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Anatomical Variations of the Anterior Part of the Circle of Willis - An Autopsic Study

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Abstract

The arterial circle of Willis (CoW), also called the arterial circle or circulus arteriosus cerebri, represents an anastomotic arterial canal located at the base of the brain, in the inter peduncular fossa, which connects the internal carotid and the verte brobasilar system. The purpose of this study is to identify anomalies/anatomical variants of the anterior part of CoW in the population of the North-Eastern region of Romania by researching macroscopic aspects of the constituent arteries of CoW obtained during the autopsy procedure. There was noted the presence or absence, variations in the shape, position, or trajectory of each arterial segment of the anterior part of the CoW, comparing them with the outcomes from other various international studies.

Keywords: Circle of Willis; Anterior; Variations; Pathology

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Introduction

The arterial circle of Willis (CoW), also called the arterial circle or circulus arteriosus cerebri, represents an anastomotic arterial canal located at the base of the brain, in the interpeduncular fossa, which connects the internal carotid and the vertebrobasilar system. This particular main arterial structure was first and correctly described by the English anatomist and physician Thomas Willis in 1664 [1]. In his honor, it is also called the circle of Willis. The normal CoW is defined as a closed circuit in which blood can flow from the point of entry to and from its point of return through the component vessels, maintaining adequate flow without additional vessels, and the vessels of the mature brain should not be smaller than 1 mm in their external diameter [2].

The importance of a symmetrical CoW is twofold. First of all, this arterial structure is essential for maintaining a stable and constant blood flow to the brain as the nerve tissue is very sensitive to lack of oxygen and lack of blood supply. It can be considered that it has compensatory capacity, depending on the presence of all arteries and their diameter. Under conditions of symmetrical CoW, even in patients with stenosis or severe occlusion of the internal carotid artery, blood can redistribute in ischemic areas to improve cerebral perfusion, preventing the occurrence of ischemic events and their progression. Any change in the morphology of CoW can lead to various vascular failure syndromes. Secondly, the anatomical abnormalities/variants of CoW are favourable factors for the appearance of aneurysms of the cerebral arteries.

A detailed knowledge of vascular variants is useful for neurosurgeons in planning their operations, in choosing patients and avoiding accidental vascular trauma during surgery. Knowing the frequency of CoW variations may also be useful during radiological interpretations of angiographies and may be reported in current anatomy treatises to alert students about these normal variations.

Although this arterial circle was originally defined by the English anatomist Thomas Willis, who first described it completely and correctly in 1664 [1] as an arterial anastomotic structure that exhibits complete symmetry in its shape and configuration, in the literature more and more articles appear reporting various variations from the original definition. Many authors report that, especially in the last two decades, more than 50% of all analyzed circles of Willis have had significant asymmetries and variations [3-5].

The purpose of this study is to identify anomalies/anatomical variants of the anterior part of CoW in the population of the North-Eastern region of Romania by researching macroscopic aspects of the constituent arteries of CoW obtained during the autopsy procedure. There was noted the presence or absence, variations in the shape, position, or trajectory of each arterial segment of the anterior part of the CoW, comparing them with other outcomes from various international studies on the anterior side variations of the CoW.

Materials and Methods

Study design

The present research is a descriptive in-hospital observational study by assuming the principles of institutional ethics.

Selected population

The searched population included patients who died of various medical causes in the Emergency Clinical Hospital "Prof. dr. N. Oblu", Iași, in a period of 30 months (01.01.2014-30.06.2016), for whom a routine autopsy was performed. The sex and age of the deceased, as well as their causes of death were registered in the Register of autopsies of the Department of Pathology within the same hospital.

Selection of the specimens

Only circles of Willis that showed anatomical anomalies/variants were taken into the account.

The measurements of the arteries of the circles of Willis

All COWs studied were observed and the arterial diameters were measured with a ruler on fresh specimens. The arteries examined were: the anterior communicating artery (ACoA), the proximal and distal segments (1 cm) of the anterior cerebral arteries (ACA), the internal carotid arteries (ACI) distal to the origin of the posterior communicating arteries, the middle cerebral arteries (ACM) at their beginning, the posterior communicating arteries (ACoP), the proximal and distal segments (1cm) of the posterior cerebral arteries (ACP), the basilar artery (AB) and the subarachnoid portion of the vertebral arteries (AV).

