Original Article

Magnetic Resonance Angiographic Study of Anatomic Variations of the Circle of Willis in a Population in Tehran

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Abstract

Background and Objectives: The circle of Willis, an anastomotic polygon at the base of the brain, forms an important collateral network to maintain cerebral blood perfusion. The aim of this study was to investigate different anatomic variations of the circle of Willis and their prevalence.

Methods: This cross-sectional study was conducted on 525 healthy participants including 205 men and 320 women. The mean age of the patients was 51.5 years. Three-dimensional time-of-flight magnetic resonance angiography (3D-TOF MRA) technique was used. Vascular variations in the anterior and posterior parts of the circle were evaluated.

Results: The findings show that the complete circle of Willis was visible in a small number of patients. The circle of Willis had a complete vascular structure in 20.9% of the patients. The anterior part of the circle of Willis had a complete structure in 80.95% of the cases, while the posterior part had a complete structure in 20.95% of the cases.

Conclusion: We observed wide variations in the circle of Willis configuration in our study. Similar to other studies, most variations are related to the posterior part of the circle of Willis. Absence of bilateral posterior communicating artery variation is more common than other types of variations in this population.

Keywords: Anatomic variation, cerebral arteries, circle of Willis, magnetic resonance angiography

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Introduction

The process of the formation of blood vessels in the human body is very complex, and the shapes of vessels in the embryonic phase are very different from those in adulthood. Numerous variations may occur during the transformation of embryonic vessels to adult vessels. Vascular variations are different and are not pathological in many cases. They may involve different origins, paths or artery diameter and size.[1,2] Due to its critical importance, blood supply to the brain is designed in such a way that vascular variations or vascular damage inflict minimum harm to this vital tissue.[3]

The presence of an arterial circle in the brain was first suggested by Thomas Willis in 1966.[4] This circle is formed jointly by internal carotid arteries (ICA) and basilar artery (BA). Anterior cerebral artery (ACA) separates from the internal carotid artery and, together with the anterior communicating artery (ACo), forms the anterior section. The posterior section is formed by the posterior cerebral artery (PCA) and posterior communicating artery (PCoA). This arterial polygon has a great potential in establishing side nutritional routes in case of occlusion in the ICAs.

Studies have shown that the classic circle of Willis is observed in 18–25% of the cases. Previous studies have reported different variations in this arterial circle.[5–7] Most of these studies have been conducted on human cadavers. For example, Eftekhar *et al*. examined variations of the circle of Willis in 102 male Iranian cadavers.[8] Other studies have been carried out on the variations of the circle of Willis and reported agenesis, hypoplasia of the anterior communicating artery, posterior communicating artery, and posterior cerebral artery. Vascular variations have been examined using various methods including autopsy,[9] angiography and magnetic resonance angiography imaging. Magnetic resonance angiography is a noninvasive sensitive method used to assess variations *in vivo*. This method, which is widely used to study brain vessels, does not require contrast injection. Three-dimensional images are prepared using the time of flight (3D-TOF) method to examine the circle of Willis.[10,11] The use of high Tesla MRI machines yields high-quality images with better details, allowing for the study of smaller vessels.[12–14]

Patients and Methods

The cross-sectional study was conducted on the circle of Willis in 525 healthy patients. Patients who referred to the Radiology department as part of their health check-up were included in this study. Clearance from Institutional Ethical committee was obtained for this study.

Inclusion criteria

Patients in both genders who referred to our hospital for health check-up.

Exclusion criteria

Patients who have claustrophobia.

Patients who have head and neck surgeries.

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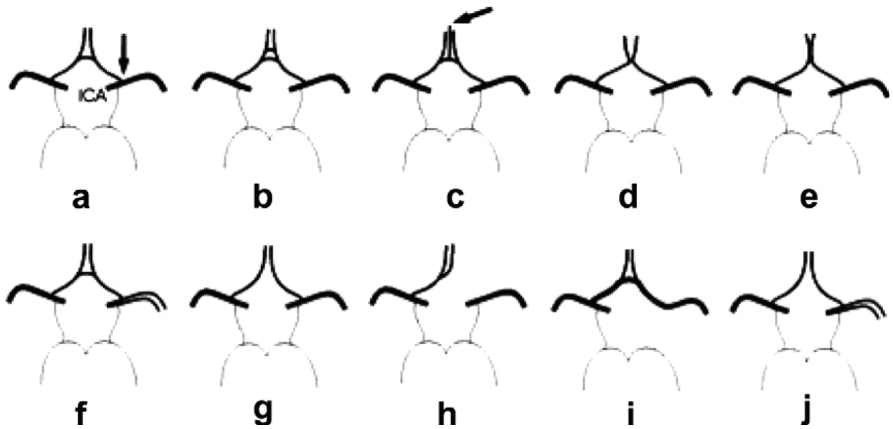

Figure 1. Anatomic variations of the anterior part of the circle of Willis.

