# Anatomical Variations of the Circle of Willis in Males and Females on 3D MR Angiograms

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## Abstract

**Objective:** The objective of the present work was to study the anatomical variations of the circle of Willis as regard its component vessels and their average diameters in a sample of adult Egyptians and to detect any sex-related differences in these variations.

**Material and Methods:** One hundred and twenty adult patients were observed (60 males and 60 females). They all had problems unrelated to any ischemic or vascular diseases, so they were considered as healthy control, concerning the morphology of the circle of Willis. In addition, ten cadavers' brains were obtained from the Anatomy department, Faculty of Medicine Ain Shams University for examination of the circle of Willis and for detection of any variations.

**Results:** The anatomical variations of the anterior part, posterior part and completeness of the circle were inspected. Also, the diameters of all component vessels were assessed.

The results indicated that, the anterior part of the circle was completed in 70% males and 75% females of the study sample. No statistically significant difference was detected between sexes. The most common variant of the anterior part was the single anterior communicating artery followed by the hypoplastic or absent anterior communicating artery.

The posterior part of the circle was completed in 48% males and 58% females. The most common variant was the bilateral posterior communicating arteries, followed by the unilateral posterior communicating artery. An entirely complete circle was found only in 45% of the entire population; and it was higher in the females than the in males. The vessels diameters were smaller in the females than in the males, except for the diameter of the posterior communicating artery. Cadavers' examination revealed six cases with complete circle, 3 cases of unilateral fetal posterior communicating and one case of absent posterior communicating artery.

**Conclusion**: The present study showed the amazing great variability of the anatomy of the circle of Willis in asymptomatic persons. Nevertheless, there were no marked differences between both sexes in most of the components and the mean diameters of the circle. Therefore, these anatomical variations have to be considered during radiological interpretation and would be reported in the current anatomy text to be aware of all these normal variations.

## Introduction

Circle of Willis is located in the interpeduncular fossa and joins the two internal carotid arteries with the basilar artery to ensure continued blood supply to vital nervous tissues in cases of occluded cerebral arteries (William *et al*., 1995; Ray *et al*., 2007 ), (Fig.1). The proximal segment of the anterior cerebral artery can provide hemispheric cerebral blood flow from the contralateral internal carotid if the anterior communicating artery is patent and the basilar artery can supply collateral flow to the anterior circulation through the proximal segment of the posterior cerebral artery with reversal flow through the posterior communicating artery (Schomer *et al*., 1994). Ability of the circle of Willis to redistribute blood flow depends on its component vessels (Miralles *et al*., 1995). Patients who suffered from occluded internal carotid artery (ICA) but their circle of Willis with efficient collateral circulation have a risk of strokes than those without such collaterals (Hoksbergen *et al*., 2003, Eftekhar *et al*., 2006). Vessels of the circle of Willis vary in caliber, being often

partially developed, sometimes even absent and about 60% of circles display anomalies (William *et al*., 1995). Higher prevalence of circle of Willis anomalies were detected in brains with signs of ischemic infarction (Hoksbergen *et al*., 2003). Identifying the functional collaterals of the circle of Willis assists in detection of patients with ICA stenosis at lower risk of strokes and transient ischemic attacks (Hederson *et al*., 2000; Hoksbergen *et al*., 2003). Knowledge of the collateral ability of the circle of Willis is important for neurosurgeons, vascular surgeons, and interventional radiologists when a procedure in the cerebral arteries is to be attempted (Hoksbergen *et al*., 2003). Magnetic resonance angiography is a non-invasive sensitive technique for detecting the anatomy of the circle of Willis (Stock *et al*., 1996). Three-dimensional time of flight magnetic resonance angiography (3D MRA) can provide valuable information regarding the collateral anatomy and function of the circle of Willis (Hoksbergen *et al*., 2003). Sex-linked variation in the circle of Willis was a point of controversy some authors proved statistically significant difference between the frequency of variations and sex (Horikoshi *et al*., 2002), but others excluded the relation between sex and variations (Macchi *et al*., 1996; Hartkamp *et al*., 1998 ). Accordingly, it was objective of the present work to study the anatomical variations of the circle of Willis as regard its component vessels and their average diameters in a sample of adult Egyptians and to detect any sex-related differences in these variations.

## Material And Methods

### Material

One hundred and twenty MR angiograms of adult patients (60 males and 60 females) of ages ranged between 40 –70 years (mean of 55 years) were obtained from the MRI unit, Ain Shams specialized hospital and Cairo centre for radiology. They all had problems unrelated to ischemic or vascular disease. Therefore, they were considered as healthy control as

regard the anatomy of the circle of Willis. Patients were not included in the study if they had a medical history suggesting possible ischemic disease (stroke, transient ischemic attacks and dementia). Moreover, patients were excluded if they had history of diabetes mellitus, hypertension, any vascular or heart disease. A written consent was taken from all patients for the research.

In addition, ten cadaveric brains were obtained from the Anatomy Department Faculty of Medicine, Ain Shams University for examination of the circle of Willis and for detection of any variations.

### Methods (Miralles *et al.,* 1995 ; Hederson *et al.,* 2000; Merkkola *et al.*, 2006,):

The patients were subjected to three-dimensional time of flight MR angiography of the circle of Willis by using 1.5 MR system. Imaging Parameters were 40/ 6.5; TR/ TE (time of repetition / time of echo), 20° flip angle, 200 x 150 mm field of view for the circle area, 225x 512 matrix, 0.67 x 0.39 mm pixel resolution, three signals acquired, 1.4 mm section thickness. The 3D time of flight MR angiographic sequence required 4 minutes 30 seconds.