Macroscopic examination of the circles of Willis: The following elements were analyzed for the CoW component vessels:

- If the arterial circle is complete or incomplete,
- The presence of any asymmetry in the CoW configuration: hypoplasia, absence, duplication, fenestration, difference in length and difference in origin of any of its costituent artery, compared to opposite segments.
- The presence of any aneurysm in these arteries.

The following definitions were taken into account in the assessment of CoW:

- Based on previous brain studies at autopsy, a CoW was considered complete when it consisted of the pre-communicating segments of the right and left anterior cerebral artery (ACA), which joined through the right and left anterior communicating artery (ACoA), respectively, and posteriorly was made up from the right and left posterior segments of the posterior cerebral artery (PCA) that connected to the corresponding internal carotid arteries (ICA) through the posterior communicating arteries (PCoA), all these arteries being visible, intact and with an outer diameter ≥1 mm, both in the front as well as in the back.
- The partially complete CoW was divided into two types: incomplete anterior and incomplete posterior.
- Incomplete CoW was considered when both the anterior and posterior part had vascular segments with different anomalies/anatomical variants [6];
- The CoW was considered typical if all component vessels (pre-communicating segments of the anterior and posterior cerebral arteries and the communicating anterior and posterior arteries) were present; when these arteries were not duplicated or tripled; when the origin of the vessels contributing to the formation of COW had the typical origin and their outer diameter was not less than 1 mm [7];
- The remaining specimens that were different from the above description were considered to be 'anatomical or abnormal variants' [8].
- The 'hypoplasia' of a COW component artery was defined as having an outer diameter of less than 1 mm, except for the communicating arteries, which were considered to be hypoplastic with an outer diameter of less than 0,5 mm [9].
- We have defined the Posterior Cerebral Artery as Fetal (PCAf) when it comes entirely from the internal carotid artery, with no connection to the basilar artery. We defined the Posterior Cerebral Artery as Partially Fetal (PCApf) when it originates from the ICA and maintains a small atresic connection with the basilar artery [10].

Photographing available specimens: The circles of Willis we

studied were numbered and photographed with a Sony digital camera for further analysis.

Data collection

The results were collected in a database using Excel and then tabulated. The data obtained were used to calculate the mean, number and percentage, as well as to make the corresponding graphs. In the end, the circles of Willis were sorted according to the classification of the morphological variation of the component arteries and were compared with the data from the literature.

Results

Identification of the study sample

Out of the total of 96 available human brains, 68 cases (70.83%) presented the classic shape of the CoW, respectively it was complete and symmetrical **(Figure 1).** The remaining 28 cases (29.17%) were classified as "abnormal" or "anatomical variants" and these were the objects of study for this research.

Demographic data of deaths with anomomical anomalies/variants of CoW

- Of the 28 deaths included in the present study, 15 (53.57%) were male and 13 (46.42%) female, so that M: F ratio was 1.15 **(Figure 2)**.
- The average age of the entire analyzed group was 61.78 years. Female cases ranged in age from 39 to 86 years, with a mean age of 60.15 years, and male cases ranged in age from 40 to 85 years, with a mean age of 65.6 years **(Figure 3)**.
- The deceased from which the circles of Willis were analyzed by us constituted a relatively homogeneous group in terms of both the age and sex. Both female and male deceased accounted for a relatively equal number, and both sexes were aged between the fifth and ninth decades **(Figure 4)**.
- The distribution of cases according to age groups shows a peak in the 6th decade for females and one in the 7th decade for males **(Figure 4)**. Overall, people with CoW abnormalities died mostly (32.14%) in their seventh decade of life.

Variations of the anterior portion of the CoW: We identified six types of morphological variations of the anterior portion of the CoW - absence, duplication, hypoplasia, fenestration, azygos artery and greater length with sinuous trajectory, present in 17 cases (60.71%) of the 28 analyzed.

