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Original Research Article

Variations in the Arterial Circle of Willis in Cadaver: A Dissection Study

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ABSTRACT

Background and objectives: The Circle of Willis is the most important route for cerebral perfusion and for collateral blood flow in severe occlusive diseases of the internal carotid artery. The knowledge of ideal configuration is required while determining the adequacy of brain circulation in operations of cerebral aneurysms and ligation of carotid artery. The present study was undertaken to study the arteries forming the Circle of Willis and to note variations in configuration or branching pattern.

Materials and methods: During routine dissection, 30 brains were removed from cadavers by a method according to standard procedure. The detailed study of the Circle of Willis with reference to the shape of the arterial circle, position and course of all the arteries, variations such as the presence, absence or hypoplasia of each arterial segment was carried out.

Results: Out of 30 brain specimens, the Circle of Willis was complete in 80% cases, incomplete in 20%. Anomalies were more common in posterior part (43.33%) than in the anterior part (16.66%). Posterior part anomaly includes variations due to either absence or hypoplasia of one or more segment. The anterior part anomaly includes azygous anterior cerebral artery or median trunk formation, duplicity, fenestration.

Conclusion: Knowledge of the Circle of Willis and its variations is essential in clinico-pathological conditions and in surgical interventions as it is one of the major collateral circulations ensuring the complete perfusion of the brain.

Key words: Circle of Willis, variations.

INTRODUCTION

Cerebrovascular variations and anomalies have always been a challenge for anatomists as well as neurosurgeons. The arrangement of arterial communications form a unique arterial circle at the base of the brain connecting the principal arterial systems supplying the brain, i.e., the Internal carotid system of both the sides and the Vertebro-basilar system which create redundancies in the cerebral circulation due to anastomotic channels being variable. This arterial circle is called "The Circulus Arteriosus" or more commonly, "The Circle of Willis", named after Thomas Willis (1621-1673) who was an English physician. [1]

The major role of the Circle of Willis is the redistribution of blood to all the areas of brain in the period of flow disturbances in case of any of the principal arterial systems being compromised. Certain morphological variations of the Circle of Willis take place if a part of the circle becomes blocked or narrowed (stenosed) which help in complete maintenance of the cerebral blood flow without any additional autoregulatory mechanisms. [2] Due to the involvement of more than three arterial anastomotic segments in the formation of Circulus Arteriosus, it presents with innumerable variations in its establishment. In the clinico-pathological considerations of cerebral hemorrhage, encephalomalacia, infarction of the brain and intracranial aneurysms, the study of normal as well as variations of the Circle of Willis is very important for us to understand and pinpoint the location of the lesion and for its interpretation, the knowledge of which may be of considerable help to neurosurgeons. [3]

The knowledge of ideal configuration is required while determining the adequacy of brain circulation in operations of cerebral aneurysms and ligation of carotid artery. Hence the present study was undertaken to study the arteries forming the Circle of Willis and to note variations in configuration or branching pattern of Circle of Willis.

MATERIALS AND METHODS

The present study was based on the 30 brains removed from embalmed cadavers given for dissection to undergraduate medical students in the Department of Anatomy. The project was approved by the Institutional Ethics committee.

The brains were removed en-mass by adopting the dissection procedures as given in the Cunninghams 'Manual of Practical Anatomy' Volume III: Head and Neck and Brain, 15th edition.

The meninges were removed carefully from the interpeduncular fossa and the Circle of Willis was observed *in situ*. The detailed study of segments of the Circle of Willis in each specimen was made and the findings were noted and tabulated with reference to: shape of the arterial circle, position and course of all the arteries which form the Circle of Willis individually (both right and left side separately).Vernier caliper, graduated to measure up to 0.1mm, were used to measure the length and the external diameter of the components of the Circle of Willis. The measurement of the external diameter of the following vessels were taken: anterior communicating artery (ACoA): at the midpoint; right & left anterior cerebral artery (A1): close to their origin; right & left internal carotid artery (ICA): between the origin of anterior cerebral and posterior communicating artery; right & left posterior communicating arteries (PCoA): at the midpoint; right & left posterior cerebral arteries (P1): at the midpoint from its origin and the anastomotic termination of PCoA; basilar artery (BA): close to its end. The arteries measuring less than 1mm in diameter were considered to be abnormal barring the communicating arteries, where less than 0.5mm diameter was considered to be abnormal.

