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Variation in the pattern of circle of willis in human brain –A morphological study and review

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Abstract: *Background:* Variation of "Circulus Arteriosus" is frequent. Knowledge of the variations of vascular anatomy of Circle of Willis will guide the neurosurgeons during intracranial surgery. *Objectives:* This is an analytical study, where the aim of our study is to analyze the variations regarding shape, symmetry, length and diameters of the component arteries. The study also includes other variations like absence, duplication and abnormal origin of component arteries. *Methods:* In the present study 80 specimens of human brains of both sexes, aged between 20-60 years are obtained from voluntary body donation at the Department of Anatomy and fresh corpses undergoing autopsy at the Department of Forensic and State Medicine in a teaching hospital in Kolkata. Careful observation & measurement of the component arteries are done after proper preservation and necessary dissection. The findings are then recorded and analyzed. *Results:* 62 out of total 80 specimens (77.5%) have been found to be complete, symmetrical and having normal length and caliber. 7 specimens (6.25%) were incomplete and not heptagonal in shape. *Conclusion:* Out of 22.5% variations most of the variations are seen in posterior communicating artery (10%), followed by anterior cerebral artery (6.25%) and anterior communicating artery (6.25%). Most common type of variation is hypoplasia.
Keyword: Circulus Arteriosus, Internal Carotid Artery, Vertebral Artery, Hypoplasia.

Abbreviations: CW- Circle of Willis ,M-Meter(S.Iunit), OC- Optic Chiasma, ACA- Anterior Cerebral Artery, RT ACA- Right Anterior Cerebral Artery, LT ACA- Left Anterior Cerebral Artery, PCA- Posterior Cerebral Artery, RT PCA- Right Posterior Cerebral Artery, LT PCA- Left Posterior Cerebral Artery, PCOM-Posterior Communicating Artery, RT PCOM- Right Posterior Communicating Artery, LT PCOM- Left Posterior Communicating Artery, ACOM- Anterior communicating artery, BA- Basilar Artery, ICA- Internal Carotid Artery.

Introduction

The arterial 'Circle of Willis' is situated at the base of the brain occupying the interpeduncular fossa within which lies the infundibulum, tuber cinereum, mamillary bodies and posterior perforated substances from before backwards.

The basilar artery which is formed at the junction of the pons and the medulla by fusion of the two vertebral arteries bifurcates at the rostral border of the pons into two symmetrical posterior cerebral arteries. The carotid system gives off right and left internal carotid arteries. The internal carotid artery of each side gives off an anterior cerebral artery which comes in close relationship with that of the opposite side and is joined by a short transverse trunk, the anterior communicating artery. Each internal carotid artery again gives rise to the posterior communicating artery which anastomoses with the proximal portion of the corresponding posterior cerebral artery [1]. There exists complete symmetry, particular in respect of shape and configuration in the pattern of the arterial circle so formed. Normally, gross anomalies such as atresia, stenosis or aneurysm are absent in the 'Circle of Willis'.

In our present study, we observed the shape, symmetry, completeness of the circle and also searched for variations in length & circumference of the component arteries, duplication or doubling of any artery and anomalous origin of posterior communicating arteries. Knowledge of the variations of

'Circle of Willis' will help us to find out causes of some cases of cerebrovascular accidents, to search for probable site of thromboembolism. Areas of insufficient communication will enable us to find out functional problems of the brain. Hence the objective of the study was to search information about variations in the pattern of 'Circle of Willis' in human brain to review other relevant previous studies.

Material and Methods

Eighty brains(male -50, female-30) were collected from the Department of Anatomy of IPGME&R, Kolkata, and the Department of Forensic & State Medicine, IPGME&R, Kolkata, during the period of February, 2010 to August, 2011.Only cadavers of known identity aged between 20-60 yrs were taken and those died of head injury and with improper preservation were excluded.

Using a scalpel, a circumferential incision was made around the scalp. After removing the scalp tissue, by a bone –saw the bone of the calvarium and a wedge of the occipital bone was removed. Reflecting the dura mater the spinal cord, vertebral arteries, and superior spinal nerves were transected for careful removal of the brain. The brain was then kept in 10% Formalin for fixation. Each brain was placed over glass wool in separate container to avoid distortion. Arachnoidmater was probed and peeled away to reveal the arteries at the base of the brain. The 'Circle of Willis' of each brain was dissected carefully and a part of the base of the brain was cut and removed, if necessary, to expose the arterial circle clearly.

