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ORIGINAL ARTICLE

Anatomical variations and dimensions of arteries in the anterior part of the circle of Willis

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Background: The aim of this study was to investigate different anatomic variations and dimensions of anterior part of the circle of Willis (CW) and their prevalence on Kosovo's population.

Materials and methods: This is an observational descriptive and retrospective study performed at the University Clinical Centre, Clinic of Radiology. The three--dimensional time-of-flight technique was used for magnetic resonance angiography imaging to evaluate the anatomy of the CW in 513 adults without clinical manifestations for cerebrovascular disease. The diameters of arteries of the CW were measured and variations were recorded.

Results: The complete anterior part of CW was found in 64.3% of cases, more evident in female at about 66% than male 62.2%. Morphologic variations of the ACA1 are agenesis or hypoplasia in 5.65%, fusion of the anterior cerebral arteries (ACAs) on a short distance in 6.5% and fusion of the ACA on a long distance in 2.5%, median ACA is presented in 11 examined patients or 2.1%. Normal anterior communicating artery (ACoA) was seen in 68.2%, hypoplasia or absence 15.66%, double ACoA in 0.6% and fenestrations in 3.89%. The mean calibrations of the vessels were measured as 2.04 mm in right A1, 2.06 mm in left A1 and 1.16 mm of ACoA. While, 14.1 mm length of right A1, 13.87 mm of left A1 and 2.99 mm of ACoA.

Conclusions: Knowledge of the variations and diameter of the anterior part of the CW has a great importance in determination of anatomical variations and diameter in general populations, also, in interventional radiology for various endovascular interventions as well as during anatomy lessons. (Folia Morphol 2019; 78, 2: 259–266)

Key words: variations of anterior part, dimensions of anterior cerebral artery, dimensions of anterior communicating artery, circle of Willis, anterior part of circle of Willis

INTRODUCTION

The circle of Willis (CW) is an anastomotic polygon at the base of the brain that supplies blood to the brain structures. It consists of the following arteries including: anterior cerebral arteries (ACAs), anterior communicating artery (ACoA), internal carotid arteries (ICAs), posterior cerebral arteries (PCAs), and posterior communicating arteries (PCoAs). ACA divides into two parts; A1 and A2. The A1 segment is also known as the pre-communicating part of the ACA, while, A2 segment is post-communicating part of the ACA. The ACoA is a small blood vessel which bridges

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the two larger ACAs. A majority of anatomic variations have been observed in the ACoA section, characterised as anatomic complexity and diversity. The ACoA, A1 and A2 segments of ACA, and the recurrent artery of Heubner, combined with their perforators and other branches, are often referred as the ACoA complex. There are very few case reports regarding the variations encountered in the ACA and ACoA. Knowledge of these variations is important for brain surgeons considering intervention to the intracranial arteries and for interventional radiologists [6]. Various authors have studied the length, diameter and anomalies in the origin of these arteries and found that the parameters in different geographical limits were different. The most common morphological changes in the blood vessels of the brain are encountered in their origins, calibre; often they are hypoplastic, duplicated or event absent, number, communication, and branching. So, presence of anatomical variations means deviation from the normal pattern without any functional impairment to the individuals. Vascular variation has been examined using various methods including autopsy, computed tomography angiography and magnetic resonance angiography (MRA). However, earlier studies are mainly based on autopsy study, with numerous limitations on the connections between morphology and physiological changes in the haemodynamic system. Moreover, the sample number was limited and their results were not comprehensive and did not reflect the normal physiological status. With the development of imaging diagnostic methods, such as MRA, have been progressed to study morphology of blood vessels. The present study was undertaken to study the origin, course and termination of the ACA, to observe the ACoA and to observe variations between the two sides. CW variations have been examined in various populations and age groups [3, 11, 12].