All MR angiograms were assessed on a special workstation, by using maximum intensity projections as well as source images. All the component vessels of the circle of Willis were assessed by measuring the diameter on the individual transverse 3D time of flight sections. Vessels that showed at least 1 mm in diameter were considered as hypoplastic.

### Classification of variations of the circle of Willis ( Overbeeke *et al.,*1991):

*1-Anatomical variations in the anterior part of the circle of Willis* (Fig 2) The variants are:
a- Single anterior communicating artery; the ICA bifurcates into anterior and middle cerebral arteries.
b- Two (or more) anterior communicating arteries.
c- Medial artery of the corpus callosum arises from the anterior communicating artery.

d- Fusion of the anterior cerebral arteries over a short distance.

e- Anterior cerebral arteries form a common trunk and split distally into two postcommunicating segments.

f- The middle cerebral artery (MCA) originates from the internal carotid artery (ICA) as two separate trunks.

g- Hypoplasia or absence of the anterior communicating artery.

h- One precommunicating segment of an anterior cerebral artery is hypoplastic or absent.

i- Hypoplasia or absence of an ICA, the contralateral precommunicating segment of the anterior cerebral artery gives rise to both postcommunicating segments.

J- Hypoplasia or absence of an anterior communicating artery and the MCA arises as two separate trunks.

## 2-*Anatomical variations in the posterior part of the circle of Willis (Fig 3)*

The variants are:

a- Bilateral posterior communicating arteries present.

b- Posterior cerebral artery originates predominantly from the ICA. This variant is known as a unilateral embryonic or fetal type posterior cerebral artery.

c- Bilateral embryonic (fetal) type posterior cerebral arteries.

d- Unilateral posterior communicating artery present.

e- Hypoplasia or absence of both posterior communicating arteries.

f- Unilateral fetal type posterior cerebral artery and hypoplasia or absence of the precommunicating segment of the posterior cerebral artery (P1).

g- Unilateral embryonic (fetal) type posterior cerebral artery and hypoplasia or absence of the contralateral posterior communicating artery.

h- Unilateral embryonic (fetal) type posterior cerebral artery and hypoplasia or absence of both a precommunicating segment (P1) of the posterior cerebral artery and the posterior communicating artery.

i- Bilateral embryonic (fetal) type posterior cerebral arteries with hypoplasia or absence of both precommunicating segments. of the posterior cerebral arteries (P1).

j- Bilateral embryonic (fetal) type posterior cerebral arteries, with hypoplasia or absence of one precommunicating segment of a posterior cerebral artery.

## 3-*Anatomical variations of the whole circle of Willis*

A-The circle as a whole was considered complete when all vessel segments of both the anterior and the posterior part of the circle were visible and continuous (Fig.1) and demonstrated diameters of at least 1 mm.

B- The circle was considered incomplete when both anterior and posterior vessels demonstrated a hypoplastic or absent segment.

C- The partially complete circles demonstrated either anterior or posterior hypoplastic or absent segment.

### Diameters of the vessels

Average diameter measurements for each of the component vessels were measured for both sexes and the hypoplastic vessels were excluded from mean diameter calculations.

### Statistical analysis:

All measures were averaged, mean and standard deviations were analyzed using student's $t$ -test. P values $\leq 0.05$ was considered significant.

## Results

### 1-Anatomical variations in the anterior part of the circle of Willis (Table 1)

The most common variation of the anterior part of the circle of Willis was the presence of two anterior cerebral arteries with single anterior communicating artery. It was 58.3% in males and 55% in females. (Table1:a, Fig.4). Two anterior communicating arteries were present in 11.7% males and 11.7% females (Table1,b, Fig.5).

Medial artery of the corpus callosum that arises from the anterior communicating artery was not found in the present study (Table1,c). Fusion of the anterior cerebral arteries over a short distance was found in 5% males and 3.3% females (Table1,d, Fig.6). Anterior cerebral arteries formed a common trunk and split distally into two postcommunicating segments was found in 3.3% in males and 5% in females (Table1,e, Fig.7).

Middle cerebral artery (MCA) originates from the internal carotid artery (ICA) as two separate trunks was not found in this study (Table1,f). Hypoplasia or abse-nce of the anterior communicating artery was detected in 15% males and 20% fem-ales; so this was the next common variation after type a variation (Table1,g, Figs.8,9). Single precommunicating segment of an anterior cerebral artery was hypoplastic or absent detected in 6.7% males and 5% females (Table1,h, Fig.6). Hypoplasia or absence of an ICA, the contralateral prec-ommunicating segment of the anterior cerebral artery gives rise to both postco-mmunicating segments of the ICA was not detected in this work (Table1,i). Hypoplasia or absence of an anterior communicating artery and the MCA arises as two separate trunks was also not detected  (Table1,j).

Therefore, males were more likely to have variations in the anterior part of the circle than the females, though this was not clinically significant.

