

Variations in the brain circulation – the circle of Willis

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Abstract

Introduction: Despite being quite common, there is little information concerning the Brazilian population on anatomic variations and anomalies in the brain circulation. This study intends to describe the most common variations found during the autopsies for the AMA Study. **Material and methods:** Fifty cadavers had their circle of Willis dissected and analyzed. **Results:** 54% presented at least one variation, and they were more common in the posterior circulation (88.5%) and on the right side of the brain (59.7%); non-classical morphology was more common bilaterally and in the posterior circulation of the circle of Willis (37.1%). The most common finding was the absence of the posterior communicating artery (32%), followed by posterior cerebral arteries originated from the internal carotid artery (18%). There were no variations in the middle cerebral arteries. Accessory anterior cerebral arteries were present in 6%, and A1 segment hypoplasia was present in only 2% of the cases. **Conclusion:** Brazilian population variations are in accordance with the literature and there seems to be no difference between races in the variation of brain circulation.

Keywords: circle of Willis, cerebral arteries, arterial malformation.

1 Introduction

The normal Circle of Willis (CW) is considered as a closed circuit in which fluid may circulate from any entrance point and return to that point by means of their vessels, with no excess vessels, the usual paired anterior cerebral arteries, and vessels of the mature brain more than 1mm in their outside diameter. (ALPERS, BERRY and PADDISON, 1959)

However, only 28.3% to 52% have no alteration, depending whether a diameter smaller than 1mm for the vessels is considered as an anomaly or not. (ALPERS, BERRY and PADDISON, 1959; KLEISS, 1941; MITTELWALLNER, 1955; ROUTSONIS, STAMBOULIS and CHRISTODOULAKI, 1973)

The maintenance of an adequate blood flow through the circle of Willis is not only necessary for keeping the brain nurtured, but also for preventing or minimizing ischemic infarctions and maintaining the perfusion during cardiac surgeries with extracorporeal circulation. (MERKKOLA, TULLA, RONKAINEN et al., 2006)

The more information there is on cerebral circulation and its common variations, the better prepared doctors can be. Considering that a difference between races in anatomic variations may exist, a hypothesis that has been considered before, (EFLEKHAR, DADMEHR, ANSARI et al., 2006) and that there is no data on anatomic variation in the brain circulation of the Brazilian population, this study will contribute to our current knowledge in anatomical variations between different races.

2 Methods and casuistic

This study was approved by the Ethics in Research Committee from *Centro de Ciências Médicas de Sorocaba*, in June, 2010, as a part of the AMA Study.

In order to be included for analysis, the cadavers' legal guardians had to agree on signing the written consent for participating in the study, all three organs (brain, heart and renal) had to be available for dissection, and the cadaver had to be 40 years old or more.

The anterior cerebral arteries (ACA) were extracted from their origin in the internal carotid artery (ICA) until their division in the frontopolar artery; the middle cerebral arteries (MCA) were dissected from their origin until their first ramification after the generation of lenticular-striate arteries; the posterior cerebral arteries (PCA) were dissected from their origin (either the basilar artery (BA) or the ICA) until the ramification in two branches: the parieto-occipital and calcarine arteries. The posterior communicating arteries (PCoA) and anterior communicating artery (ACoA) were also obtained for each specimen.

The most important anatomic variations and anomalies were enumerated, before the arteries were divided and sent for microscopic analysis. A basic criterion for considering the circle as anomalous was being unable to maintain an adequate flow, what is, as defined by Alpers, Berry and Paddison (1959) one in which blood can circulate from any entrance point and return to that same point. Other morphological differences were regarded as anatomic variations.

Therefore, extra arteries or uncommon anastomosis were considered as anatomic variations, whereas the absence of arteries, no communication between them, and abnormal origin were considered as anomalies. A small diameter was considered as an anatomic variation only if the artery was smaller when compared to the contralateral artery.

3 Results

Fifty cadavers were obtained for this analysis. Thirty two (64%) were male; mean age was 60.39 years.

