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ORIGINAL ARTICLE

Medicine Science International Medical Journal

Medicine Science 2026;15(1):72-7

Anatomical variations of the circulus arteriosus cerebri (Circle of Willis): A computed tomography angiography study

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Received 01 June 2025; Accepted 05 July 2025
Available online 19 February 2026 with doi: 10.5455/medscience.2025.05.145

Abstract

This study primarily aims to examine the frequency of anatomical variations in the Circle of Willis (CW) among the Turkish population using computed tomography (CT) angiography. The study included CT angiography images of 298 patients in total, comprising 131 females and 167 males. The configurations of the anterior and posterior parts of the Circle of Willis (CW) were analyzed and categorized. The frequency of each variant, along with the number of complete anterior and posterior circles, was recorded. The most common CW variation was found in the posterior segment. In the posterior segment, posterior communicating arteries (PComA) hypoplasia was the most frequently observed variation in both males (right: 51, left: 54) and females (right: 49, left: 56), followed by bilateral PComA hypoplasia. The adult configuration was seen in 243 individuals (99 females, 144 males). The fetal configuration was identified in 46 individuals (29 females, 17 males), while the transitional configuration was found in 9 individuals (3 females, 6 males). CTA is a safe and simple method to map blood vessels. Knowing Circle of Willis variations can help plan surgeries and reduce stroke risk. Checking CW anatomy routinely may support better treatment decisions.

Keywords: Brain, Circle of Willis, variation, computed tomographic angiography

Introduction

The Circle of Willis (CW) is an arterial anastomotic system situated at the base of the brain. Its primary role is to preserve cerebral and cerebellar perfusion by compensating for diminished or obstructed blood flow in any of its contributing arteries. [1]. The CW ensures the continued perfusion of brain tissue by redirecting blood flow in the event of any pathological condition or during surgical interventions involving the major arteries supplying the brain [2,3]. The arterial circle is formed by contributions from the internal carotid arteries (ICA), anterior cerebral arteries (ACA), the anterior communicating artery (AComA), and their branches, collectively known as the "anterior circulation" or "carotid system." In contrast, the posterior circulation—also called the vertebrobasilar system—comprises the posterior cerebral arteries (PCA), posterior communicating arteries (PComA), basilar artery (BA), and vertebral arteries (VA) [3].

In neurologically healthy human populations, the prevalence of anatomical variations of the CW is estimated to be approximately 68.22%±14.32% [4,5]. An anatomical variation is characterized by two main criteria: (1) it originates from embryological development, and (2) it does not inherently lead to a pathological condition [6]. Anatomical variations in the CW can influence blood hemodynamics, thereby contributing to the development of aneurysms or strokes These variations are most commonly seen in the form of hypoplasia, where a vessel is too narrow to significantly contribute to collateral circulation; aplasia, where the vessel is completely absent; or as a duplication, where the vessel shows double branching [5]. The most commonly encountered variation is the hypoplasia of the PComA, which has been reported in 6-21% of the general population [7,8]. Although PComA hypoplasia is considered a risk factor in cases of ICA occlusion, studies have shown that it can also contribute to the risk of ischemic stroke even in individuals without ICA occlusion

CITATION
Er Ulubaba H, Ciftci R, Tasdemir R, Cihan OF. Anatomical variations of the circulus arteriosus cerebri (Circle of Willis): A computed tomography angiography study. Med Science. 2026;15(1):72-7.

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[9]. The hypoplasia of the A1 segment of the ACA is observed in approximately 1-21% of the healthy population. Studies have shown that A1 segment hypoplasia can lead to the formation and rupture of aneurysms in the AComA [10]. Hypoplastic or aplastic vessels observed in the Circle of Willis are of clinical significance, particularly in relation to aneurysm formation and surgical interventions [5,10].

This study aims to examine the anatomical variations of the Circle of Willis (CW) in the Turkish population and to provide data that may assist neurosurgeons and interventional neurologists in clinical practice.