## 2-Anatomical variations in the posterior part of the circle of Willis (Table 2)

The commonest variation of the posterior part of the circle was the presence of bilateral posterior communicating arte-ries. It was found in 30% males and 26.6% females (Table 2,a Fig.4). Posterior cerebral artery originates predominantly from the ICA, which is known as a unilateral embr-yonic (fetal) type posterior cerebral artery was detected in 16.7% males and 20% fem-ales (Table2,b). Bilateral embryonic (fetal) type posterior cerebral arteries were found in 1.7% males and 8.3% females (Table 2,c Fig.7). Unilateral posterior communicating artery was present in 21.7% males and 20%

females (Table 2,d) so it was the next common variation in the posterior part. Hypoplasia or absence of both posterior communicating arteries was detected in 13.3% males and 11.7% females (Table 2,e Figs. 8,9). Unilateral fetal type posterior cerebral artery and hypoplasia or absence of the precommunicating segment of the post-erior cerebral artery were detected in 3.3% males and 1.7 females (Table 2,f). Unilateral fetal type posterior cerebral artery and hypoplasia or absence of the contralateral posterior communicating artery were noticed in 6.7% males and 8.3% females (Table 2,g). Unilateral fetal type posterior cerebral artery and hypoplasia or absence of both a precommunicating segment of the posterior cerebral artery and the posterior communicating artery of the other side were detected in 3.3% males and 1.7% females (Table 2,h Figs. 6,10). Bilateral embryonic (fetal) type posterior cerebral arteries with hypoplasia or absence of both precommunicating segments of the posterior cerebral arteries were detected in 3.3% males and 1.7% females (Table 2,I Fig.7). Bilateral fetal type posterior cerebral arteries with hypoplasia or absence of one precommunicating segment of a posterior cerebral artery were not noticed in both sexes (Table 2,j).No statistically significant difference was detected in the variations of the posterior part in both sexes.

## 3-Anatomical variations in the whole circle of Willis (Table3)

Along with the whole subjects, 45% demonstrated complete circle of Willis. A complete circle was encountered more in females (50%) than males (40%). Males exhibited a slightly higher percentage of partially complete circles (41.7%) and incomplete circles (18.3 %) than females (35% and 15% respectively); however, these differences were not statistically significant.

## 4-Sex-related differences in the vessel diameters (Table4)

Mean diameters of the male vessels was larger than the female vessels. While

the posterior communicating artery tended to be larger in females (Table 4).

**5- Variations in the circle of Willis of the cadavers**

Cadavers' examination revealed six cases with complete circle with single anterior communicating and bilateral posterior communicating arteries (Fig.11). In addition, 3 cases of unilateral fetal posterior communicating artery were found (Fig.12). One case of absent posterior communicating artery was detected but the circle was injured before photography.

**Table (1): Prevalence of variants in the anterior part of the circle of Willis**

| Group | Prevalence of variants | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | f | g | h | i | j |
| Male (n = 60) | 35 (58.3%) | 7 (11.7%) | 0 (0%) | 3 (5%) | 2 (3.3 ) | 0 (0%) | 9 (15%) | 4 (6.7%) | 0 (0%) | 0 (0%) |
| Female (n = 60) | 33 (55%) | 7 (11.7%) | 0 (0%) | 2 (3.3%) | 3 (5%) | 0 (0%) | 12 (20%) | 3 (5%) | 0 (0%) | 0 (0%) |

Note:. The anterior circle variants (a-j) refer to those shown in figure (2).

**Table (2): Prevalence of variants in the posterior part of the circle of Willis**

| Group | Prevalence of variants | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | a | b | c | d | e | f | g | h | i | j |
| Male (n =60) | 18 (30%) | 10 (16.7%) | 1 (1.7%) | 13 (21.7%) | 8 (13.3%) | 2 (3.3%) | 4 (6.7%) | 2 (3.3%) | 2 (3.3%) | 0 (0%) |
| Female (n =60) | 16 (26.7%) | 12 (20%) | 5 (8.3%) | 12 (20%) | 7 (11.7%) | 1 (1.7%) | 5 (8.3%) | 1 (1.7%) | 1 (1.7%) | 0 (0%) |

Note: The posterior circle variants (a-j) refer to those shown in figure (3).

**Table (3): Prevalence of the type of the circle of configuration as a whole, complete, partially complete or incomplete**

| Group | Entirely complete | Partially complete | Incomplete |
|---|---|---|---|
| Male (n = 60) | 24 (40%) | 25 (41.7%) | 11 (18.3 %) |
| Female (n = 60) | 30 (50%) | 21 (35%) | 9 (15%) |
| All subjects (n = 120) | 54 (45 %) | 46 (38.3%) | 20 (16.7%) |

**Table (4): Mean vessel diameters according to sex**

| Vessel | Vessel diameter (mm) ± SD | |
|---|---|---|
| | Male | Female |
| P1(The precommunicating segment of post. cerebral a) Right | 1.9 ± 0.06 | 1.7 ± 0.05 |
| Left | 1.9 ± 0.07 | 1.7 ± 0.04 |
| Both right and left | 1.9 ± 0.06 | 1.7 ± 0.04 |
| P2 (The postcommunicating segment of post. cerebral a) Right | 1.9 ± 0.03 | 1.8 ±0.03 |
| Left | 1.9 ± 0.04 | 1.8 ± 0.04 |
| Both right and left | 1.9 ±0.03 | 1.8 ±0.03 |
| PCo (posterior communicating artery) Right | 1.1 ± 0.01 | 1.2 ±0.02 |
| Left | 1.1 ± 0.01 | 1.2 ± 0.01 |
| Both right and left | 1.1 ± 0.01 | 1.2 ± 0.01 |
| ICA (internal carotid artery) Right | 4.0 ±0.08 | 3.8 ±0.07 |
| Left | 3.8 ±0.06 | 3.7 ±0.06 |
| Both right and left | 3.9 ±0.07 | 3.8 ±0.06 |
| A1(precommunicating segment of ant. cerebral a) Right | 1.9 ±0.04 | 1.8 ±0.05 |
| Left | 1.8 ±0.05 | 1.7 ± 0.06 |
| Both right and left | 1.8 ±0.04 | 1.8 ±0.06 |
| ACo (anterior communicating artery) | 1.2 ± 0.02 | 1.1 ±0.02 |

$P < 0.05$ is significant.