The most common cause of death was respiratory failure, followed by heart failure. In 10 cases, cause of death could not be defined (Figure 1). Among the brains, 46% had no anatomic variations or anomalies; 24% had one, 18% had two, 6% had three, and 6% had four or more.

The main anatomic variations and/or anomalies (alterations) found are represented in Table 1.

The most common anomaly was the absence of PCoA, in 36% of the cases; both were absent in 14%, left PCoA was absent in 6%, and right PCoA was absent in 12%. The second most common anomaly was uncommon origin of PCA (18%): right PCA originated from the ICA, rather than from the BA, in 12%; left in 2%, and both in 4%. The BA had no connection to the circle in the two cases (4%) in which both PCA originated from the ICA (Figures 2 to 4).

The most common anatomic variation was PCoA hypoplasia in comparison to the contralateral one in 10%; they originated from the ICA, rather than from the PCA, in 4% of the cases. No alterations were found in the MCA. The only anatomic variation found in the ACoA was the generation of accessory ACA (in 6%), as shown in Figure 5. A1 segment was hypoplastic in 2%; ACA had anastomosis between them in 4% of the cases.

Non-classical morphology was more common in the posterior circulation (which presented 88.5% of all alterations) and on the right side of the brain (59.7%), as shown in Table 2.

Fifty four percent of all brains had a non-classical morphology; non-classical morphology was more common bilaterally and in the posterior circulation of the circle of Willis (37.1%), followed by posterior and on the right side of the circle (22.2%). Anterior bilateral alterations were not found, as well alterations that affected both posterior and anterior circulation and only one side of the brain, as shown in Table 3; if both the anterior and posterior arteries were affected, it also affected both sides (7.4%).

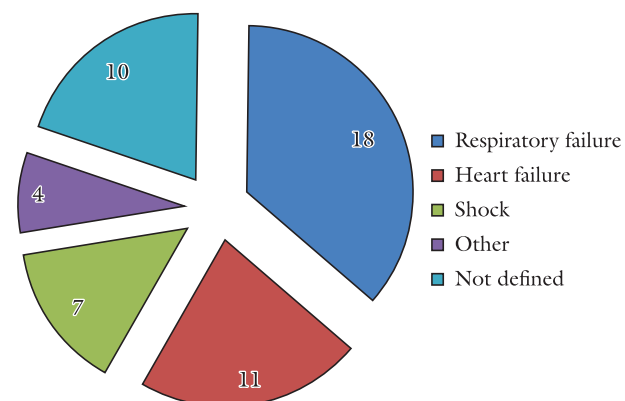
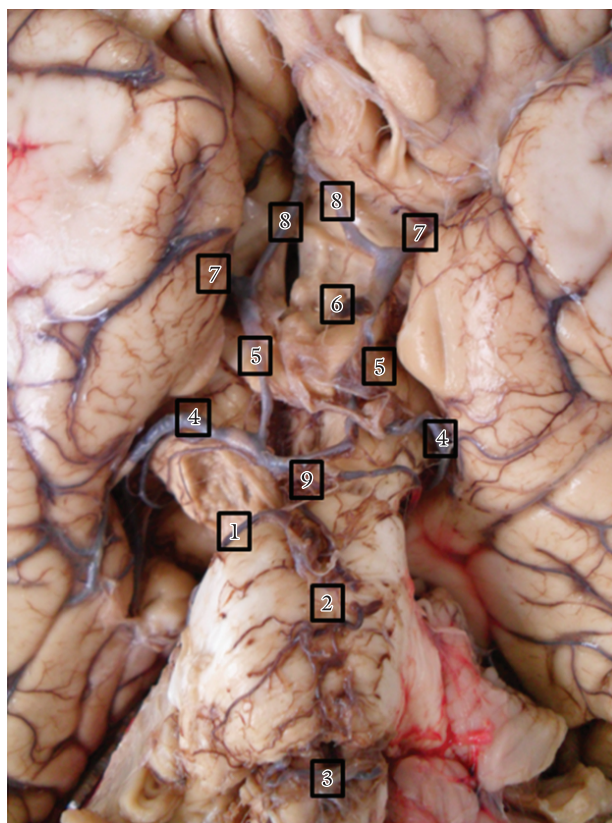


