

Morphometric and Morphological Analysis of the Circle of Willis and its Variants in Adult Human Cadaver: A Retrospective Observational Study

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ABSTRACT

Introduction: Knowledge of variations in the vascular anatomy of the circle of Willis is necessary for radiologists and neurosurgeons performing radiological procedures and intracranial surgeries.

Aim: To identify vessels forming the Circle of Willis and to determine the incidence of its variations in the Circle of Willis in cadaveric brain specimens.

Materials and Methods: A retrospective observational study was conducted in the Department of Anatomy, PSG Institute of Medical Sciences and Research, Coimbatore Tamil Nadu, India, from February 2021 to January 2024. A total of 30 brain specimens, including those of both genders, were removed and fixed in formalin. The variations that were observed are hypoplasia, aplasia, duplication, and differences in the dimensions between

opposite segments. Observations regarding shape, symmetry and architecture were noted. The variations in the vessels that form the Circle of Willis were identified. Comparison of length and diameter between right and left-sided arteries of the Circle of Willis was done with Student's paired t-test.

Results: Out of the total of 30 available human brain specimens, 22 specimens presented with the classic shape (heptagonal) of the Circle of Willis. Eight specimens showed variation in the Anterior Cerebral Artery (ACA). One specimen showed variation in the Posterior Cerebral Artery (PCA). Ten specimens showed variation in the Anterior Communicating Artery (ACoA) and 12 specimens showed variations in the Posterior Communicating Artery (PCoA).

Conclusion: Knowledge of variations in the Circle of Willis is essential for radiologists and neurosurgeons to interpret angiography and plan neurovascular procedures accurately.

Keywords: Diameter, Duplication, Hypoplasia, Multiple anomalies

INTRODUCTION

The circulus arteriosus cerebri (cerebral arterial circle, circle of Willis) is a large arterial anastomosis that unites the internal carotid and vertebrobasilar systems. It lies in the subarachnoid space within the basal cisterns that surround the optic chiasma and infundibulum. The anterior cerebral arteries are derived from the internal carotid arteries and are linked by a small but functionally important ACoA. Posteriorly, the division of the basilar artery forms the two posterior cerebral arteries, which are joined to the ipsilateral internal carotid artery by a PCoA [1].

There is considerable individual variation in the pattern and calibre of the vessels that make up the circulus arteriosus. Although a complete circular channel almost always exists, one vessel is sufficiently narrowed to reduce its role as a collateral route and the circle is rarely functionally complete [1]. Individual cerebral and communicating arteries may be absent, variably hypoplastic, double or triple. The most significant variation in calibre occurs in the PCoA, which is usually very small, so that only limited flow is possible between the anterior and posterior circulations [1]. Sometimes, the ACoA becomes double; on occasion, the proximal part of one of the anterior cerebral arteries is small, and in such a condition, the ACoA assumes a large calibre [2].

Variations in the size of the vessels forming the cerebral arterial circle are common. The posterior communicating arteries are absent in some individuals; in others, there may be two anterior communicating arteries [3]. The study aimed to identify the vessels which form the Circle of Willis and to determine the incidence of its variations in the Circle of Willis in cadaveric brain specimens.

MATERIALS AND METHODS

A retrospective observational study was conducted in the Department of Anatomy at PSG Institute of Medical Sciences and Research, Coimbatore, Tamil Nadu, India, from February 2021 to January 2024. The specimens were collected and analysed after obtaining ethical clearance (No. 024/54).

Inclusion criteria: The Circle of Willis with intact branches was included in brain specimens.

Exclusion criteria: The damaged the Circle of Willis and its branches were excluded.