Variations of the anterior communicating artery: At the ACoA level, we identified three types of anatomical anomalies/variants in 9/28 cases (32.14%), in the form of absence, duplication and hypoplasia of the vessel **(Figure 5)**. The absence of ACoA by merging the two ACAs, right and left, on a variable length was identified in 6/28 cases (21.42%), ACoA duplication was present in 2/28 cases (7.14%), and hypoplasia were present only in 1/28 cases (3.57%) **(Figure 6)** Types of anatomical anomalies/variants

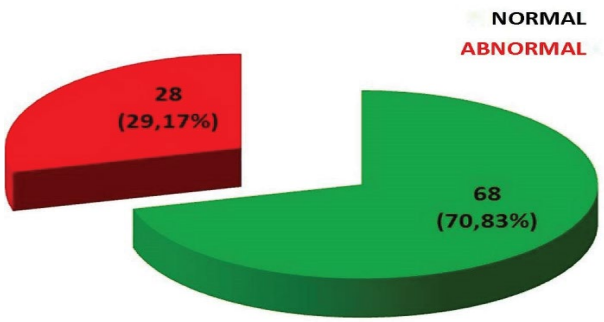

Figure 1 The distribution of cases according to the morphological aspect of the circles of Willis.

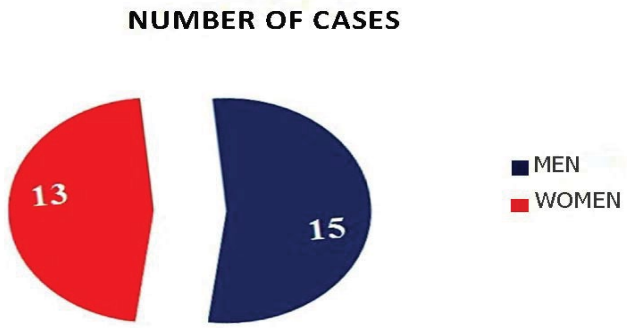

Figure 2 Distribution of CoW cases with anatomic variations according to the gender of the deceased patients we have studied.

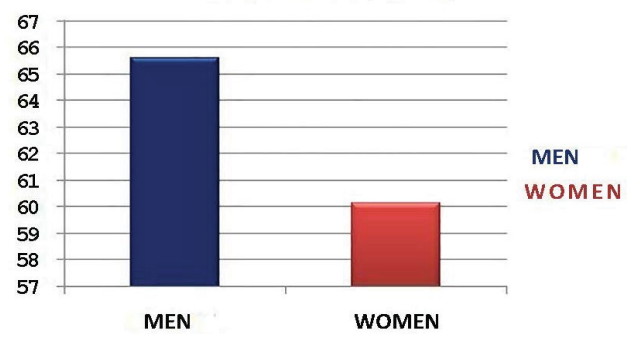

Figure 3 The average age (years) of the autopsied patients with variations of the CoW according to their gender.

of ACoA from the 28 COW analyzed. No significant differences were found on CoW variations by gender. The results of the t-test of independent samples indicated $t(26) = -0.12$, $p = 0.90$, $p>0.05$.

Variations of the anterior cerebral artery: Anomalies/anatomical variants of the anterior cerebral artery (ACA) were present in 13/28 cases (46.42%), in the form of hypoplasia, fenestration, duplication and longer length of the vessel with the appearance of a sinuous trajectory. The most anatomical variations encountered in ACA were hypoplasia (9/28 cases, 32.14%), which affected more the arteries on the left side (5 cases on the left, respectively 4 cases on the right) **(Figure 7).** The longer ACA, which followed

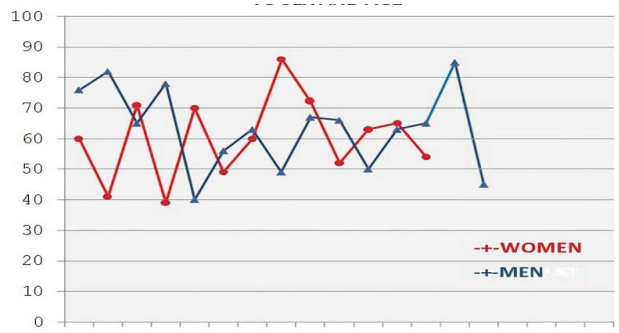

Figure 4 Distribution of CoW we have analyzed according to the gender and age of the deceased patients.