MATERIALS AND METHODS

Five hundred and thirteen patients, without clinical manifestations of cerebrovascular diseases, have been included in the study and are considered as healthy subjects. All patients (222 men and 291 women; mean age: 46 years) underwent the three-dimensional (3D) time of flight MRA of the CW, using a 1.5T scanner (Avanti, Siemens, Germany). Following imaging parameters were used: repetition time/echo time 23/7.0, flip angle 25 degrees, slice thickness 0.7 mm, number of slice 44/slab, number of slabs 4, slice overlap 25%, flow direction feet to head with 40 mm saturation at the head end, field of view 180 × 158 and 256 matrix size. All MRA were evaluated by using native source images and maximum intensity projections (MIP) images. These axial source images were post processed by the MIP algorithm to produce 8 projections rotating about the section axis and 1 axial image (projection images). All component vessels of the CW were accessed by measuring the diameter on the individual MIP images. Whenever there was a doubt in determining the diameter of one vessel due to overlapping vessels in the MIP images, the 3D time-of-flight source images are then reviewed on the advanced workstation (GE ADW 4.0 workstation). Occasionally, it was necessary to cut off the unwanted branching vessel on the images by an experienced radiologist to better depict the target vessels and assess correct diameter. So, each patient was positioned in the supine position, the head was immobilised by the coil for head; noise protectors were placed in the ears of patients to reduce noise. During the examination, patients' vital signs were kept under control and monitored all the time through the monitor. Vessels that were visualised as continuous segments of at least 0.8 mm in diameter were considered present; arteries when seen as non-continuous segments those smaller than 0.8 mm in diameter were considered hypoplastic or absent. Arteries when seen as non-continuous segments were considered as absent [12].

The A1 segment of the ACA and ACoA, which are components of the CW, was studied for its length and diameters (Fig. 1). The following two points were marked separately for ACA: at its origin from the ICA (taken as point 'A'), at the proximal part of its junction with the ACoA (taken as point 'B'). Then, the lengths of the A1 segment of the ACA on the right and left sides were measured between the two points (point 'A' and 'B'). In cases with the tortuous course of the A1, with angulations, the length was measured in segments, which were then added and the total length was calculated. The projections which showed the anterior part of the CW with minimum overlapping were selected for taking measurements. The cases in which points 'A' and 'B' at which the measurements were to be taken were not clear, either because of overlapping in the projections, or because of any other reasons, were not included. Also, the cases in which any of the projections of the A1 segment could not make the entire course clear were not included in the study. The length of the ACoA was taken between two points of communication between right A1 segments and the left A1 segment.
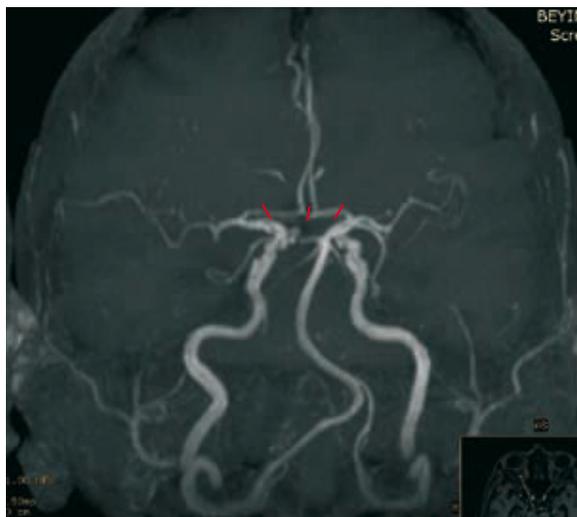
Figure 1. Standardised method for vessel diameter measurement with transversal cuts 5 mm from their origin and length of the arteries, axial maximum intensity projections reconstruction three-dimensional time-of-flight magnetic resonance angiography.
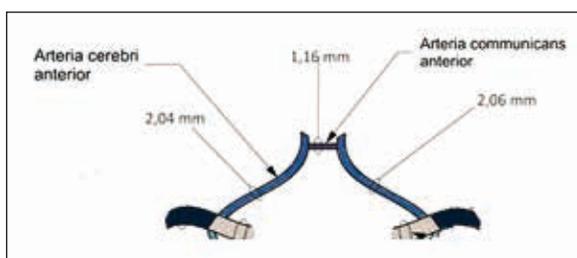
Figure 2. Schematic representation of arteries in anterior part of circle of Willis.

RESULTS

The present study focuses on the distribution of diameter and length among the subjects studied including age and gender. Most of the patients were female 291 (56.72%) while 222 (43.27%) male. About 61% of the patients were ≥ 40 years age. The patients were ranged in ages from 11 to 83; the mean age was 46 years.

The inner diameters and lengths of the ACAs and ACoAs are shown in Table 1 and Figure 2. The differences between right and left sides and their statistical signifi-cance are shown in Table 2. The differences of measured values between individuals younger and older than 40 years are in Table 3, and the differences between results of the measurements in the male and female persons, and their statistical significances are shown in Table 4.

Comparing the right and the left A1 segments, the average length was found to be larger on the right side than on the left side.

