Original Article

# Morphometric analysis of Willis circle arteries

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## ABSTRACT

**Introduction:** Willis arterial circle (circulus arteriosus cerebri Willisi) is the most important part of the collateral circulatory system of the brain. It functions in normal and pathological situations such as valvular mechanism and thus allows optimal blood supply of all parts of the brain tissue, which reduces the risk of transient ischemic attack (TIA) and stroke. The main pre-requisite for the normal function of the circle is its completeness and the lack of hypoplastic vessels. **Materials and Methods:** In this research, we used 100 angiograms of carotid system shown by serial angiography by Seldinger taken from the archives of the Department of Radiology, Clinical Center University of Sarajevo. For morphometric analysis of blood vessels, we used specially designed software program ELLIPSE (ViDiTo, Zoltan Tomoris, Kosice, Slovak Republic, tomori@saske.sk. In this way, it was possible to more easily store and analyze angiograms that were used for morphometric analysis. **Results:** In our study, larger diameters of blood vessels in Willis circle were observed in the younger subjects compared to older except the diameter of the internal carotid artery, which was about 0.2 to 0.3 mm larger in the older subjects. In both age groups among males, we recorded larger diameters of the internal carotid artery and segment before the circle of the posterior cerebral artery in relation to the female population, while the rear communicating artery in females was 0.1 mm wider in diameter compared to men in category of younger respondents.

## INTRODUCTION

As far back as in the 1658 originates the first description of the arterial ring at the base of the brain (circulus arteriosus cerebri Willisi), through the detailed description given by Tomas Willis in 1664th to date were conducted numerous studies related to this circle.[1,2]

Researchers agree that the circle of Willis is one of the most important parts of the collateral circulatory system of the brain. Collateral circulation has large functional and clinical significance. Under normal circumstances, at the level of the anastomotic cerebral vessels of Willis circle (for example communicating arteries), there is no mixing of blood because of hemodynamic balance between anastomotic arterial systems. However, in some states, there is a functional disturbance of this balance and transfer of blood from one system to another. Thus, during the flexion or especially extension of the head vertebral artery compression occurs, while during the lateral rotation, internal carotid artery or the common carotid artery compression occurs.[3] In the case of occlusion of some cerebral artery, the transfer of blood from one system to another can be much more intense. However, this transfer of blood may be minimal or completely absent if there are some anatomic variations. Variations such as aplasia, excessive hypoplasia ("string - like – vessels"), and lack of connection between individual components of the Wilson circle are the most significant factors because they cause anatomical and functional discontinuity of the Willis circle.

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Many previously conducted studies that have dealt with the measurement of blood vessels in the Willis circle showed that there is disagreement among researchers what may be declared hypoplastic blood vessel, which is extremely important in clinical practice in order to evaluate the status of cerebral circulation in case of certain neurosurgical procedures.

In recent years, to the assessment of hemodynamic status of cerebral circulation is devoted a lot of attention, while follow-up of the above situation is possible thanks to the application of many of the contemporary diagnostic procedures. One of the many common diagnostic procedures is MR-angiography,[4] serial angiography, and transcranial color Doppler.[5,6] By applying the last two mentioned methods in combination with a compression test on the internal carotid artery can be analyzed collateral circulatory cability of the Willis circle.

### Goal

The main objective of this work was to measure the diameters of blood vessels that are part of the Willis circle using specially designed software in people with normal cerebrovascular status.

## MATERIALS AND METHODS

As the material for this paper, we used 100 angiogram carotid area shown by serial angiography Seldingeru obtained by the Department of Radiology, Clinical Center University of Sarajevo. All subjects have been divided into two age groups, i.e. younger age group consisted of respondents aged 25-34 years (15 males and 25 females), while the second group consisted of patients aged over 60 years (30 males and 30 females). Because the symptoms that led them to report to the doctor (transient loss of consciousness and pain of various localization and intensity) leads to a working diagnosis of transient ischemic attack (TIA) following diagnostic tests were done. After serial angiography done in all these patients was established a normal cerebrovascular status. All patients during the recording during compression test was performed on the internal carotid artery, in order that on the opposite side show the front and rear communicating artery. All scans obtained were transferred to specially designed software 'program ELLIPSE (see, Zoltan Tomoris, Kosice, Slovak Republik, tomori@saske.sk [Figure 1]. So, was able to easily store images that are used for morphometric analysis.