**LEGEND**
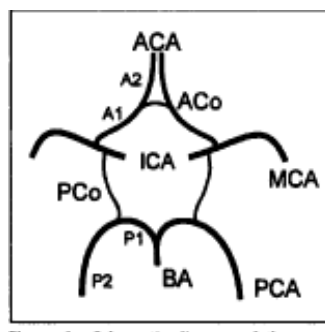


**Fig. (1):** Schematic diagram of the vessels that form the circle of Willis. The precommunicating segments (A1) of the right and left anterior cerebral arteries (ACA) and an anterior communicating artery (ACO) between them form the anterior part of the circle. The pre-communicating segments (P1) of the right and left posterior cerebral arteries (PCA) form the posterior part of the circle together with the right and left posterior communicating arteries (PCO). The postcommunicating portions of the anterior and posterior cerebral arteries are A2 and P2, respectively. BA = basilar artery, MCA = middle cerebral artery (after Hartkampe *et al.*, 1998).
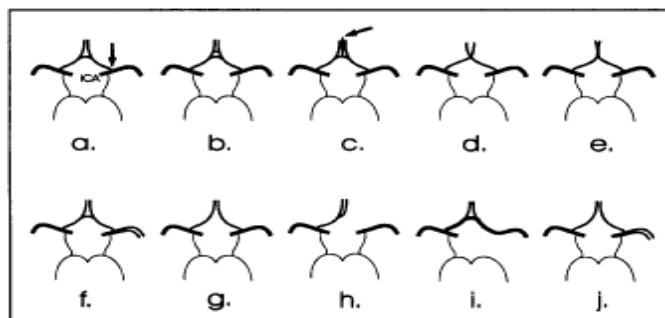
**Fig. (2):** Schematic diagram of the anatomical variations in the anterior part of the circle of Willis. (a) a single anterior communicating artery. The ICA bifurcates (arrow) into the precommunicating segment of the anterior cerebral artery and the MCA. (b) Two (or more) anterior communicating arteries. (c) Medial artery (arrow) of the corpus callosum arises from the anterior communicating artery. (d) Fusion of the anterior cerebral arteries over a short distance. (e) Anterior cerebral arteries form a common trunk and split distally into two postcommunicating segments. (f) MCA originates from the ICA as two separate trunks. (g) Hypoplasia or absence of an anterior communication. (h) One precommunicating segment of an anterior cerebral artery is hypoplastic or absent, the other precommunicating segment gives rise to both postcommunicating segments of the anterior cerebral arteries. (i) Hypoplasia or absence of an ICA. The contralateral precommunicating segment of the anterior cerebral artery gives rise to both postcommunicating segments. (j) Hypoplasia or absence of an anterior communicating artery and the MCA arises as two separate trunks (after Hartkampe *et al.*, 1998).
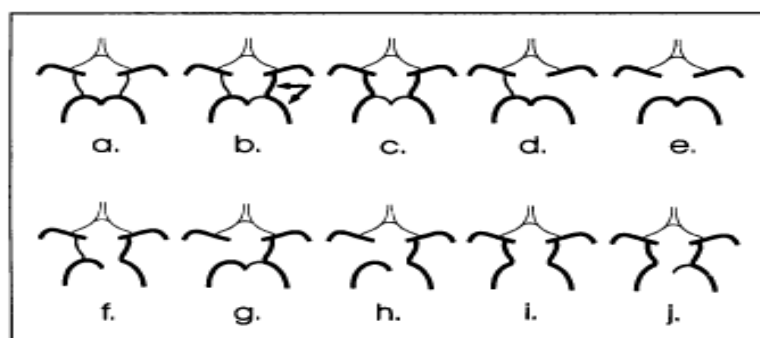