Study Procedure

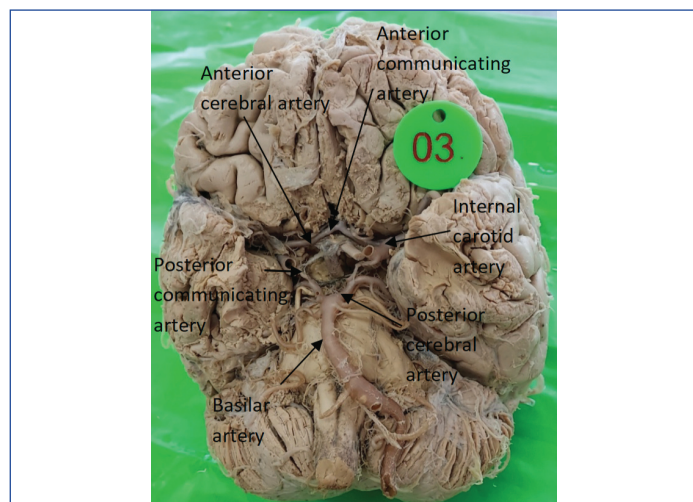
A total of 30 brain specimens, including those of both genders, were removed during undergraduate teaching dissections and were fixed in formalin. The cerebral arterial circle was studied in detail with reference to the following parameters in each specimen: completeness, pattern, variations, and symmetry of the circle of Willis; presence, origin, external diameter, and number of component vessels of the Circle of Willis; and the presence of any variation. The external diameter and length of all the arteries (ACoA, ACA on both sides, PCoA on both sides and PCA) forming the Circle of Willis were measured using a digital vernier calliper. To minimise errors in measurements, two observers measured the length and diameter of each vessel three times and finalised all the measurements. A magnifying lens was used to observe the vessels closely. The normal pattern and the variations of all the vessels involved in the formation of the circle of Willis were noted and photographed.

STATISTICAL ANALYSIS

Statistical analysis was done by using the Statistical Package for the Social Sciences (SPSS) software, version 29.0. Comparison of length and diameter between right and left-sided arteries of the circle of Willis was done with Student's paired t-test.

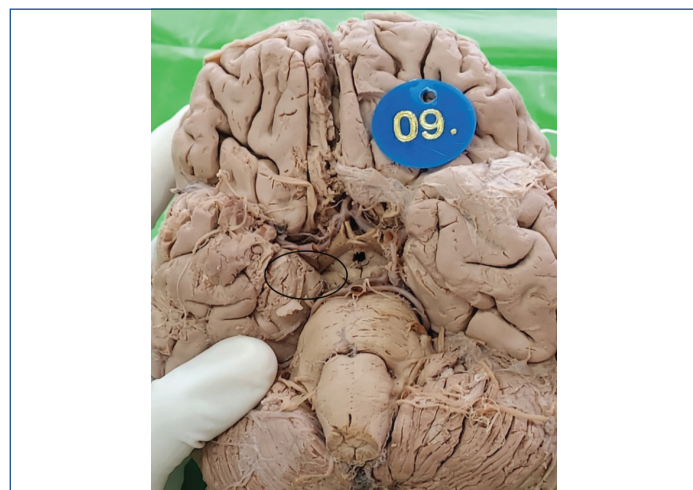
RESULTS

Out of the total of 30 available human brain specimens, 21 specimens (70%) presented with the classic shape (heptagonal) of the Circle of Willis [Table/Fig-1] [4]. An irregular shape was found in the remaining nine specimens (absence of the PCoA in three specimens, fenestration of the ACoA in three specimens, duplication of the ACoA in two specimens and a long PCoA in one specimen).



[Table/Fig-1]: Hexagonal shape of the Circle of Willis.

Asymmetry was observed in 13 (43.3%) specimens [Table/Fig-2]. These specimens showed incomplete, non heptagonal vessels with variations in branching patterns, vessel calibre, and vessel duplication. The variations are as follows:

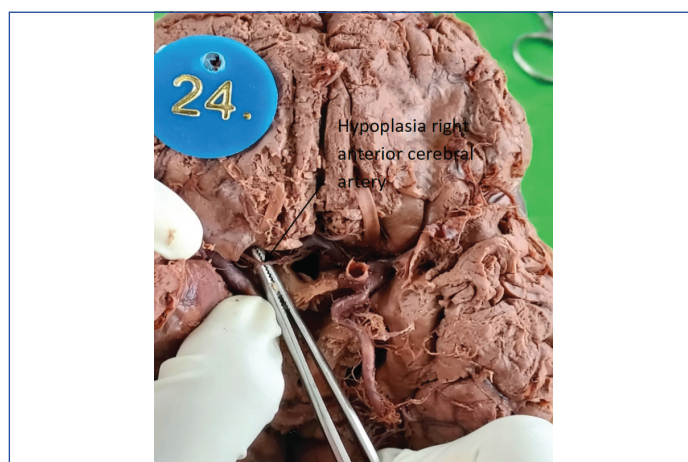


[Table/Fig-2]: Asymmetry of the Circle of Willis (Absent right PCoA).