Observations regarding shape, completeness, symmetry, abnormal architecture were noted. Length and circumference of the component arteries were measured by malleable copper wire and then it was converted into diameter. Lastly photographs of the abnormal specimens were taken. It is to be realized, however that the term 'normal' means not a fixed point but a range. Hence, the 'Circle of Willis' in question would be considered 'normal' only when there exists no gross or markedly conspicuous deviation from the "Standard description" in respect of shape and configuration of the said circle, or in other words, when no grossly apparent dissimilarities were revealed in the pattern and architecture of the different arteries and their branches taking part in the formation of this circle. Rest of the specimens those were not following the aforesaid description was stamped as 'variant or abnormal'. 'Aplasia' of component artery was defined as absence of artery by naked eye with magnifying glass after repeated meticulous examination. 'Hypoplasia' of component artery was defined as diameter less than0.001M. All such definitions are as per convention as well as previous and current literature support. In case of measuring the diameter and length of double Anterior communicating artery(ACOM), after taking the length and diameter of individual ACOM, average were finally taken. During statistical analysis, valid number of specimens was taken as per statistical principle.

Results

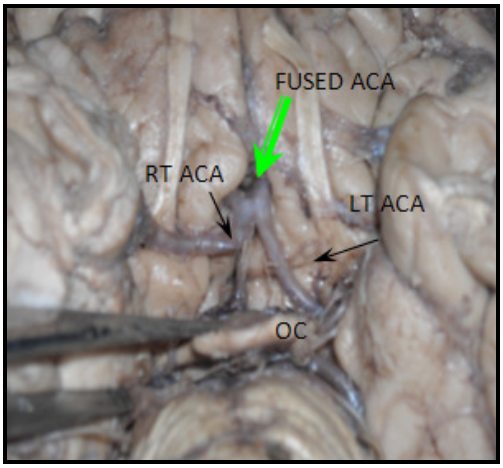
- 62 out of total 80 specimens(77.5%) of human brain observed, has been found to conform the classic form of 'Circle of Willis', that was, complete, symmetrical, normal caliber and heptagonal in shape. These 62 specimens have, therefore, been considered as 'Normal'. The rest 18 specimens (22.5%) of human brain were stamped as 'variant'.
- 73 out of 80 specimens (91.25%) of human brain were found 'Heptagonal' in shape and complete; rest 7 specimens (6.25%) were incomplete and not heptagonal in shape.
- 62 out of 80 specimens (77.5%) were found 'symmetric'; rest 18 specimens (22.5%) were found to be 'asymmetric'.
- There is no statistically significant age difference between the either sex populations. Variation of length and diameter between the two sexes are also statistically insignificant.
- Comparison of length and diameter between right and left sided arteries of the circle of Willis are depicted with the help of Student's paired t test below: (Table-1)

Table-1: Comparison of Length and diameter between Right and Left side of circle of Willis								
Group	**Mean**	**SD**	**N**	**Diff.**	**Std. Dev. Diff**	**t**	**df**	**p**
AcaR_L	14.29	1.290	80	-0.0437	0.1629	-2.4019	79	0.0186
AcaL_L	14.33	1.268						
AcaR_D	2.26	0.399	79	-0.0081	0.1988	-0.3601	78	0.7197
AcaL_D	2.27	0.364						
PcaR_L	6.93	1.061	77	2.3861	0.1754	-0.575	76	0.567
PcaL_L	6.94	1.114						
PcaR_D	2.17	0.456	80	0.0040	0.0356	1	79	0.3203
PcaL_D	2.17	0.464						
PcomR_L	14.23	0.719	77	-0.0779	0.4061	-1.684	76	0.0963
PcomL_L	14.31	0.782						
PcomR_D	1.51	0.173	72	0.0110	0.0723	1.297	71	0.1988
PcomL_D	1.50	0.175						

Several types of variations of 'Circle of Willis' were found during the course of study. They are described as follows:

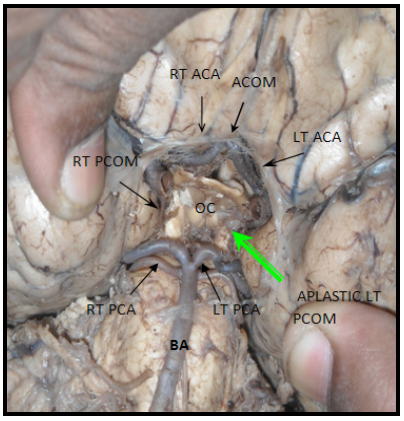
- Complete, heptagonal form of CW with Right hypoplastic anterior cerebral artery. One such specimen was found.
- Complete form of CW with no anterior communicating artery, that is, anterior cerebral artery were fused .Four such specimens were found. (fig-1)

Figure-1: Fused ACA



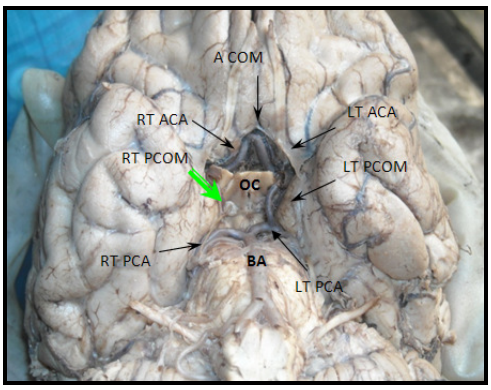
- Incomplete form of CW with absence or aplasia of Left posterior communicating artery. Two such specimens were found. (fig-2)

Figure-2: Left Aplastic PCOM



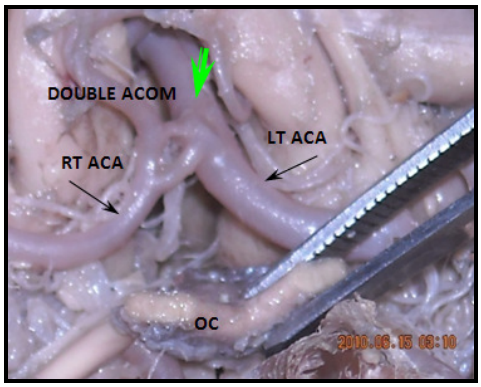
- Incomplete form of CW with absence or aplasia of Right posterior communicating artery. One such specimen was found.
- Complete form of CW with hypoplasia of right posterior communicating artery. Three such specimens were found. (fig-3)

Figure-3: Right Hypoplastic PCOM



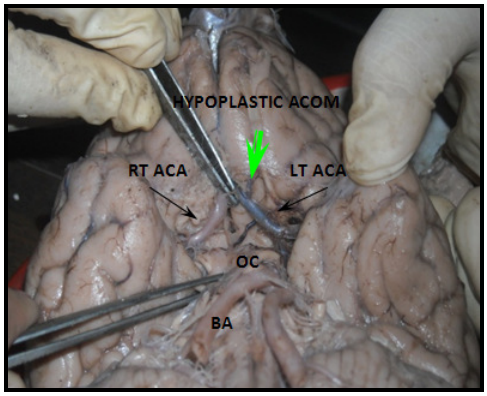
- Complete form of CW with hypoplasia of leftt posterior communicating artery. Two such specimens were found.
- Complete form of CW with two (one proximal and one distal) anterior communicating artery. Four such specimens were found. (fig-4)

Figure-4: Double ACOM



- Complete form of CW with hypoplasia of anterior communicating artery. One such specimen was found. (Fig-5)

Figure-5: Hypoplastic ACOM



- Out of 80 specimens total variants were 18. Out of 18 variants, numbers of variations of anterior cerebral artery were five; posterior communicating artery was eight; anterior communicating artery was five. No variations of posterior cerebral artery were seen. Percentage of variation of total specimen has been shown in the table-2.

