Configuration of the circle of Willis and its two parts among Egyptian: a magnetic resonance angiographic study

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Background: We hypothesized that the collateral circulation differs in different ethnic groups. So, the aim of our work was to study variations of the circle of Willis (COW) among Egyptian and to compare our findings with the findings of other nationalities.

Materials and methods: One hundred patients were studied using magnetic resonance angiography (3D-TOF-MRA). Frequency and morphologic variations in COW were studied. The diameters of the arteries of the anterior and posterior circle were verified. Finally, the differences among the mean diameters of these arteries regarding age and sex were also studied.

Results: Complete, partially complete and incomplete COW were encountered in 28%, 38% and 34% in the studied cases. The incomplete anterior circle was found in 34% (10% isolated incomplete anterior circle and 24% combined incomplete anterior and posterior circles) and the incomplete posterior circle came across in 62% (38% isolated incomplete posterior circle and 24% combined incomplete anterior and posterior circles). Seven anterior circle variations were found. The commonest type was the classical type “a” with a prevalence of 56%, being higher in male (57.1%). The 2nd common type was type “g” (hypoplasia or aplasia of the anterior communicating artery) with a prevalence of 24%, being higher in male (66.7%). Six posterior circle variations were found. The commonest variation was the classic type “a” with a prevalence of 26%, being higher in male (61.5%). Posterior circles types “d, e, h” (18%, 24%, 20%) constituted 62% and were characterised by hypoplasia/absent of the posterior communicating arteries.

Conclusions: The prevalence of complete COW (classic or textbook type) was encountered only 28% of the studied cases. Variations of COW were found to be more common in the posterior circulation (62%). The incomplete anterior circle was found in 34% and it is mostly caused by hypoplasia or aplasia of the anterior communicating artery which was found to be more common compared to the literature. (Folia Morphol 2019; 78, 4: 703–709)

Key words: circle of Willis, variations, Egyptian

INTRODUCTION

Circle of Willis (COW) is an anastomotic arterial ring that exists at the base of the brain. It comprises the posterior cerebral arteries (PCAs), posterior communicating arteries (PcomAs), internal carotid arteries (ICAs), anterior cerebral arteries (ACAs) and
anterior communicating artery (AcomA) [5]. The ICAs and their branches that supply the anterior portion of the brain referred to as the anterior circulation. Whereas, the vertebralbasilar system that supplies the posterior portion of the brain referred to as the posterior circulation [18].

Many variations of COW were detected. Such variations reduce the collateral availability and increase the risk of transient ischaemic attacks and stroke in cases of severe stenotic ICA. Knowledge of the compensatory capacity of the COW is also important for neurosurgeons, vascular surgeons and interventional radiologists [10].

Formerly, the studies concerning COW were based on the autopsy findings. Many studies have established that three-dimensional time-of-flight (3D-TOF) magnetic resonance angiography (MRA) is a sensitive, noninvasive modality suitable for detecting the anatomy of COW [14]. Also, it provides an anatomical basis for future prognosis and treatment of cerebrovascular diseases [21].

We hypothesized that the collateral circulation differs in different ethnic groups. So, the aim of our work was to study the frequency and morphologic variations in COW among Egyptian using 3D-TOF-MRA and to compare our findings with the findings of other nationalities. The diameters of the arteries of the anterior and posterior circle were verified. Finally, the differences among the mean diameters of these arteries as regards to age and gender were also shown.

**MATERIALS AND METHODS**

One hundred patients of both sexes (64 males and 36 females) were included in the study. Patients diagnosed with cerebrovascular diseases, brain tumours or any significant pathological vascular brain abnormalities as well as trauma were excluded from the study. All procedures were carried out in accordance with the Declaration of Helsinki 1975, revised 2013. The study was approved by the institutional review board (5674/2018). Informed consent from the patients was obtained.

**Scanning technique [16]**

The patients were imaged in supine position. Dedicated, optimised high-resolution 3D-TOF-MRA protocol with repetition time (TR)/echo time (TE)/flip angle of 19/5.7 ms/16°, respectively, with isotropic resolution of 0.6 × 0.6 × 0.6 mm³ was used. Scanning parameters included; slice thickness 1.2 mm, 0.6 mm slice overlap, field of view of 100 × 100 mm, and matrix 0.6 × 0.6 × 0.6 mm³ and TR — 19 ms, TE — 5.7 ms, and flip angle — 16°. Totally 50 slices covering a volume of 30 mm (50 × 0.6 mm effective slice thickness) was obtained. The total imaging time was 15 min, of which the 3D-TOF-MRA sequence required 3 min 24 s. These axial source images were post-processed by the maximum intensity projection (MIP) algorithm to produce eight projections rotating about the section axis.