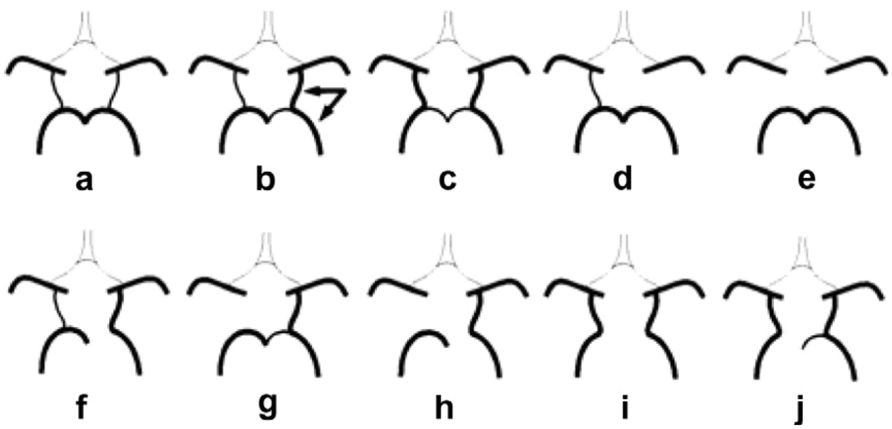

Figure 2. Anatomic variations of the posterior part of the circle of Willis.

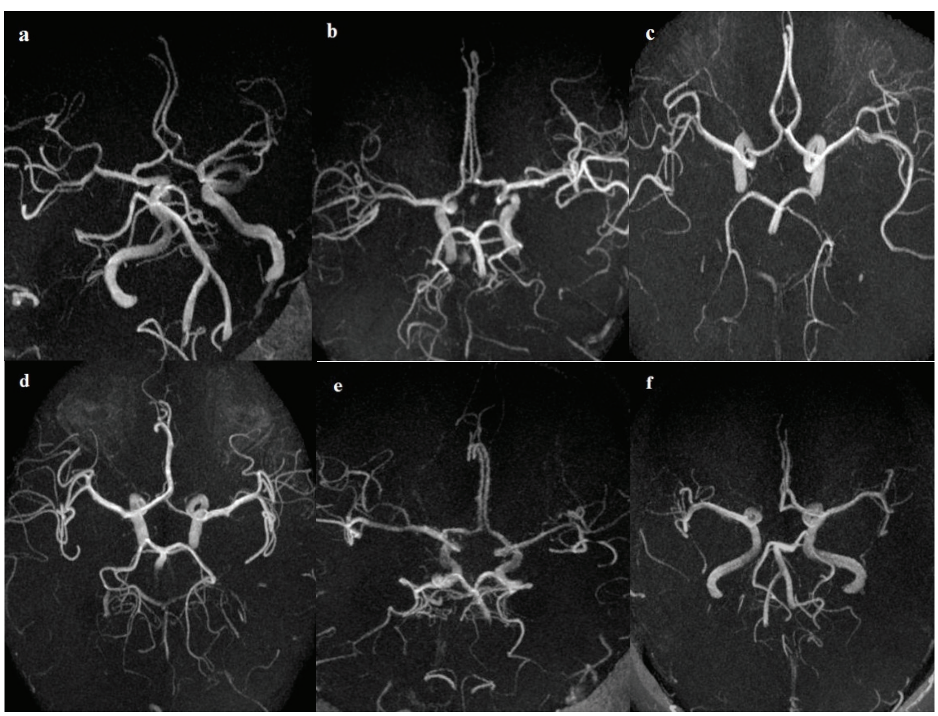

Figure 3. MRA images of circle of Willis vessels showing anatomical variations in the anterior part, **(a)** Anatomic variation type 1b, **(b)** Anatomic variations type 1c, **(c)** Anatomic variations type 1d. **(d)** Anatomic variations type 1e. **(e)** Anatomic variations type 1g. **(f)** Anatomic variations type 1h.

