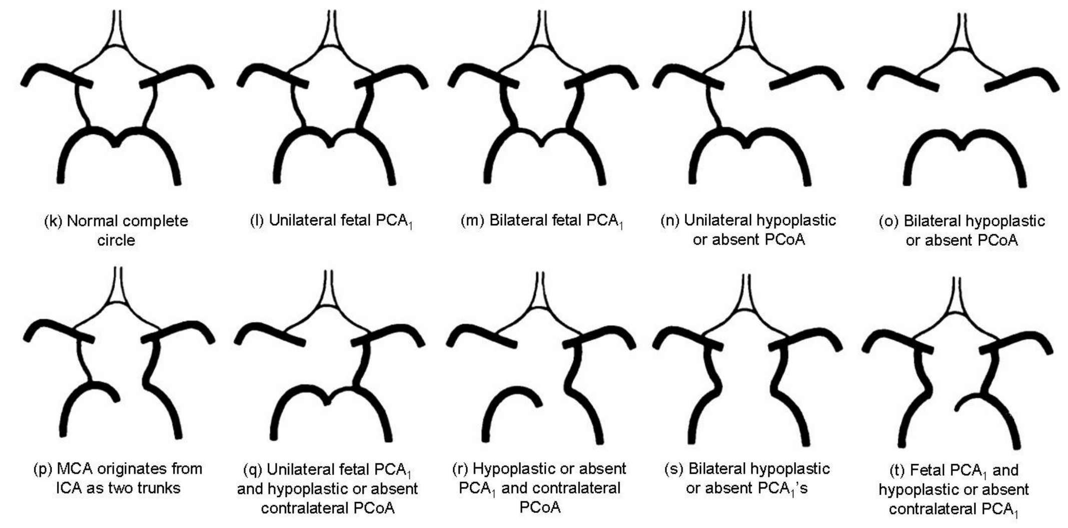
- Anterior circulation was complete in 74% cases. Further he noted that, 86% of the younger subjects had complete anterior circulation where as in older subjects it reduced to 68%.
- Posterior circulation was complete in 52% cases. 62% of the younger subjects showed a complete posterior circulation but it dropped to 47% in older subjects.

The important conclusions drawn from this study were that patients suffering from internal carotid artery stenosis showed a higher prevalence of a complete circle of

Willis, the implication being that they had only survived the significant level of stenosis due to the ability of their circle of Willis to provide collateral flow. [52]

The various configurations found in anterior and posterior circulations are depicted in the following diagrams.





Anne Osborn (1999) illustrated that the circle of Willis is an arterial polygon, specifically a nonagon. She listed the 10 constituents of a complete circle of Willis as follows.

- 2 Internal carotid arteries.
- 2 Anterior cerebral arteries.
- 1 Anterior communicating artery.
- 2 Posterior communicating arteries.
- 2 Posterior cerebral arteries.
- 1 basilar artery.

She stated that a complete circle of Willis is seen in 50% of the population only even though a complete circular channel is seen in 90% cases. In 50% of the cases one or more vessels are insufficiently narrowed, reducing its role as a potential collateral route.[3]

Hoksbergen A W J, Fulesdi B and Legemate (2000) studied the collateral circulation of circle of Willis in 12 acute stroke cases using Transcranial Colour Coded Duplex ultrasonography (TCCD) and carotid compression tests. The reports were compared with postmortem findings.

The results surprisingly showed that collateral circulation could still be maintained in string like communicating arteries (when the diameter was less than 1mm). The study contradicted the criteria for defining hypoplasia of vessels as diameter less than 1mm. The study reported that collateral circulation could still be maintained in vessels measuring upto 0.4mm in diameter. The study suggested that the threshold diameter for defining hypoplasia of communicating arteries be reduced to 0.5mm.[53]

Kanchan Kapoor (2001) studied 1000 brains obtained from medicolegal autopsies . The reported findings are as follows.

- The anterior cerebral artery was found to be tortuous in 23.6% of males and 18.9% of females.

- Asymmetry of anterior cerebral artery was seen in 33.3% of males and 25.8% of females.
- A1 segment of anterior cerebral artery was absent in 3 male and 1 female specimens.
- Hypoplastic A1 segment was seen in 15 males and 2 females.
- Both anterior cerebral arteries joining to form a single median artery was seen in 9 cases. [54]

Behzad Efthekar (2006) classified variations in circle of Willis into 23 types in their study of 102 male Iranian brain specimens. The study was conducted only on male brain specimens to avoid the possible confounding factor of sex distribution from the study. Their findings are as listed below.

1. All segments are normal (31.5%).
2. All segments are hypoplastic (0%).
3. Hypoplastic anterior communicating artery (0%)
4. Hypoplastic posterior communicating artery (22%).
5. Unilateral hypoplastic posterior communicating artery and anterior communicating arteries (4.5%).
6. Bilateral hypoplastic posterior communicating arteries (30.6%).
7. Bilateral hypoplastic posterior communicating arteries and hypoplastic anterior communicating arteries (4.5%).
8. Hypoplastic A1 segment of anterior communicating artery (0%).
9. Hypoplastic P1segement of posterior communicating artery (1%).
10. Bilateral hypoplastic P1 segments (0%).
11. Hypoplastic P1 and contralateral A1segments (0%).

12. Hypoplastic P1 and ipsilateral A1segments (1%).

13. Bilateral hypoplastic P1 and A1segments (0%).

14. Hypoplastic A1 and contralateral posterior communicating artery (0%).

15. Hypoplastic anterior communicating artery and P1 segment (1%).

16. Hypoplastic posterior communicating artery, ipsilateral A1 segment and anterior communicating artery (0%).

17. Hypoplastic posterior communicating artery and contralateral P1 segment (2%).

18. Bilateral hypoplastic posterior communicating artery and A1 segment (0%).

19. Hypoplastic posterior and anterior communicating arteries with contralateral P1 hypoplasia (1%).

20. Hypoplastic P1 and ipsilateral A1 segments, with hypoplastic contralateral posterior communicating artery (0%).

21. Bilateral hypoplastic P1segments and anterior communicating artery (0%).

22. Hypoplastic posterior communicating artery with hypoplasia of ipsilateral A1 and contralateral P1 segments (0%).

23. Hypoplasia of anterior and posterior communicating arteries along with P1 segment and contralateral P1 segment continuing as basilar artery (1.02%).[55]

METHODOLOGY

The present study is based on 50 adult brains dissected from embalmed cadavers in Department of Anatomy, Jawaharlal Nehru Medical College, Belgaum.

Each brain was removed in one piece by dissection. Only complete and intact specimens were used for the study. Observations were made in 50 such specimens which were later preserved in 10% formalin solution.

Dissection procedure:

A) **Reflection of scalp:** The head was supported on a wooden block. The glabella and external occipital protuberance were marked using a skin marking pencil. A sagittal incision was made on the scalp connecting these two points. Another incision at right angles and midway to this incision reaching the root of auricles of the ears was made. The four flaps were then reflected downwards, exposing the cranium, orbital margins at the front and superior nuchal line at the back.

B) **Removal of calvaria:** A string was tied tightly around the cranium to mark a line for sawing the calvaria. Ventrally the string was placed 1 cm above the orbital margins and dorsally 1 cm above the external occipital protuberance. A line was drawn around the string with a skin marking pencil. The line thus marked guided the saw cutting. By making short and smooth to and fro movements, the saw was maintained under control and the depth of the cut was regulated. A preliminary encircling cut all around was made and the cut was deepened as required with care.

The inner table of bone was broken with a chisel. The final separation of the calvaria was done by using the chisel as a wedge, specially in the occipital region where the bone was much thicker.

C) Cutting the duramater: An incision was made through the duramater on each side of the superior sagittal sinus along its whole length. From the midpoint of each incision, another cut was made downwards to join the cut edge of the skull immediately above the root of the auricle. The falx cerebri was detached from the crista galli and pulled posteriorly between the hemispheres.

D) Removal of brain: A wooden block was placed under the shoulders to allow the head to fall back. This facilitated easy removal of frontal lobes from the anterior cranial fossae and exposed the olfactory bulbs, which were gently elevated from the cribriform plate of ethmoid by a blunt probe. The optic nerves were divided close to the optic canal. The internal carotid arteries with the infundibulum passing vertically to the hypophysis between them were also divided. The oculomotor nerves were identified on either side of dorsum sellae and the trochlear nerves, just under the free margin of tentorim cerebelli. These nerves were also divided. The tentorium cerebelli was divided along its attachments to the petrous temporal bone on both sides. The brain was then allowed to fallback so as to draw the brain stem away from the anterior wall of posterior cranial fossa and bring the nerves into view. The trigeminal, abducent, facial and vestibulocochlear nerves were identified on each side and divided. The pons was pressed further posteriorly and the two vertebral arteries uniting to form the basilar artery on its anterior surface was seen. The medulla oblongata and vertebral arteries were severed at the level of foramen magnum and the brain was removed in one piece.[56]

E) Identification, study and analysis of circle of Willis: The arachnoid mater was removed. The circle of Willis and the major arteries were dissected. Each circle was examined in the intact brain and a drawing was made. After removing the meninges carefully from the base of the brain, the circle of Willis was observed in situ and a detailed study of the circle and associated arteries was made. The findings were noted and tabulated. The arteries and the circles were studied under the following parameters:

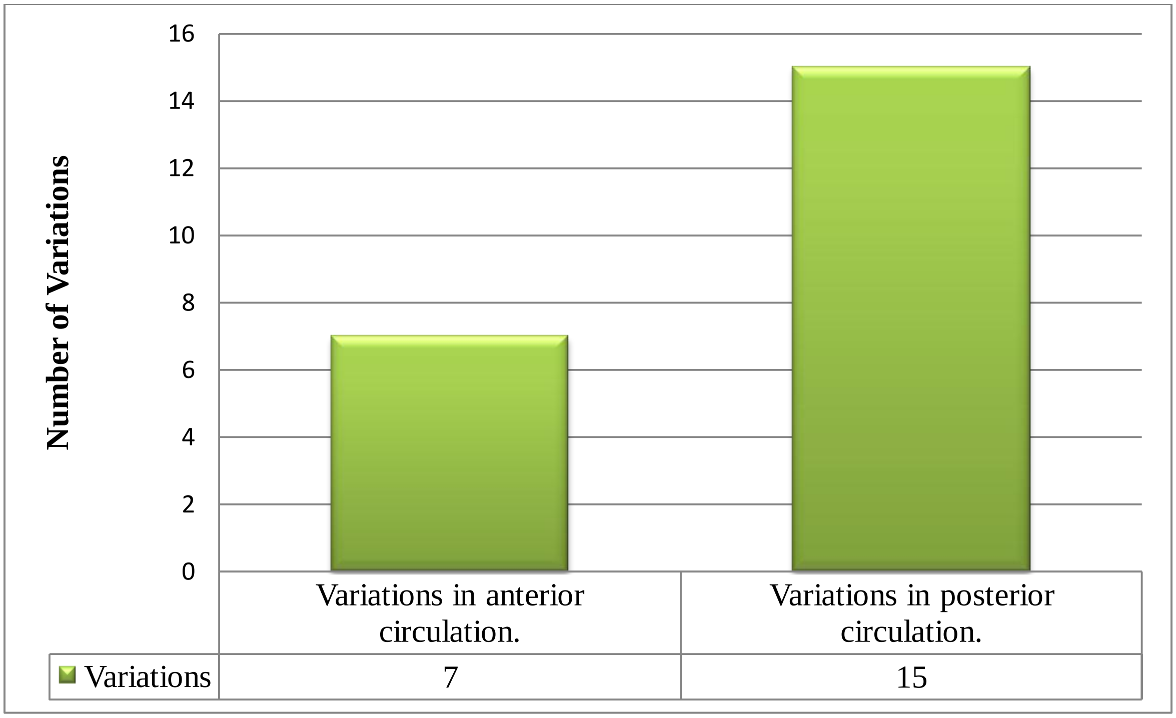
- Origin of cerebral and communicating arteries.
- Branching pattern of cerebral and communicating arteries.
- Position and course of the above arteries.
- Shape of the arterial circle.
- Abnormalities if any.

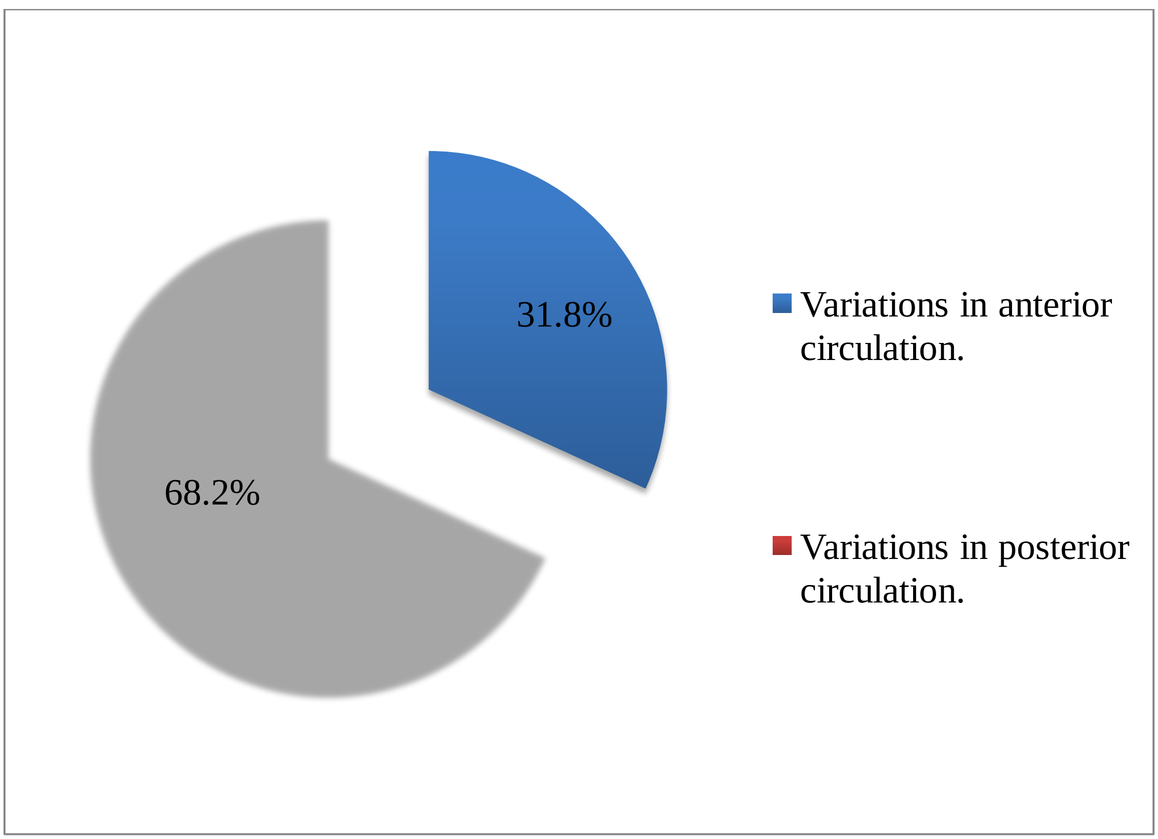
A thorough search was again made for any variations in the cerebral arteries, their branches and communicating arteries. A search was also made for aneurysmal dilatations under magnification. A magnifying lens was used whenever required.

High resolution photographs were taken using Nikon 8.0 megapixel digital camera with 3X optical magnification at various convenient angles.

F) Preservation of the brain specimens: All the dissected whole brain specimens were preserved in 10% formalin solution for storage.