The measurement of the lengths of the components of the Circle of Willis were taken: right and left A1 segment from the point of its origin to the point of the ACoA communication; anterior communicating artery from the point of communication between right A1 segment to the left A1 segment; right and left PCoA from the point of their origin to the point of their termination; right and left P1 segment from their origin at the bifurcation of the basilar to the point of communication of the PCoA.

Variations were observed with reference to the presence or absence of the differences in each segment of the circle in size, shape, mode of anastomosis. Finally, photographs were taken on Pentax 6.0 mega pixel, 3x optical zoom camera and were digitally painted on Adobe Photoshop CS3 Software.

RESULTS

30 adult cadavers were dissected irrespective of any particular age group. Brains were neatly washed and studied properly regarding the component vessels forming the Circle of Willis.

Circle Morphology: In the present study, the circle was complete in 24 (80%) cases and incomplete in 6 (20%) cases.

Circle Symmetry:

Circle which has the external diameters of the vessels on the right side exactly equal to that on the left side is the symmetrical circle as stated by Prof. Fawcett (1905). [4] Circle with variation in external diameters of corresponding vessels are considered as asymmetrical circles. In the present study, 10 circles (33.33%) were symmetric and 14 (46.66%) were asymmetric (Figure 1). The circle was incomplete in one of the 30 (3.33%) cases in the anterior part and in 5 (16.66%) cases in the posterior part. Out of 30 brain specimens, in anterior part, the circle was normal/complete in 25 (83.33%) cases and anomalous in 5 (16.66%) cases. In the posterior part, the circle was normal/complete in 17 (56.66%) cases and anomalous in 13 (43.33%) cases. Out of 30 brain specimens, in 20 (66.66%) specimens, the shape of the circle was a nonagon and in 4 (13.33%) specimens, the circle was a polygon. The length and external diameter of the components of the Circle of Willis was measured with venire caliper. The average of the length and external diameter of the components of Circle of Willis is given in table 1.

Table 1: Average Length & External Diameter of the components of Circle of Willis

Name of the arterial segment	Length (mm)		Diameter (mm)	
	Right	Left	Right	Left
BA			3.5 ± 0.10	
P1	8.06 ± 0.48	8.12 ± 0.52	2.0 ± 0.08	2.19 ± 0.18
PCOA	14.03±0.54	14.56 ± 0.54	1.09 ± 0.12	1.10 ± 0.11
A1	14.4 ± 0.53	14.5 ± 0.16	1.96 ± 0.09	2.06 ± 0.08
ACOA	4.4 ± 0.23		2.00 ± 0.16	
ICA			3.63 ± 0.13	3.82 ± 0.14

Circle of Willis- Posterior part

The pre-communicating artery (P1 Segment) was present in 25 (83.33%) specimens and absent in 5 (16.66%) and hypoplastic in two specimens, one on each side. The P1 segment originated from terminal bifurcation of basilar artery in 26 (86.66%) specimens; in 4 (13.33%) the artery originated from the ICA, 2 on each side accounting for 6.66% each. (table2).

Table 2: P1 Segment and PCoA Segment

P1 segment	Present	Absent- 5 (16.66%)			Hypoplasia		
		Both	P1- R	P1- L	Both	P1- R	P1- L
No. of cases	25	-	3	2	-	1	1
Percentage	83.33%	-	10%	6.66%	-	3.33%	3.33%
PCoA segment	Present	Absent-4 (13.33%)			Hypoplasia		
		Both	PCoA-R	PCoA-L	Both	PCoA-R	PCoA-L
No. of cases	26	-	3	1	4	5	2
Percentage	86.66%	-	10%	3.33%	13.33%	16.66%	6.66%

The Posterior Communicating Artery (PCoA) was present in 26 (86.66%) specimens and absent in 4 (13.33%) and hypoplastic on both sides in 4 (13.33%) specimens, on the right side in 5 (16.66%) cases and on the left side in 2 cases (6.66%).(table 2) PCoA originated from ICA in 29 (96.66%) specimens, only in a single specimen(3.33%), it was found that the PCoA originated from the basilar artery on the left side.

