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Influence of Gender and Age on Average Dimensions of Arteries Forming the Circle of Willis Study by Magnetic Resonance Angiography on Kosovo's Population

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Keywords: The circle of Willis; MRA; 3D-TOF; diameters of arteries; length of arteries.

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Abstract

BACKGROUND: Circulus arteriosus cerebri is the main source of blood supply to the brain; it connects the left and right hemispheres with anterior and posterior parts. Located at the interpenducular fossa at the base of the brain the circle of Willis is the most important source of collateral circulation in the presence of the disease in the carotid or vertebral artery.

AIM: The purpose of the research is to study the diameter and length of arteries and provide an important source of reference on Kosovo's population.

METHODS: This is an observative descriptive study performed at the University Clinical Center of Kosovo. A randomised sample of 133 angiographic examinations in adult patients of both sexes who were instructed to exploration is included.

RESULTS: The diameters and lengths measured in our study were comparable with other brain-cadaver studies especially those performed by MRA. All dimensions of the arteries are larger in male than female, except the diameter of PCoA that is larger in female ($p < 0.05$) and length of the ACoA ($p < 0.05$). Significant differences were found in diameters of arteries between the younger and the older age groups.

CONCLUSION: Knowing the dimensions of the arteries of the circle of Willis has a great importance in interventional radiology as well as during anatomy lessons.

Introduction

Even though it consists about 2% of body weight, the brain is one of the most active metabolic systems of the body and dependent on a continuous supply of oxygenated blood [1]. Located at the interpendicular fossa at the base of the brain, *circulus arteriosus cerebri* is the main source of blood supply to the brain. It is named after the famous British surgeon Thomas Willis in his book "Cerebri Anatome" 1664 [2]. This arterial circle was well known before, but it is said that with his detailed description he also recognised its function. According to Thomas Willis, the function of this circle is a collateral pathway to maintain adequate cerebral perfusion that provides constant and regular blood flow to the brain in case of reduced arterial perfusion, stenosis or occlusion of an internal carotid artery or vertebral artery. [3,4]. Internal carotid arteries (ICA) and basilar artery bring the blood in the CW. Therefore these are considered as an incoming artery (afferent artery), while their lateral branches are the delivery artery (efferent artery). The internal carotid artery is divided into the anterior and middle cerebral artery and forms the anterior part of the CW. The basilar artery formed by the joining of the two vertebral arteries which is divided into the posterior cerebral arteries and presents the posterior part (segment) of the circle. Anterior communicating artery (ACoA) connects the left and right ACA, while posterior communicating arteries (PCoA) connects a posterior cerebral artery to the terminal part of the same side of ICA and as such closes the circle being formed the Circle of Willis. Also, this anastomosis slows down blood flow to the brain and helps in collateral circulation. Although in anatomical terminology (TA) is described as a circle, it has more polygonal form. Completely formed appears on the 52nd day of embryonic development, but, all its segments are thin and have the same calibre [5, 6]. Classification of variations is not easy because of their large number. Studies have shown that the anatomical variations of the circle of Willis were probably genetically determined, develop in early embryonic stage and persist in post natal life [7]. 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, the presence of anatomical variations means deviation from the normal pattern without any functional impairment to the individuals. Vascular variations have been examined using various methods including autopsy, CT angiography and Magnetic Resonance Angiography. However, earlier studies are mainly based on autopsy study, with numerous limitations on the connections between morphology and physiological changes in the hemodynamic 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 magnetic resonance angiography (MRA) have been progressed to study the morphology of blood vessels [8]. In our study, these variations are observed and classified using MRA. Magnetic resonance angiography is a noninvasive sensitive method, possible to survey on massive healthy population and used to assess variations in vivo.

Given that the origin of the Albanian people is ancient and specific, and considering that the isolation by distance and genetic drift have been still important factors in determining the genetic structure of the Albanian population we suppose that this reflects on some differences in the structure of the circle of Willis [9]. In Kosovo's population, evidence of the presence and distribution of variations of the circle of Willis is scarce. Research has indicated that these anatomical variations have to be considered during radiological interpretation, neurosurgical interventions and in a greater care for those who teach anatomy [10].

The objectives of this study are to evaluated and describe the prevalence of variations of the circle of Willis and correlation between age and gander in Kosovo's population.