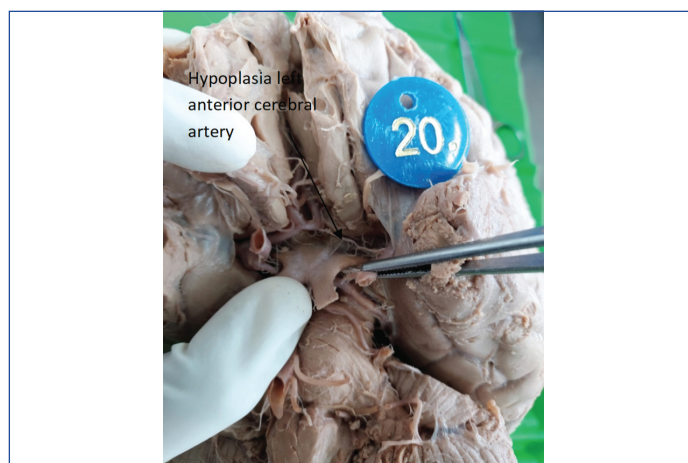
Seven specimens showed variation in the ACA. Among these seven specimens, five specimens showed hypoplastic vessels (three on the right-side and two on the left-side) [Table/Fig-3-5]. Duplication of the right ACA was found in two specimens (on the right-side) [Table/Fig-6,7]. In the right ACA originated (from the right ICA) as a single vessel and was found to be divided into two [Table/Fig-6]. The upper vessel continued as the ACA, and the lower vessel continued as the ACoA, with partial communication near the right end of the ACoA. In the Right ACA originated (from the right ICA) as a single vessel [Table/Fig-7]. It was found to be divided into two, with the upper vessel continuing as the ACA, and the lower vessel joining at the middle of the ACoA. These anomalies were not previously reported.



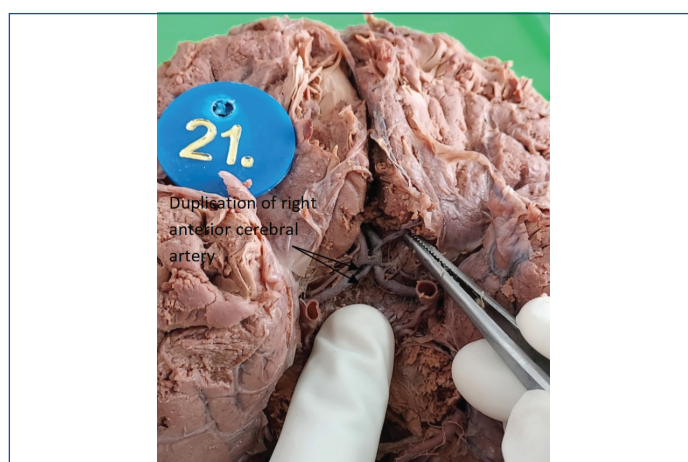
[Table/Fig-3]: Hypoplasia left Anterior Cerebral Artery (ACA).



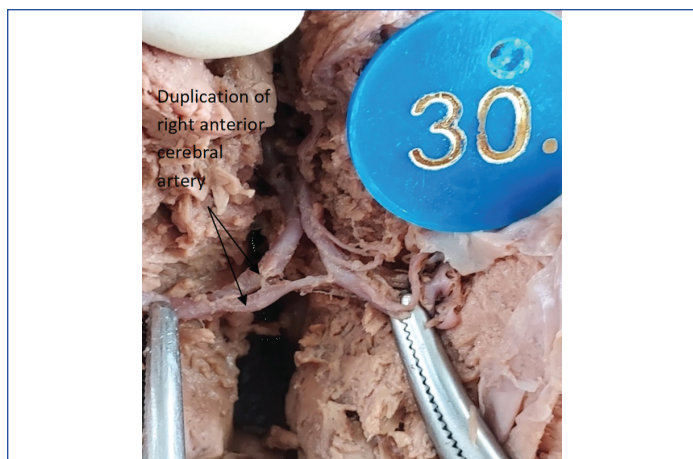
[Table/Fig-4]: Hypoplasia right Anterior Cerebral Artery (ACA).