Anterior Part:

The pre-communicating Anterior Cerebral Artery (A1 segment) was present in 28 (93.33%) specimens and absent in 2 (6.66%) specimens, one on right side and one on the left side. The artery was found to be hypoplastic in one specimen on the right side (3.33%).

The Anterior Communicating Artery was absent in 4 of the 30 specimens (13.33%). Out of these 4 specimens, a complete absence was seen in only one specimen(3.33%); a median trunk (Azygous ACA) formation was seen in 3 (10%) specimens .The artery was present in 26 (86.66%) of 30 specimens.(table 3)

Table 3: ACoA, ACoA- ACA complex

ACoA- ACA complex	**Absent ACoA- 4 (13.33%)**		**Present-26 (86.66%)**			
	Complete absence	**Azygous ACA**	**V complex**	**H complex**	**Fenestrated**	**Double**
No. of cases	1	3	3	21	1	1
Percentage	3.33%	10%	10%	70%	3.33%	3.33%

ACoA-ACA Complex: Out of the 26 specimens; the 'H' shaped ACoA-ACA complex was most commonly found i.e. in 21 (70%) specimens and 'V' complex in 3 (10%) specimens. The artery was fenestrated and double in one specimen each which accounted to 3.33 %.(table 3)

Basilar Artery:

The terminal bifurcation of the basilar artery was found to be equal in 27(90%) specimens and unequal in 3 (10%) specimens. Out of the 3 unequally bifurcating basilar artery it was found that the artery continued as right PCA in 1 specimen (3.33%) & as left PCA in 2 specimens (6.66%).

Table 4 showing segmental variations of Circle of Willis in comparison with previous studies

Refs	**N0.**	**ACoA Aplasia**	**ACoA Hypoplasia**	**ACA Aplasia**	**ACA Hypoplasia**	**PCoA Aplasia**		**PCoA Hypoplasia**		**P1 Hypoplasia**		**P1 Aplasia**
						Uni	**Bi**	**Uni**	**Bi**	**Uni**	**Bi**	
Alpers [11]	350	2%	3%	-	2%	0.6 %	-	13.5%	9%	11%	3.7%	-
Fawcett [5]	700	0.14%	-	-	-	3.2 %	0.4%	21.5%	0.7%	42%	0.14%	-
Riggs [12]	994	-	27%	-	16%	-	-	21%	30%	16%	6%	-
Windle [13]	200	1.5%	-	-	-	11%	1.5	21.5%	3.5%	10%	2%	-
Khamlichi [14]	100	-	32%	-	4%	-	-	25%	35%	14%	1%	-
Fisher [15]	414	-	29%	-	13%	-	-	32%	49%	22%	7%	-
Lazorthes [16]	200	-	29.5%	-	7.5%	-	-	29.5%	40%	7.5%	4.5%	-
Puchades [17]	62	3.2%	6.4%	0.8%	6.4%	2.4 %	-	51.6%	-	11.3	11.3	2.4%
Eftekhar [6]	102	1%	11%	-	1%	7%	3%	27%	33%	7%	-	-
Present study	30	3.33%	-	-	3.33%	16.6 %	-	29.9%	16.66%	6.66%	-	-