LOCATION OF VARIATIONS





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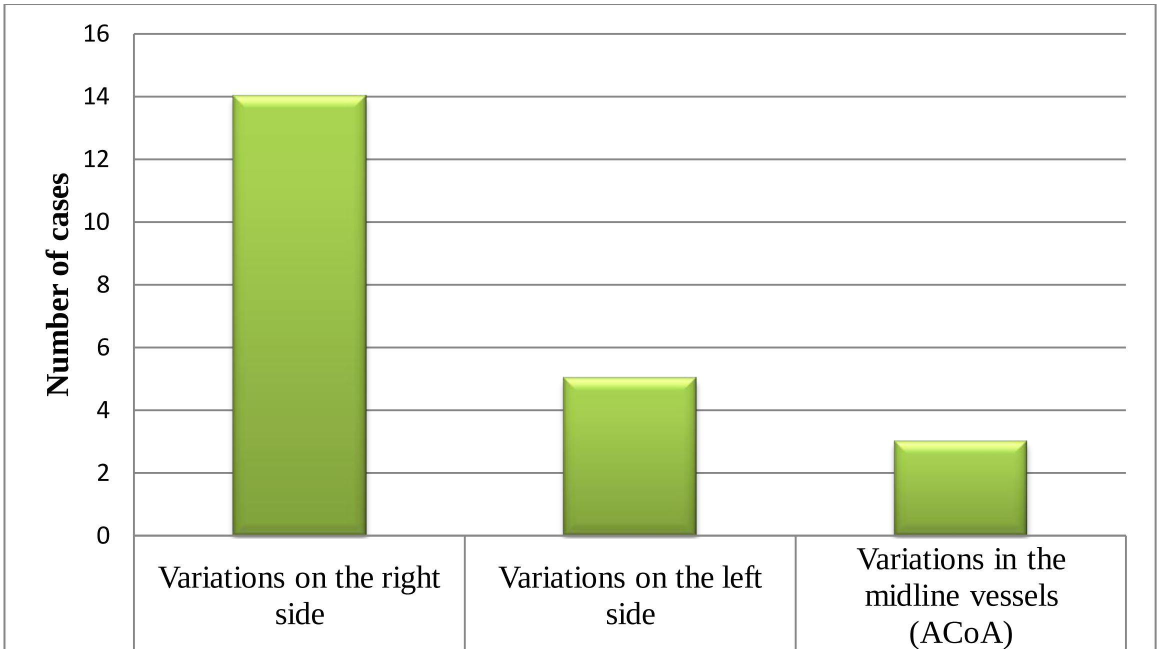
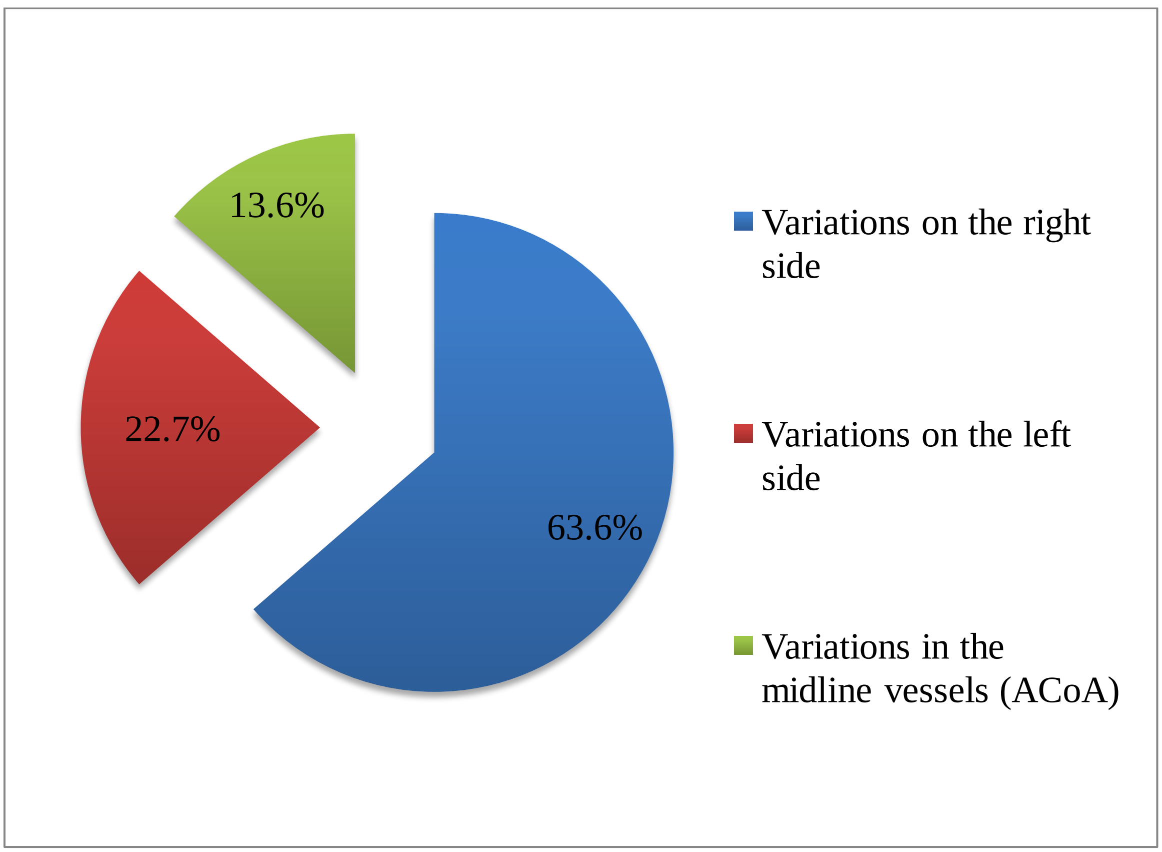
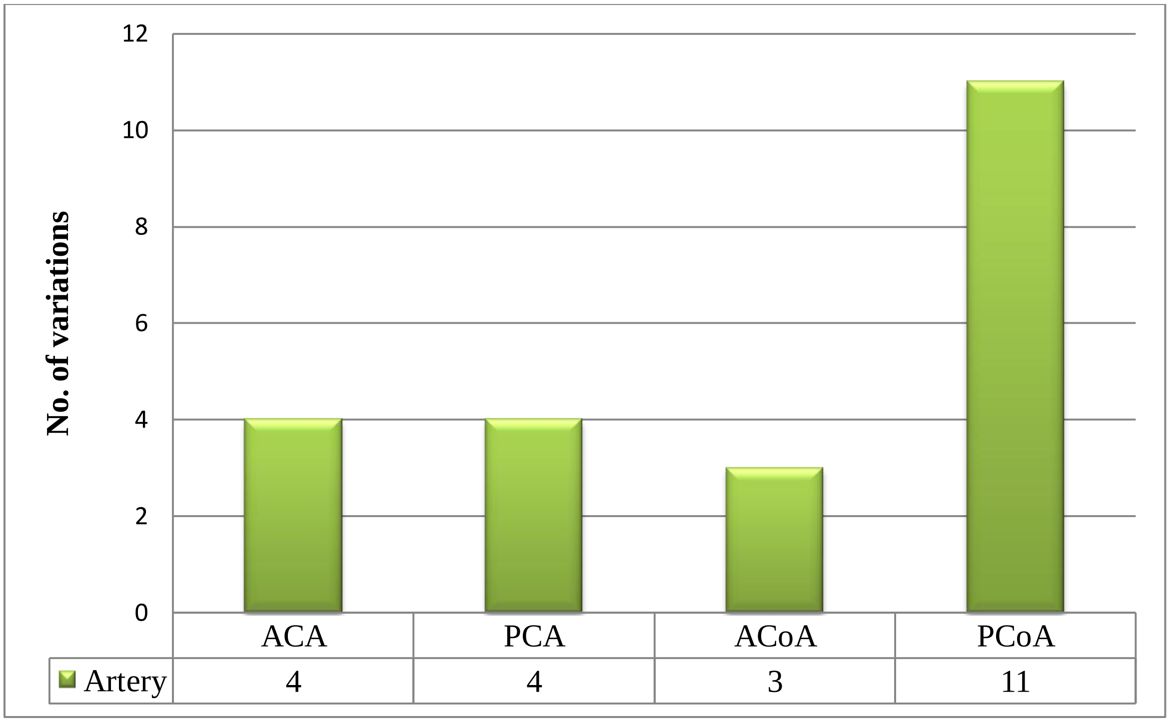
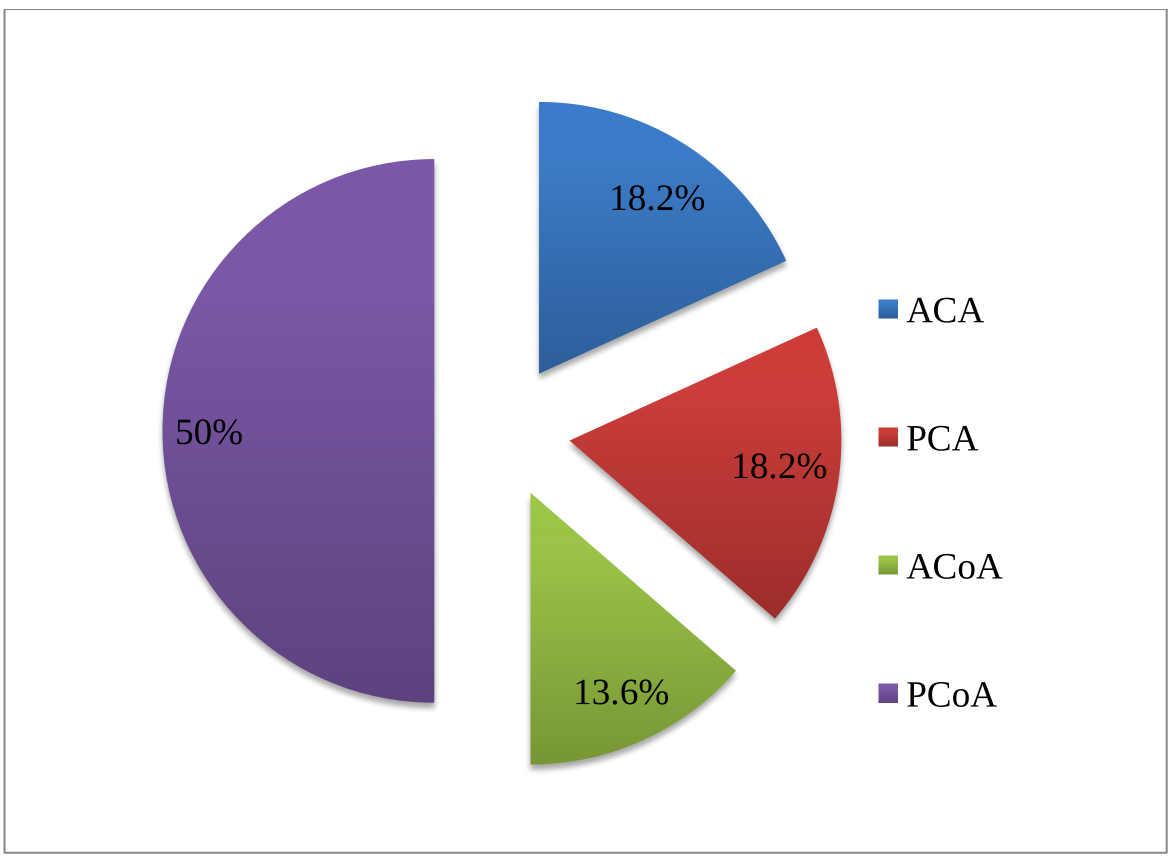


	Variations on the right side	Variations on the left side	Variations in the midline vessels (ACoA)
	14	5	3