Morphometric measurements were used to obtain information on the diameters of the blood vessels that form part of the circle of Willis circle of people with normal cerebrovascular status. For this measurement, Line System program was used. Measurements were performed on those scans that allowed the best visualization of certain blood vessels. For each blood vessel, three measurements were carried out to get the

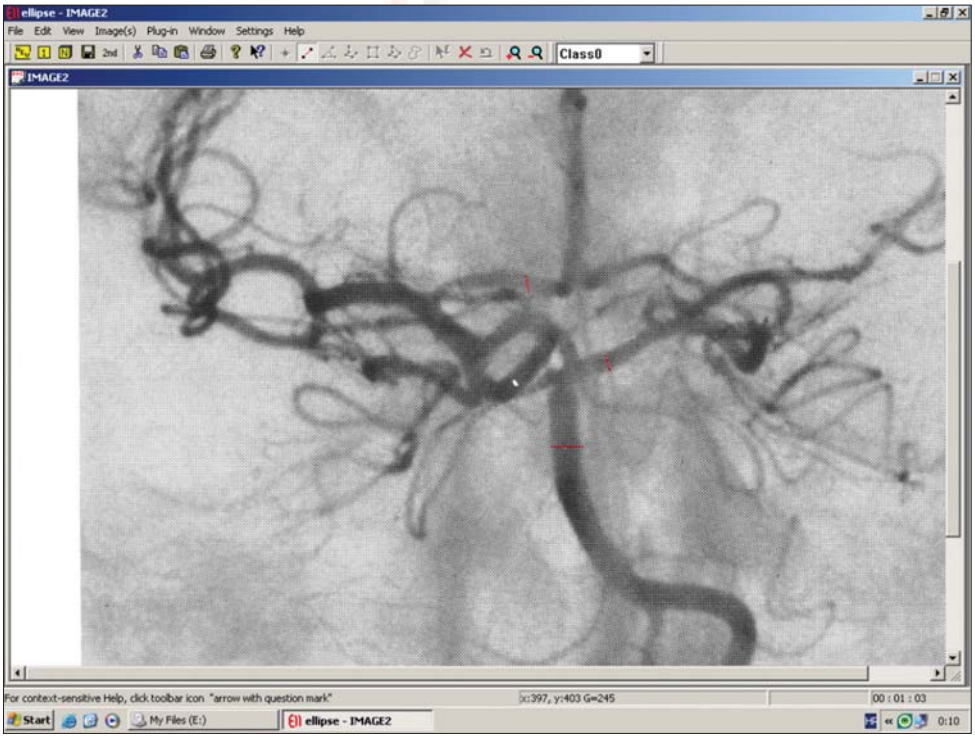


**Figure 1:** Presentation of the Ellipse software interface used for this research

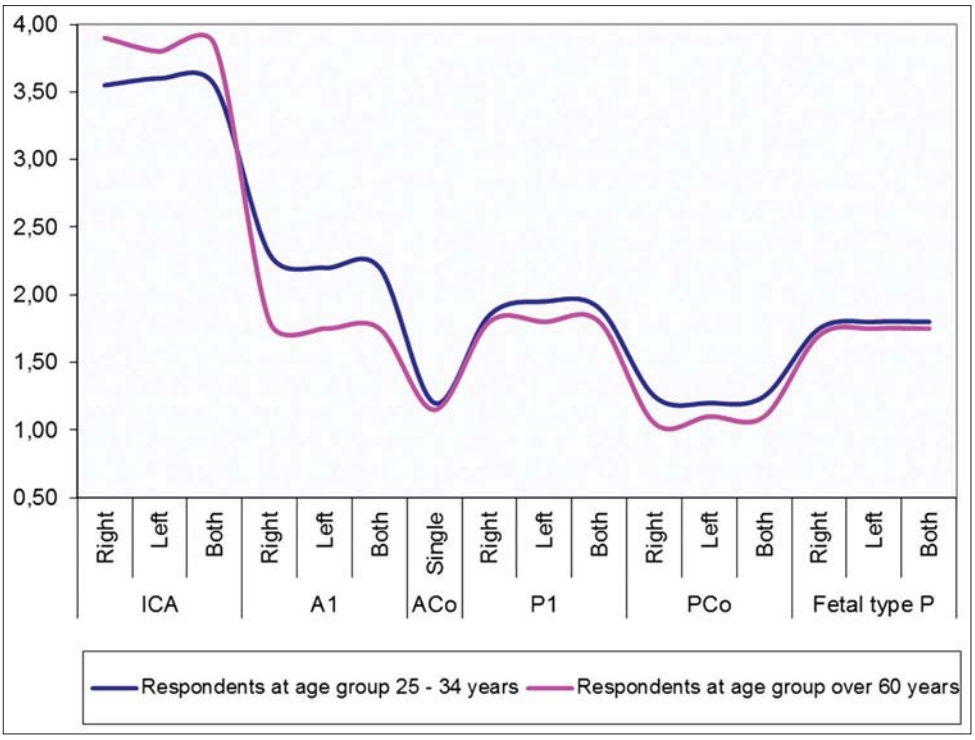


**Figure 2:** Presentation of blood vessel diameters in Willis circler in relation to age

average value. All data were processed by Statistica, and the results are shown by graphs and tables.

## RESULTS

The results obtained in this study are shown in Table 1 and represent a systematic review of the diameters of the blood vessels that form the Willis circle.

The table shows that the diameters of the blood vessels in Willis circle are larger for subjects in younger age group, except the diameter of the internal carotid artery, which in people aged over 60 years showed a larger diameter by 0.2-0.3 mm compared to the younger group of respondents. The level of significance of the presented results difference is $P < 0.001$.

Mutual fluctuations in the diameters of vessels showed by Figure 2 shows the mean value of the blood vessels diameters.