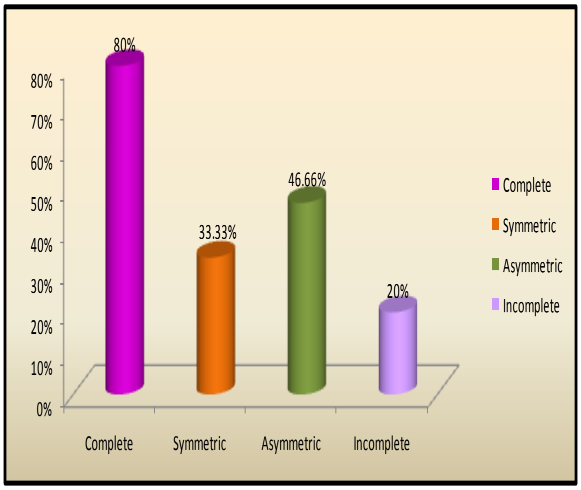


Figure 1: Bar diagram showing percentage of morphology of Circle of Willis

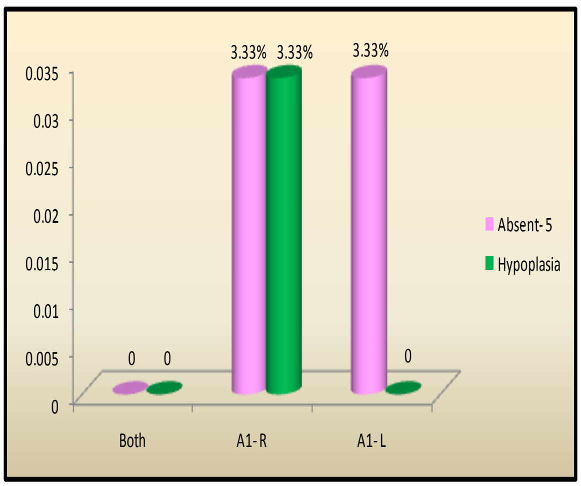


Figure 2: Bar diagram showing percentage of absent and hypoplastic A1 segment

Keys to photograph: R – Right, L- Left, **PCoA-** Posterior Communicating Artery, **PCA-** Posterior Cerebral Artery,**P1** - Posterior Cerebral Artery before PCoA, **ACoA-** Anterior Communicating Artery, **ACA-** Anterior Cerebral Artery,**A1** - Anterior Cerebral Artery before ACoA 1.Right Internal Carotid Artery 2. Left Internal Carotid Artery, BA - Basilar Artery

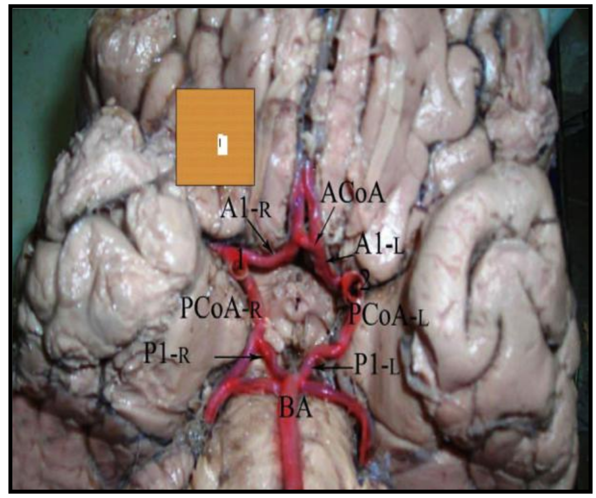
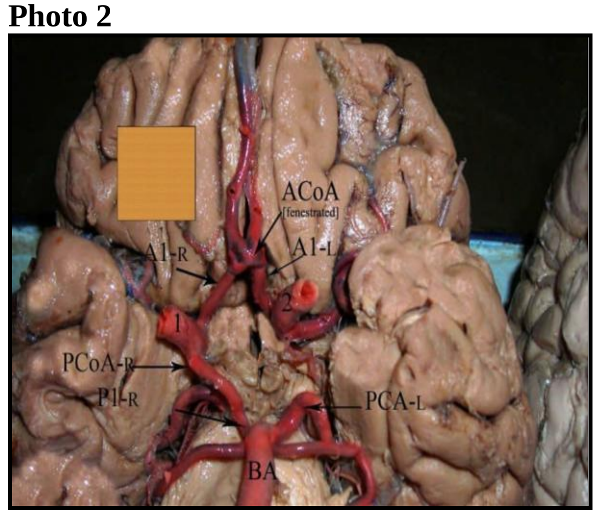


Photo 1.