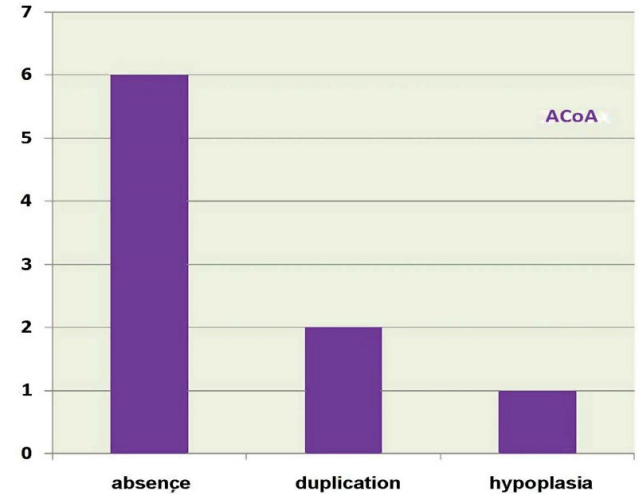

Figure 5 Types of anatomical anomalies/variants of ACoA from the 28 CoW analysed.

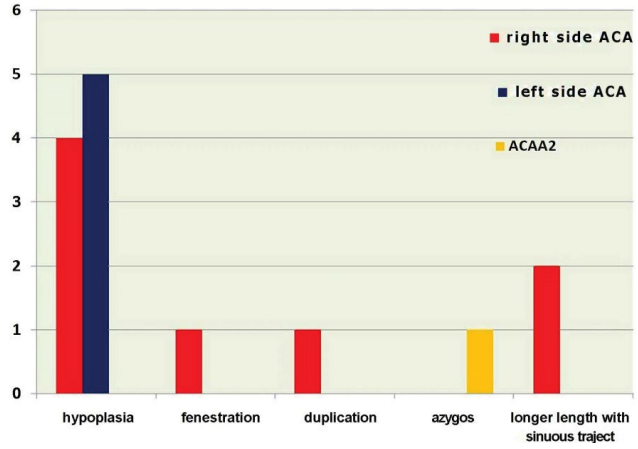

Figure 6 Types of anatomical anomalies/variants of ACA from the level of the 28 CoW analyzed.

a sinuous trajectory, was found in 2/28 cases (7.14%), only on the right side. Fenestration and duplication were identified only in one case out of the 28 analyzed (3.57%), also only on the right side.

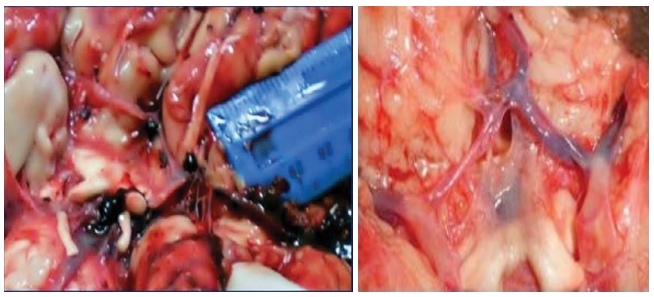

Figure 7 Base of the brain (autopsy specimen): Left ACA hypoplasia. Brain base (autopsy specimen): Right ACA hypoplasia.

Discussion

The Willis polygon (CoW) plays an important role in cerebral hemodynamics, the presence of this intact anastomotic canal facilitating much more efficient blood flow compared to situations in which it is deficient. But in the literature, even among normal individuals, a CoW of classical appearance, as described by Thomas Willis (8), seems to represent only a percentage with wide variation, depending on the country, the method of study or the number of cases analysed.