We can draw a conclusion that the highest variation in the recorded values are in the internal carotid artery in favor of the older respondents. Significant fluctuations in the values were observed in the A1 segment of the anterior cerebral artery, but in this case, in favor of the younger respondents. Other shown arteries as it was mentioned before had a larger diameters among younger participants, but the fluctuations in the values were not as pronounced.

**Table 1: Presentation of blood vessel diameters in Willis circler in relation to age**

| Blood vessels | Respondents at age group 25-34 years | | | Respondents at age group over 60 years | | |
|---|---|---|---|---|---|---|
| | Mean | Min. | Max. | Mean | Min. | Max. |
| ICA | | | | | | |
| Right | 3.55 | 3.40 | 3.70 | 3.90 | 3.80 | 4.00 |
| Left | 3.60 | 3.40 | 3.80 | 3.80 | 3.70 | 3.90 |
| Both | 3.55 | 3.40 | 3.70 | 3.85 | 3.80 | 3.90 |
| A1 | | | | | | |
| Right | 2.30 | 2.20 | 2.40 | 1.80 | 1.70 | 1.90 |
| Left | 2.20 | 2.10 | 2.30 | 1.75 | 1.70 | 1.80 |
| Both | 2.20 | 2.10 | 2.30 | 1.75 | 1.70 | 1.80 |
| ACo | | | | | | |
| Single | 1.20 | 1.10 | 1.30 | 1.15 | 1.10 | 1.20 |
| P1 | | | | | | |
| Right | 1.85 | 1.70 | 2.00 | 1.80 | 1.70 | 1.90 |
| Left | 1.95 | 1.80 | 2.10 | 1.80 | 1.70 | 1.90 |
| Both | 1.90 | 1.80 | 2.00 | 1.80 | 1.70 | 1.90 |
| PCo | | | | | | |
| Right | 1.25 | 1.20 | 1.30 | 1.05 | 1.00 | 1.10 |
| Left | 1.20 | 1.10 | 1.30 | 1.10 | 1.00 | 1.20 |
| Both | 1.25 | 1.20 | 1.30 | 1.10 | 1.10 | 1.10 |
| Fetal type P | | | | | | |
| Right | 1.75 | 1.70 | 1.80 | 1.70 | 1.60 | 1.80 |
| Left | 1.80 | 1.60 | 2.00 | 1.75 | 1.60 | 1.90 |
| Both | 1.80 | 1.70 | 1.90 | 1.75 | 1.70 | 1.80 |