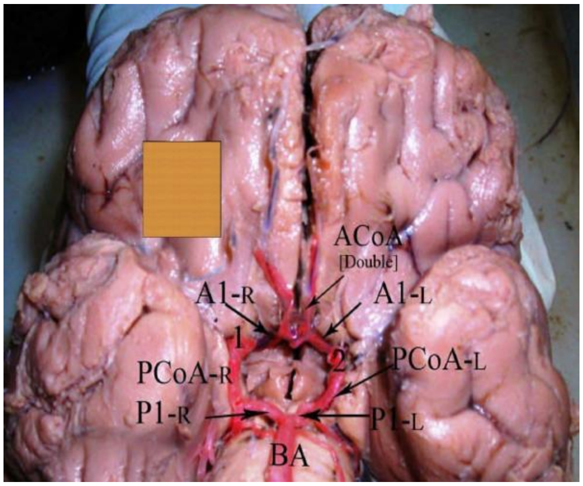
Circle: Complete , **Shape**: Nonagon; Symmetric **Components**: **Posterior part**: All components, PCoA, P1 segment and BA present; normal in their origin and size. Bifurcation of BA is equal and symmetric. **Anterior part**: ACoA-ACA complex – 'H' shaped, all the components, A1 segment and ACoA present; normal in their origin and size.

Photo 2



Circle: Incomplete **Components**: **Posterior part**: PCoA- L absent; P1-R present,P1- L absent; BA bifurcates unequally and PCA- L is continuation of it on the left side. **Anterior part**: ACoA is fenestrated; all the components- A1 segments and ACoA present; normal in their origin and size.

Photo3



Circle: Complete **Shape**: Nonagon; Asymmetric **Components**: **Posterior part**: All components- PCoAs, P1 segments and BA present; normal in their origin and size. P1- R longer than P1- L. bifurcation of BA equal and symmetric. **Anterior part**: ACoA-ACA complex- 'H' shaped; double ACoA present- ACoA- 1 is 5.2 mm long while ACoA- 2 is 5.5 mm long and their external diameter is 1.1 mm each. A1 segments present; normal in their origin and size.

DISCUSSION

The cerebral arterial circle (Circle of Willis) and its branches are subjected to numerous morphological variations and this has been universally accepted. The arterial segments forming the Circle of Willis also vary in size. Knowledge of the Circle of Willis and its variations is essential in clinico-pathological conditions such as surgical hemorrhage, infarction of the brain, intra cranial aneurysms and in different vascular surgeries of brain as it is one of the major collateral circulations ensuring the complete perfusion of the brain. Cerebrovascular diseases, internal carotid artery occlusion, unilateral flow-restrictive extra cranial carotid artery disease together with their signs and symptoms grossly depend upon the variations of anatomical pattern of Circle of Willis. [5,6]

In the present study, out of 30 brain specimens, the circle was complete in 24 (80%) cases and incomplete in 6 (20%) cases. In the study of Behzadd et al [7] (2006) complete circle was found in 90.19% cases and incomplete in 9.81%. Fawcett & Blackford[4] in 1905 documented 96.1% of complete Circle of Willis. In the present study, 33.33% circles are symmetrical while 46.66% circles are asymmetrical. Kawther H [8] (2007) found symmetrical circle in 45% cases. Fawcett [4] (1905) came across 73.4% symmetrical circles and 26.55 asymmetrical circles.

In the present study, the anatomical variations in the Circle of Willis were studied and anomalies were more common in posterior part (43.33%) than in the anterior part (16.66%). Previous workers have similar findings. Saeki et al [9] had reported anomalies of the posterior part of the circle in 49% of the cases, Jain et al [10] in 51.38% and Hartkamp [6] in 47% cases.

Posterior part anomaly includes variations due to either absence or hypoplasia of one or more segment. The anterior part anomaly includes azygous ACA or median trunk formation, duplicity, fenestration. The findings of segmental variations in the present study were comparable with previous published data. (table 4)

CONCLUSION

Knowledge of anatomical variations is of vital importance in surgery, the aim being to preserve arteries in unusual locations, which if injured can determine invalidating sequelae. So a detailed knowledge on various configurations of the Circle of Willis is an important factor affecting the results of surgical interventions.

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