**Data analysis**

The circle components were divided into two parts; anterior and posterior circles [11]. The anterior circle includes the ICA, the pre-communicating segment of the anterior cerebral arteries (A1) and the AcomA [11]. The posterior circle includes the pre-communicating segment of the posterior cerebral arteries (P1) as well as the PcomAs [11]. The diameters of these components were studied as regards the age and sex groups.

The studied population was subjected to a classification system of COW morphology, based on completeness of the anterior and posterior circle parts according to the potential for collateral flow development (Fig. 1a, b). The anterior circle variant types (a) through (f) are classified as complete types, since their morphology enables collateral flow development through the anterior channels. Similarly, the posterior circle variant types (a) through (c) are classified as complete types since they possess the potential for collateral flow development through the posterior circle [17].

All component vessels of COW were assessed by measuring the diameter on the original slices and not measuring on 3D reconstructed images to exclude the limitations and pitfalls of post-processing measurements. About the whole COW, the circle was classified as complete, incomplete or partially complete. In complete type all components of the anterior and posterior parts of the circle were visible, continuous and demonstrated diameters of at least 0.8 mm. In incomplete type both the anterior and posterior parts demonstrated a deficient vessel segment (a non-continuous, hypoplastic, or absent segment) [17]. The remaining circles, with a complete either anterior or posterior configuration, were classified as partially complete [18].
Statistical analysis

Statistical analysis was performed using the statistical package for the social sciences statistical software (SPSS) version 21.0 (IBM Corporation, Somers, NY, USA). Prevalence of variants of the anterior and posterior parts of the circle was studied. In addition, prevalence of the configuration of the circle and its two parts were also considered. Mean ± standard deviation (SD) of the diameters of the arteries forming the two parts of the circle was calculated. Finally, comparing the diameter of the arterial circuit regarding gender and age was deliberated. Significance was considered when the p-value was ≤ 0.05.

RESULTS

Seven anterior circle variations were found. The commonest type was type “a” with a prevalence of 56%, being higher in male (57.1%) with equal age groups prevalence. The 2nd common type was type “g” with a prevalence of 24%, being higher in male (66.7%) with high prevalence (62.5%) before the age of 40. The 3rd common type was type “h” 10%, being higher in male (80%) with 60% prevalence above the age of 40. The next coming type was type “d” 4%, being equally occurring in both sexes and totally found above 40. Types “b, c, e” equally taking place 2% for each one. Finally, types “f, i, j” weren’t notable in our study (Fig. 2, Table 1).

Six posterior circle variations were found. The commonest variation was type “a” with a prevalence of 26%, being higher in male (61.5%) with nearly equally occurring age. The 2nd common variation was type “e” with a prevalence of 24%, being higher in male (75%) and in the elderly studied group (58.3%). The 3rd common type was type “h” 20%, being higher in male (60%) with equal age groups prevalence. The next coming type was type “d” nearly equally occurring in both sexes with high prevalence (72.2%) above the age of 40. Types “b, c” take place in 8% and 4%, respectively. Finally, types “f, g, i, j” weren’t notable in our study (Fig. 3, Table 2).

We encountered 28 cases with a complete circle, 38 cases with a partially complete circle and 34 cases with an incomplete circle. The complete anterior circle was encountered in 66% and the incomplete anterior circle was encountered in 34%. In addition, the complete posterior circle came across in 38% and the incomplete posterior circle came across in 62% (Figs. 2–4, Table 3).

The diameters of the arteries of the anterior and posterior circles were verified in Tables 4 and 5. Finally, the differences between the mean diameter of the
was found to be the most sensitive method in the evaluation of COW arteries [24].

The present work proved the previous studies of the difference between the anterior and the posterior circles, in respect to the type of anomaly [2]. The anterior circle variations are of great clinical importance as cerebral infarct due to occlusion of ACA is common [24]. We detected seven anterior circle variations out of the ten reported types. The commonest anterior circle variation was type "a" (classic type) with a prevalence of 56% in our study compared to 47.2% in Polish population and 76% in Chinese population [15, 17].

The 2nd common anterior circle variation and the commonest anomaly was type "g" (hypoplasia or...
aplasia of the AcomA) which existed in 24% of the cases. Many authors reported hypoplastic vessels as the most common anomaly observed in COW [1].