The difference of the length on the two sides was not significant (p > 0.05). The average diameter of the ACA was larger on the left side than on right (p > 0.05; Table 2).

In the individuals younger than 40 years, the aver-age diameters of ACA and ACoA were larger than in older but not significantly, while the mean lengths were longer in older than in younger persons, also not significantly (Table 3).

As show in Table 4, the mean diameter of ACA in the female was larger than in male, but not signifi-cantly, while the average diameter of ACoA tended to be larger in female (p < 0.05). There were no notable differences among the ACA and ACoA between male and female (p > 0.05).

Variations of the anterior part of the CW

Morphologic variations of the A1 segment of ACA are agenesis or hypoplasia, fenestration, fusion of the ACAs on a short distance and fusion of the ACA on a long distance. Normal structure, when presented a single ACoA and ICA which bifurcates into the A1 segment of the ACA and the middle cerebral artery, was found in 64.3% of cases, more in female 66% than male 62.2%, shown in Figure 3. Unilaterally agenesis of A1 was found in 29 (5.65%) cases, more in male than female (Fig. 4). Fusion of the ACAs for a short distance was presented in 6.5%, while for a long distance in 2.55% (Figs. 4, 5).

Median ACA is presented in 11 examined pa-tients or 2.1%, in women 2.4% and in men 1.8%. Normal ACoA was seen in 68.2% (350/513) of the cases, presented in Figure 3. Hypoplasia or absence of an anterior communication was seen in 15.66%; while

Table 1. Diameter and length (mm) of A1 of anterior cerebral artery (ACA) and anterior communicating artery (ACoA)

Artery	Diameter [mm]					Length [mm]				
	AM	SD	SE	Min.	Max.	AM	SD	SE	Min.	Max.
ACA A1	2.05	0.27	0.01	1	3.8	14.01	1.4	0.08	8.9	21
ACoA	1.16	0.17	0.01	0.9	2.1	2.99	0.62	0.05	1	5.6

AM — arithmetic mean; Max. — maximum value; Min. — minimum value; SD — standard deviation; SE — standard error

Table 2. The average diameters and lenghts (mm) of the right and left A1 segments, and statistical significances between left and right sides values

A1 segment [mm]	Right				Left				T-test	P-value	SE
	AM	SD	Min.	Max.	AM	SD	Min.	Max.			
Diameter	2.04	0.28	1	3.8	2.06	0.26	1	2.93	1.14	0.2	0.17
Length	14.1	1.51	8.9	20.4	13.87	1.3	9.6	21	0.11	0.9	1.9

AM — arithmetic mean; Max. — maximum value; Min. — minimum value; P-value: p > 0.05 (not significant), p < 0.05 (significant), p < 0.01 (highly significant); SD — standard deviation; SE — standard error; T-test — Student's t-test

Table 3. The average diameters and lengths (mm) of the A1 segment of anterior cerebral artery (ACA) and anterior communicating artery (ACoA) with statistical significance between two groups of different aged persons

Arteries [mm]	> 40 year				< 40 year				T-test	P-value	SE
	AM	SD	Min.	Max.	AM	SD	Min.	Max.			
ACA A1 (d)	2.05	0.2	1.1	2.8	2.06	0.24	1	2.93	0.5	0.5	0.01
ACoA (d)	1.16	0.15	0.89	2.1	1.17	0.18	0.9	1.7	1.08	0.2	0.009
ACA A1 (l)	14	1.29	8.9	21	13.9	1.22	10	19.7	0.8	0.3	0.1
ACoA (l)	3.2	0.6	1	5	3.15	0.6	1.8	5.19	0.9	0.3	0.05

AM — arithmetic mean; d — diameter; l — length; Max. — maximum value; Min. — minimum value; P-value: p > 0.05 (not significant), p < 0.05 (significant), p < 0.01 (highly significant); SD — standard deviation; SE — standard error; T-test — Student's t-test

Table 4. The average diameters and lenghts (mm) of the of the A1 segment of anterior cerebral artery (ACA) and anterior communicating artery (ACoA) with statistical significance between two groups of patients with different gender