[Table/Fig-5]: Hypoplasia of left Anterior Cerebral Artery (ACA).

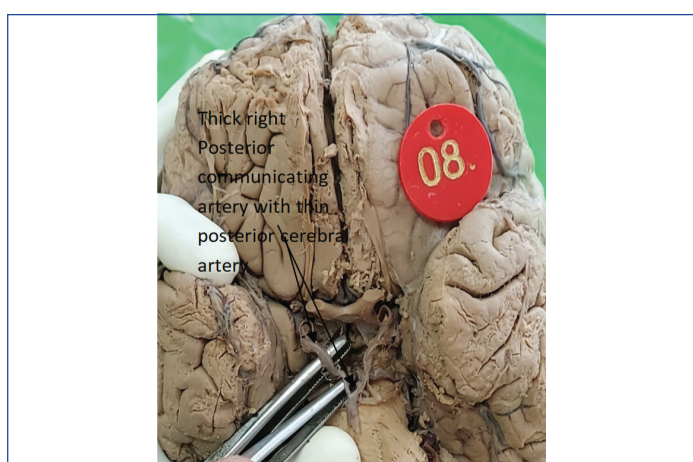


[Table/Fig-6]: Duplication of right Anterior Cerebral Artery (ACA).



[Table/Fig-7]: Duplication of right Anterior Cerebral Artery (ACA).

One specimen showed variation in the PCA. The PCA was thin and hypoplastic with a thick PCoA on the right-side (Partial foetal type right PCA) [Table/Fig-8].

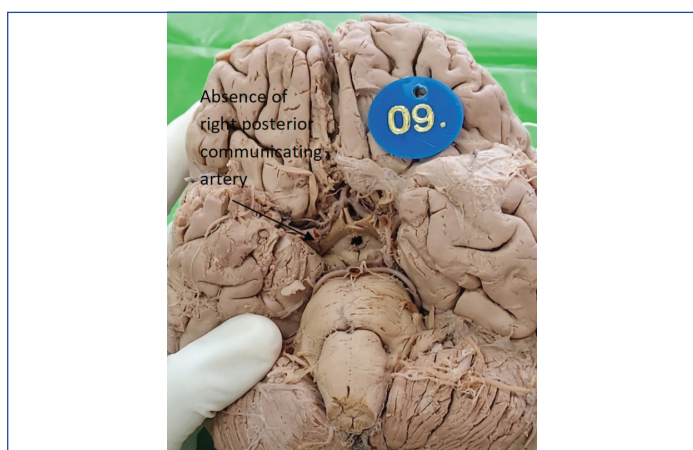


[Table/Fig-8]: Partial foetal type right Posterior Cerebral Artery (PCA).

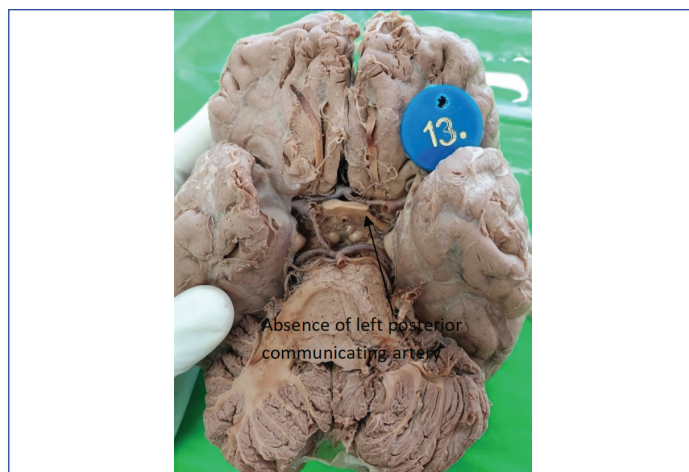
Twelve specimens showed variations in the PCoA. Three specimens showed the absence of PCoA (one on the right-side and two on the left-side) [Table/Fig-9,10]. Eight specimens showed hypoplastic vessels (two on the right-side, three on the left side, and three on both sides) [Table/Fig-11]. One specimen showed thin and long PCoA (on the right-side) [Table/Fig-12].

Five specimens showed variation in the ACoA. Three specimens showed fenestration of ACoA [Table/Fig-13]. Two specimens showed duplication [Table/Fig-14].