Analyzing blood vessel diameters of the Willis circle in male and female respondents, whose presentation we give in Table 2, we can conclude that in both age

groups among males, slightly higher diameters of the internal carotid artery (0.1-0.2 mm) was recorded compared to the female population and higher values of the P1 segment of the posterior cerebral artery, while the rear communicating artery in females was 0.1 mm larger in diameter than in males within younger group of respondents. The level of significance of the presented results differences was $P < 0.001$.

**Table 2: Presentation of the mean diameters of the blood vessels of the Willis circle in relation to gender**

| Blood vessels | Respondents at age group 25-34 years | | Respondents at age group over 60 years | | Total | |
|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female |
| ICA | | | | | | |
| Right | 3.60 | 3.50 | 4.00 | 3.80 | 3.80 | 3.65 |
| Left | 3.70 | 3.50 | 3.80 | 3.70 | 3.75 | 3.60 |
| Both | 3.70 | 3.50 | 3.90 | 3.80 | 3.80 | 3.65 |
| A1 | | | | | | |
| Right | 2.30 | 2.30 | 1.90 | 1.80 | 2.10 | 2.05 |
| Left | 2.20 | 2.20 | 1.80 | 1.70 | 2.00 | 1.95 |
| Both | 2.20 | 2.20 | 1.80 | 1.80 | 2.00 | 2.00 |
| ACo | | | | | | |
| Single | 1.20 | 1.20 | 1.20 | 1.10 | 1.20 | 1.15 |
| P1 | | | | | | |
| Right | 2.00 | 1.70 | 1.90 | 1.70 | 1.95 | 1.70 |
| Left | 1.90 | 1.90 | 1.90 | 1.70 | 1.90 | 1.80 |
| Both | 2.00 | 1.80 | 1.90 | 1.70 | 1.95 | 1.75 |
| PCo | | | | | | |
| Right | 1.20 | 1.40 | 1.10 | 1.10 | 1.15 | 1.25 |
| Left | 1.20 | 1.20 | 1.10 | 1.10 | 1.15 | 1.15 |
| Both | 1.20 | 1.30 | 1.10 | 1.10 | 1.15 | 1.20 |
| Fetal type P | | | | | | |
| Right | 1.80 | 1.80 | 1.70 | 1.70 | 1.75 | 1.75 |
| Left | 1.90 | 1.70 | 1.90 | 1.80 | 1.90 | 1.75 |
| Both | 1.90 | 1.70 | 1.80 | 1.70 | 1.85 | 1.70 |

In the older group of patients are recorded by 0.1 mm larger values among males than in females.

Figure 3 illustrates the fluctuations in the diameters of blood vessel in the Willis circle among respondents of both genders. We can conclude that higher oscillations are recorded among male respondents and that the highest variations are seen in the values of the internal carotid artery diameter, as well as P1 segment of the posterior cerebral artery.

## DISCUSSION

Previous studies have shown disagreement among researchers about which diameters of the arteries in the Willis circle can be declared as hypoplastic.

In numerous anatomical studies, the claim is presented that every blood vessel with a diameter of 1 mm is considered as hypoplastic and that blood vessel is such condition cannot establish collateral circulation.[7-13] On the other hand, on the basis of clinical tests carried out in patients with occlusion of the internal