Materials and Methods

Our study included 133 Magnetic Resonance Angiography examination subjects from all age groups regardless of gender within Kosovo's population. The patients were ranged from 18 to 83 years old. Thus, for control the potential confounding factor we have including in examination just Albanians who live in Kosovo.

Patients who were referred to Clinic of Radiology in a tertiary hospital, University Clinical Center of Kosovo as part of their health check-up were included in this study. Clearance from Institutional Ethical committee was obtained for our study. All patients were examined with a 3D time of flight MR angiography (3D TOF MRA) (Fig. 1). This study scanned by using a 1.5T scanner (Avanto, Siemens, Germany). Following imaging parameters were used repetition time/echo time 23/7.0, flip angle 25 degrees, slice thickness 0.7mm, number of slice 44/slab, number of slabs 4, slice overlap 25%, flow direction feet to head with 40mm saturation at the head end, field of view 180 x 158 and 256 matrix size. All MR angiograms were evaluated by using native source images and maximum intensity projections (MIP) images. 3D TOF MRA is a sensitive, non-invasive imaging modality suitable for evaluation of the circle of Willis. Thus, each patient was positioned supine, and the head was immobilized by the head coil, ear protection was used for each patient. During the scan, vital signs for all patients were monitored.

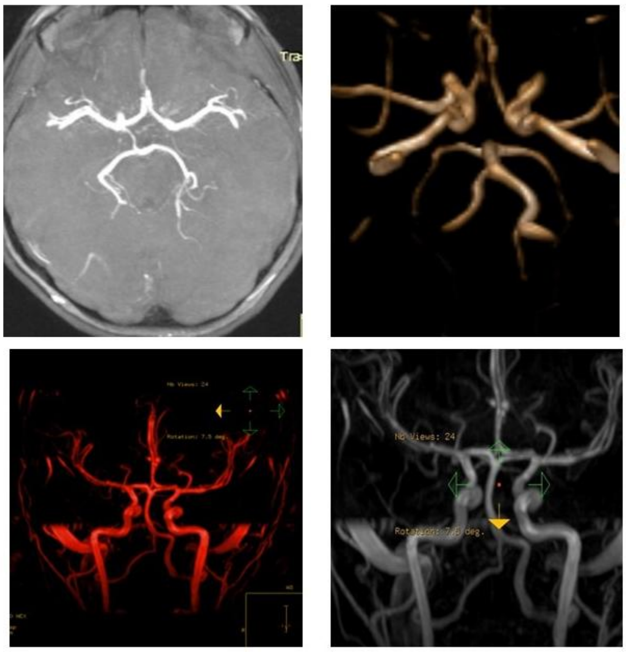

Figure 1: an A. Standardized method for vessel diameter measurement with transversal cuts 5 mm from their origin and length of the arteries. B, C and D -axial MIP- 3D reconstruction TOF MRA

Inclusion criteria in the study:

- All age groups, both of sexes, without distinction territory. Exclusion criteria:

- patients who have the disease in central nervous system, patients with a pacemaker, ferromagnetic intracranial aneurysm clips or other metallic implants, patients with arterial aneurysms, arteriovenous malformation, subarachnoid haemorrhages, intracerebral, with embolism, thrombosis, with claustrophobia and patients who have head and neck surgeries were excluded.

To avoid errors when interpreting results:

- patients with head trauma, surgical interventions in this particular region, also images that not clear, including images where the patients moved, these data were not included in the study.

The study aimed to determine the inner diameter of the arteries of the CW in the Kosovo's population, about gender and age.

Only the arteries forming the circle of Willis were studied: internal carotid artery (ICA), anterior cerebral artery (ACA), middle cerebral artery (MCA), posterior cerebral artery (PCA), basilar artery (BA), anterior communicating artery (ACoA) and posterior communicating artery (PCoA).

The variations of the CW were classified by the arterial configurations described in previous adult studies. MRA provides 89.2% sensitivity to the communicating artery and 81.3% for the posterior communicating artery, while 100% for the anterior, medial and posterior cerebral artery. For the identification, the circle of Willis is divided into an anterior part which consists of ACA, ICA and ACoA and posterior part from PCA, PCoA and BA. All arteries are measured in length along the extension of the respective segment and diameter through a transversal cut placed 5mm from the vessel origins in a typical angiographic frontal incidence.