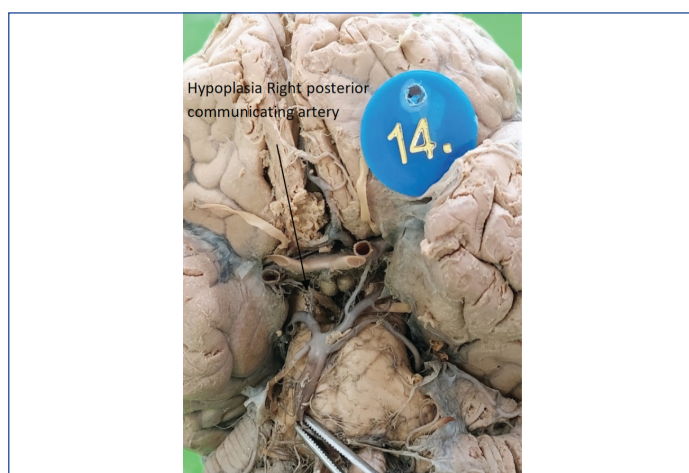
Multiple anomalies were noted in two specimens. Thin right PCoA, thin left ACA and long left PCA in the first specimen [Table/Fig-15]. Three specimens showed fenestration of the ACoA. ACoA continued as left ACA. Left ACA did not have its origin from the left internal



[Table/Fig-9]: Absence of right Posterior Communicating Artery (PCoA).



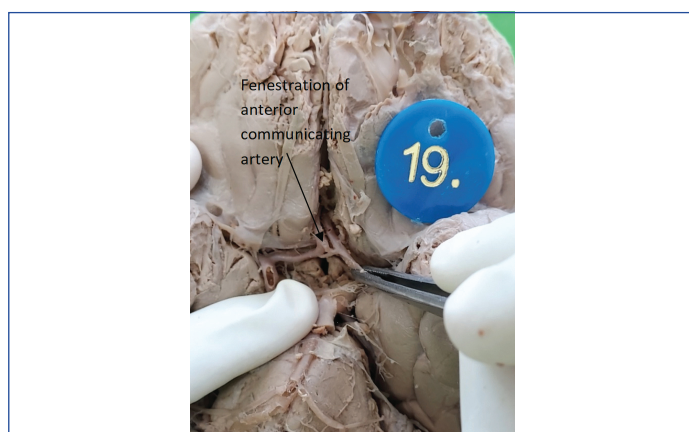
[Table/Fig-10]: Absence of left Posterior Communicating Artery (PCoA).



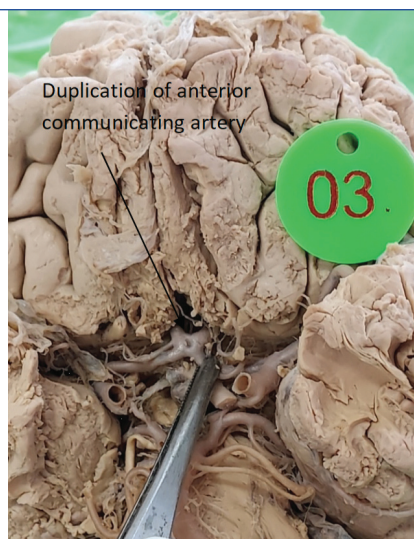
[Table/Fig-11]: Hypoplasia of right Posterior Communicating Artery (PCoA).



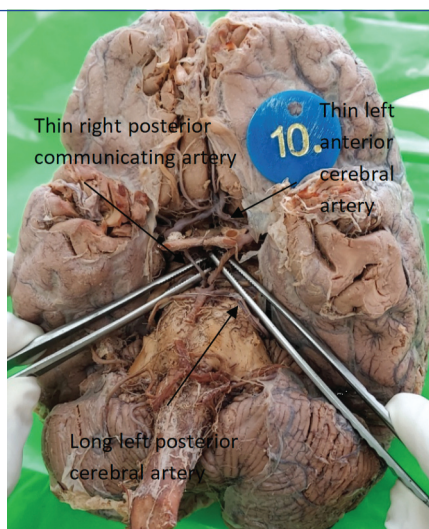
[Table/Fig-12]: Thin & long right Posterior Communicating Artery (PCoA).



[Table/Fig-13]: Fenestration of Anterior Communicating Artery (ACoA).