Material and Methods

Patient Population

Prior to initiating the study, a power analysis was performed using G*Power software (version 3.1.7) to calculate the required sample size. It was determined that at least 112 subjects were necessary to ensure 80% power with a 95% confidence interval and an α value of 0.05. The study was conducted retrospectively using cranial computed tomography angiography (CTA) of 298 individuals who presented to the Department of Radiology at Gaziantep Islam Science and Technology University Faculty of Medicine for various reasons. The research was initiated following approval from the Ethics Committee for Non-Interventional Clinical Studies at Gaziantep Islam Science and Technology University (2023/240) (Decision No:240.25.17) (Application Date:30.05.2023).

Exclusion criteria were defined as poor image quality due to motion artifacts or inadequate contrast distribution, failure to capture the CW in the imaging field, or prior surgical or endovascular treatment of the brain vessels. No age restriction was applied. All measurements were performed by a single expert radiologist.

Imaging Protocol and Methods

The images of the patients included in the study were obtained from a dual-source spiral computed tomography angiography (CTA) scanner, the Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany, located at the Department of Radiology, X University Faculty of Medicine. The device was a 256-slice multislice CTA scanner. The dose was set at 120 kV and 35 mA.

Vessel diameters were measured in the axial plane using the institutional PACS (Picture Archiving and Communication System) software with a calibrated digital caliper tool. The diameters were obtained from the narrowest segment of each artery along a standard anatomical plane. Measurements below 1 mm were classified as hypoplastic in accordance with previous studies [11], and care was taken to avoid partial volume effects and motion artifacts. All measurements were conducted by a single experienced radiologist to ensure consistency.

The configurations of the vessels forming the CW were classified into three groups: adult, fetal, and transitional, and were assessed according to gender. When the diameter of the posterior communicating artery (PComA) is less than that of the P1 segment of the posterior cerebral artery (PCA), it is termed an adult configuration. Conversely, if the PComA diameter exceeds that of the PCA's P1 segment, it is classified as a fetal configuration. A transitional configuration is identified when the diameters of the PCA and PComA on the same side are equal or nearly equal [3] (Figure 1).

Additionally, the anterior and posterior vessels of the CW were evaluated separately for aplasia and hypoplasia. In the literature, if the diameter of a vessel in the CW is smaller than 1 mm, it is considered hypoplastic, and if the vessel is not visible at all, it is considered aplastic [3,12] (Figure 2) (Figure 3).

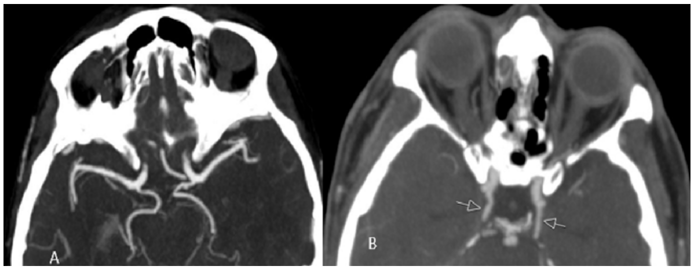


Figure 1. A. Fetal-type configuration of the posterior cerebral circulation. The right posterior communicating artery (PComA) is dominant and larger than the ipsilateral P1 segment of the posterior cerebral artery (PCA), while the P1 segment is aplastic. B. Transitional configuration. The diameters of the PComA and P1 segment of the PCA on the right side are nearly equal, indicating a transitional pattern between fetal and adult types

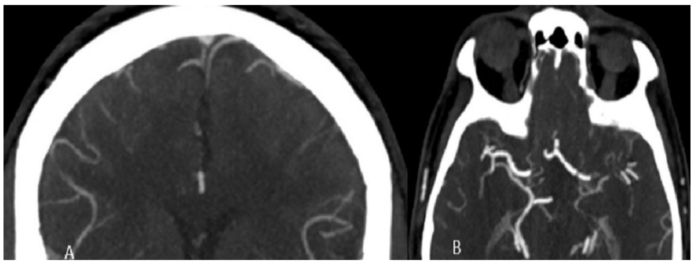


Figure 2. A. Right A1 segment of the anterior cerebral artery (ACA) shows hypoplasia, with a diameter less than 1 mm, limiting effective anterior cross-flow via the anterior communicating artery (AComA). B. Right A1 segment is aplastic, completely absent, resulting in unilateral ACA supply depending on contralateral flow through AComA