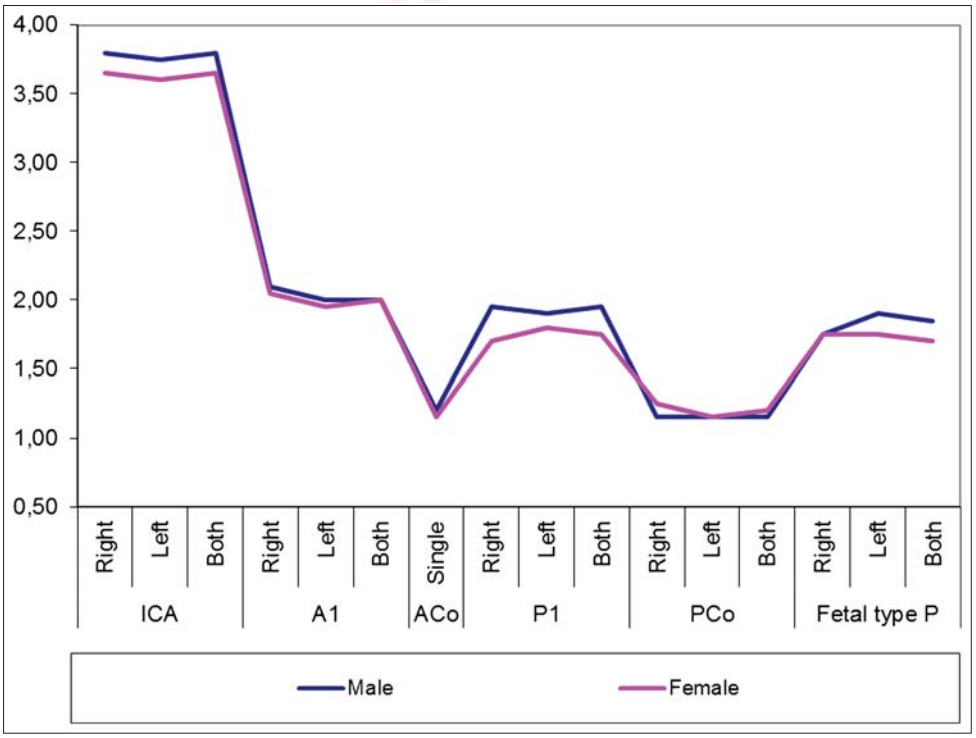


**Figure 3:** Presentation of the mean diameters of the blood vessels of the Willis circle in relation to gender

carotid artery and occlusion of the basilar artery, it was concluded that the increased risk of stroke exist in patients whose posterior communicating artery diameter was < 0.5 mm and these arteries should be considered as hypoplastic blood vessels.[14,15] In a small number of clinical studies is presented the fact that blood vessel with diameter of 0.5 mm is considered as hypoplastic blood vessel.[16,17]

Studies[18,19] which investigated hemodynamic ability of the Willis circle found that anterior cerebral artery with recorded diameter of 0.4 mm has the ability to establish collateral circulation. But, the same authors found that the patients with occlusion of the internal carotid artery who had a diameter of front and rear communicating artery ranging from <0.5 mm to 0.6 mm were not able to establish a collateral circulation and thus fed with blood ischemic area, which places an emphasis on studies in which it was stated that a much greater importance in the collateral circulation has completeness of the Willis circle because in this case, it has a protective role in the prevention of stroke in patients with occlusion of the internal carotid artery.[14,20-22]

It is also important to emphasize that the assessment of surgical intervention feasibility in case of the carotid arteries at the advanced state of the disease depends on the functional ability of the Willis circle.[19]

Based on morphometric measurements of the blood vessels in the Willis circle in people with normal cerebrovascular status conducted in our study, we came to the data that the blood vessel diameters are larger in younger than in older subjects and in male compared to female respondents. What has been shown in this study after the compression test is that the Willis circle functions as a valvular mechanism or in all cases have been recorded transfer of blood from one basin to another and all circles showed complete configuration. Accordingly, our study confirmed earlier studies which emphasize that the main prerequisite for the normal functioning which is the complete cerebral configuration of the Willis circle.[14,20-22] The size of the diameter of the analyzed blood vessels was not smaller than 1 mm and, therefore, we are not able to speak about hypoplastic vessels.

## CONCLUSIONS

By the analysis of patient's angiograms with normal cerebrovascular status, it is not possible to get a complete picture of the true hemodynamic capabilities of the Willis circle, because of that our further research will be directed toward analysis of angiograms of patients with various degrees of obstruction in the internal carotid artery.

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