There are a relatively large number of studies that have analyzed the appearance of CoW by angiography, either Computed Tomography (CT) or magnetic resonance imaging (MRI). Siddiqi, Ansar, and Fatih in Lahore, Pakistan, conducted an angio-CT study of 54 unselected patients with hemorrhagic stroke and found only 13% of them had a complete and symmetrical CoW, the remaining 87% presenting different anomalies and/or anatomical variants [5]. Similar percentages were obtained by Klimek-Piotrowska et al. from Poland, who analyzed 250 patients by angio-CT. In their study, 16.80% of the analyzed COWs had the classic appearance, the remaining 83.20% had different morphological variations [4]. Cristea et al. in Romania, through an angio-CT study combined with angio-MRI, they found even fewer CoWs with a normal, classic appearance (only 8% of 50 patients investigated) [11].

However, there are also angiographic studies that have identified only a few CoWs with anatomical abnormalities/variations. In Sudan, Alawad et al. analyzed 143 patients by angio-MRI and found variations in CoW in only 28% of cases. Also, Harizi (Shemsi) et al. in Albania, analyzed by angio-CT 60 stroke patients and 60 control persons and identified in one-fifth of cases for each group the presence of abnormalities/anatomical variants of COW, although the percentage was higher, of course, in the group of patients with strokes (23.3% and 16.7%, respectively) [12]. In Italy, Macchi et al. obtained only a slightly higher percentage for cases with variations in CoW [13].

The studies that analyzed CoW obtained at autopsy, either anatomical-clinical or forensic, show much more diverse variations. Poudel and Bhattarai (2010), in Nepal, analyzed 35 formalized brains, obtained by anatomo-clinical autopsy, and reported the presence of classic CoW in a very high percentage (91.4%), the remaining 8.6% showing various variations [14]. At

the opposite pole is a study by De Silva et al. in Sri Lanka who reported only 14.2% the presence of classical CoWs when they analyzed 225 formalinized brains obtained at forensic autopsies [3]. A slightly higher percentage (23.6% of classic COWs were reported by Siddiqi, Tahir and Lone in a study performed on 51 brains also obtained at forensic autopsies [7]. The rest of the authors identified almost similar values between classical CoWs and CoWs with various variations Kapoor et al. in India, Iqbal, also in India, and Nordon and Rodrigues Júnior (2012), in Brazil reported the presence of CoW with slightly higher percentages than classical COW: similar brain values obtained at autopsies, either anatomical-clinical or forensic (54.8% vs. 45.2%; 52% vs. 48%; 54% vs. 46%) [15]. There are also authors who found slightly higher percentages for the presence of classic CoW compared to CoW with various variations. In their study, performed on 50 fresh brains obtained at the anatomo-clinical autopsy at a hospital in India, Raghavendra et al. reported a percentage of 56% of classic CoW compared to 44% of COW with variations [16].

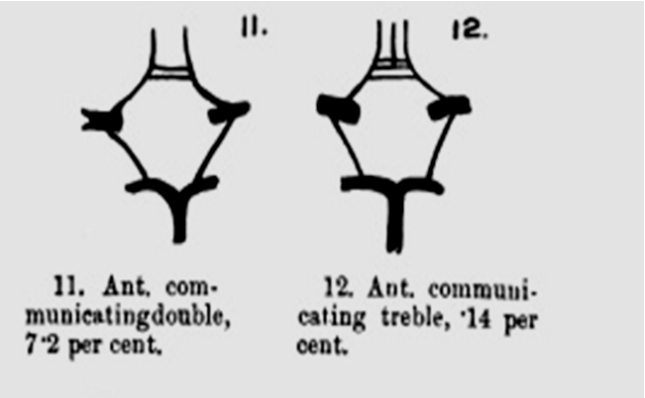

Figure 8 Illustration of anatomical variants of AcoA: 11) Double AcoA; 12) Triple AcoA and median accessory ACA in segment A2, originating in AcoA (Fawcett and Blachford, 1905).