[Table/Fig-14]: Duplication of Anterior Communicating Artery (ACoA).

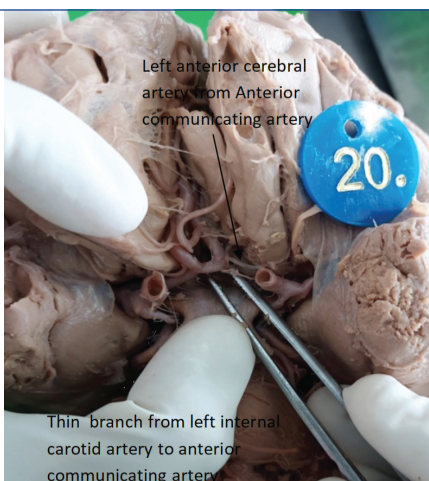


[Table/Fig-15]: Multiple anomalies 1- Thin right Posterior Communicating Artery (PCoA), thin left Anterior Cerebral Artery (ACA) and long left Posterior Cerebral Artery (PCA).

carotid artery; the left internal carotid artery was smaller than the right internal carotid artery, a small thin branch from the left internal carotid artery to the ACoA in the other specimen [Table/Fig-16].

Variations in the vessels of the Circle of Willis, with their incidence, were noted in [Table/Fig-17].

A comparison of various parameters mentioned in the revealed that they were statistically not significant [Table/Fig-18].



[Table/Fig-16]: Multiple anomalies 2: Anterior Communicating Artery (ACoA) continued as left Anterior Cerebral Artery (ACA), left ACA did not have the origin from the internal carotid artery, left internal carotid artery was smaller than the right internal carotid artery, small thin branch from left internal carotid artery to ACoA.

Name of artery	n (%)	Nature/Number
1. Anterior cerebral artery	7 (23.3%)	Hypoplasia -5 (16.6%) Duplication- 2 (6.6%)
2. Anterior Communicating Artery (ACoA)	5 (16.6%)	Fenestration - 3 (10%) Duplication - 2 (6.6%)
3. Posterior communicating artery	12 (40%)	Aplasia -3 (10%) Hypoplasia - 8 (26.6%) Very long - 1 (3.3%)
4. Posterior Cerebral Artery (PCA)	1 (3.3%)	Hypoplasia with thick PCoA - 1 (3.3%)
5. Multiple anomalies	2 (6.6%)	Thin right Posterior Communicating Artery (PCoA), thin left ACA and long left posterior cerebral artery - 1 (3.3%) Anterior Communicating Artery (ACoA) continued as left ACA, left ACA did not have the origin from internal carotid artery, left internal carotid artery was smaller than the right internal carotid artery, small thin branch from left internal carotid artery to ACoA - 1 (3.3%)

[Table/Fig-17]: Shows variations in the Circle of Willis.

Groups	Mean±SD	t-test	p-value	
Length of Anterior Cerebral Artery (ACA) - Right-side	8.48±4.31	1.903	0.062	
Length of ACA - Left-side	8.08±3.72			
Diameter of ACA - Right-side	3.78±1.29	0.093	0.926	
Diameter of ACA - Left-side	3.76±1.26			
Length of PCA - Right-side	5.03±2.02	1.000	0.326	
Length of PCA - Left-side	5±2.05			
Diameter of PCA - Right-side	3.43±1.19	1.000	0.326	
Diameter of PCA - Left-side	3.40±1.19			
Length of Single Anterior Communicating Artery (ACoA)	2.04±0.34	2.04	0.34	
Diameter of single ACoA	0.34±0	1.0	0	
Length of Posterior Communicating Artery (PCoA) – Right-side	9.07±2.78	1.162	0.255	
Length of PCoA - Left-side	9.64±2.73			
Diameter of PCoA - Right-side	3±0	Undefined (variance is 0)		
Diameter of the PCoA – Left-side	3±0			

[Table/Fig-18]: Comparison of length and diameter between right and left-sided arteries of the Circle of Willis is illustrated with the help of students' paired t-test.

DISCUSSION

The blood supply to the brain is primarily from the Circle of Willis, which Thomas Willis described in 1662 [5]. In most arterial variations, brain function may not be affected due to collateral circulation and compensation from the artery on the other side [6].