The anterior cerebral artery (proximal segment-ACA) defined as a part of ACA from its origin at the internal carotid thought to the junction with the anterior communicating artery and posterior cerebral artery (proximal segment-PCA) from its origins at the termination of the basilar artery to the junction with the posterior communicating artery within interpeduncular cistern. The middle cerebral artery (proximal segment –MCA) also known as the horizontal or sphenoid segment originates from ICA passes laterally behind to the Sylvain fissure. The basilar artery (BA) formed by the union of the two vertebral arteries at the junction between the medulla oblongata and the Pons and extends to the upper border of the Pons.

Thus, for comparative statistical analysis, the tests were divided into groups based on patient's gender and age.

The differences in mean vessel diameter and length were correlated according to age and gender by T-test and P-values, $p > 0.05$ (not significant), $p < 0.05$ (significant), $p < 0.01$ (highly significance, $p < 0.001$ (very highly significance).

Results

In the present study, the diameter and length vessel of the circle of Willis was studied by Magnetic Resonance Angiography. All participants underwent three-dimensional time-of-flight Magnetic Resonance Angiography (3D-TOF MRA) of the Circle of Willis (CW) examination at our institution for explorative purposes. The present study focuses on the distribution of diameter and length among the subjects studied including age and gender. From the total structure of the patients, 54% were female. About 53 % of the patients belonged to ≥ 40 years age group, out of them about 52% were female. The patients were ranged from 18 to 83 years old; the mean age was 45 years (SD = 18). The inner diameter and the length of the measured CW arteries in all examination are shown in Table 1.

Table 1: Dimensions of arteries of the circle of Willis

	Diameter (mm)					Length (mm)				
Arteries	AM	SD	SE	min.	max.	AM	SD	SE	min.	max.
ACA	2.09	0.27	0.01	1.1	2.93	13.96	1.4	0.08	9.9	21
ACoA	1.5	0.22	0.01	0.9	2.4	2.74	0.62	0.05	0.9	4.9
MCA	3.35	0.31	0.01	2.45	4.34	15.75	1.15	0.07	13.2	21.6
ICA	3.79	0.19	0.01	2.81	4.2	-	-	-	-	-
PCoA	1.22	0.2	0.01	0.9	2.1	12.93	0.92	0.08	10	16.4
PCA	1.99	0.31	0.01	0.9	2.8	6.59	1.09	0.06	3.2	9.9
BA	3.27	0.33	0.04	1.9	4.15	30.2	1.88	0.16	23.6	35.6

AM = arithmetic mean; SD = standard deviation; SE = standard error; Min = minimum value; Max = maximum value; ACA = anterior cerebral artery; ACoA = anterior communicating artery; MCA = Middle cerebral artery; ICA = internal carotid artery; PCoA = posterior communicating artery; PCA = posterior cerebral artery; BA =basilar artery, T = T-test, P > 0.05 (not significant), P<0.05 (significant), P < 0.01 (highly significant), P<0.001 (Very highly significant).

Differences between male and female diameter and their statistical significance are shown in Table 2, whereas individual younger and older than 40 years old, respectively, results are shown in Table 3. Differences between male and female length and their statistical significance are shown in Table 4, also, individuals younger and older than 40 years old, respectively, results are shown in Table 5.

Table 2: The diameters (mm) of the arteries of the circle of Willis and statistical significance between male and female

	MALE					FEMALE						
Arteries	AM	SD	SE	min.	max.	AM	SD	SE	min.	max.	T-test	P-value
ACA	2.12	0.29	0.02	1.1	2.93	2.04	0.23	0.01	1.2	2.7	2.5	0.01
ACoA	1.52	0.26	0.03	0.9	2.4	1.49	0.18	0.02	0.9	2.1	0.78	0.05
MCA	3.4	0.32	0.02	2.45	4.34	3.31	0.29	0.02	2.48	4	2.5	0.01
ICA	3.8	0.14	0.02	3.45	4.2	3.79	0.22	0.01	2.81	4.15	0.51	0.05
PCoA	1.2	0.2	0.01	0.9	2.1	1.26	0.23	0.02	0.9	2.1	2.24	0.05
PCA	2.04	0.3	0.02	1.07	2.8	1.95	0.31	0.02	0.9	2.6	2.25	0.05
BA	3.28	0.33	0.04	2.09	4.15	3.26	0.2	0.01	1.9	3.9	1.11	0.05