The anterior circle type “b” (two or more AcomA; fenestrated AcomA) existed in 2% of our studied cases. Type “b” variation mostly developed from the

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Table 2. Prevalence of the posterior circle variations

| Gender | Variations | Count (%) |
|--------|------------|-----------|
|        | a | b | c | d | e | h | Total |
| Male   | 16 (61.5%) | 6 (25.0%) | 2 (50.0%) | 10 (55.6%) | 18 (75.0%) | 12 (60.0%) | 64 (64.0%) |
| Female | 10 (38.5%) | 2 (25.0%) | 2 (50.0%) | 8 (44.4%) | 6 (25.0%) | 8 (40.0%) | 36 (36.0%) |

Age groups:

< 40 | 14 (53.8%) | 6 (75.0%) | 3 (75.0%) | 5 (27.8%) | 10 (41.7%) | 10 (50.0%) | 49 (49.0%) |
≥ 40 | 12 (46.2%) | 2 (25.0%) | 1 (25.0%) | 13 (72.2%) | 14 (58.3%) | 10 (50.0%) | 52 (52.0%) |
Total | 26 (100.0%) | 8 (100.0%) | 4 (100.0%) | 18 (100.0%) | 24 (100.0%) | 20 (100.0%) | 100 (100.0%) |

% — per cent within posterior circle variations

Table 3. Prevalence of the configuration of the circle of Willis according to sex

| Configuration | Entirely complete | Partially complete | Incomplete | Total | Complete | Incomplete | Total |
|---------------|------------------|--------------------|------------|-------|----------|------------|-------|
| Male (%)      | 25.0%            | 37.5%              | 37.5%      | 100.0%| 62.5%    | 37.5%      | 100.0%|
| Female (%)    | 33.3%            | 38.9%              | 27.8%      | 100.0%| 72.2%    | 27.8%      | 100.0%|
| Total (%)     | 28.0%            | 38.0%              | 34.0%      | 100.0%| 66.0%    | 34.0%      | 100.0%|

Table 4. The mean diameters of the arteries of the anterior circle

| Age group | Right A1 [mm] | P | Left A1 [mm] | P | AcomA [mm] | P | Right ICA [mm] | P | Left ICA [mm] | P |
|-----------|---------------|---|--------------|---|------------|---|---------------|---|--------------|---|
| < 40      | Mean ± SD     |   | Mean ± SD    |   | Mean ± SD  |   | Mean ± SD     |   | Mean ± SD    |   |
| Male      | 2.4 ± 0.6     | 2.2 ± 0.5 | 1.4 ± 0.4    | 4.9 ± 0.9 | 4.7 ± 0.9  | 4.7 ± 1.1 |
| Female    | 2.0 ± 0.5     | 2.3 ± 0.5 | 1.4 ± 0.4    | 4.6 ± 0.7 | 4.5 ± 0.9  | 4.5 ± 0.9 |
| ≥ 40      | Mean ± SD     |   | Mean ± SD    |   | Mean ± SD  |   | Mean ± SD     |   | Mean ± SD    |   |
| Male      | 2.4 ± 0.6     | 2.2 ± 0.5 | 1.4 ± 0.4    | 4.9 ± 0.9 | 4.7 ± 0.9  | 4.7 ± 1.1 |
| Female    | 2.0 ± 0.5     | 2.3 ± 0.5 | 1.4 ± 0.4    | 4.6 ± 0.7 | 4.5 ± 0.9  | 4.5 ± 0.9 |

% — per cent within posterior circle variations

*Statistical significance; Acom — anterior communicating artery; ICA — internal carotid artery; SD — standard deviation; Min — minimum; Max — maximum

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incomplete fusion of the plexiform structure connecting both ACA during the embryonic life [20]. Such anomaly is important in planning of interventional measures [9]. Both types “g, b” was found to be higher among patients with cerebral occlusive disease and aneurysm compared to normal patients [13]. In addition, fenestration can pose unexpected difficulties in surgical treatment because of the accompanying aneurysms [9].

Regarding the posterior circle variations, 6 variations were encountered in our study out of the 10 variations reported in other studies [8]. Posterior circle variations may be the result of rapid growth of the occipital lobe in the foetal period [26].

Posterior circles types “d–h” are characterised by hypoplasia/absent PcomA. In our study, the only observed of these types are types “d, e, h” (18%, 24%, 20%) which constitute about 62% of the all studied cases. The first type was equally occurring in both sexes, while the last two types were higher in male. The PcomA hypoplasia is a contributor to risk of ischaemic stroke, even in the absence of ICA occlusion [4].