The most common anomaly of the Circle of Willis in normal brains was hypoplasia of one or other components of the circle. Arteries of less than 1mm in external diameter were considered hypoplastic except for the communicating artery, where less than 0.5 mm was considered hypoplastic [7].

Iqbal S performed a study on the Circle of Willis in 50 brain specimens. In his study, he found a regular polygonal pattern in 24 (48%) brain specimens [7]. Hypoplasia of the PCoA was the most frequent, followed by hypoplasia of the PCA, the ACA and the ACoA. In the present study, the authors' found a normal heptagonal pattern in 21 (70%) specimens. In the present study, similar findings were reported as hypoplasia of the PCoA, the most frequent variation found, followed by hypoplasia of the ACA. The authors did not find ACoA hypoplasia. Absence of PCoA was found in three specimens in his study, which was similar to the present study.

Siddiqi H et al., studied 51 specimens. They reported the heptagonal shape of the Circle of Willis in 37 specimens [8]. ACA, PCA and

multiple anomalies were not found in their study. Regarding asymmetry of paired vessels, PCoA was asymmetrical in 23.5% followed by PCA- 7.8% and ACA- 5.8% in their research. In the current study, asymmetry in PCoA (40%), PCA (3.3% and ACA (23.3%) was found.

Sahin H and Pekcevik Y performed cerebral angiography in 751 patients and found that variations related to PCoA were the most frequent which was similar to the present study [9]. Singh R et al., studied 85 specimens [10]. Classic heptagonal shape was seen in 67 (89.3%) specimens. Twenty (22.6%) specimens were found to be asymmetric. A normal heptagonal pattern in 19 (63%) specimens, and 26 (86.6%) were asymmetric in the present study.

Kabakci AG and Bozkir MG studied 32 brain specimens [11]. They found variations in 24 specimens. Aplasia of PCoA was found in 4 (8.51%) specimens. Thin PCoA was found in 11 (23.4%) specimens and long and thin PCoA was seen in 3 (6.38%) specimens. Duplication of ACoA was seen in 2 (4.2%) specimens. Fenestration of ACoA was not present in their study. Triplication of ACA was found in a specimen. Double PCA was seen in 2 (4.2%) and the origin of PCA from ICA was about 8 (17.02%) specimens in their study. The variations were not similar to the present study.

Rajan ML studied 215 MR angiography and observed variations in the posterior part of the Circle of Willis. Among them, 80 (37.21%) pictures were incomplete [12]. Hyperplasia of right PCoA was 40 (18.6%) and left PCoA was 34 (15.8%).

Dumitrescu Am et al., examined 96 autopsy brain specimens and identified a normal heptagonal configuration of the Circle of Willis in 68 cases (70.83%) [13]. Variations of the ACoA included aplasia in 6 cases (21.42%), duplication in 2cases (7.14%), and hypoplasia in 1case (3.5%).

Hafez KA et al., studied 120 MR angiograms and ten brain specimens. They found duplication of ACoA in 11.7% and fusion of ACoA in 5% [14]. Fenestration was found in ACoA as a frequent

anomaly. Hypoplasia of PCoA was seen in 13.3% in males and 11.7% in females. Hypoplasia of PCA was observed in 3.3% in males and 1.7% in females. Similar anomalies were found. Foetal type PCA was found in 6.7% of pictures whereas it was not found in the present study.

De Silva KR et al., performed a study on the Circle of Willis in 225 autopsied brain specimens. He found PCoA in all specimens [15].

Kapoor K et al., performed a study on 1000 brain specimens. They found a heptagonal pattern in 42.2% and symmetry in 96.8% of specimens [16]. They found aplasia of ACA in 0.4% and, hypoplasia of ACA in 1.7% and absence of ACoA in 1.8% of specimens. Duplication of ACoA was observed in 22.2%. Also, aplasia of ACA in 3% and hypoplasia of ACA in 16.6% of specimens were found in the present study. Gunnal SA et al., found hypoplasia of ACA in 5.33% and absence of ACA in 2.66% and aplasia of ACoA in 8% [17]. Siddiqi H found hypoplasia of ACA in 4% and absence of ACA in 3.6%. Similar result were found in case of aplasia of ACA in the present study [18].