**Fig. (3):** Schematic diagram of the anatomical variations in the posterior part of the circle of Willis. (a) Bilateral posterior communicating arteries present. (b) Posterior cerebral artery originates predominantly from the ICA. This variant is known as a unilateral embryonic (fetal) type posterior cerebral artery (arrows). (c) Bilateral embryonic type posterior cerebral arteries. (d) Absence of one posterior communicating artery. (e) Hypoplasia or absence of both posterior communicating arteries. (f) Unilateral fetal type posterior cerebral artery and hypoplasia or absence of the precommunicating segment of the posterior cerebral artery. (g) Unilateral fetal type posterior cerebral artery and hypoplasia or absence of the contralateral posterior communicating artery. (h) Unilateral fetal type posterior cerebral artery and hypoplasia or absence of both the precommunicating segment of the posterior cerebral artery and the posterior communicating artery. (i) Bilateral fetal type posterior cerebral arteries with hypoplasia or absence of both precommunicating segments of the posterior cerebral arteries. (j) Bilateral fetal type posterior cerebral arteries with hypoplasia or absence of one precommunicating segment of a posterior cerebral artery (after Hartkampe *et al.*, 1998).
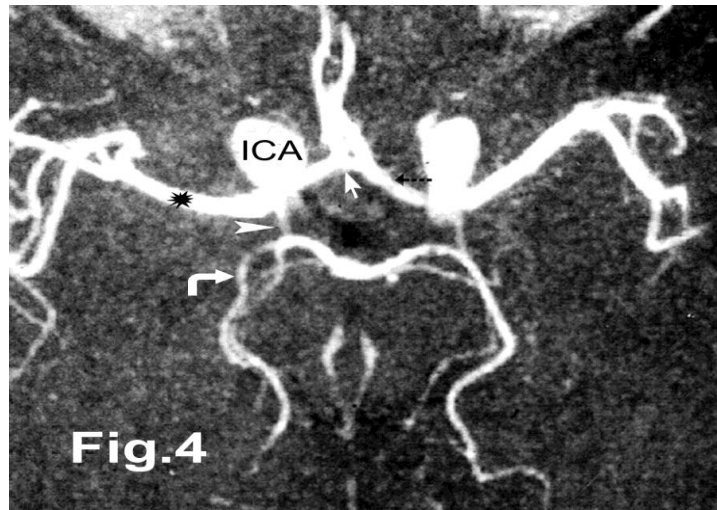
**Fig. (4):** Magnetic resonance (MR) angiogram of complete circle of Willis in 40-years old male showing internal carotid a (ICA) dividing into the ACA (dotted arrow) and the MCA (*). Notice the single ACO (arrow), the two PCO (arrow head) and the PCA (curved arrow).
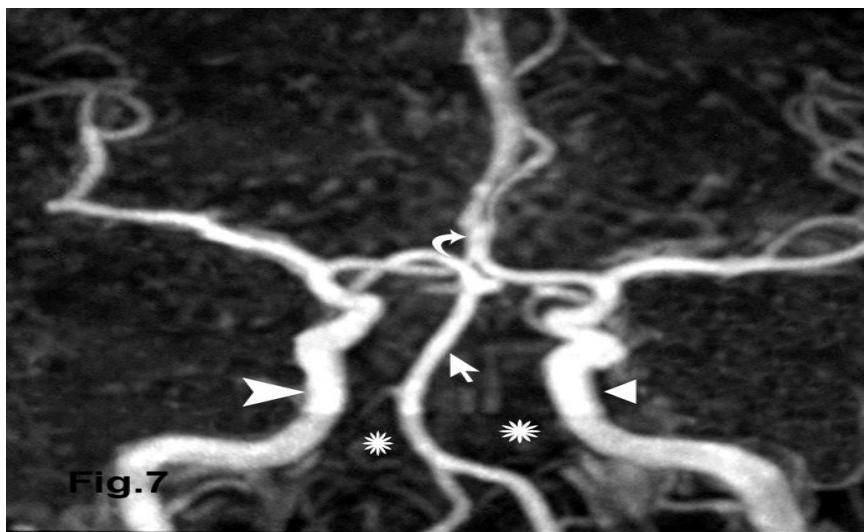