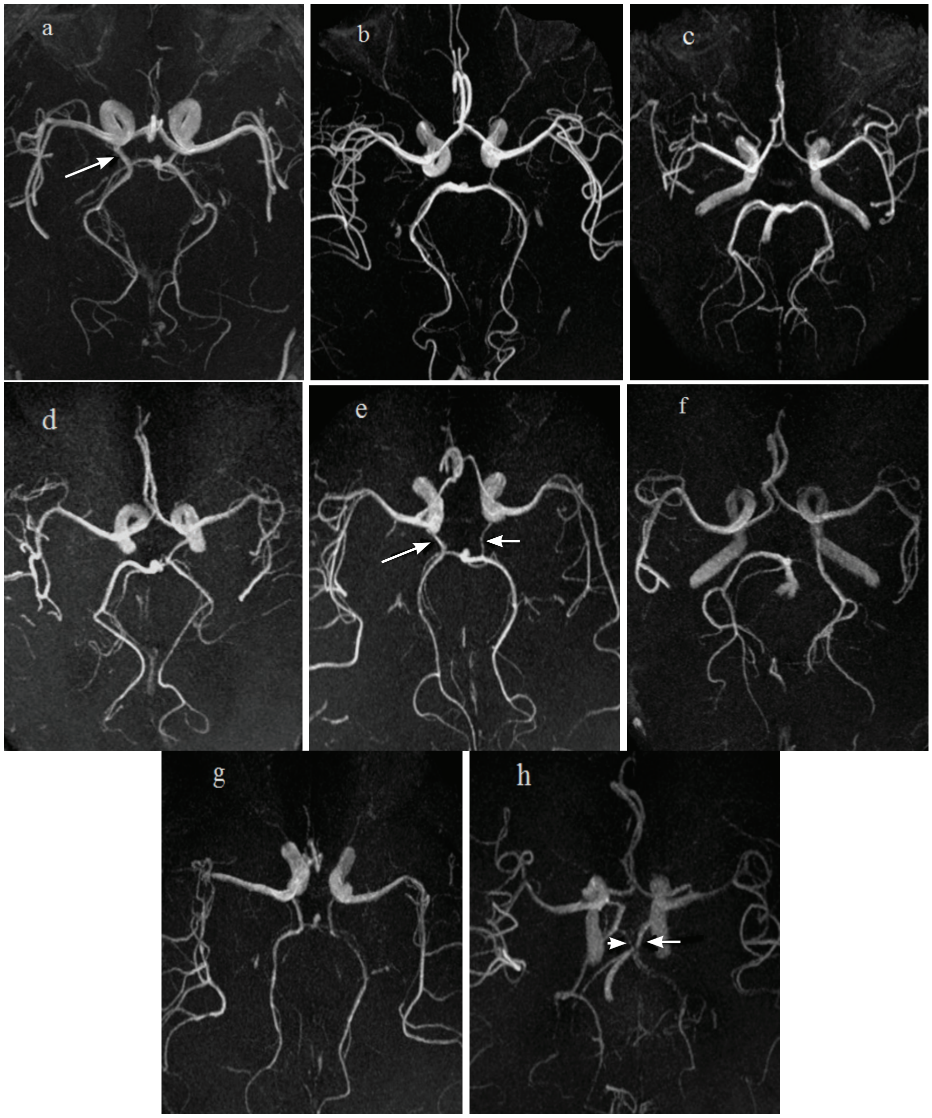

Figure 4. Axial MRA images of the circle of Willis vessels showing anatomical variations in the posterior part, **(a)** anatomic variation type 2b. PCA originates from ICA (long arrow), **(b)** anatomic variation type 2d, **(c)** anatomic variation type 2e, (d) anatomic variation type 2g, **(e)** anatomic variation type 2f, PCA originates from ICA (long arrow). The precommunicating part of PCA can be observed in the other side (arrow head), **(f)** anatomic variation type 2h, **(g)** anatomic variation type 2i, both PCA arteries originate from ICA. Thee precommunicating part of PCA is absent on both sides. (h) Anatomic variation type 2j. PCAs on both sides originate from ICA. PCA is not connected to basilar artery on one side (long arrow). The precommunicating part of PCA can be observed on the other side (arrow head).