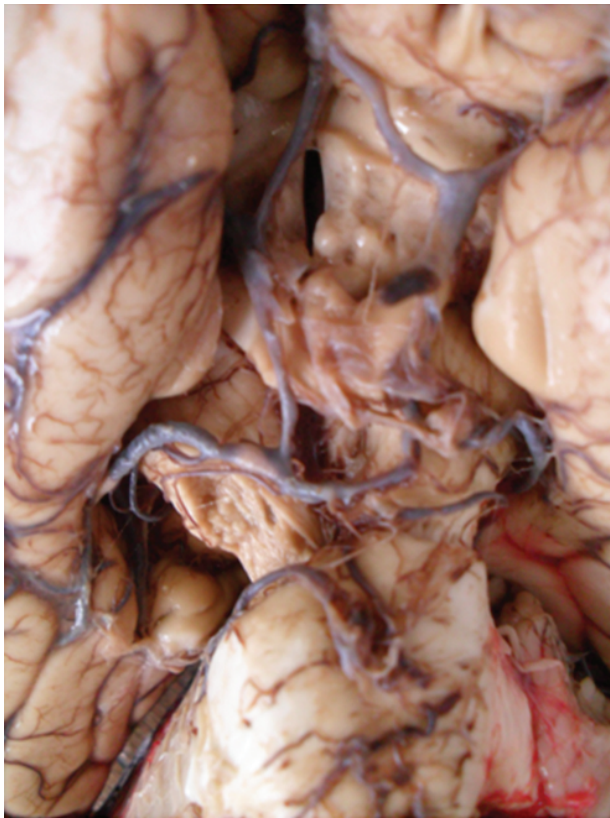
Figure 1. Causes of death. Respiratory failure includes: pneumonia, bronchopneumonia, pulmonary collapse, pulmonary edema. Heart failure includes: infarction, dilated cardiopathy, cor pulmonale due to pulmonary embolism. Shock includes: either septic or ischemic.

Table 1. Main alterations found.

Artery	Anatomic variation/Anomaly	N	%
Left ACA	Anastomosis to the other ACA	1	2
Right ACA	Anastomosis to the other ACA	1	2
	A1 hypoplasia	1	2
ACoA	Accessory ACA generation	3	6
MCA	-	0	0
Left PCA	Left ICA origin	1	2
Right PCA	Right ICA origin	6	12
Both PCA	ICA origin	2	4
Left PCoA	Absence	3	6
	Hypoplastic	3	6
	Left ICA origin	1	2
Right PCoA	Absence	6	12
	Hypoplastic	2	4
	Right ICA origin	1	2
	No connection to the right MCA	1	2
Both PCoA	Absence	7	14
BA	No connection to the circle	2	4



Figures 2. Posterior circulation malformation with no connection to the basilar artery. Inferior view of the encephalon. 1: Anterior superior cerebellar artery. 2: BA (partially cut). 3: Posterior inferior cerebellar arteries. 4: PCA. 5: PCoA. 6: ICA (cut). 7: MCA. 8: ACA. 9: Arterial malformation connecting both posterior cerebral arteries.



Figures 3. Posterior circulation malformation with no connection to the basilar artery. Close up on the circle of Willis.

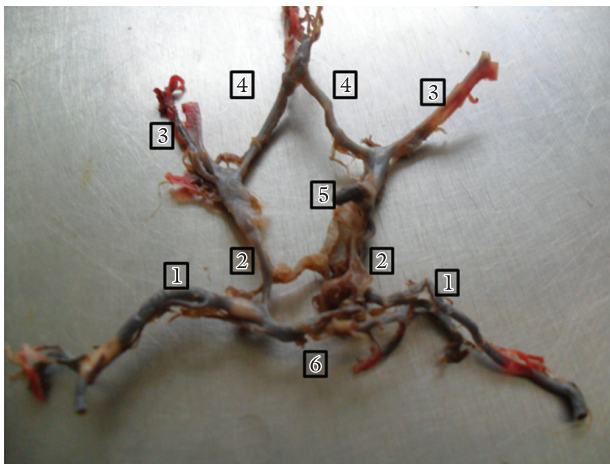


Figure 4. Close up on the circle of Willis. Dissected circle of Willis. 1: PCA. 2: PCoA. 3: MCA. 4: ACA. 5: ICA. 6: Vascular malformation connecting both posterior cerebral arteries (no signs of previous anastomosis to the basilar artery).