Fawcett E and Blachford JV found the heptagonal shape of the Circle of Willis in 72.2%. Most common finding was duplication of ACoA, which was seen in 2.6% [19]. Absence of ACoA was found in 0.14%. Fenestration of ACoA was found more common anomaly than duplication in the present study.

Alpers BJ et al., found aplasia of ACoA in 3%, hypoplasia of PCoA was 22% and ACA was 2% [20]. Duplication of ACoA was seen in 9% and embryonic origin of PCA from ICA was seen in 15%. Hypoplasia of PCoA was similar to the present study. Aplasia of ACoA and Embryonic origin of PCA from ICA were not found in the present study. Fenestration of ACoA was more frequent anomaly than duplication of ACoA in the present study.

Karatas A et al., found hypoplasia of PCoA in 85% and aplasia in 5% in their study. Also in the current study, hypoplasia of PCoA (26.6%) was found as most frequent anomaly [21]. The findings from different studies are tabulated in [Table/Fig-19,20].

S. No.	Various author's names, year & place of study	ACA hypoplasia (%)	ACA duplication (%)	ACoA hypoplasia (%)	ACoA fenestration (%)	ACoA duplication (%)
1	Iqbal S [7], 2013, Kerala	4	4	8	-	8
2	Siddiqi H et al., [8], 2013, Pakistan	0	0	13.7	9.8	5.8
3	Sahin H and Pekcevik Y [9], 2018,Turkey	14	-	-	10.1	-
4	Singh R et al., [10], 2017, West Bengal	10.6	-	-	13.3	-
5	Kabakci AG and Bozkir MG [11], 2002 Turkey	6.3	-	-	10	4.2
6	Rajan ML [12], 2021, Kerala	-	-	-	-	-
7	Dumitrescu AM et al., [13], 2021, Romania	32.14	3.5	-	-	7.14
8	Hafez KA et al., [14], 2007, Egypt	-	-	-	-	11.7
9	Kapoor K et al., [16], 2008, India	1.7	2.6	6.6	-	22.2
10	Gunnal SA et al., [17], 2014, India	5.3	6	-	3.3	10
11	Siddiqi H [18], 2013, Pakistan	4	-	-	-	-
12	Present study, 2025, India	16.6	6.6	-	10	6.6

[Table/Fig-19]: Comparison of the present study with the previous author's studies in relation to anterior part of the Circle of Willis.

S.No.	Various author's names, year and place of study	PCoA aplasia (%)	PCoA hypoplasia (%)	PCoA very long (%)	PCA hypoplasia (%)
1	Iqbal S [7], 2013, Kerala	6	10	-	6
2	Siddiqi H et al., [8], 2013,Pakistan	23.4	33.3	-	0
3	Sahin H and Pekcevik Y [9], 2018,Turkey	27.5	-	-	6
4	Singh R et al., [10] 2017, West Bengal	7	3.5	-	-
5	Kabakci AG and Bozkir MG [11], 2002 Turkey	8.5	23.4	6.38	0
6	Rajan ML [12], 2021, Kerala	2.3	4.5	6.3	26
7	Dumitrescu AM et al., [13], 2021, Romania	-	-	-	-
8	Hafez KA et al., [14], 2007, Egypt	-	15	-	5
9	Kapoor K et al., [16], 2008, India	-	-	-	-

10	Gunnal SA et al., [17], 2014, India	-	-	-	-
11	Siddiqi H [18], 2013, Pakistan	-	-	-	-
12	Present study, 2025, India	10	26.6	3.3	3.3

[Table/Fig-20]: Comparison of the present study with the previous author's studies in relation to the posterior part of the Circle of Willis.

Clinically, variations in the posterior part can compromise vascular blood flow before or after the transition from the internal carotid artery to the vertebrobasilar system, thereby impairing the normal development of the cerebral hemisphere. Variations in the posterior circulation are associated with a higher incidence of migraine and stroke due to posterior cerebral infarcts in patients who have atherosclerosis. Hypoplasia or aplasia of the PCoA is a risk factor for infarction. Fenestration of ACoA is more common in the current study. These fenestrations are frequently associated with aneurysms.

Limitation(s)

More number of specimens may show more variations in the Circle of Willis for clinical correlation.

CONCLUSION(S)

Variations in the vessels forming the Circle of Willis are equally crucial for clinicians, radiologists and surgeons. Knowledge of vascular variations will increase the success rate of the surgical procedure.

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