In our study, the prevalence of the entire complete type (the classic or textbook type) was encountered only 28% (with higher prevalence in male; 16/28), coming after the partially incomplete and incomplete types (38%, 35%, respectively). Similar entire complete type prevalence was encountered in Chinese study (27%) [17]. The prevalence of complete circle was low in Sri Lankans (14.2%) [6], moderate in Indian population (45.2% and 53.2%) [12, 22] and extremely high in the Japanese population (89.7%) [25]. Surprisingly, a wide range of complete circle was observed in the western population studies; from 28% (an MRA study) to 52.3% (an autopsy study) [1, 16]. The wide range in the prevalence of the typical formation among numerous races may be related to environmental, genetic, regional, and haemodynamic factors or the combination of these factors.

The prevalence of complete anterior circle in our study was 66%. In earlier studies, the prevalence of complete anterior circle varied from 74% to 90% in different ethnic groups [7, 16].

Table 5. The mean diameters of the arteries of the posterior circle

|                | Right P1 [mm] | P | Left P1 [mm] | P | Right PcomA [mm] | P | Left PcomA [mm] | P |
|----------------|--------------|---|--------------|---|-----------------|---|----------------|---|
| Sex            |              |   |              |   |                 |   |                 |   |
| Male           | N 64        | 0.173 | 64        | 0.543 | 36             | 0.306 | 34         | 0.004* |
|                | Mean ± SD 2.1 ± 0.5 | 2.0 ± 0.4 | 1.5 ± 0.5 | 1.8 ± 0.6 |                 |   |                 |   |
|                | Min/Max 1.2/3.0 | 1.0/3.0 | 0.7/3.0 | 1.0/3.0 |                 |   |                 |   |
| Female         | N 36        | 36 | 36           | 20   | 24              |   |                 |   |
|                | Mean ± SD 1.9 ± 0.5 | 2.0 ± 0.5 | 1.7 ± 0.5 | 1.4 ± 0.5 |                 |   |                 |   |
|                | Min/Max 0.8/3.3 | 1.0/2.5 | 1.3/2.7 | 0.8/2.5 |                 |   |                 |   |
| Age group      |              |   |              |   |                 |   |                 |   |
| < 40           | N 48.0      | 0.117 | 48.0 | 0.497 | 32.0         | 0.009* | 29.0 | 0.335 |
|                | Mean ± SD 1.9 ± 0.6 | 2.0 ± 0.4 | 1.7 ± 0.5 | 1.6 ± 0.5 |                 |   |                 |   |
|                | Min/Max 0.8/3.3 | 1.0/3.0 | 1.0/3.0 | 0.8/2.5 |                 |   |                 |   |
| ≥ 40           | N 52        | 52  | 52           | 24   | 29              |   |                 |   |
|                | Mean ± SD 2.1 ± 0.4 | 2.0 ± 0.4 | 1.4 ± 0.4 | 1.7 ± 0.7 |                 |   |                 |   |
|                | Min/Max 1.3/3.0 | 1.0/2.6 | 0.7/2.1 | 1.0/3.0 |                 |   |                 |   |
| Total          | N 100       | 100 | 100         | 56   | 58              |   |                 |   |
|                | Mean ± SD 2.0 ± 0.5 | 2.0 ± 0.4 | 1.6 ± 0.5 | 1.7 ± 0.6 |                 |   |                 |   |
|                | Min/Max 0.8/3.3 | 1.0/3.0 | 0.7/3.0 | 0.8/3.0 |                 |   |                 |   |

*Statistical significance; PComA — posterior communicating artery; SD — standard deviation; Min — minimum; Max — maximum
circle and 24% combined incomplete anterior and posterior circles). According to these findings, most of the circle variations were found to be the posterior circle, which is consistent with the literature on the Turkish population [13]. A direct relation between incompleteness of the posterior circle type and development of migraine was reported [3].

We studied the variations of COW in two different age groups as haemodynamic changes are not limited to the embryonic period and can disturb the formation of the circle in the first decade of life [11].

CONCLUSIONS

In conclusion, the prevalence of complete COW (classic or textbook type) was encountered only 28% of the studied cases. Variations of COW were found to be more common in the posterior circulation (62%). The incomplete anterior circle was found in 34% and it is mostly caused by hypoplasia or aplasia of the AcomA which was found to be more common compared to the literature.

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