Arteries [mm]	Male (n = 222)				Female (n = 291)				T-test	P-value	SE
	AM	SD	Min.	Max.	AM	SD	Min.	Max.			
ACA A1 (d)	2.04	0.23	1	2.7	2.06	0.32	1	3.8	0.97	0.33	0.02
ACoA (d)	1.15	0.14	0.9	2.1	1.18	0.2	0.89	2.1	1.9	0.05	0.01
ACA A1 (l)	14.1	1.1	10	21	13.9	1.6	8.9	13.8	1.6	0.1	0.1
ACoA (l)	3.3	0.63	2	5.1	3.31	0.27	2.5	4	0.2	0.8	0.04

AM — arithmetic mean; d — diameter; l — length; Max. — maximum value; Min. — minimum value; P-value: p > 0.05 (not significant), p < 0.05 (significant), p < 0.01 (highly significant); SD — standard deviation; SE — standard error; T-test — Student's t-test

double ACoA was present in 3 (0.6%) cases (Fig. 6). Fenestrations of ACoA existed in 3.89 (20/513).

Morphologic variations of ACoA were present in 35.5% of cases while anterior part of CW has a complete structure in 77.7%, meaning that the arteries constituting the front of the CW have origin, diameter and regular extension.

Our results show that the more completed anterior part of CW is presented in female (78.57%), comparing to male (76%). A single ACoA is the most common type (64.5%) and hypoplasia or absence of ACoA (15.6%), in all age and both sex groups.

In 9 specimens or 1.75% an aneurysm of the proximal segment of the ACA and the ACoA was observed on its right side. Intracranial aneurysms are acquired dilatations of intracranial arteries. They are typically located at the arterial branching points near the skull base (Fig. 7A, B).

Fenestration of the anterior cerebral artery has been known in the anatomical field but it has rarely been reported in the radiological literature. The purpose of this paper is to present cases with fenestration of the ACA; in our study it was present in 3 (0.58%) cases, shown in Figure 7C.

DISCUSSION

The CW is the main source of supply to the brain and many authors have studied the diameter and length of the blood vessels that form the CW in cadaver-brain. Thus, Ghazali et al. [4] tested digital subtraction angiography with 3D time-of-flight MRA

Figure 3. A–C. Image by three-dimensional time-of-flight magnetic resonance angiography — a single anterior communicating artery. The internal carotid artery bifurcates into the pre-communicating segment of the anterior cerebral artery and the middle cerebral artery.
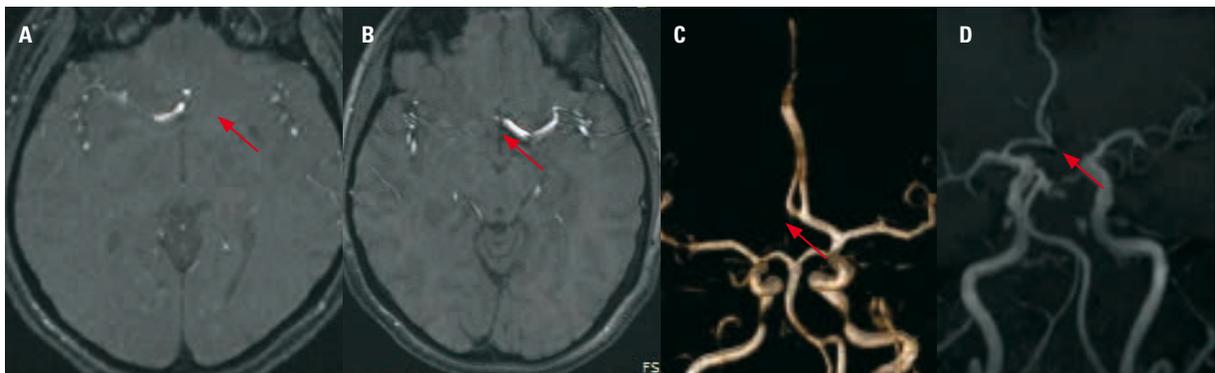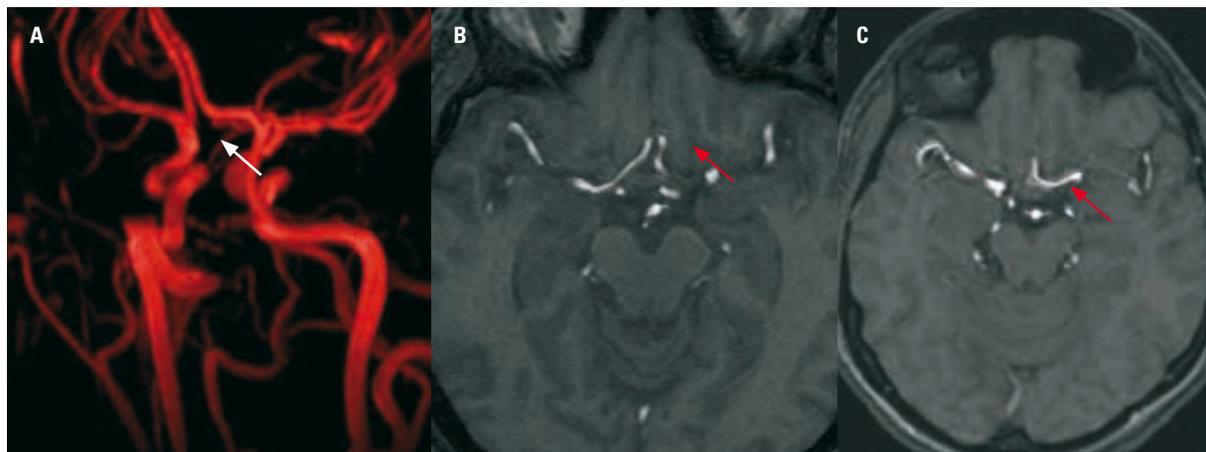