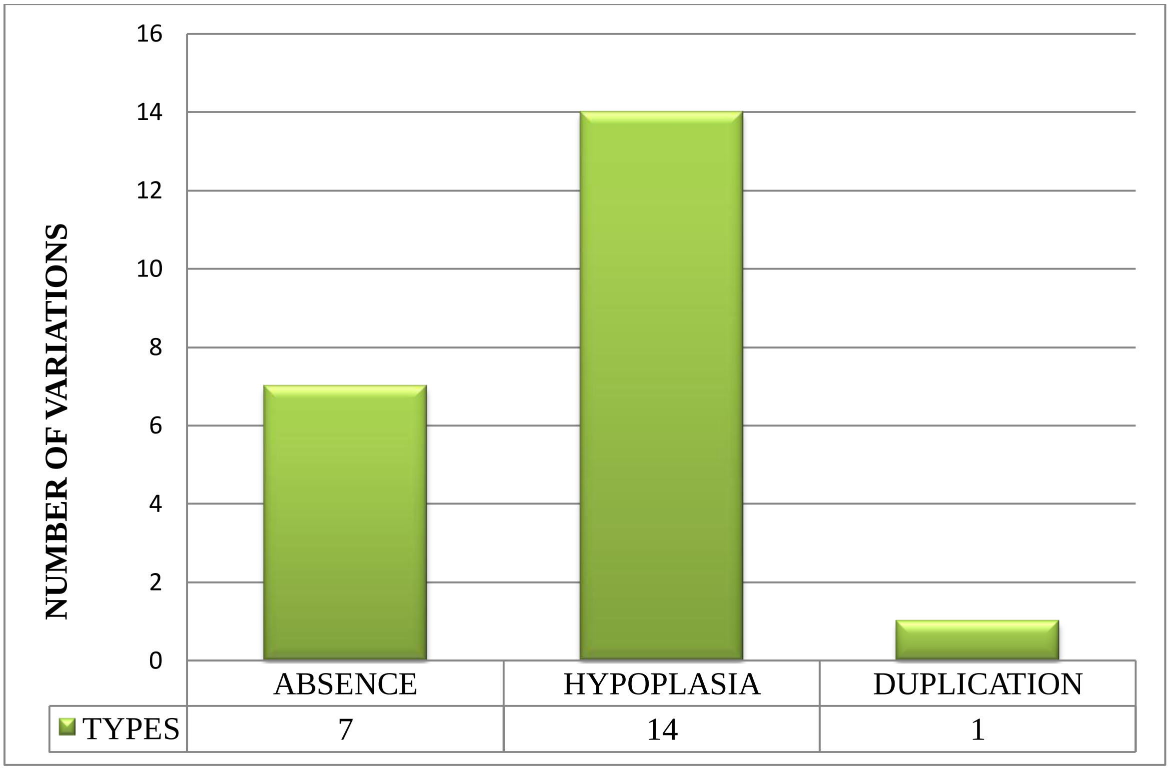


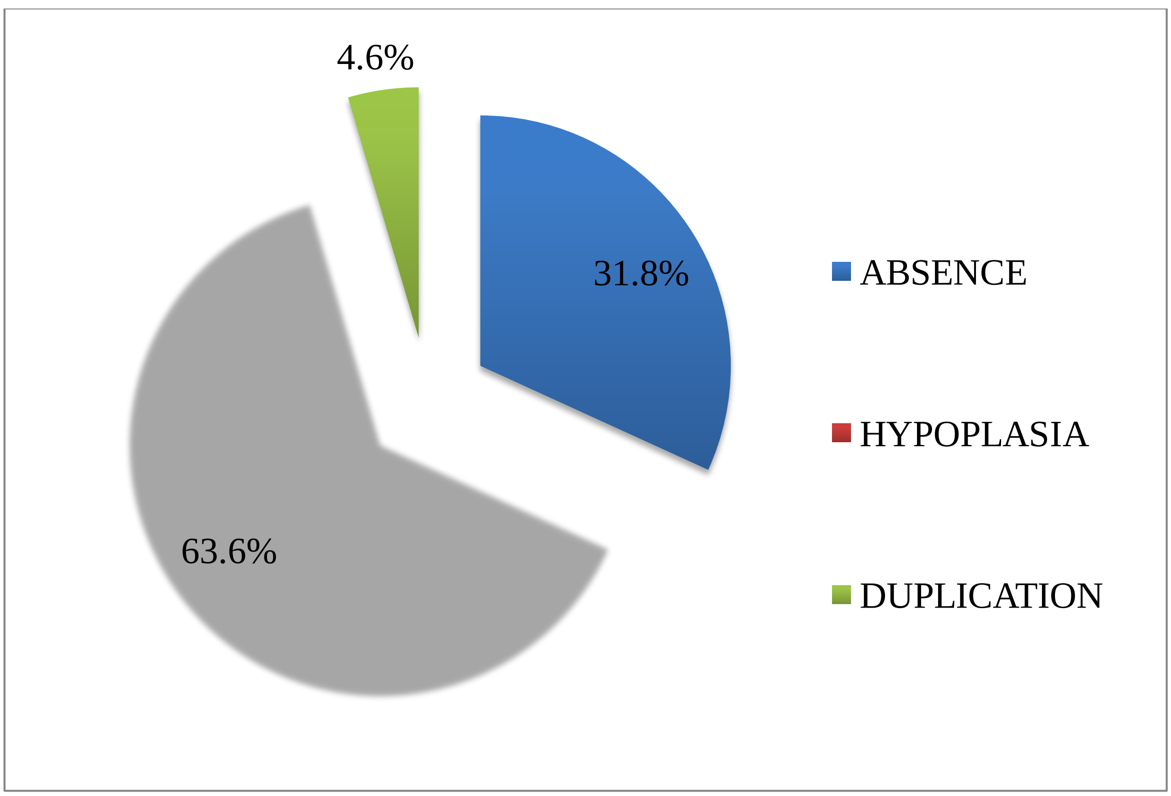
VARIATIONS IN INDIVIDUAL ARTERIES





TYPES OF VARIATIONS





RESULTS

Among the 50 specimens of circle of Willis dissected and observed in the present study, typical description of normal circle was seen in 28 cases (56%). Variations were found in the remaining 22 cases (44%).

Of the 22 variations seen, 7 variations (31.8%) were seen in the anterior circulation and 15 variations (68.2%) were seen in the posterior circulation.

More variations were seen on the right side than on the left side. 14 variations (63.6%) were observed on the right side as compared to 5 variations (22.7%) on the left side. 3 variations (13.6%) were seen in the anterior communicating artery.

All the variations observed are described under each individual constituent artery of circle of Willis as follows.

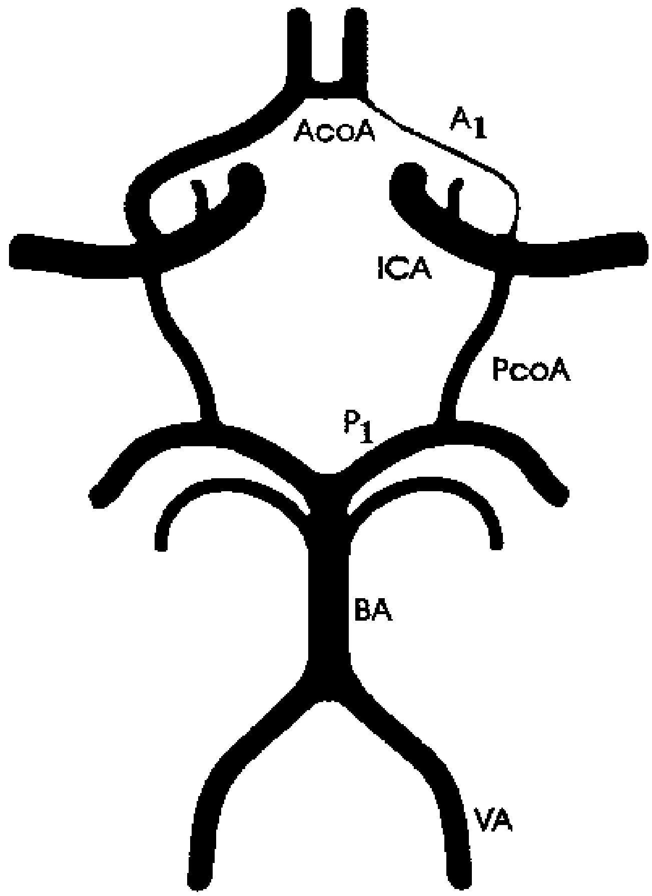
Internal carotid artery and basilar artery:

No variations were seen in these main supply channels. They were found to be approximately constant with respect to their location, caliber and branching pattern in all the specimens.

Anterior cerebral artery:

Anterior cerebral artery variations were seen in 4 cases (18.2%) among the 22 variations found. Variations observed are grouped as follows.

- Hypoplastic (string like) A1 segment in 3 cases(13.65%) . In one case it was on the left side (specimen no. 15) and in two cases on the right side (specimen no. 25 and 48).



Hypoplasia of Anterior Cerebral Artery (A1 segment).

- Hypoplastic (string like) A2 segment was seen in one case (4.55%) on the right side (specimen no. 36). In this case the right cerebral hemisphere was predominantly supplied by branches from an enlarged A2 segment of left anterior cerebral artery.

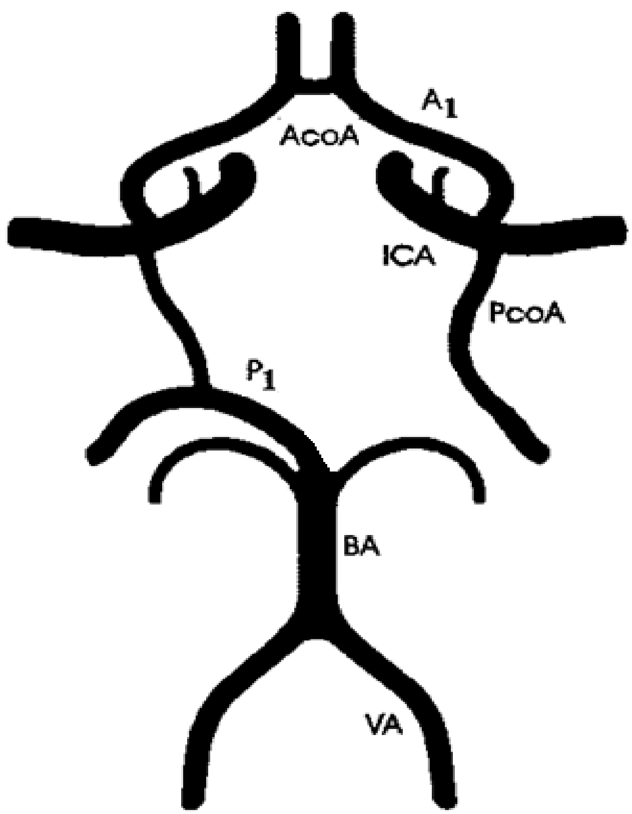
Middle cerebral artery:

Middle cerebral artery was the most consistent artery among the branch arteries. No variations were observed in its main trunk with respect to circle of Willis in any of the 50 specimens studied.

Posterior cerebral artery:

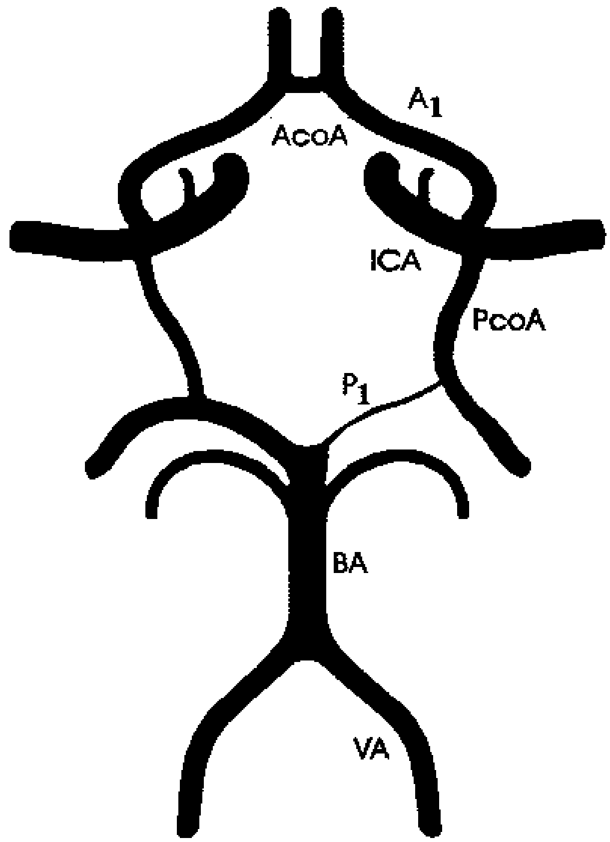
Among the 22 variations found in the study, 4 variations (18.2%) were seen in posterior cerebral arteries. They are grouped as follows.

- Absence of P1 segment was seen in one case (4.55%) on the right side (specimen no. 45).



Absence of P1 segment of Posterior Cerebral Artery.

- Hypoplastic P1segment (fetal or embryonic type) was seen in 3 cases (13.65%). On all the 3 occasions the variation was present on the right side (specimen no. 8, 18 and 27).

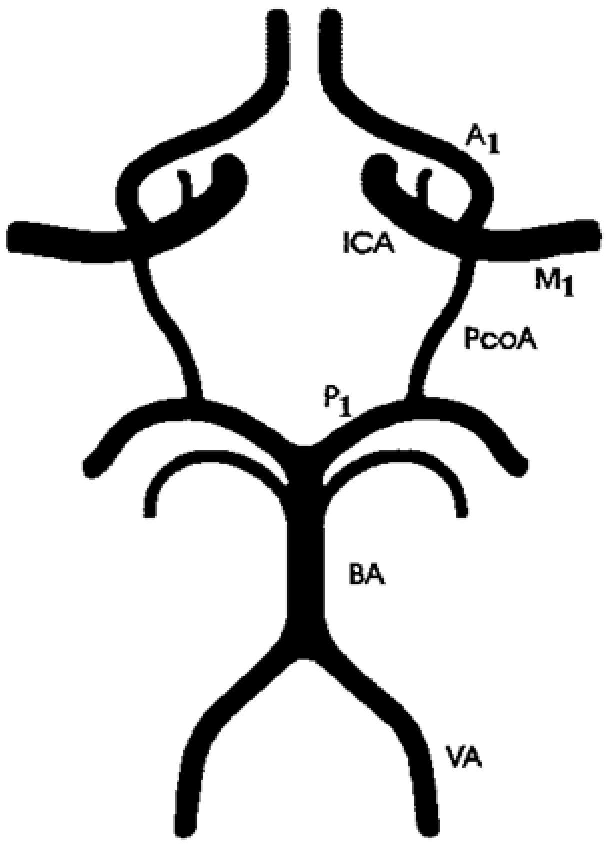


Hypoplasia of Posterior Cerebral Artery (P1 segment).