The patients' age ranged from 25 to 78 years. The mean age was 51.54 years. In total, 205 were male and 320 were female. The 3D time of flight MRA technique using 8-channel coils designed for head in the MRI machine was first performed for all patients. The TR and TE parameters were 25 and 5.2 milliseconds, respectively, and Flip angle was 20°. Field of view of 230 × 150 mm and slice thickness of 0.5 mm were used. Raw images were processed using the maximum intensity projection (MIP) algorithm to obtain the angiography images. Vessels with a diameter less than 0.8 mm were considered as hypoplastic.

Anatomic variations in the anterior and posterior of circle of Willis were categorized based on the findings recorded in studies by Lippert and Pabst.[15] Categorization is shown in Figures 1 and 2.

Results

Anatomic variations of the anterior and posterior parts on the circle of Willis were examined separately. Variations in the anterior and posterior parts of the circle of Willis are shown in Figures 3 and 4, respectively.

The results showed that the anterior part of the circle of Willis had a complete structure in 80.95% of the cases . The vascular structure of the posterior part was complete in 20.95% of the cases (Table 1). Circle of Willis had a complete structure in 20.9% of the cases.

Table 1. Prevalence of variants of the anterior and posterior part of the circle of Willis.

Type of variants of anterior part	a	b	c	d	e	f	g	h	i	j	Complete configuration of the anterior part (%)
Prevalence	375	5	10	30	5	0	75	25	0	0	80.95
Type of variants of posterior part	a	b	c	d	e	f	g	h	i	j	Complete configuration of the posterior part (%)
Prevalence	95	15	0	90	235	40	10	30	5	5	20.95

Table 2. Prevalence of entirely complete and incomplete configuration of the entire circle of Willis according to sex.

Group	Prevalence of Entirely complete configuration	Prevalence of incomplete configuration	Entirely complete configuration (%)
Male (*n* = 205)	40	170	19.5
Female (*n* = 320)	70	245	21.8
Total (*n* = 525)	**110**	**415**	**20.9**

According to the results of this study, no significant differences were found between men and women in the prevalence of variants (Table 2).

Discussion

Study of embryonic development of the circle of Willis shows that hemodynamic changes during fetal life may play an important role in determining the final form of the circle of Willis. A study conducted on the formation of the circle of Willis in fetus showed that, in a 29-day-old embryo, the posterior communicating artery originated from ICA. In the early stages of growth, the vertebrobasilar system is supplied by the carotid through the trigeminal artery. Following the formation of the posterior cerebral artery, the circle closes and perfusion is established from the vertebrobasilar system to the carotid system. That study suggested that hemodynamic changes at this stage can cause different variations.[16]

Van Overbeek *et al.* concluded that rapid growth of the occipital lobe in the fetal period significantly affects the final form of the circle of Willis, especially in the posterior part.[17] In addition, some researchers believe that hemodynamic changes are not limited to the embryonic period and can even affect the formation of the circle in the first decades of life. Many other factors may be also involved in the formation of different variations. In some cases, variations are pathological and, therefore, important.

Extensive research conducted on the effect of variations of the circle of Willis has proven the association between these variations and incidence of some neurovascular problems. For example, in a clinical study, Chuang *et al.* (2008) found that the absence or hypoplasia of PCoA can increase the risk of stroke in cases of ICA occlusion.[18]

Similar to many previous studies, the present study confirms the wide range of variations in the circle of Willis. The prevalence of variations is different in previous studies, which is probably due to the type of study population and method of study. The findings of the present study are consistent with those reported by Chen *et al*[11]: In our study, full circle of Willis was observed in 20.9% of the cases, which was 21.3% in that study.[11] Complete structure of the circle of Willis in the anterior and posterior parts was observed in 80.95% and 20.95% of the cases, respectively, which were 78.3% and 25.44% in the aforementioned study.

In conclusion, MRA findings showed that most variations are related to the posterior part of the circle of Willis. The interesting point in our findings is the high prevalence of absence of bilateral posterior communicating artery in our population. Since the absence or hypoplasia of PCoA can increase the risk of stroke in cases of ICA occlusion, prevalence of this type of variation can be important.

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