**Fig.(5):** MR angiogram of a circle of Willis in 42-years old female showing double anterior communicating arteries (arrows). Notice the absent posterior communicating artery (double arrows).
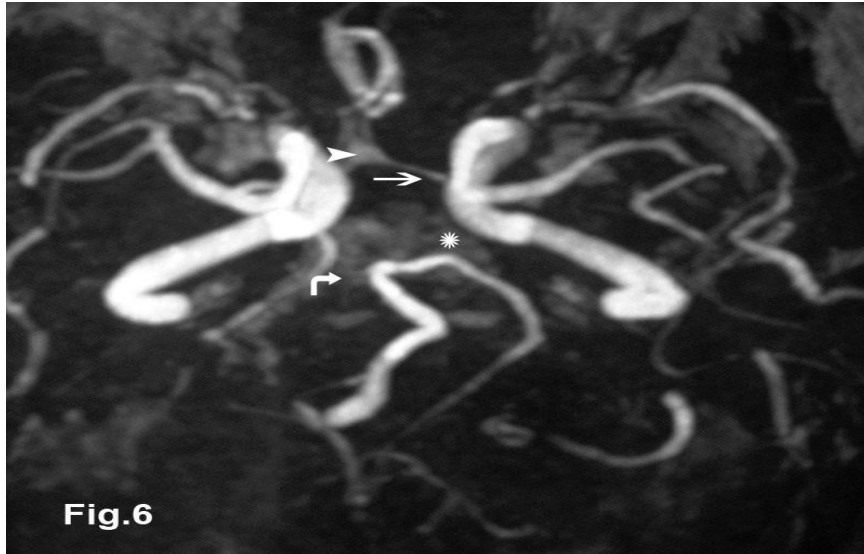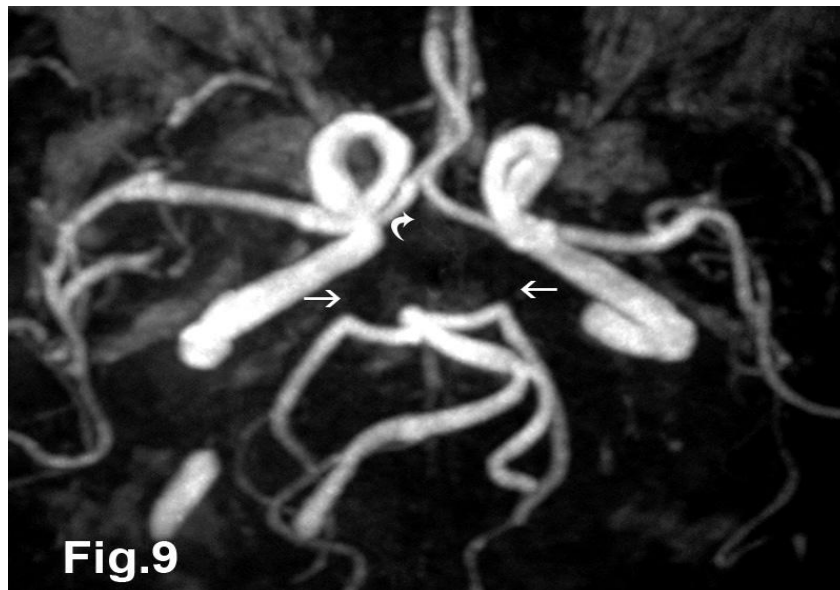
**Fig. (6):** MR angiogram of a circle of Willis in 76-years old female showing fused anterior communicating arteries forming short trunk (arrowhead) and the two ant. cerebral arteries arising from it. Notice the hypoplastic precommunicating part of the ant. cerebral artery (arrow), absent posterior communicating artery (*) and the fetal posterior communicating artery of the other side with the hypoplastic precommunicating part of the posterior cerebral artery (P1) (curved arrow).
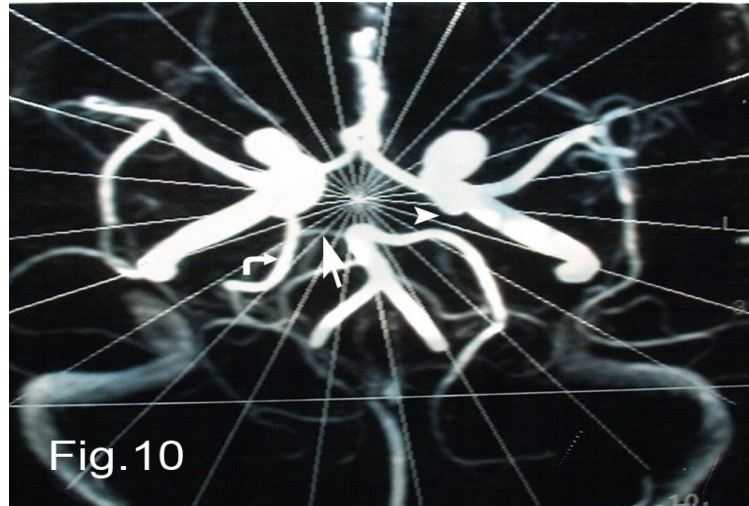


**Fig. (7):** MR angiogram of a circle of Willis in 52-years old male showing the anterior cerebral arteries forming a common trunk and split distally into two postcommunicating segments (curved arrow). Notice the bilateral fetal cerebral arteries (arrowheads) with the bilateral absent P1 (*) and the basilar artery ascends upward and bifurcates into two divisions (arrow).

**Fig. (8):** MR angiogram of a circle of Willis in 53-years old male showing absent anterior communicating artery.



**Fig (9):** MR angiogram of a circle of Willis in 76-years old male showing absent anterior cerebral artery (curved arrow). Notice the bilateral absent posterior communicating arteries (arrows).

**Fig. (10):** MR angiogram of a circle of Willis in 40-years old female showing absent posterior communicating artery (arrowhead). Notice the fetal posterior cerebral artery (curved arrow) with the hypoplastic P1(arrow).
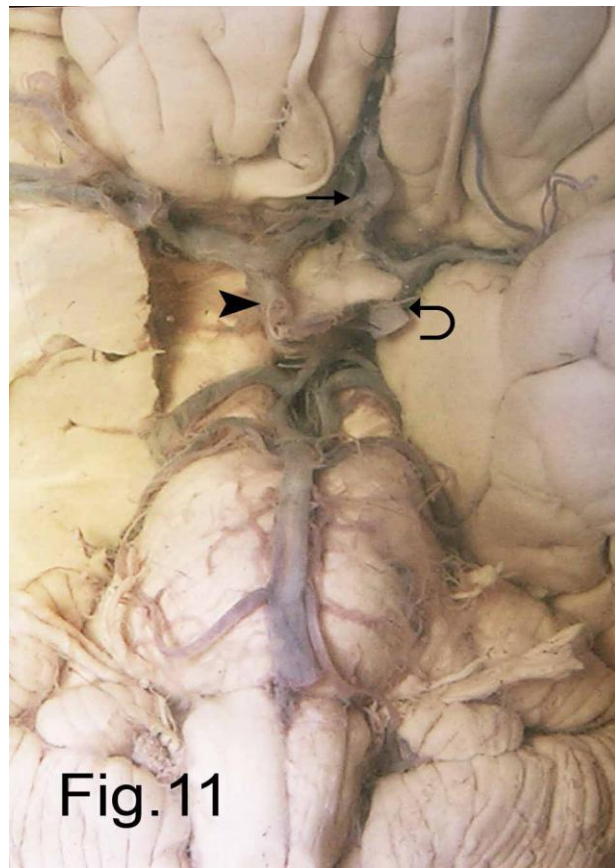