Anterior communicating artery:

3 variations (13.6%) were seen in this vessel. They are grouped as follows.

- Complete absence of anterior communicating artery was seen in 2 cases (9.1%) (specimen no. 3 and 42).
- Duplication was seen in 1 case (4.55%) (specimen no. 19).

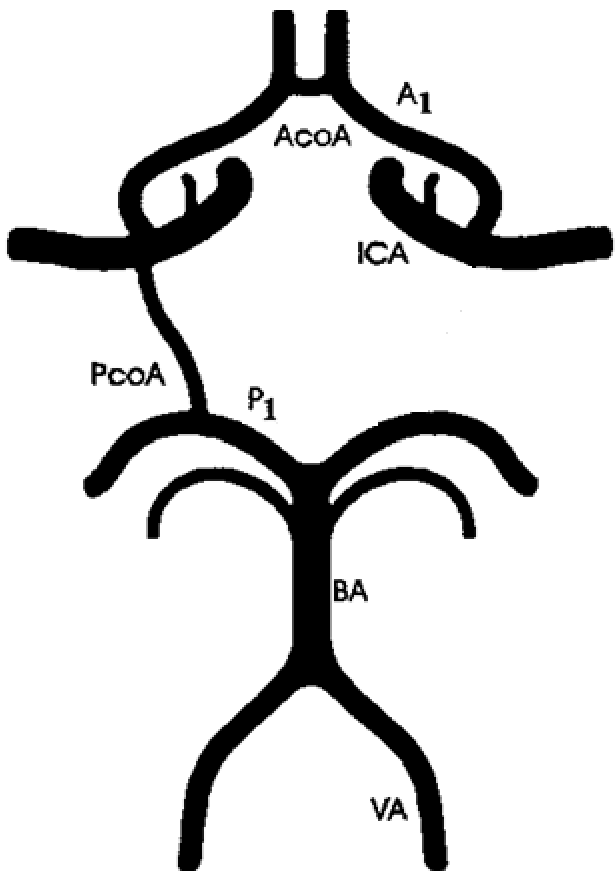


Complete absence of Anterior Communicating Artery.

Posterior communicating artery:

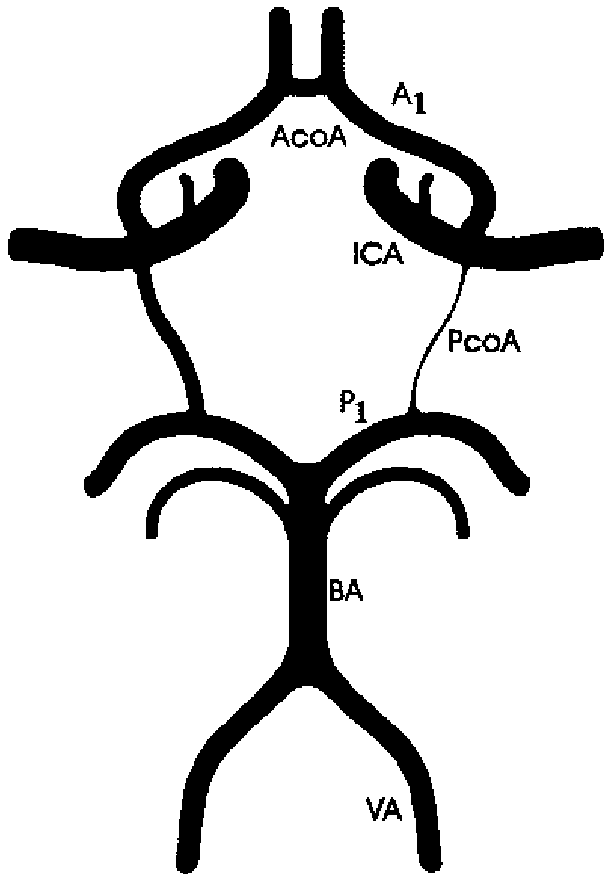
Highest number of variations was seen to be associated with posterior communicating artery. 11 variations among the 22 variations (50%) were found to be exclusively due to posterior communicating artery. Complete absence and hypoplastic (string like) artery were the variations seen in this artery. They are grouped as follows.

- 4 cases (18.2%) had complete absence of posterior communicating artery. In 2 cases it was seen on the right side (specimen no. 22 and 38) and in 2 cases on the left side (specimen no. 5 and 34).



Complete absence of P1 segment of Posterior Cerebral Artery

- 7 cases (31.8%) had a hypoplastic (string like) posterior communicating artery. In 5 cases it was on the right side (specimen no. 6, 17, 30, 31 and 46). In 2 cases it was seen on the left side (specimen no. 10 and 39).



Hypoplastic Posterior Communicating Artery.

50% of the variations were seen in the posterior communicating artery. Hence it is the most variable and least consistent vessel in the present study.

No aneurysms were seen in any of the arteries in any of the cases. No other unusual or unreported variations were seen in the study sample. No cases had bilateral variations. Double, triple or multiple variations in a single specimen were not seen. Hence, all the variations were singular and no associated variations were found in any specimen.

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 two sides of the same individual. Various dissection and angiographic studies by several workers have shown that variations occur in a very high proportion of cases. Inspite of numerous studies conducted over several decades in several countries employing various methods across different geographical and racial background, there is no clarity as to how and why the variations occur. Different studies have quoted different facts and figures which has led to a spectrum of findings. In the following discussion, findings of the present study have been compared with those of the other authors under each individual constituent artery.

In about one third of all individuals, one of the posterior cerebral arteries arises from the internal carotid artery. Such anomalous condition suggests persistence of embryological origin of the posterior cerebral artery.[4]

Sometimes the anterior communicating artery becomes double, on occasions the proximal part of one of the anterior cerebral arteries is unusually small and in such condition anterior communicating artery assumes a large caliber.[4]

The arterial circle is thought to equalise the blood flow to the different parts of the brain and under normal condition little interchange of blood takes place across anastomotic channel due to equality of blood pressure. However, in case of occlusion of one of the large feeder arteries, the blood crosses the midline through the communicating branches and maintains nutrition of the opposite half of the brain by contralateral flow.[4]

Circle of Willis: Normal pattern

In the present study, of the 50 brain specimens observed 28 cases (56%) had normal pattern of circle of Willis. Incidence of normal pattern reported by various authors is as follows.

- Fawcett and blachford (1905) [19] - 96.1%
- Blackburn (1907)[9] - 29.5%
- Alpers et al. (1959)[25] - 52.3%
- Riggs (1963)[28] - 19%
- Vare A M and Bansal P C (1970)[29] - 26.86%
- Raja Reddy et al. (1972)[34] - 53.3%
- N Jayasree and G Sadasivan (1981)[37] - 18%
- Kamath S (1981)[38] - 56%
- P N Jain and V Kumar (1990)[45] - 19.45%
- Stephen and John (1991)[47] - 52%
- Macchi et al. (1996)[50] - 41%
- Hartkamp et al. (1998)[52] - 42%
- Present study (2011) - 56%

Thus the findings of the present study are approximately similar to the findings of Alpers et al. (1959)[25], Raja Reddy et al. (1972)[34], Kamath S (1981)[38], Stephen and John (1991)[47] with respect to normal pattern of circle.

Circle of Willis: Variations

Of the 50 brain specimens observed in the present study, 22 cases (44%) had variations in the pattern of circle of Willis. Incidence of variations reported by various authors is as follows.

- Fawcett and blachford (1905)[19] - 3.9%
- Blackburn (1907)[9] - 70.5%
- Alpers et al. (1959)[25] - 47.7%
- Riggs (1963)[28] - 81%
- Vare A M and Bansal P C (1970)[29] - 73.14%
- Raja Reddy et al. (1972)[34] - 46.7%
- N Jayasree and G Sadasivan (1981)[37] - 82%
- Kamath S (1981)[38] - 44%
- P N Jain and V Kumar (1990)[45] - 80.55%
- Stephen and John (1991)[47] - 48%
- Macchi et al. (1996)[41] - 59%
- Hartkamp et al. (1998)[52] - 58%
- Present study (2011) - 44%

Thus the findings of the present study are approximately similar to the findings of Alpers et al. (1959)[25], Raja Reddy et al. (1972)[34], Kamath S (1981)[38], Stephen and John (1991)[47] with respect to incidence of variations in the circle.

Circle of Willis: Location of Variations

In the present study, it was observed that variations were approximately twice as common in the posterior circulation (15 cases, 68.2%) as compared to the anterior circulation (7 cases, 31.8%).

AUTHOR		Anterior circulation	Posterior circulation
P N Jain and V Kumar (1990)[45]	-	29.16%	51.38%
Hartkamp et al. (1998)[52]	-	26%	48%
Present study (2011)	-	31.8%	68.2%

Thus the findings of the present study have a correlation with the findings of P N Jain and V Kumar (1990)[45] and Hartkamp et al. (1998)[52] with respect to location of variations.

Anterior Cerebral Artery: Hypoplastic (string like) A1 segment.

In the present study, hypoplastic A1 segment of anterior cerebral artery was seen in 3 cases (13.65%) among the 22 cases with variations. In 1 case it was on the left side and in 2 cases on the right side. Frequency of occurrence of this variation as reported by various authors is as follows.

- N Jayasree and G Sadasivan (1981)[37] - 4.4%
- Lippert (1985)[41] - 10%
- Arthur et al. (1996)[51] - 10.4%
- Kanchan Kapoor (2001)[54] - 1.7%
- Present study (2011) - 13.6%

Thus, the findings of the present study are approximately similar to the findings of Lippert (1985)[41] and Arthur et al. (1996)[51] with respect to hypoplastic A1 segment of anterior cerebral artery.

Anterior Cerebral Artery: Hypoplastic (string like) A2 segment.

Hypoplastic A2 segment of anterior cerebral artery was seen on the right side in one case (4.55%) among the 22 cases with variations. The right cerebral hemisphere was predominantly supplied by branches from an enlarged A2 segment of left anterior cerebral artery.