Table 2. Number of alterations per location. N (%).

Side/ Region	Anterior	Posterior	Total
Left	2 (3.8%)	19 (36.5%)	21 (40.3%)
Right	4 (7.7%)	27 (52%)	31 (59.7%)
Total	6 (11.5%)	46 (88.5%)	52 (100%)

4 Discussion

4.1 General findings

The number of brains with non-classic morphology is in accordance with the literature (48-71.7%); (ALPERS, BERRY and PADDISON, 1959; KLEISS, 1941; MITTELWALLNER, 1955; ROUTSONIS, STAMBOULIS and CHRISTODOULAKI, 1973) if arteries with a diameter smaller than 1mm had been considered as an anomaly, this statistics would have certainly been larger, as commented by Routsonis, Stamboulis and Christodoulaki (1973).

4.2 Anterior circulation

Variations in the anterior circulation are quite uncommon. Rarely (1%) the ACoA is aplastic, which is also rare for the A1 segment. (EFLEKHAR, DADMEHR, ANSARI et al., 2006; MORRIS, 1996) ACoA, on the other hand, may be duplicated or differently fenestrated. (MORRIS, 1996) When only the A2 trunk is present and it distributes blood to both hemispheres, it is known as an aziguous ACA, what is found in only 0.3% of the cases; a fused short A2 trunk is more commonly found. In general, the most common variation within anterior circulation is one ACA to be dominant and provide blood supply for both hemispheres in its distal aspect (MORRIS, 1996).

Duplications or triplications are most common in the anterior circulation (19%); (ALPERS, BERRY and PADDISON, 1959) however, a very proximal origin of the callosal-marginal artery, close to the ACoA, may be

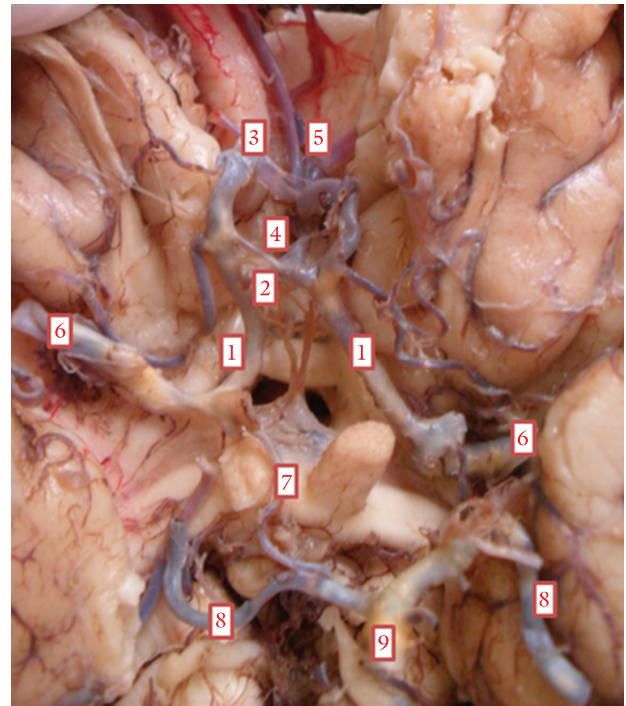


Figure 5. Left-right ACA anastomosis and "extra ACA". Inferior view of the encephalon. 1: ACA (proximal segment). 2: ACoA. 3: Left ACA anastomosed to the right ACA. 4: Additional branch from the "extra ACA" originated from the ACoA. 5: Branches from the "extra ACA" supplying both frontal lobes, especially the left one. 6: MCA (cut). 7: Right PCoA. 8: PCA (cut). 9: BA.