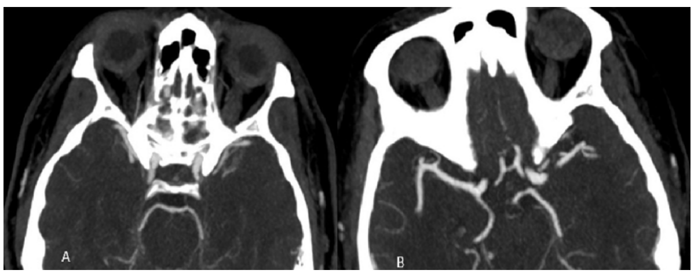


Figure 3. A. Bilateral absence (aplasia) of the posterior communicating arteries (PComAs), disrupting the potential for posterior-to-anterior collateral circulation. B. Aplasia of the right P1 segment of the posterior cerebral artery (PCA), with a patent PComA supplying the corresponding PCA territory (fetal-type configuration)

DOI: 10.5455/medscience.2025.05.145

Statistical Analysis

In addition to descriptive statistics, inferential statistical methods were used to evaluate the associations between CW configurations and sex. Specifically, chi-square tests were applied to compare categorical variables such as the presence of hypoplasia or aplasia between sexes. For comparing configuration types across more than two groups (e.g., adult, fetal, transitional), the Kruskal-Wallis test was used, given the non-parametric nature of the data. These analyses were conducted using SPSS version 22.0, and statistical significance was set at $p<0.05$.

Result

A total of 298 patients, including 131 (44%) females and 167 (56%) males, were included in the study with cranial CTA images. The average age was 57.44±11.16 years. Regarding the configuration of the CW, the adult configuration was observed in 99 females (33.22%) and 144 males (48.32%), totaling 243 individuals. The fetal configuration was identified in 29 females (9.73%) and 17 males (5.71%), totaling 46 individuals. The transitional configuration was found in 3 females (1%) and 6 males (2%), totaling 9 individuals. When examining the relationship between CW configurations and gender, males showed statistically significantly higher rates compared to females ($p<0.05$) (Table 1).

When examining the completeness of the CW, a complete polygonal structure was detected in 48 females (36%) and 35 males (21%), totaling 83 individuals (28%). A complete anterior circulation was observed in 93 females (71%) and 106 males (63.4%), totaling 199 individuals (66.7%). A complete posterior circulation was found in 35 females (26.7%) and 39 males (23.3%), totaling 74 individuals (25%) (Table 2).

When examining the anterior portion, the most common variation was AComA hypoplasia, observed in 37 individuals (12.4%), followed by AComA aplasia, seen in 28 individuals (9.3%). Combined A1 hypoplasia and aplasia were not observed in either gender, while the least common variations were left A1 hypoplasia and A1 aplasia, both found in 6 individuals (2%) (Table 3).

Table 1. Number and proportions of shapes seen in the vessels forming the Willis polygon

Gender	Adult configuration	Fetal configuration	Transitive configuration	Total	P
Woman	99 (33.2%)	29 (9.7%)	3 (1.0%)	131 (44.0%)	
Male	144 (48.3%)	17 (5.7%)	6 (2.0%)	167 (56.0%)	0.016
Total	243 (81.5%)	46 (15.4%)	9 (3.0%)	298 (100.0%)	

Table 2. The completeness of the Circle of Willis

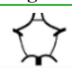
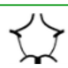
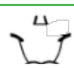
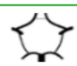
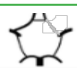
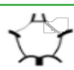
Variations	Figure	Woman	Male	Total
Complete polygonal configuration		48 (36%)	35 (21%)	83 (28%)
Complete anterior circulation		93 (71%)	106 (63.4%)	199 (66.7%)
Complete posterior circulation		35 (26.7%)	39 (23.3%)	74 (25%)