AM = arithmetic mean; SD = standard deviation; SE = standard error; Min = minimum value; Max = maximum value; ACA = anterior cerebral artery; ACoA = anterior communicating artery; MCA = Middle cerebral artery; ICA = internal carotid artery; PCoA = posterior communicating artery; PCA = posterior cerebral artery; BA =basilar artery, T = T-test, P>0.05 (not significant), P<0.05 (significant), P<0.01 (highly significant), P<0.001 (Very highly significant).

As shown in Table 2, the mean diameters of the male vessels were larger than female, except PCoA which tended to be larger in female ($p < 0.05$).

There were distinctive differences among the ACoA, ACI and BA between male and female ($p > 0.05$), while ACA, PCA and MCA have larger calibres in male than female $p < 0.01$. In the individuals older than 40 years, ACA, MCA and PCA have a large diameter than another group with significance difference of MCA $p < 0.01$. Thus, average diameters of the proximal vessels which supply the CW were larger in older age subjects (afferent vessels), while the contrary was seen for the distal branches (efferent vessels) which tend to have smaller mean diameters in older subjects (Table 4).

Table 3: The length (mm) of the arteries of the circle of Willis and statistical significance between male and female

	MALE					FEMALE						
Arteries	AM	SD	SE	min.	max.	AM	SD	SE	min.	max.	T-test	P-value
ACA	2.12	0.29	0.02	1.1	2.93	2.04	0.23	0.01	1.2	2.7	2.5	0.01
ACoA	1.52	0.26	0.03	0.9	2.4	1.49	0.18	0.02	0.9	2.1	0.78	0.05
MCA	3.4	0.32	0.02	2.45	4.34	3.31	0.29	0.02	2.48	4	2.5	0.01
ICA	3.8	0.14	0.02	3.45	4.2	3.79	0.22	0.01	2.81	4.15	0.51	0.05
PCoA	1.2	0.2	0.01	0.9	2.1	1.26	0.23	0.02	0.9	2.1	2.24	0.05
PCA	2.04	0.3	0.02	1.07	2.8	1.95	0.31	0.02	0.9	2.6	2.25	0.05
BA	3.28	0.33	0.04	2.09	4.15	3.26	0.2	0.01	1.9	3.9	1.11	0.05

AM = arithmetic mean; SD = standard deviation; SE = standard error; Min = minimum value; Max = maximum value; ACA = anterior cerebral artery; ACoA = anterior communicating artery; MCA = Middle cerebral artery; PCoA = posterior communicating artery; PCA = posterior cerebral artery; BA =basilar artery, T = T-test, P>0.05 (not significant), P < 0.05 (significant), P < 0.01 (highly significant), P < 0.001 (Very highly significant).

Table 3 depicts and compares the length of vessel among males and females. The mean length of arteries in male was larger than female expect ACoA which is larger in female $p < 0.01$. Comparison of the length of vessels between the ages is shown in table 5. Even though ACoA, PCoA, PCA, BA have slightly increased length in subjects younger than 40, while ACoA and MCA were greater in subjects older than 40, though this was not a significant difference ($p > 0.05$) except ACA which have a larger length in younger subjects, with $p < 0.001$.

Table 4: The diameters (mm) of the arteries of the circle of Willis and statistical significance between age

	<40				≥40					
Arteries	AM	SD	Min.	max.	AM	SD	min.	max.	T-test	P-vale
ACA	2.021	0.312	1.1	2.8	2.07	0.268	1	2.93	1.28	0.05
ACoA	1.192	0.256	0.89	2.1	1.149	0.127	0.9	1.7	1.23	0.05
MCA	3.325	0.262	2.7	3.9	3.411	0.354	2.45	3.41	2.25	0.01
ICA	3.788	0.214	2.81	4.15	3.406	0.72	1.63	4.14	5.87	0.001
PCoA	1.297	0.262	0.9	2.1	1.149	0.166	0.9	2.1	5.46	0.001
PCA	1.979	0.357	0.9	2.8	2.028	0.262	1.03	2.55	1.27	0.05
BA	3.46	0.465	1.9	5.2	3.21	0.331	2.09	3.89	3.66	0.001