Table 3. Number of brains with non-classical morphology of the circle of Willis per location. N (%).

Side/Region	Anterior	Posterior	Both	Total
Left	2 (7.4%)	3 (11.1%)	0 (0%)	5 (18.5%)
Right	4 (14.8%)	6 (22.2%)	0 (0%)	10 (37%)
Bilateral	0 (0%)	10 (37.1%)	2 (7.4%)	12 (44.5%)
Total	6 (22.2%)	19 (70.4%)	2 (7.4%)	27 (100%)

seen, which appears as a duplication of triplication of A2. (MORRIS, 1996) This may represent our most common finding in the anterior circulation; in our 3 cases of “extra ACA”, they were all originated directly from the ACoA.

4.3 Middle cerebral artery

Alterations in the MCA are quite uncommon and none was found in this study. Only 3% of the population may have an accessory MCA originated from the ACoA (MORRIS, 1996).

4.4 Posterior circulation

Arteries from the circle of Willis are formed from a primitive network surrounding the neural tube in the embryo. First, both carotid arteries are formed; then, they divide into branches which will form the anterior cerebral artery, the PCoA and both segments P2 and P3 of the PCA. All the other arteries are additional branches to the primitive ring. As the fetus develops, the PCoA diminishes, whereas the segment P1 develops and the PCA acquires the classic morphology, originated from the BA. (DEVRIESE, 1905; VANDER ECKKEN, 1961; RIGGS and GRIFFITH, 1938; SAEKI and RHOTON, 1977)

Fetal type PCA is considered as a PCA originated from the ICA; its variation with a large PCoA is fairly common (14.6-40%). (ALPERS, BERRY and PADDISON, 1959; HASEBE, 1928; PADGET, 1945; MATTI, 1973) It was one of our most common findings; in 18% of the cases the PCA was considered as a fetal type artery. Duplication of the P1 segment and fusion of the superior cerebellar artery to the P1 are regarded as common, though we did not find any (MORRIS, 1996).

PCoA variations are regarded as the most common variations in brain circulation; they are missing in 10% to 46% of the cases, (MERKKOLA, TULLA, RONKAINEN et al., 2006; EFLEKHAR, DADMEHR, ANSARI et al., 2006) and are hypoplastic (i.e., external diameter smaller than 1mm) in 12% to 60% of the cases. (EFLEKHAR, DADMEHR, ANSARI et al., 2006; STOPFORD, 1916; BAKER, DAHL and SANDLER, 1963) In this sample, PCoA were missing in 32%, and were hypoplastic (in comparison to the contralateral artery) in 10% of the cases.

4.5 Comparison between left and right, anterior and posterior and concomitant alterations

Non-classic morphology was more commonly found in the posterior circulation and on the right side of the brain; also, most brains had bilateral posterior alterations and, if an alteration affected both anterior and posterior circulation, it also affected both sides of the brain. We have also identified, as described elsewhere (NORDON, CAMARGO NETO, GUIMARÃES et al., 2011), that there is a correlation

between variations in the posterior circulation of the brain and the coronary dominance pattern. Such comparisons and relations are curious findings that have so far no explanation and may be related to the embryologic development of the circulatory system.

4.6 Differences between races

All in all, there seems to be no difference between races in the anatomic variations and/or anomalies of brain circulation, concerning North-Americans, Europeans, Asians, Middle-Easterns or Brazilians, (KLEISS, 1941; MITTELWALLNER, 1955; ROUTSONIS, STAMBOULIS and CHRISTODOULAKI, 1973; MERKKOLA, TULLA, RONKAINEN et al., 2006; EFLEKHAR, DADMEHR, ANSARI et al., 2006; MORRIS, 1996; HASEBE, 1928; MATTI, 1973) being such variations sometimes more common than no variations at all.

5 Conclusion

In the Brazilian population, variations in the posterior circulation of the brain are very common, being the absence of the PCoA the most common. This represents an incomplete circle of Willis which has an important clinical impact. Variations are more common in the posterior than in the anterior circulation and on the right than on the left side of the brain. There seems to be no difference between races concerning the anatomic variations of brain circulation.

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