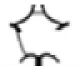
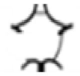
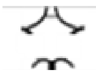
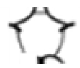
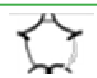
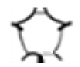
Table 3. Variations of the anterior section of the circle of Willis

Variations	Figure	Woman	Male	Total
Aplasia of the AComA		7 (5.3%)	21 (12.5%)	28 (9.3%)
Right (A1 aplasia)		3 (2.2%)	5 (2.9%)	8 (2.6%)
Left (A1 aplasia)		2 (1.5%)	4 (2.3%)	6 (2%)
Bilateral (A1 aplasia)		0	0	0
AcomA hypoplasia		15 (11.4%)	22 (13.1%)	37 (12.4%)
Right (A1 hypoplasia)		7 (5.3%)	8 (4.7%)	15 (5%)
Left (A1 hypoplasia)		4 (3%)	2 (1.1%)	6 (2%)
Bilateral (A1 hypoplasia)		0	0	0

DOI: 10.5455/medscience.2025.05.145

The most common variation in the CW was found in the posterior portion. In the posterior segment, PComA hypoplasia was most frequently observed, with a total of 100 individuals (33.5%) on the right side and 110 individuals (36.9%) on the left side, particularly in males (right: 51, left: 54). This was followed by bilateral PComA hypoplasia, seen in 57 individuals, with 30 males (17.9%) and 30 females (17.9%). The least common variations were P1 hypoplasia on the right (4 cases) and left (3 cases) in males, while left P1 aplasia (8 cases) was the least observed variation in females (Table 4).

Table 4. Willis polygon posterior section options

Variations	Figure	Woman	Male	Total
Right (PComA aplasia)		15 (11.4%)	21 (12.5%)	36 (12%)
Left (PComA aplasia)		13 (9.9%)	17 (10.1%)	30 (10%)
Bilateral (PComA aplasia)		10 (7.6%)	8 (4.7%)	18 (6%)
Right (P1 aplasia)		8 (6.1%)	6 (3.5%)	14 (4.6%)
Left (P1 aplasia)		5 (3.8%)	9 (5.3%)	14 (4.6%)
Right (PComA hypoplasia)		49 (37.4%)	51 (30.5%)	100 (33.5%)
Left (PComA hypoplasia)		56 (42.7%)	54 (32.5%)	110 (36.9%)
Bilateral (PComA hypoplasia)		27 (20.6%)	30 (17.9%)	57 (19.1%)
Right (P1 hypoplasia)		4 (3%)	0	4 (1.3%)
Left (P1 hypoplasia)		3 (2.2%)	0	3 (1%)

Discussion

The anatomical variations of the CW found in this series of brain samples represent those observed in the general population. According to the literature, the CW begins to take its shape around the 5th week of embryonic development. It has been reported that, in addition to the normal polygonal structure, variations can also occur, although the exact reasons and timing for the formation of these variations remain unclear [3,13]. In this study investigating Circle of Willis variations in the Turkish population, we observed that anatomical differences were more prevalent in the posterior circulation, with the posterior communicating artery (PComA) showing the greatest variability, and hypoplasia being the most common variation. The literature shows a consensus in studies where a vessel diameter of <1 mm is used as the criterion for diagnosing hypoplasia in cerebral vessels [14-16].

CW with all segments present and without any hypoplastic arteries is rarely observed in individuals, and in the literature, its prevalence ranges widely from 4.6% to 72.7% [14,17,18]. The wide range in prevalence can be attributed to differences in naming conventions, criteria for hypoplasia, and the inability to perform accurate measurements in some studies. In our study, we identified a complete polygonal structure in 28% of the cases.

