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ORIGINAL ARTICLE

Three dimensional magnetic resonance angiography of the circle of Willis: Anatomical variations in general Egyptian population

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KEYWORDS

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Abstract *Objective:* Aimed to evaluate the different anatomical variations of the circle of Willis (COW) and determined average vessels diameters in general Egyptian population.
Patients and methods: We retrospectively evaluated the 3D-time of flight (TOF) MR angiogram (MRA) of 250 patients. One hundred and eighty patients out of them had no manifestations of cerebrovascular diseases included in the study. All of them were examined by 3D TOF MRA. The anatomical variants of the anterior and posterior components of the COW were studied. The complete COW were assessed and the diameters of all the components were measured. The correlation between the vessel diameters in relations to age and sex were evaluated.
Results: Complete anterior and complete posterior parts of the COW were seen in 68.3%, and 38.3%, respectively. Entirely complete COW was seen in 46.7%. The prevalence of entirely complete COW was slightly higher in females and young than males and older subjects. The study illustrated that there are statistically significant differences in some vessel diameters according to sex and age.
Conclusion: The anatomical variants of the COW and the normal reference values for vessels diameter were determined in general Egyptian population based on measurements in 3DTOF MRA.

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1. Introduction

The circle of Willis (CW) is located at the base of the brain and considered as an important potential collateral pathway in maintaining adequate cerebral blood flow in patients with internal carotid artery (ICA) obstruction. Its ability to redistribute blood flow depends on its morphology, the presence and size of the component vessels. The potential of the circle of Willis to develop collateral flow in the case of impaired afferent supply has been known since Sir Thomas Willis first described the collateral function of the arterial anastomosis in 1664 [1]. In the circle of Willis, there is a confluence of flow from three vessels: both internal carotid arteries and the basilar artery (BA). Therefore, the hemodynamics in the circle of Willis is anatomically significantly different from the hemodynamics in normal branching situations addressed by the optimality principle. Accordingly, the normal physiology of flow and the likely impact of deviation from normality in the circle of Willis are not fully understood [2]. Variations in the circle of Willis significantly correlate with the relative contributions of the flow rates of proximal arteries [3]. In patients with obstruction of the internal carotid arteries (ICAs), adequate cerebral blood flow is maintained by numerous collateral pathways that redistribute blood to the deprived side. The development of such pathways depends on the individual morphological and hemodynamic factors. The collateral potential of the CW is believed to be dependent on the presence and size of its component vessels [4–6]. The anatomical variations of the circle of Willis have been reported in previous studies [7–10]. Volume flow rates in the feeding arteries of the brain, such as the internal carotid artery and the basilar artery, have been used to evaluate blood flow dynamics in vascular disease [11–14]. For these evaluations, reference data of volume flow rates in normal subjects are essential and have been reported by several investigators. The anatomic variations in the circle of Willis presumably affect the volume flow rates in the feeding arteries. Accordingly it is important to obtain reference data of volume flow rate for these common variations. Correlation between anatomic variation in the circle of Willis and volume flow rates in the internal carotid arteries and the basilar artery has been investigated [15–17]. Nevertheless, variations in the circle of Willis are common and findings from previous studies have demonstrated that three dimensional time of flight magnetic resonance angiography (3D-TOF MRA) is a sensitive, non-invasive imaging modality suitable for evaluation of the circle of Willis in healthy volunteers and patients with carotid artery disease [8,18,19].

2. Patients and methods

At the start of the study, the 3D TOF MR angiogram of circle of Willis in 250 patients was retrospectively evaluated and 70 patients with manifestations of cerebrovascular disease were excluded. One hundred and eighty patients without clinical manifestations of cerebrovascular disease are involved in the study and considered as healthy subjects with regard to the anatomy of the circle of Willis. They were aged between 20 and 75 years. Sixty patients were under 40 years, mean age 37 years, 38 males and 22 females. One hundred and twenty patients, 70 males and 50 females were $\geqslant$ 40 years, mean age 51 years. Distribution of males and females in the study population is seen in Table 1. They were examined for follow up or evaluation of cerebral tumors (n = 61), search for metastasis (n = 49), epilepsy (n = 40) and chronic headache (n = 30, 10 of them with migraine). Clinical presentations of the study population showed in Table 2.

All patients were examined with 3D TOF MR angiography. This study was performed in radiology departments of Menofyia and Zagazig university hospitals. MR examination was performed with 1.5 T MR machine. The MR angiography examination was performed with standard head coil. The MR angiography protocol consisted of non-contrast 3DTOF transaxial acquisition which was used for examination of all patients with the following parameters (Table 3): TR/TE/FA (30–40/6–10 ms/20–25°). Rectangular field of view (FOV) 150×200 mm, matrix size 192×256 with slice thickness of 0.8–1 mm and 96 partitions with the total imaged volume (effective slab thickness) 72 mm. To obtain the best resolution in the section selection direction, the smallest possible slice thickness was used Using matrix size 192×256, this resulted in an anisotropic voxel size of 0.8×0.8 mm^2 in plane resolution and 0.8 mm slice thickness. MTC and TONE were applied in all examinations to increase the contrast between flowing blood and stationary tissues. The post-processing algorithm, maximum intensity projection (MIP) was used to produce angiographic-like images at 15° increments generating 12 MIP projections. In addition the axial MIP of COW was included.

The normal population was subjected to a classification system of circle of Willis morphology, based on completeness of the anterior and posterior circle parts according to the potential for collateral flow development as indicated schematically in Figs. 2 and 3. Anterior circle variant types a through (f) are classified as complete types, since their morphology enables collateral flow development through continuity of the anterior channels. Likewise, posterior circle variant types a through (c) are classified as complete types since they posseses the potential for collateral flow development through the posterior circle.

The data were evaluated on work station. All MR angiograms were evaluated by using native source images and maximum intensity projections (MIP) images.

All component vessels of the circle of Willis are assessed by measuring the diameter on the original slices and not measured in MIP images to exclude the limitations of MIP.

Vessels that were visualized as continuous segments of at least 0.8 mm in diameter were considered present; those smaller than 0.8 mm in diameter were considered hypoplastic. The discrimination between the posterior communicating arteries from the anterior choroidal arteries was critical and determined by scrolling through the slices and judging the course of the arteries in a sequential display and cine loop. The anterior and posterior parts of each circle were assessed separately

Table 1 Distribution of the males and females in the study population.

Age	Male	Female	Total
40 <	38 (63%)	22 (37%)	60 (33%)
$\geqslant$40	70 (58%)	50 (42%)	120 (67%)
Total	108 (60%)	72 (40%)	180