AM = arithmetic mean; SD = standard deviation; SE = standard error; Min = minimum value; Max = maximum value; ACA = anterior cerebral artery; ACoA = anterior communicating artery; MCA = Middle cerebral artery; ICA = internal carotid artery; PCoA = posterior communicating artery; PCA = posterior cerebral artery; BA =basilar artery, T = T-test, P > 0.05 (not significant), P < 0.05 (significant), P < 0.01 (highly significant), P < 0.001 (Very highly significant).

Discussion

The circle of Willis is the main source of oxygen and nutritional supply to the brain. Previous studies have described the anatomy of the circle of Willis in cadaver [6, 11, 12]. While in our study the arterial dimensions of the circle of Willis will be described by Magnetic Resonance Angiography.

Table 5: The length (mm) of the arteries of the circle of Willis and statistical significance between ages

	<40				≥40					
Arteries	AM	SD	Min.	max.	AM	SD	min.	max.	T-test	P-vale
ACA	14.32	1.65	8.9	21	13.6	0.96	10	19.7	4.27	0.001
ACoA	2.93	0.79	1	4.5	2.95	0.66	1.5	4.06	0.13	0.05
MCA	16.17	1.62	13.4	21.3	16.2	1.32	14	19.9	0.41	0.05
PCoA	15.86	3.05	3.4	20	15.5	2.08	6.89	19.3	0.85	0.05
PCA	6.62	1.2	3.2	9.9	6.55	0.97	3.5	9.8	0.58	0.05
BA	30.2	1.88	24	35	30.07	1.88	23.6	35.4	0.76	0.05

AM = arithmetic mean; SD = standard deviation; SE = standard error; Min = minimum value; Max = maximum value; ACA = anterior cerebral artery; ACoA = anterior communicating artery; MCA = Middle cerebral artery; PCoA = posterior communicating artery; PCA = posterior cerebral artery; BA =basilar artery, T = T-test, P>0.05 (not significant), P < 0.05 (significant), P < 0.01 (highly significant), P < 0.001 (Very highly significant).

In our study the average length of BA is 30.2 mm (SD = 1.88, SE = 0.16) and diameter at its origins is 3.27 mm (SD = 0.33, SE = 0.04). There were no significant differences found on the length, between gender and age, while the diameter of the basilar artery is larger on subjects younger than 40 years old (SD = 0.46, $p < 0.001$).The study carried out by El Barhoun et al. showed that the BA diameter had a significant association with age in Australian population [13]. When comparing the data obtained from our study with the previous data published by Wollschaeger et al. (the diameter of BA is 3.28 mm while and length 31.91 mm) [14], Harish et al. (diameter is 3.63 mm, SD = 0.22 and length 29.9 mm, SD = 2.9) [15]. The results achieved in our study are similar to the data published by Wollschaeger et al., whereas less similarity is seen with data published by Harish et al. on the population of India.

PCA crosses over the oculomotor nerve and extends from BA to PCoA. In our study average diameter of PCA is 1.99 mm (SD = 0.31, SE = 0.01), which is lower value compared to the value of other authors Kamath et al. (2.2 mm) [15], Iqbal et al. (2.4 mm) [11] though our results are close to the results published by Krabbe-Hartkamp et al (2 mm) [16]. While the length of PCA is 6.59 mm (SD = 1.09, SE = 0.06), almost the same length result in Caucasian published by other authors [17, 18] and less comparable with the results South India [11, 15]. In length, there is no significant difference between age and sex, while the diameter of PCA is larger in male than female ($p < 0.05$), similar results are published by Maaly et al. [19].

PCoA is an important element of collateral circulation between the anterior and posterior circle of Willis. In our study, diameter of PCoA is 1.22 mm (SD = 0.2, SE = 0.01), while length is 12.93 mm (SD = 0.92, SE = 0.08). There are no studies showing the potential changes in the diameter in cadaver-brain arteries of the fixed brains in comparison to in vivo studies [20, 21]. Based on our study the diameter and the length in the male are larger than in female with significance p < 0.05 while the diameter of PCoA in individuals younger than 40 years is larger than another group (p < 0.001), compares with a length which is no significant between age. Thus, knowing the dimensions of the PCoA has its importance in neurological examinations related to cerebral ischemia and hypoplasia of the PCoA, and in neurosurgical operations, especially the clipping of an aneurysm located in this region [22].