A similar variation where a single median anterior cerebral artery is formed by the joining of both the right and the left anterior cerebral arteries has been reported by several authors as follows.

- Vare A M and Bansal P C (1970)[29] - 1.7%
- N Jayasree and G Sadasivan (1981)[37] - 2%
- P N Jain and V Kumar (1990)[45] - 0.7%
- Macchi et al. (1996)[50] - 2%
- Kanchan Kapoor (2001)[54] - 0.9%

Middle cerebral Artery:

No variations were observed in the main trunk of middle cerebral artery with respect to the circle of Willis in any of the 50 cases.

Posterior Cerebral Artery: Hypoplastic (fetal or embryonic type) P1 segment:

Hypoplastic P1 segment of posterior cerebral artery was seen in 3 cases (13.65%) among the 22 cases with variations, all on the right side. Incidence of this variation reported by various authors is as follows.

- Alpers et al. (1959)[25] - 15%
- N Jayasree and G Sadasivan (1981)[37] - 24%
- Pedroza et al. (1987)[44] - 22%
- P N Jain and V Kumar (1990)[45] - 16%
- Van overbeeke et al. (1991)[46] - 14%
- Present study (2011) - 13.65%

Thus, the findings of the present study are similar to the findings of Alpers et al. (1959)[25], P N Jain and V Kumar (1990)[45] and Van overbeeke et al. (1991)[46] with respect to hypoplastic P1 segment of posterior cerebral artery.

Posterior Cerebral Artery: Absence of P1 segment

Complete absence of P1 segment of posterior cerebral artery on the right side was seen in one case (4.55%). Here the basilar artery continued as the left posterior cerebral artery. The posterior circulation on the right side was maintained by an enlarged right posterior communicating artery. Such absence of P1 segment was reported by Vare A M and Bansal P C (1970) in 19.4% cases.

Anterior Communicating Artery: Duplication (doubling)

Duplication of anterior communicating artery was seen in one case (4.5%) among the 22 cases with variations in the present study. Incidence of variations reported by various authors is as follows.

- Fawcett and blachford (1905) [19] - 7.2%
- Stopford (1915)[20] - 10%
- Alpers et al. (1959)[25] - 9%
- Vare A M and Bansal P C (1970)[29] - 10.3%
- Raja Reddy et al. (1972)[34] - 7%
- N Jayasree and G Sadasivan (1981)[37] - 14%
- P N Jain and V Kumar (1990)[45] - 5.5%
- Present study (2011) - 4.5%

Thus, the findings of the present study are approximately similar to the findings reported by Fawcett and blachford (1905)[19], Raja Reddy et al. (1972)[34] and P N Jain and V Kumar (1990)[45] with respect to duplication of anterior communicating artery.

Anterior Communicating Artery: Absence

Absence of anterior communicating artery was seen in 2 cases (9.1%) among the 22 cases with variations in the present study. Incidence of variations reported by various authors is as follows.

- Fawcett and blachford (1905) [19] - 0.14%
- Blackburn (1907)[9] - 0.9%
- Stopford (1915)[20] - 0%
- Alpers et al. (1959)[25] - 2%
- Vare A M and Bansal P C (1970)[29] - 1%
- Raja Reddy et al. (1972)[34] - 0.5%
- N Jayasree and G Sadasivan (1981)[37] - 6%
- P N Jain and V Kumar (1990)[45] - 2.1%
- Macchi et al. (1996)[50] - 2%
- Present study (2011) - 9.1%

Thus, a higher incidence of absence of anterior communicating artery has been observed in the present study in comparison to the results of various other studies.

Posterior Communicating Artery: Absence

Absence of posterior communicating artery was seen in 4 cases (18.2%) among the 22 cases with variations in the present study. In 2 cases it was seen on the right side and in 2 cases it was seen on the left side. Incidence of variations reported by various authors is as follows.

- Fawcett and blachford (1905) [19] - 23%
- Blackburn (1907)[9] - 0.5%
- Stopford (1915)[20] - 7.33%
- Alpers et al. (1959)[25] - 0.6%
- Vare A M and Bansal P C (1970)[29] - 10.2%
- Raja Reddy et al. (1972)[34] - 1.6%
- N Jayasree and G Sadasivan (1981)[37] - 2%
- P N Jain and V Kumar (1990)[45] - 13.88%
- Present study (2011) - 18.2%

Thus, a higher incidence of absence of posterior communicating artery has been observed in the present study as compared to the results of previous studies.

Posterior Communicating Artery: Hypoplastic (string like)

Hypoplastic posterior communicating artery was seen in 7 cases (31.8%) among the 22 cases with variations. In 5 cases it was on the right side and in 2 cases it was seen on the left side. Incidence of this variation reported by various authors is as follows.

- Pedroza et al. (1987)[44] - 34%
- Schomer (1994)[8] - 21%
- P N Jain and V Kumar (1990)[45] - 18.05%
- Macchi et al. (1996)[50] - 21%
- Present study (2011) - 31.8%

Thus, the findings of the present study are approximately similar to the findings of Pedroza et al.(1987)[44] .

Collectively it was observed that the findings of the present study are approximately similar to the results of various other larger and significant studies conducted previously. The only exception being the increased incidence of absence of both the anterior and posterior communicating arteries in the present study.

Scope for future work

An exclusive study of the anterior and posterior communicating arteries conducted on a larger sample size and by avoiding the possible confounding factors of age and sex could possibly strengthen the present findings and establish a significant geographical correlation to the distribution of variations.

CONCLUSION

On observing the 50 specimens of circle of Willis in the present study the following inferences were drawn.

- The normal pattern of circle of Willis was observed in 28 cases (56%) cases and the remaining 22 cases (44%) had one or the other variations.

- 7 cases (31.8%) cases had variations in the anterior circulation and 15 cases (68.2%) had variations in the posterior circulation. Thus, the prevalence of variations is approximately twice in the posterior circulation compared to anterior circulation.

- 14 cases (63.6%) had variations on the right side compared to 5 variations (22.75%) on the left side. 3 cases (13.65%) had variations in the anterior communicating artery. Thus, the variations are more prevalent on the right side than on the left side.

- No variations were observed in the middle cerebral artery and basilar artery. Thus, they are the most consistent and least variable vessels in this study.

- All variations were singular and unilateral. Thus no multiple variations were observed in this study.

- No aneurysms were observed in any of the specimens.

The distribution pattern of variations among the 22 cases with variations is as follows.

- 3 cases (13.65%) had hypoplastic A1 segment of anterior cerebral artery.
- 1 case (4.55%) had hypoplastic A2 segment of anterior cerebral artery.
- 3 cases (13.65%) had hypoplastic P1 segment of posterior cerebral artery.
- 1 case (4.55%) had absence of P1 segment of posterior cerebral artery.
- 1 case (4.55%) had duplication of anterior communicating artery.
- 2 cases (9.1%) had absence of anterior communicating artery.
- 4 cases (18.2%) had absence of posterior communicating artery.
- 7 cases (31.8%) had hypoplastic posterior communicating artery.

Thus, from this distribution pattern of variations the following conclusions can be drawn.

- The most common variation observed in the present study is hypoplastic posterior communicating artery (7 cases, 31.8%).
- The most variable artery in the present study is posterior communicating artery (11 cases, 50%).
- The most consistent blood vessel in the present study is middle cerebral artery.

Collectively it can be inferred that the findings of the present study are consistent with the results of various significant studies. No significant deviation has been observed in the study results from what has been reported in the literature. The only exception is the increased incidence of absence of both the anterior and posterior communicating arteries in the present study. This finding is of potential clinical significance to neurologists and neurosurgeons in this geographical location of North Karnataka. A higher incidence of variations in the communicating arteries is likely to manifest as a higher incidence in disorders like migraine, schizophrenia and cerebrovascular disorders due to compromised collateral circulation and poor redistribution of blood. Thus, an exclusive study focusing on the variations of the anterior and posterior communicating arteries with a larger sample size can further establish the higher prevalence of variations of communicating arteries in this geographical area.

SUMMARY

A comprehensive study of the circle of Willis was carried out on a sample size of 50 adult brain specimens. Each brain was removed in one piece by dissection and the circle of Willis was observed for its formation, pattern and variations.

The findings of the study were compiled and tabulated. The results were compared and correlated with the available literature to discuss the clinical significance and seek possible explaination for the occurrence of variations.

The importance of circle of Willis in collateral circulation and redistribution of blood to all areas of the brain was studied in the light of available literature. The influence of abnormal circulation in circle of Willis in disorders like cerebral aneurysm, subarachnoid hemorrhage, cerebrovascular disorders, migraine and schizophrenia were also reviewed from literature.

Among the 50 specimens studied, 28 cases (56%) had a normal pattern of circle of Willis and variations were observed in the remaining 22 cases (44%). More number of variations was observed on the right side than on the left side. The most common variation observed was hypoplastic posterior communicating artery (7 cases, 31.8%). Posterior communicating artery was found to be the most variable vessel while middle cerebral artery was the least variable vessel.

A significant outcome of this study was the observation of increased incidence of absence of both the anterior and posterior communicating arteries. This finding is of clinical significance to neurologists and neurosurgeons in this geographical location of North Karnataka as a higher incidence of variations in the communicating arteries is likely to manifest as a higher incidence in disorders like migraine, schizophrenia and cerebrovascular disorders due to compromised collateral circulation and poor redistribution of blood. The results with respect to other component arteries and circle of Willis as a whole were consistent with the results of the available literature.