Table-2: Percentage of variation with total specimens

Group	n	% 0f variant	% of total
VACA	5	27.78%	6.25%
VPCOM	8	44.44%	10%
VACOM	5	27.78%	6.25%

VACA- variation in ACA; VPCOM- variation in PCOM; VACOM- variation in ACOM;

Most of the variation was seen in Posterior communicating artery (10%). Number of specimens exhibiting variation of ACA, PCOM and ACOM; nature of abnormalities; their number and percentage with the total are depicted below through table-3.

Table-3: Nature, Number and Percentage of variation with variants and total specimens

Name of artery	Nature	Number	% of total variants	% of total specimen
ACA	Hypoplastic, right	1	5.56%	1.25%
ACA	fused	4	22.22%	5%
PCOM	Aplastic, left	2	11.11%	2.5%
PCOM	Aplastic, right	1	5.56%	1.25%
PCOM	Hypoplastic, left	2	11.11%	2.5%
PCOM	Hypoplastic, right	3	16.67%	3.75%
ACOM	double	4	22.22%	5%
ACOM	hypoplastic	1	5.56%	1.25

Discussion

The prevalence of the 'typical or classic circle', the "normal" textbook polygon ranges from 4.6% to 72.2% [2]. A possible reason for the wide range may be the diversity in nomenclature and the criteria used to define hypoplastic vessels. There is little unanimity in nomenclature and quantitative measurement of the diameters of all the component vessels of 'circle', which has not been measured in several studies and has relied upon rough estimations of the vessel diameter in determining the anomalies of the CW rather than actual measurements. Vessels have been described as 'thread-like', 'string-like', 'minute', and 'very small' without regards to measured diameter. In the present study, typical or classic configuration was found only in 77.5% and variant in the rest 22.5% of the brains. These observations appear to be more or less in accord with those of Windle (1888) [2], Fawcett (1905) [3] who observed normal pattern in 72.8% to 82.5% cases and variant pattern in 18% to 27.2%. But the present observation are at great variance with those of Alper's etal(1959)[4], Baptista (1963)[5], who recorded typical or classic pattern in 30% to 90% and variant in 10% to 70% cases. As mentioned earlier, in our present study most of the variations are seen in posterior communicating artery (10%, table 2), followed by anterior cerebral artery (6.25%) and anterior communicating artery (6.25%).No variations are found in Posterior cerebral artery in the present study.

Most common variation is seen in the posterior communicating artery (10%), most common type of variation is hypoplasia. Other variations are double or duplication of artery, fused artery, absent or aplastic artery. Statistically significant difference in length but not in diameter of both sides in anterior cerebral artery has been seen. In the present study, the usual posterior communicating artery has been found absent or aplastic in 3.75% cases on either right or left side; 2.5% on left side, 1.25% on right side (table 3). Reported incidence of absent arteries in the CW in normal brains leading to an incomplete circle range from 0.6% [3] to 17% [6]. Our observations regarding the absence of the usual posterior communicating artery corroborate with those Gardener et al (1963) [7], and Romanes(1964)[8], who mentioned that this artery may be absent on one or both side. The above investigation also appear to be fully in accord with those of Windle (1888)[2]. Furthermore, Alper's et al (1959) [4] mentioned that this artery is never absent on both side, which is consistent with our finding. Hypoplsia of posterior communicating artery in our present study was found 6.25%; 2.5% on left side and 3.75% on right side. As a whole, we observed 10% variations in posterior communicating artery (table 2). No both sided hypoplasia and aplasia of PCOM were seen during the course of the study. No abnormal origin of the posterior communicating artery was seen. The most frequent site of abnormal diameter was seen in the posterior half of the circle, and the proportion in the present study is similar to other reported series, [3-4,9]. This may be related to the embryological development of the posterior half of the CW, where the basilar and the ICAs anastomose during development of the cerebral arteries. Posterior communicating artery was seen to exibit maximum instances of abnormalities resulting in anomalous circle. These observations corroborate with those of Windle (1888) [2], Romanes (1964)[8] who emphasized that the majority of anomalies occur in the posterior portion of the CW, particularly in the posterior communicating artery.