Anomalies and anatomical variations ACoA have been identified since 1905 by two Bristol physicians (Fawcett and Blachford) who published the results of their study of 700 autopsy specimens **(Figure 8).** They report and illustrate double, triple or absent AcoA [17]. Then, in 1916, the English anatomist and physician from Manchester JSB Stopford [18] provided an illustration of several types of variations encountered in his autopsy series **(Figure 9)** showing that AcoA can be unique, absent by merging the two ACAs, complete double or partial double, triple, quadruple or networked.

In recent years, with the help of angiographic investigations, it has been found that the most common variation of ACoA is duplication (10% of subjects), but it can also be hypoplastic, fenestrated, with oblique trajectory. The rarest are the plexiform model (3%) and the tripling (1%) [19]. The plexiform variant is considered an incomplete regression of embryonic ACoA, and hypoplasia or aplasia is considered an abnormal regression of ACoA. As an anomaly, the absence of ACoA is described [19].

In the literature there are studies that have analyzed only the anatomy of the ACoA, only the anatomy of the anterior part of the CoW or that have investigated the anatomy of all the component arteries of the CoW. There are also differences in the way ACoA variations are reported: either in the total number of brains studied, which show both typical and atypical CoWs, or only CoWs with variations are analyzed.

Kapoor et al. and Gunnal et al. both in India, found ACoA absent, hypoplastic, duplicate, triplicate, plexiform, or fenestrated, but in small percentages because they reported these cases to the entire series analyzed [20]. However, in their studies, ACoA was duplicated in a high percentage.

When the reports were made only to the number of cases of CoW with variations [21], the duplicate ACoA was also in the first place among the variations of this artery. Kardile et al. in India conducted a study almost similar to ours in terms of the manner of investigation and the number of brains investigated, but focused only on the analysis of ACoA variations [19]. They analyzed 100 formalinized brains and found a number of 38 CoWs that showed various abnormalities and/or anatomical variants of the component arteries. At the ACoA level, they reported the absence of the vessel in 21.05% of cases, duplication in 26.31%, tripling in 2.63%, hypoplasia in 15.79% and plexiform appearance in 7.89% of all cases with variations. In the study by Sinha et al. ACoA was double in a percentage of 22, 5% of all variants and hypoplastic in 5.6% of cases. We identified absent ACoA, by merging the two ACAs, in most cases (21.42%), ACoA duplication in 7.14% of cases and hypoplastic ACoA in 3.57% of the 28 CoW analyzed. We did not identify tripling, fenestration or plexiform appearance at this artery **(Table 1).** ACA variations were described and illustrated almost two hundred years ago by the Irish anatomist and surgeon Richard Quain who mentioned a case of hypoplasia of this artery [22].

Forty years later, in 1888, the English anatomist Bertram Windle found a classic COW in only 119 cases out of 200 analyzed at autopsy (59.5%), the rest showing various anomalies. At the ACA level he reported the presence of an anatomical variant in the form of a single median artery that formed from the ACoA (what we now call the azygos artery) to 9 cases out of the 200 analyzed, and in one case he identified double ACA on one side and the absence of the other party [23].

Recent studies on computed angiography **(Table 2)** have shown that the most common anatomical variation of the A1 segment of the ACA is hypoplasia (frequency being 10-35%), fenestration (0.1-8%), aplasia, low origin and infraoptic tract, accessory ACA or duplication and ACA tripling, which can be seen in 1% of subjects.

In an autopsy study, Kapoor et al. reported the most abnormalities and anatomical variants of ACA (absence, hypoplasia, duplication, tripling, single artery), but very small percentages for each of them because they reported them to the 1000 brains taken into research. Siddiqi et al. and Sinha et al. identified ACA deficiency or hypoplasia also in low percentages. Gunnal et al. reported both hypoplasia and lack of ACA, but also ACA duplication, also in low percentages [20]. However, when only CoW with variations is analyzed, the percentage of different anomalies