**Fig. (11):** A photograph of a cadaveric brain showing circle of Willis. The circle is complete with single anterior communicating artery (arrow) and the posterior communicating artery. Note the internal carotid (arrowhead).
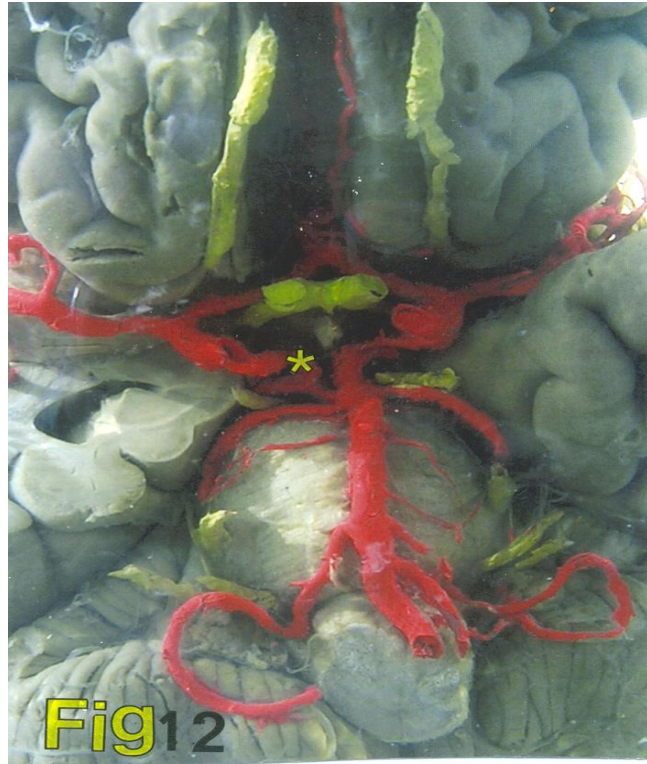
**Fig. (12):** A photograph of a cadaveric brain showing circle of Willis after red latex injection (from the anatomy museum). The circle has right fetal posterior communicating artery (↑).

## Discussion

Basic knowledge of the hemodynamic integrity of the circle of Willis is important as its collaterals influence the clinical outcome of patients with internal carotid artery occlusion (Capua *et al,.* 2000 and Hoksbergen *et al*., 2003 ). In the present work, anatomical variations of the circle of Willis and the correlation between sex and these variations were studied.

**1-Anatomical variations in the anterior part of the circle of Willis**

In this study, the commonest variation in the anterior part of the circle of Willis was the presence of complete arteries with single anterior communicating artery. It was 58.3% in males and 55% in females. This was nearly in agreement with Hori-koshi *et al.* (2002) who detected a higher percentage of complete circles (66.8% in males and 57% females) in control patients.

The next common variation in the present study was hypoplasia or absence of the anterior communicating artery; it was 15% in males and 20% in females. Similar result was reported by prior studies (Hartkamp *et al.,* 1998, Hartkamp *et al*., 1999 and Merkkola *et al*., 2005). In contrary Eftekhar *et al*. (2006) found only one case in their study to 102 brains.

Two anterior communicating arteries were detected in 11.7% in males and females. Macchi *et al*. (1996) accounted a slight lower result (9%) in their MRA study on 100 healthy subjects. Other variations in the anterior part were nearly similar to the Hartkamp *et al.* (1998) and Hartkamp *et al.* (1999) studies.

In the current work, males were more likely to have variations in the anterior part of the circle than females, though this was not statistically significant. This was in

accordance with Horikoshi *et al.* (2002) who concluded that there was a slight higher tendency in males to have variations in the anterior part of the circle than females.

## 2-Anatomical variations in the posterior part of the circle of Willis

In the present study, the commonest variation of the posterior part of the circle was the presence of bilateral posterior communicating arteries. It was found in 30% males and 26.6% females followed by unilateral posterior communicating artery that was detected in males(21.7%) and females (20%.) Hartkamp *et al.* (1998) reported comparable results. Fetal type posterior cerebral artery was detected in 16.7% males and 20% females. This was nearly in agreement with Eftekhar *et al.* (2006) and Hoksbergen *et al.* (2003) who assumed that fetal origin of the posterior cerebral artery was the commonest variation after the ordinary circles. In the current work, bilateral fetal type posterior cerebral arteries were found in 1.7% males and 8.3% females. Overbeeke *et al.* (1991) described in their study that the circle of Willis was fully formed at 7 weeks of gestational age and they classified its configuration into, the transitional pattern which was noticed in early gestational age (in which the diameter of the posterior communicating artery (PCO), equal to the diameter of the posterior cerebral artery PCA), with development of the fetus; this form would be changed into either the adult form (in which the diameter of PCO is lesser than the size of the PCA) or to the fetal form (in which the size of the PCO is wider than that of the precommunicating part (P1) of PCA). Vasovic *et al.* (2002) proved that in the fetal form, the posterior communicating part of the posterior cerebral artery (P2) originated from the internal carotid artery, by showing that the sympathetic fibers around P2 were continuous with those from the internal carotid artery and not with the fibers around the basilar artery.

Many studies tried to explain the occurrence of the fetal type of the posterior cerebral artery.Former study by Milenkovic

*et al.* (1985) denoted that at the age of 22nd-24th week of gestational age there were rapid growth of the occipital lobes that demanded an increase in the vasculature of these lobes and that the afferent arteries enlarged to satisfy that demand so the adult form or the fetal form might developed from the transitional form. They added that the preference for an increase in the size of either one of P1 or PCO depended on the most favorable hem-odynamic situation. Other study by Vasovic *et al.* (2002) postulated that genetic factors were probably responsible for the fetal characteristics of the posterior cerebral artery.