In the present study, the anterior cerebral artery, one of the components of CW has been found to exhibit abnormalities by the way of fusion between the arteries of one side with that of the contralateral side, forming fused ACA. 5% of such specimens were found (table3). Fusion of the anterior cerebral artery may cause absence of ACOM artery. Absence of ACOM is also possible without fusion of anterior cerebral artery. The present observations largely corroborate with those of Windle (1888)[2]and Alpers et al (1959)[4] who recorded 3% and 2% cases of absence of the ACOM due to fusion of the two anterior cerebral arteries respectively. The present observations fail to demonstrate the complete absence of ACOM without fusion of anterior cerebral artery and so unable to compare the finding with those of Fawcett et al (1905)[3] who found complete absence of anterior communicating artery in 0.14% cases. Another form of variation was found, that is,

right sided hypoplastic anterior cerebral artery (1.25%, in table3). The diameter below which the segment of ACA that is part of CW could be called hypoplastic has not been well defined, but Perlmutter and Rhoton [10] used 1.5 mm as the cut off value. They found 10% of the brains to have less than 1.5 mm in diameter in the aforesaid segment. Alpers *et al* (1959) [4] found string like components of one of the vessels of the CW in 28% cases, with that part of ACA being the predominant site. Riggs and Rupp (1963) [11] observed hypoplasia of that part of ACA in 7% cases. No other form of abnormalities has been found in ACA. During the course of the study, we had not observed any third anterior cerebral artery (artery of the corpus callosum).

In the present study, the anterior communicating artery, one of the components of CW was found to exhibit abnormalities by the way of doubling, that is, presence of two anterior communicating arteries; one proximal, another distal to connect ACA of both side. 5% of specimens had such type of abnormalities. (table3). This finding is largely in accord with the observations of Fawcett et al (1905) [3], Alpers et al(1959)[4]. It is to be noted further that Gardener et al (1963) [7] and Romanes (1964) [8] also mentioned that the anterior communicating artery may exist as double. Another form of variation was found, that is, hypoplastic anterior communicating artery (1.25%, table3). No other form of abnormalities has been found in Acom. Total variations found in our study in ACOM was 6.25 %(table 2). The state of the circle becomes important in determining the adequacy of the brain circulation. The possibility of by-passing or shunting effects in occlusion of one of the cerebral vessels and the adequacy of recovery or lack of recovery after vascular occlusions may be explained in part by variations in the anatomy of the CW [12]. A rapid, high reperfusion strongly increases survival in the ischemic penumbra, inhibiting the growth of the core region.

In our present study we could not detect any aneurysm or arteriovenous malformation. This is not in accord with findings by Martinez et al 2004 [13] where they recorded vascular malformation in their study. The knowledge of these anatomical variants is of vital importance in surgery, the aim being to preserve the arteries in unusual locations, which if injured can determine invalidating sequel. So a detailed knowledge of various configurations of the CW is an important factor affecting the result of surgical interventions. Cerebrovascular diseases, internal carotid artery occlusion, unilateral flow restrictive extracranial carotid artery disease together with their signs and symptom grossly depend upon the variations of the anatomical pattern of CW (Kluytmans et al 1999[14]; Emsley et al 2006[15]). The hemodynamic profile of cerebral artery in both symptomatic and asymptomatic patients with carotid artery stenosis is of clinical importance. In those cases, important role in maintaining collateral within the CW is played by anterior communicating artery, although in some patients middle cerebral artery may also be supplied by posterior communicating artery.

In patients with symptomatic internal carotid occlusion blood supply of collateral flow, which is affected by the pattern of collateral pathways, may be important factors determining the severity of hemodynamic impairment (Yamauchi et al 2004[16]). Hendrikse et al (2005) [17] suggested that large asymmetries in volume flow between the right and left internal carotid arteries or decreased volume flow in the basilar artery is not necessarily caused by vascular diseases but may be caused by variations in the anatomy of the CW. In Moyamoya disease which primarily occurs among oriented people (Japanese, Koreans, Caucasians), there is progressive intracranial vascular obliteration of the CW, resulting in successive ischaemic or haemorrhagic events (Marcinkevicius et al 2006[18]). Again, anterior communicating artery aneurysms are frequently associated with an asymmetrical CW .In such case the anterior communicating artery is probably exposed to high hemodynamic stress caused by a considerable shunt flow across the anterior communicating artery to the distal segment of the contralateral anterior cerebral artery (Ujiie et al 1996, [19]).

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