Figure 4. A–D. Image by three-dimensional time-of-flight magnetic resonance angiography — one pre-communicating segment of an anterior cerebral artery is hypoplastic or absent, the other pre-communicating segment gives rise to both post-communicating segments of the anterior cerebral arteries.
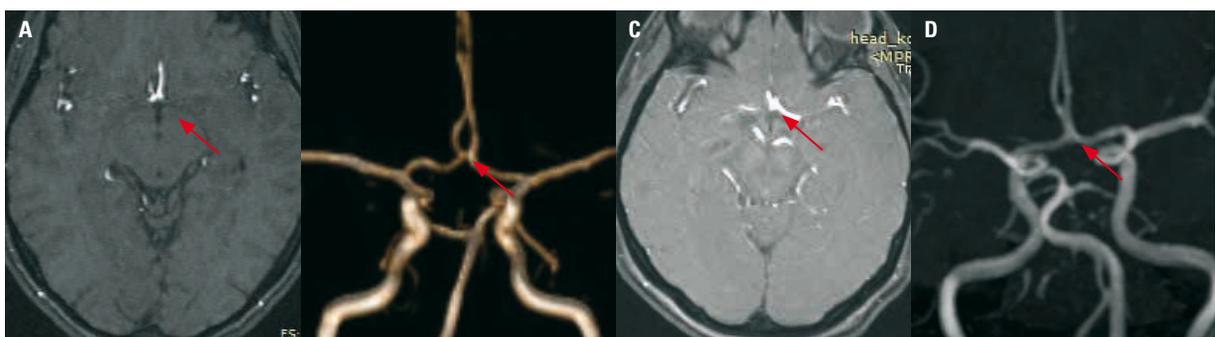
Figure 5. Image by three-dimensional time-of-flight magnetic resonance angiography; **A, B.** Fusion of the anterior cerebral arteries occurs for a short distance; **C, D.** Anterior cerebral artery forms a common trunk and split distally into two post-communicating segments.

in the comparison of the morphology of CW arteries. With the exception of PCoA, MRA was found to be a more sensitive method in the evaluation of the other CW arteries. In this respect, MRA seems to be more advantageous than CTA, as it does not require the use of contrast substance, it does not use ionising radiation, the processing of data is easy and there is not the visualisation of pure bone artefacts as seen on computed tomography in the posterior fosse and particularly in the base of the skull.

Figure 6. Image by three-dimensional time-of-flight magnetic resonance angiography; **A, B.** Hypoplasia or absence of an anterior communication; **C.** Two or more anterior communicating artery.

Figure 7. Image of three-dimensional time-of-flight magnetic resonance angiography; **A, B.** Aneurysm on right side of anterior cerebral artery; **C.** Fenestration of anterior cerebral artery.