Other variations in the posterior part of the circle were nearly similar to the former studies (Macchi *et al.,* 1996, Hartkamp *et al.,* 1999 and Horikoshi *et al.,* 2002). In the current work, no statistically significant difference were detected in variations in the posterior part in both sexes. On the contrary, Horikoshi *et al.* (2002) indicated a statistically significant tendency of the females to have variations in the posterior part of the circle.

## 3-Anatomical variations of the whole circle of Willis

This work showed that 45% of the whole subjects demonstrated a complete circle of Willis. Complete circles were encountered more in females (50%) than in males (40%). Horikoshi *et al,* (2002) detected that the occurrence of complete circles was slightly higher in females than in males.

This study revealed that males exhibited a slight higher percentage of partially complete circles (41.7%) and incomplete circles (18.3 %) than females (35% and 15% respectively) however, these differences were not statistically significant. These results were parallel with other researchers (Macchi *et al.,* 1996, and Hartkamp *et al.,* 1998 ) who found no statistically significant difference in the frequency of variation between both sexes.

## 4-Sex-related differences in the vessel diameters

In the current work, the mean diameters of the male vessels were larger than the female vessels. While the posterior

communicating artery tended to be larger in the females. These results completely coincided with Hartkamp *et al.* (1999) and Horikoshi *et al.* (2002).

### 5-Variations in the circle of Willis of the cadavers

Cadavers' examination revealed six cases with complete circle. In addition, 3 cases of unilateral fetal posterior communicating artery and one case of hypoplastic posterior communicating artery were detected. This result compared well with Eftekhar *et al.* (2006) who studied 102 brains and reported that more than 58% of them had complete circles and they recorded that 11% had hypoplastic posterior communicating artery and 27% of cases demonstrated fetal posterior cerebral arteries.

**In conclusion,** the present study showed the amazing great variability of the anatomy of the circle of Willis in asymptomatic persons. Nevertheless, there were no marked differences between both sexes in most of the components and the mean diameters of the circle. Therefore, these anatomical variations have to be considered during radiological interpretation and would be reported in the current anatomy text to be aware of all these normal variations.

### Acknowledgment

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# الاختلافات التشريحية في حلقة ويليس فى الذكور و الاناث باستخدام الرنين المغناطيسى ثلاثى الأبعاد لرسم الأوعية الدموية

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الهدف من العملِ الحالي هو دراسة الإختلافات التشريحيةَ لحلقة ويليس من حيث الأوعية الدموية المكوّنة لها ولأقطارها المتوسطة فى اشخاص مصريين بالغين ، و معرفة مدى حدوث هذه الاختلافات فى كلاً من الذكور والإناث.

وقد تم فحص و دراسة مائة و عشرون رسم مغناطيسى للأوعية الدموية لأشخاص بـالغين(٦٠ مـن الـذكور و ٦٠ مـن الأنـاث ) تم فحصـهم لأسبابُ غيرمتعلقة بـاى أمـراض وعائية، لذا فقد إعتبروا اشخاصا طبيعيين بما يَتعلّقُ بشكل حلقة ويليس. بالأضافة الى ذلك فقد تم الحصول على أمخاخ عشر جثث من قسم التشريح, كلية الطب, جامعة عين شمس لدارسـة الإختلافـات التشـريحية للأجزاءِ الأماميـة والخلفيةِ للحلقـة والحلقـة ككل فى كـل العينات.

و قد وجد الجزء الأمامى للدائرة كاملا في ٧٠ ٪ من الذكور و٧٥ ٪من الإناث لأفراد الدراسة. ولم توجد فيه أختلافات احصائية بين الجنسين .وكان الإختلاف الأكثر شيوعاً فى الجزءِ الأمامى هو وجود شريان موصل أمامى وحيد تلاه ضمور أو غياب لهذا الشريان.

أمـا الجزء الخلفي للدائرةِ فكَانَ كـاملا في ٤٨ ٪ للذكور و ٥٨ ٪ للإنـاث من أفراد الدراسة. وكان الإختلاف التشريحي الأكثر شيوعاً هو وجود شريانين موصلين خلفيين ، تَلاه غياب أحد هذين الشريانين.و أما الحلقـة الكاملـة ككل فوُجِدتْ فقط في ٤٥ ٪ من كل العينات؛ و كَانتَ أعلى في الإناث مِنْ الذكورِ. وبالنسبة لاقطار الشرايين فقد وجدت أصغر في الإناث مِنْ الذكورِ، ماعدا قطرِ الشريان الموصل الخلفي.

وبالفحص التشريحى لحلقة ويليس لأمخاخ العشرة جثث فقد وجدت الحلقة كاملـة فى ست حالات و وجد الشريان الموصل الخلفي جنينى النوع فى ثلاث حالات وكانت هنالك حالة واحدة لضمور الشريان الموصل الخلفي .

وفى نهاية البحث لوحظ وجود اختلافات تشريحية واضحة فى حلقةِ ويليس في الأشخاصِ الطبيعيين. وبرغم وجود هذه الاختلافات فلم توجد فروق واضحة بين الذكور و الإنـاث فى معظـم الأوعيـة الدمويـة المكوّنـة للحلقـة ولا فـى أقطارهـا المتوسطة. و يَجِبُ مراعاة تلك الاختلافات الطبيعيةِ أثناء مناقشة صور الحلقة. ويقترح إضافة هذه الاختلافات الطبيعيةِ فى كتب التشريح للإلمام بها.