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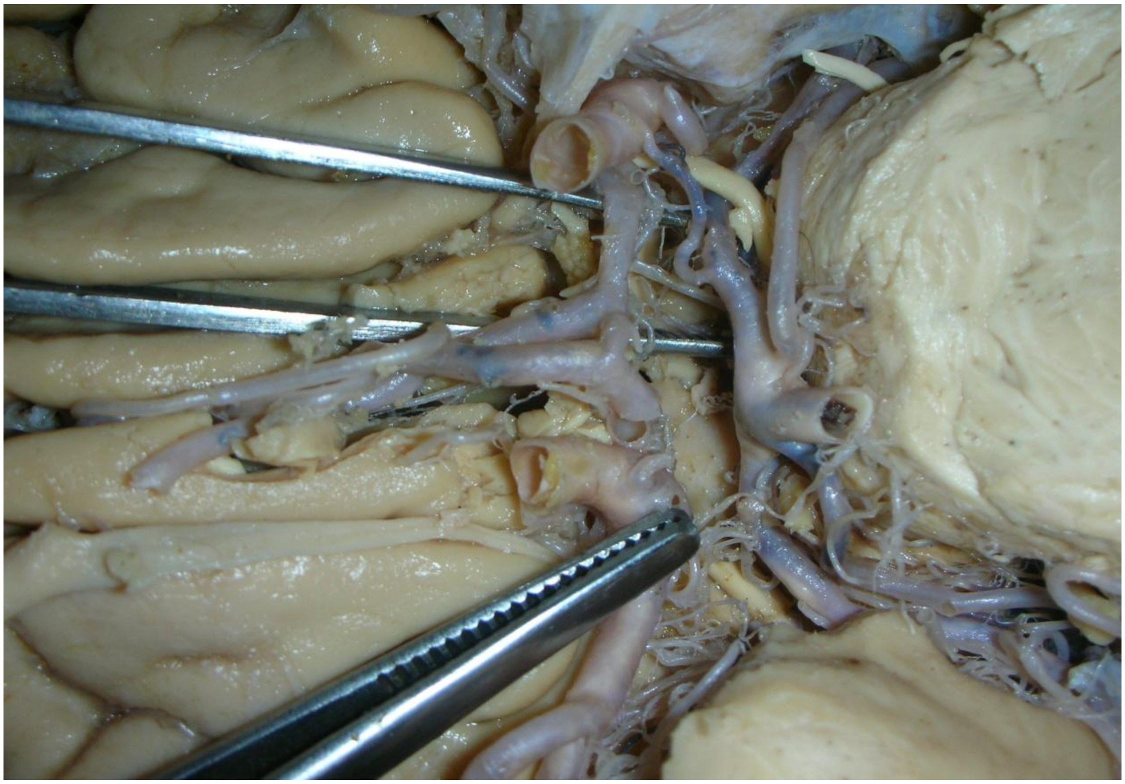
SL. No.	COMPLETE CIRCLE	CONSTITUENT ARTERIES							ANOMALY/ VARIATION OBSERVED
		ICA	**BA**	**ACA**	**MCA**	**PCA**	**ACoA**	**PCoA**	
1.	Complete	N	N	N	N	N	N	N	None
2.	Complete	N	N	N	N	N	N	N	None
3.	Incomplete	N	N	N	N	N	Ab	N	ACoA is absent.
4.	Complete	N	N	N	N	N	N	N	None
5.	Incomplete	N	N	N	N	N	N	Ab	(L) PCoA is absent .
6.	Complete	N	N	N	N	N	N	Hyp	(R) PCoA Hypoplastic.
7.	Complete	N	N	N	N	N	N	N	None
8.	Complete	N	N	N	N	Hyp	N	N	(R) P1 segment is Hypoplastic.
9.	Complete	N	N	N	N	N	N	N	None
10.	Complete	N	N	N	N	N	N	Hyp	(L) PCoA is Hypoplastic.
11.	Complete	N	N	N	N	N	N	N	None
12.	Complete	N	N	N	N	N	N	N	None
13.	Complete	N	N	N	N	N	N	N	None
14.	Complete	N	N	N	N	N	N	N	None
15.	Complete	N	N	Hyp	N	N	N	N	(L)A1 segment is Hypoplastic.
16.	Complete	N	N	N	N	N	N	N	None
17.	Complete	N	N	N	N	N	N	Hyp	(R) PCoA is Hypoplastic.
18.	Complete	N	N	N	N	Hyp	N	N	(R) P1 segment is Hypoplastic.
19.	Complete	N	N	N	N	N	Dup	N	Duplication of ACoA.
20.	Complete	N	N	N	N	N	N	N	None

SL. No.	COMPLETE CIRCLE	CONSTITUENT ARTERIES							ANOMALY/ VARIATION OBSERVED
		ICA	**BA**	**ACA**	**MCA**	**PCA**	**ACoA**	**PCoA**	
21.	Complete	N	N	N	N	N	N	N	None
22.	Incomplete	N	N	N	N	N	N	Ab	(R) PCoA is Absent
23.	Complete	N	N	N	N	N	N	N	None
24.	Complete	N	N	N	N	N	N	N	None
25.	Complete	N	N	Hyp	N	N	N	N	(R) A1 segment is Hypoplastic.
26.	Complete	N	N	N	N	N	N	N	None
27.	Complete	N	N	N	N	Hyp	N	N	(R) P1 segment is Hypoplastic.
28.	Complete	N	N	N	N	N	N	N	None
29.	Complete	N	N	N	N	N	N	N	None
30.	Complete	N	N	N	N	N	N	Hyp	(R) PCoA is Hypoplastic.
31.	Complete	N	N	N	N	N	N	Hyp	(R) PCoA is Hypoplastic.
32.	Complete	N	N	N	N	N	N	N	None
33.	Complete	N	N	N	N	N	N	N	None
34.	Incomplete	N	N	N	N	N	N	Ab	(L) PCoA is absent.
35.	Complete	N	N	N	N	N	N	N	None
36.	Complete	N	N	Hyp	N	N	N	N	(R) A2 segment is Hypoplastic.
37.	Complete	N	N	N	N	N	N	N	None
38.	Incomplete	N	N	N	N	N	N	Ab	(R) PCoA is Absent.
39.	Complete	N	N	N	N	N	N	Hyp	(L) PCoA is Hypoplastic.
40.	Complete	N	N	N	N	N	N	N	None

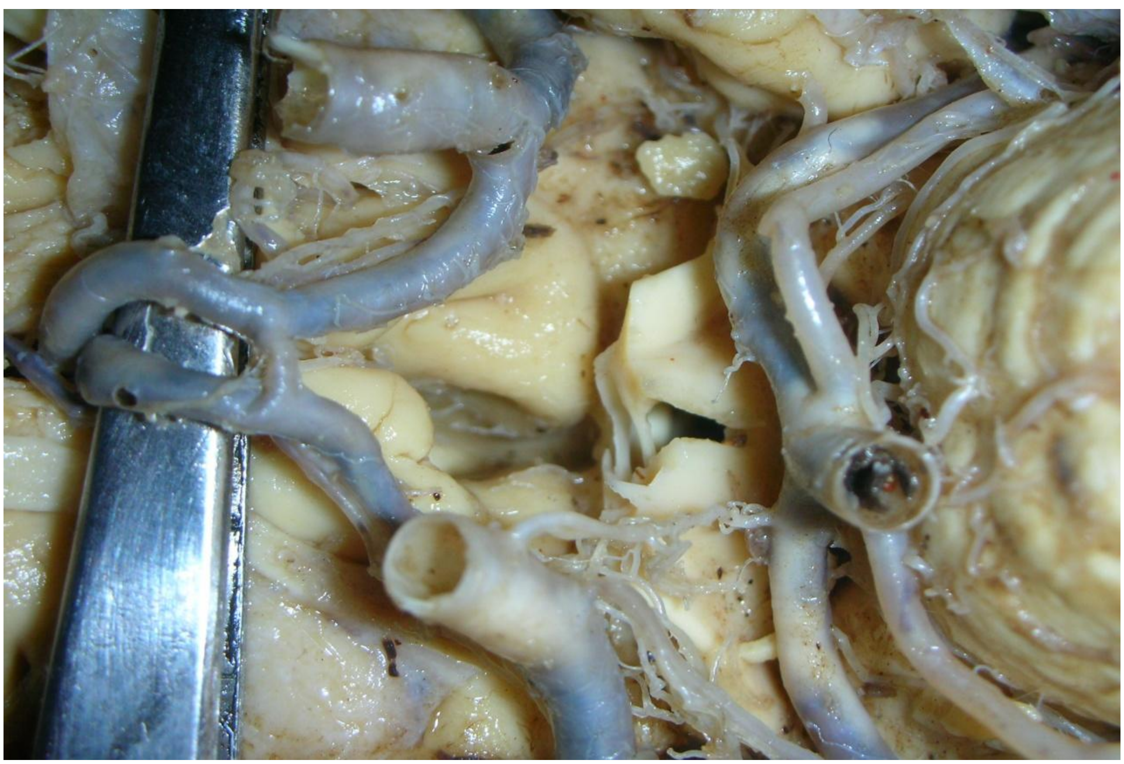
SL. No.	COMPLETE CIRCLE	CONSTITUENT ARTERIES							ANOMALY/ VARIATION OBSERVED
		ICA	**BA**	**ACA**	**MCA**	**PCA**	**ACoA**	**PCoA**	
41.	Complete	N	N	N	N	N	N	N	None
42.	Incomplete	N	N	N	N	N	Ab	N	ACoA is absent.
43.	Complete	N	N	N	N	N	N	N	None
44.	Complete	N	N	N	N	N	N	N	None
45.	Incomplete	N	N	N	N	Ab	N	N	(R) P1 segment is absent.
46.	Complete	N	N	N	N	N	N	Hyp	(R) PCoA is hypoplastic.
47.	Complete	N	N	N	N	N	N	N	None
48.	Complete	N	N	Hyp	N	N	N	N	(R) A1 segment is hypoplastic.
49.	Complete	N	N	N	N	N	N	N	None
50.	Complete	N	N	N	N	N	N	N	None

DUPLICATION OF ANTERIOR COMMUNICATING ARTERY

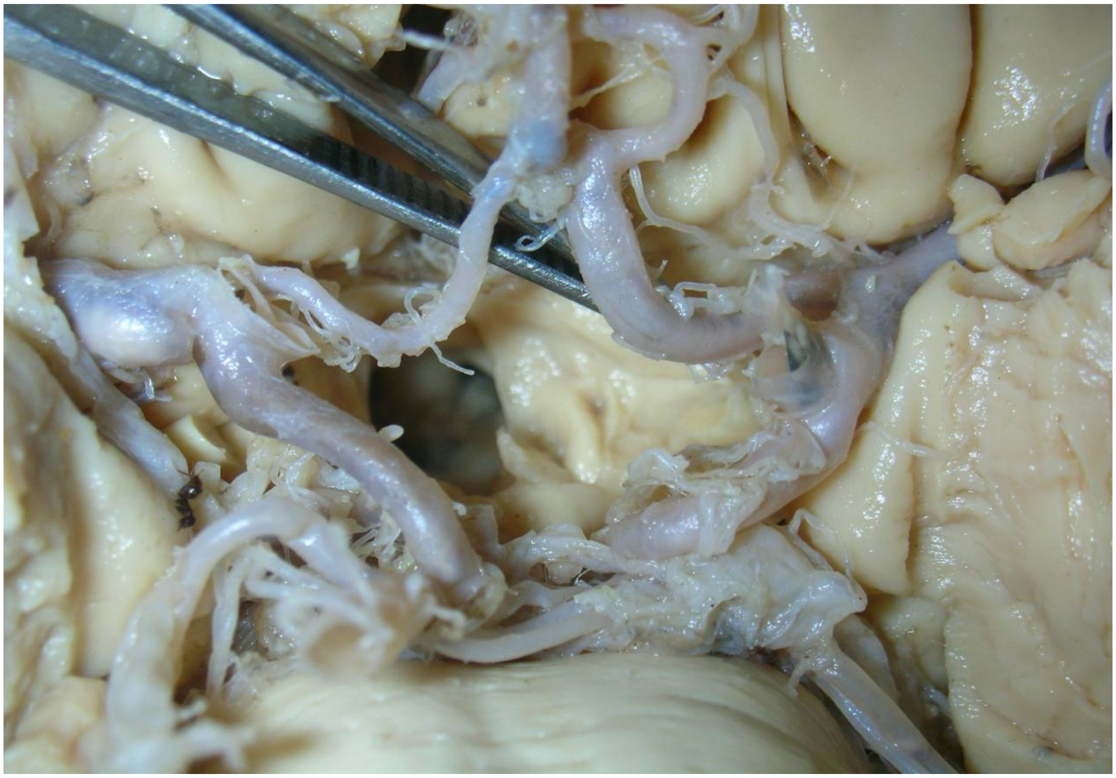
ABSENCE OF ANTERIOR COMMUNICATING ARTERY