Different studies in the literature have been conducted to determine the presence of a complete or incomplete polygonal structure in the CW, resulting in varying outcomes [5,8,19]. Kondori et al. reported in a study that the complete CW structure was observed in 21% of cases, a complete anterior circulation in 81%, and a complete posterior circulation in 21% [19], in another study, it was stated that the percentage of a complete CW was 22%, a complete anterior circulation was 81%, and a complete posterior circulation was 22% [20]. In this study, a complete CW configuration was observed in 28%, a complete anterior circulation was seen in 66.7%, and a completed posterior circulation was found in 25%. Studies examining CW variations according to gender have reported the prevalence of a complete CW in women as 52.8%, 46%, 50%, and 27.5%, while in men, it was reported as 42.6%, 37%, 40%, and 25.9% [5,21,22]. In this study, a complete CW was detected in 36% of females and 21% of males.

DOI: 10.5455/medscience.2025.05.145

When examined according to the CW configuration, the adult configuration has been reported in the literature at rates of 87%, 85%, and 84%. The fetal configuration was reported at 9%, 14%, and 13%, while the transitional configuration was observed at 4%, 2%, and 2% [3,23,24]. In this study, the adult configuration was detected in 81.5% of cases, the fetal configuration in 15.4%, and the transitional configuration in 3%, aligning with previously reported rates in the literature.

The variations of the CW are more frequent in the posterior portion of the polygon, with the most common variations occurring in the PComA (3,5,8) . In this study, consistent with the literature, the most frequent variation was observed in the PComA. Among the PComA variations, the most common were right and left PComA hypoplasia. At this point, our study supports the existing literature. However, there are studies that do not align with our findings, with some identifying aplasia as the most common variation. Li et al., in their study using CTA to examine cerebral vessels, reported PComA aplasia as the most frequent variation in the CW [25]. Another study, using the CTA technique to examine CW variations, found that the most frequent variation was PComA aplasia [26].

Being familiar with the most common variations of the CW and knowing their prevalence is of vital importance for clinicians. In one study, it was reported that PComA aplasia was found in 0.6% of normal brains, 1.5% in infarcted brains, and 3% in brains with aneurysms. The frequency of fetal PComA was found to be 15% in normal brains, 29% in infarcted brains, and 22% in aneurysmal brains. As a result, the study concluded that PComA aplasia, hypoplasia, and fetal PComA are more prevalent in cerebral occlusive patients and brains with aneurysms compared to normal brains [17].

In cases where certain arteries of the CW are very thin or completely absent, radiological intervention may become impossible. This obstructive condition is significant in cerebrovascular diseases and cerebrovascular surgery. In any surgical intervention for the treatment of these conditions, knowing the variations or anomalies of the CW is of critical importance. The presence of hypoplasia or aplasia in the PComA is considered an independent risk factor for ischemic cerebral infarction when the ICA is occluded [27,28]. On the other hand, A1 segment hypoplasia has also been reported as an important independent risk factor for complications such as AComA aneurysm and ACA infarction during and after surgery [10]. It has been reported that the presence of an incomplete CW may contribute to the development and rupture of intracranial aneurysms [4,29].

Beyond descriptive reporting, our study statistically confirmed a significantly higher prevalence of adult-type configurations in males (p=0.016), aligning with previous findings in similar demographic cohorts. The use of chi-square and Kruskal-Wallis tests helped us identify meaningful associations between sex and variation types, thereby lending quantitative support to the discussion. Furthermore, the prevalence values in our study closely mirror those reported in prior studies from Turkish and other populations, thereby enhancing the external validity of our findings.

Conclusion

CTA provides a non-invasive and reliable tool for preoperative vascular mapping. Knowledge of specific CW variations, such as PComA hypoplasia or A1 segment aplasia, is especially critical in surgical planning and risk stratification for ischemic stroke. Therefore, routine evaluation of CW anatomy in relevant clinical scenarios may contribute to more informed surgical decisions and better patient outcomes.

Conflict of Interests

The authors declare that there is no conflict of interest in the study.

Financial Disclosure

The authors declare that they have received no financial support for the study.

Ethical Approval

The study received ethical approval from the Ethics Committee for Non-Interventional Clinical Research at Gaziantep Islam Science and Technology University (2023/240) (Decision No:240.25.17) (Application Date:30.05.2023).

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