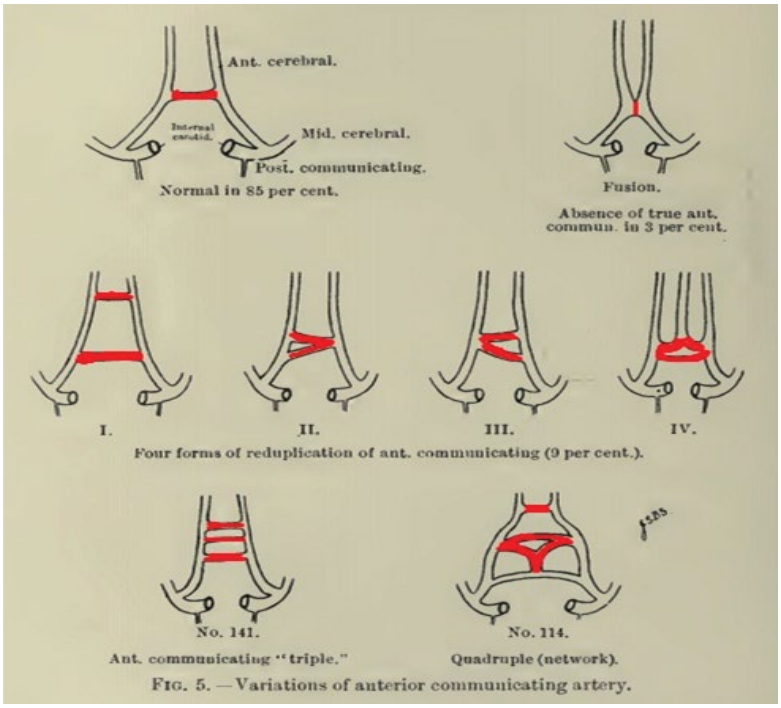

Figure 9 The AcoA may be single, absent by merging the two ACAs, full double or partial double, triple, quadruple or networked (Redesign Stopford, 1916).

Table 1 Comparison between studies that analyzed the anatomy of ACoA.

Authors	The country	ACoA					
		Absence	Hypoplastic	Duplicate	Triplicate	Plexiform	Fenestrated
Kapoor et al.	India	1.80%	-	10%	1.20%	0.40%	-
Gunnal et al.	India	8%	6.66%	10.66	-	-	3.33%
Sinha et al.	India	-	5.56%	22.22%	-	-	-
Kardile et al.	India	21.05%	15.79%	26.31%	2.63%	7.89%	-
The present study	Romania	21.42%	3.57%	7.14%	-	-	-

Table 2 Comparison between studies that analyzed the anatomy of ACA.

Authors	The country	Study material	ACA						
			Absence	Hypoplastic	Duplicate	Triplicate	Single	Fenestration	Longer length
Kapoor et al.	India	1000 brains	0.40%	1.70%	2.60%	2.30%	0.90%	-	-
Siddiqi et al.	Pakistan	51 brains	3.60%	4%	-	-	-	-	-
Sinha et al.	India	80 brains	-	5.56%	-	-	-	-	-
Gunnal et al.	India	150 formalinized brains	2.66%	5.33%	6%	-	-	-	-
Paşcalău et al	Romania, Cluj	10 formalinized brains with COW with variation	-	2. 3%	-	-	-	-	-
The present study	Romania, IASI	28 fresh brains with CoW with variations	-	32.14%	3.57%	-	-	3.57%	7.14%

and/or anatomical variants encountered at ACA level is much higher. Thus, Paşcalău et al. in Romania found ACA hypoplasia in a percentage of 23% of the analyzed CoW [24].

Conclusion

In our study there is presented a wide range of variations of the anterior part of the circle of Willis that affect both ACA and ACoA. The variations of the ACoA were represented by absence, hypoplasia and duplication, with a predominance of its absence, due to the fact of the two ACAs merging together. ACA variations were mainly represented by hypoplasia, but we identified at this level other variations as well, such as duplication, fenestration and sometimes a longer length of the vessel that took a sinuous

path. The anatomical variants identified by us in this study are significant for the population living in the region of northeastern Romania, because they represent its particularities compared to other populations, but at the same time it has similarities with data from other recent international articles. In this context, the study aims to offer to practitioners from various medical and surgical specialties (neuroanatomy, neurology, neurosurgery, pathology and internal medicine) an insight into the possible variants of the anterior side of the CoW that may occur in clinical practice.

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