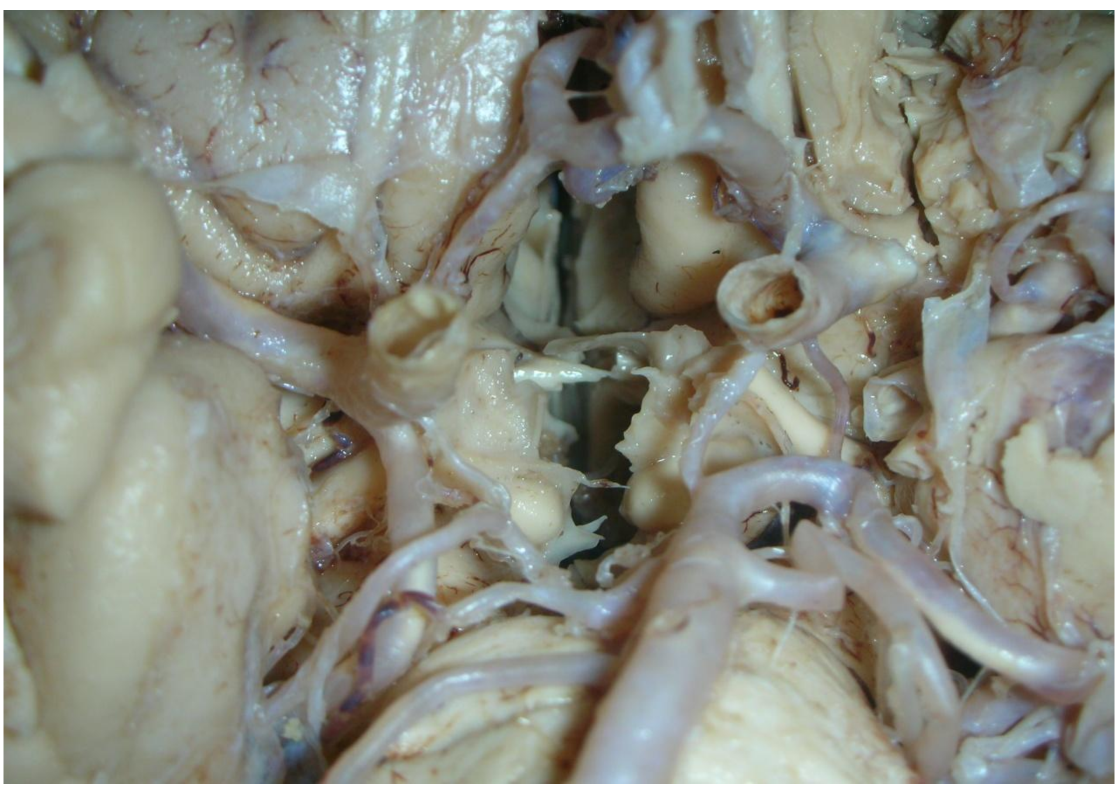
HYPOPLASTIC RIGHT POSTERIOR COMMUNICATING ARTERY



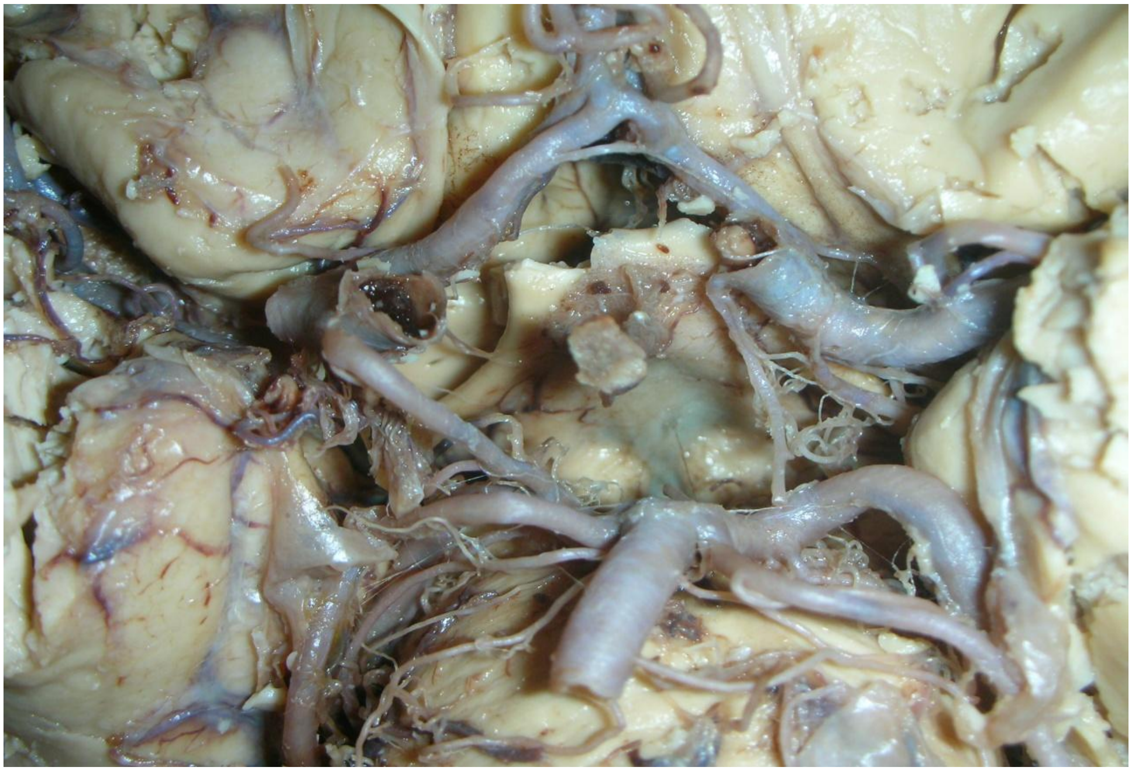
ABSENCE OF LEFT POSTERIOR COMMUNICATING ARTERY



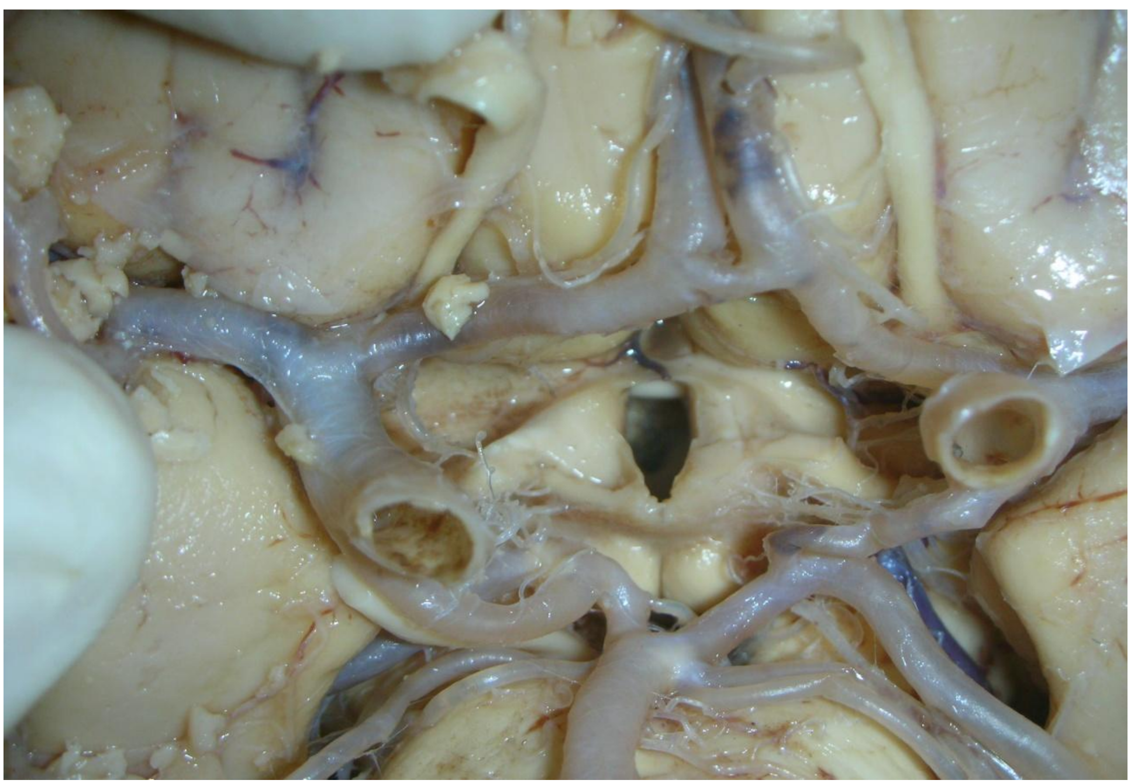
HYPOPLASTIC A1 SEGMENT OF RIGHT ACA



HYPOPLASTIC P1 SEGMENT OF RIGHT PCA



HYPOPLASTIC LEFT POSTERIOR COMMUNICATING ARTERY



NORMAL PATTERN OF CIRCLE OF WILLIS

PHOTOS

SPECIMENS DISSECTED FOR THIS STUDY