The proximal segment of anterior cerebral artery (A1) supplies the basal surface of the cerebral hemisphere. The diameter of A1 according to Kamath et al. [10], 2.3 mm for diameter and 14.25 mm length, Iqbal et al. [8] diameter 2.3 mm and length 12.4 mm, on Turkish population length of A1 is 14.4 mm [11] while diameter 1.58 mm in the right A1, 1.64 mm in the left A1 [18], in Kosovo's population the diameters of A1 was 2.09 mm while length 13.96 mm [16]. In our study the diameter of ACA was 2.05 and length 14.01 mm. There were no significant differences in diameter and length of A1 segments based on gender, age or side. The ACoA represents an important anastomosis between the left and right ACA. Also, demarcates the junction between the A1 and A2 segment. ACoA diameter ranged from 0.8 to 2.3 mm and from 1.9 to 2.5 mm by Kamath et al. [10], 2.1 mm and 2.5 mm in by Krishnamurthy et

al. [13]. In our study the mean diameter of ACoA was 1.16 mm and length 2.99 mm compared with the studies in other people we noticed no greater differences in the values obtained in Kosovo. The largest diameter is observed in individuals younger than 40 years, but without significant difference, while, the length in older persons was larger, but with no significance.

The absence of ACA-A1 of one side is present in 5.6% or 29 examined cases, almost proportionally in women 6.75% and in male 4.8% comparing to 4% [7], 4.76% [9] and 5% [2]. Median ACA is presented in 11 examined patients or 2.1%, in women 2.4% and in men 1.8%, similar results are 2.5% and 5%

If the artery on one side is narrowed, the vascular insufficiency is compensated by crossing over by opposite side artery, or by giving branches that cross over to the other side. It indicates that the CW offers

a potential shunt in abnormal conditions such as occlusions and spasms. In normal circumstances it is not an equalizer and distributer of blood from different sources [15]. Cerebral infarct due to occlusion of ACA is common in stroke and has grave morbidity. Therefore variation in anterior circulation of the brain is of great importance particularly in the surgery of the region. Some authors associate ACA-A1 deficiency with the presence of aneurysm in ACoA. The absence of proximal segment of ACA-A1 is a common finding in ACoA aneurysm patients and can be considered as a risk factor for the formation of aneurysm.

Data's from this study about ACA dimensions and variations can provide accurate micro anatomic information for surgical treatment of aneurysms or during surgical procedures about reconstructing blood vessels in circulus arteriosus cerebri. Also, anatomic parameters of the ACA can be used to plan and design equipment such as angiographic micro catheter and guide used in endovascular procedures. The vascular anatomy of the region of ACoA is generally complex due to its development. In the 24 mm embryo the ACoA is still a plexiform structure connecting both ACA. Incomplete fusion of this anastomosis may lead to fenestration, doubling or tripling of the ACoA [15]. Fenestration can be a protective mechanism for stenosis, injury to, or occlusion of one of the duplicated limbs. Such anomalies may become important in the planning of interventional procedures [5]. Fenestration can pose unexpected difficulties in the surgical treatment, as unilateral or bilateral fenestration often accompanies aneurysms or other anomalies. The most common variant is when ACoA is absent and appears in 80 patients or 15.6%, most common among women 9.75% than men 5.45%. The frequency of lack of ACoA is related to other studies such Jalali Kondori et al. [9], Chen et al. [1], respectively 11.6, 14.28 and 11.44. Also in cases when ACoA is missing both ACAs join in a trunk or run as united for a certain length. The first variant was present in 6.8% of patients, in equal proportion between females and males, while the next is less common and appears in 2.55% of examined cases, 2.4% in female and 1.8% in male. Our results are similar with findings of Jalali Kondori et al. [9] 5.7% and 0.95%, Chen et al. [1] 5.92% with 1.38%. Duplication of ACoA occurred in 0.6%, or 3 patients, 0.3% in female and 0.9% in men, comparing with similar results of 0.95% [9] or 0.6% [14]. When an intracranial aneurysm ruptures, it causes subarachnoid haemorrhage. Intracranial aneurysms

are found in about 2% of the general adult population, and are considered to be acquired lesions.

The A1 fenestration was found in: 0.1% of cases, respectively, 0.58% was seen in the distal half of the A1 segment of ACA.

Also, anatomic parameters of the anterior cerebral artery can be used to plan and design equipment such as angiographic micro catheter and guide used in endovascular procedures [17].

CONCLUSIONS

The morphological variations and diameter differences demonstrated in our study providing an important reference value for the 3D time-of-flight MRA. Our findings show that the configuration of the CW may vary largely in general population. The prevalence of complete configuration of the circle is higher in younger individuals as well as in female. Some of these variations may be associated with certain risks like aneurismal development or watershed infractions.

Knowledge of the variations and diameter of the anterior part of the CW has a great importance in determination of anatomical variations and diameter in general populations especially in Kosovo's population, also, in interventional radiology for various endovascular interventions and anatomy teaching.

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