The internal carotid artery (ICA) divides into ACA and MCA with larger dimensions and in PCoA with a smaller dimension. In our population the diameter of ICA was found to be 3.79 mm (SD = 0.19, SE = 0.01), similar results were shown by Karatas et al. (3.55 mm) [23] in Turkish population and Maaly et al. (3.72 mm) in the population of Egypt [19] while lower diameter results were published by Kamath et al. (4.2 mm) [15] in USA. The diameter of the ICA was significantly greater in the population younger than 40 years old (3.78 ± 0.21) than in other groups (3.4, ± 0.72, P < 0.001). There was no side-to-side difference between genders observed in our study; this does not compare with the study published by Krejza et al. which finds a significant difference between men and women [29]. Not finding significant differences in our study can be attributed to the genetics of our population.

The diameter of MCA-proximal segment (M1) is (3.35, SD = 0.31, SE = 0.01) and length (15.75, SD = 1.15, SE = 0.07). Therefore, the internal vascular calibres observed in the MRA studies were slightly smaller about the ones observed of the external diameters in the anatomical studies (Gibo et al-1981, Krabbe-Hartkamp et al. 1998). So it is believed that this should be the reason why the Kosovo population has a smaller diameter than the other studies performed in the different population [11, 21].

ACA is one of the largest ending branches of ICA and supplies the medial surface of the cerebral hemisphere. In our study the inner diameters of ACA were found to be 2.09 mm, SD = 0.27, SE = 0.01 and length 13.96 mm, SD = 1.4, SE = 0.08. The diameter is larger in males than in females (p < 0.01), and slightly larger in individuals older than 40 years old. The length is significantly larger in the population younger than 40 years old (p < 0.001) and slightly larger in the male population. The diameter of ACA in Kosovo's population is similar to the data from other authors from a different population [11, 19, 24, 25].

The anterior communicating artery (ACoA) arises from the ACA and is the important anastomosis because it connects the right and left ACA. Also, demarcates the junction between the pre and post communicating segment. The mean diameter of ACoA is (1.5, SD = 0.22, SE = 0.01) and length (2.74 mm, SD = 0.62, SE = 0.05). Compared with the studies published in other populations a greater difference was obtained in the values gained from the population of Kosovo [12, 15, 26, 27]. The largest diameter is observed in the male population younger 40 years old but without significant difference. The mean ACoA length in males is 2.6 mm SD = 0.59, while in females is 2.86 mm. The SD = 0.62 represents a significant difference p <0.01 though the length was no significant in the population younger than 40-year-old. These findings in our study are similar with that have been previously published [11, 19, 24, 25].

Thus, the diameters and lengths measured in our study are comparable with other brain-cadaver studies but especially with the MRA studies. The average diameters and lengths of ACA, PCA, MCA in males were significantly larger than females, and the average diameter of ACoA, BA, ICA were almost equal both on males and females, while the length of PCoA was significantly larger in females compared to males (p < 0.05).

Therefore, since the length of PCoA was significantly larger in females than males (p < 0.05). Maaly and Ismail showed that ICA, BA, ACA, PCOA have smaller diameters in subject older than 40 years old [19]. Stefani et al. found that the diameter of the ACA was equal in both groups [28]. While in our study the diameter of ICA, PCoA, BA in subject older than 40 years, were significantly smaller than in individuals younger than 40 years old. The diameters of the ACA, PCA, ACoA were equal in both groups while diameter and length of MCA and ACoA were larger in individuals older than 40 years old.

Thus, knowledge of the diameter and the length of the arteries of the circle of Willis have a great importance in interventional radiology for various endovascular interventions as well as during anatomy lessons.

The results of our study show that some dimensions of the vessels have statistically significant difference according to age and sex. On the future studies, we will include a larger number of examinations to create a database for dimensions of arteries of the circle of Willis in Kosovo's population.

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