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Radio-Anatomical Study of Anterior Variants of the Polygon of Willis

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Abstract

The anterior system of the polygon of Willis plays an anastomotic role between the carotid territories and communicates with the posterior system. It ensures adequate cerebral blood flow in the event of internal occlusion. Its ability to redistribute blood flow depends on its morphology, the presence and size of the vessels that constitute it and their variants, knowledge of which is essential. The morphology of the carotid system is not constant and a number of variants are well recognized with greater hemodynamic importance. In this context, we undertook this work which aims to seek the anatomical variants of the anterior part of the PW; to determine the diameters of the vessels of the latter and to correlate these results with epidemiological data. We carried out a retrospective, descriptive and analytical study over a period of 4 months at Fann University Hospital, targeting patients who had undergone brain MRI with a 3D TOF sequence whatever the indication. Patients with lesions of cerebrovascular pathologies such as ischemia, hemorrhage, aneurysm, arteriovenous malformations or presenting a limited analysis examination due to the presence of kinetic or other artifact, were not included. Demographic data and anatomical variants were studied as well as the measurements of any continuous arterial segment greater than 0.8 mm in diameter. Those less than 0.8 mm in diameter were considered hypoplastic. The C3 segment of the internal carotid arteries, the A1 segment of the anterior cerebral arteries, the anterior communicating artery, constituted our main measurement sites. The sex ratio was 1.06, the mean age of the patients was 43 years ± 17.9 with extremes of 11 and 85 years. The anterior configuration of the polygon was complete in 57.5% representing 50% of men and 65.5% of women, in 56% of subjects under 40 years old and 58% in subjects over 40 years old. We noted a predominance of type a in 47% of patients followed by type g found in 35% of patients. The morphology of the anterior system of the Willis polygon is a function of its variants, some of which have greater hemodynamic importance than others. Its knowledge is essential for the management of cerebrovascular diseases.

Keywords

Polygon of Willis, Anamicals Variants, Vascular Diseases

1. Introduction

The polygon of Willis (PW) is the arterial circle of the brain. It is made up of two anterior and posterior arterial systems joined by the communicating [1] [2]. Its anterior system plays an anastomotic role between the carotid territories, thus enabling it to ensure adequate cerebral blood flow in the event of occlusion in this territory with sometimes, if necessary, the assistance of the posterior territories. The ability to redistribute blood flow depends on the morphology, presence and size of the vessels that make up the system concerned [1] [2] [3].

The morphology of the carotid system is not constant and a number of variants are well recognized. Some of them have a greater hemodynamic importance than others depending on whether or not the polygon is continuous, especially in the anterior [4] [5] [6] [7]. Knowledge of these variants is essential for neurosurgeons, vascular surgeons and interventional radiologists before any intervention on the cerebral arteries [8].

Advances in imaging have allowed a better *in vivo* knowledge of the anatomy of the anterior system with magnetic resonance angiography (MRA) [5]-[11].

In this context we undertook this work which aims to detect the anatomical variants of the anterior part of the PW; to determine the diameters of the latter's vessels and to correlate these results with epidemiological data.

2. Méthodology

This was a retrospective, descriptive and analytical study over a period of 4 months, between August 1 and November 30, 2021 at Fann University Hospital.

The examinations were carried out with a SIEMENS MAGNETOM LUMINA 1.5 Tesla high-field MRI.

The patients included in this study underwent a brain MRI and had benefited from a 3D TOF sequence in their examination protocol regardless of the indication.

However, were not included in our study, patients who presented lesions of cerebrovascular pathologies such as ischemia, hemorrhage, aneurysm, arteriovenous malformations or presenting a limited analysis examination of the due to the presence of kinetic or other artifacts.

The patient was placed in the supine position, head first and arms along the body. The MRA examination was performed with a standard helicoidal head coil. The examination protocol consisted of transaxial TOF gradient echo acquisition, T1-weighted without injection of contrast product.

The native images obtained were transferred to a Syngovia brand post-processing console where 3D type reconstructions in Maximum Intensity Projection (MIP) were performed.

The parameters studied are:

- Demographic data.
- Anatomical variants of the anterior part of the polygon of Willis (**Figure 1**).
- Vessel diameters assuming any continuous arterial segment greater than 0.8 mm in diameter is present. Those less than 0.8 mm in diameter were considered hypoplastic. The C3 segment of the internal carotid arteries, the A1 segment of the anterior cerebral arteries, the anterior communicating artery, the P1 segment of the posterior cerebral arteries constituted our main measurement sites.

3. Résultats

3.1. Demographic Data

The population consisted of 62 men and 58 women, giving a sex ratio of 1.06. The mean age of patients was 43 years, with extremes of 11 and 85 years, a median of 41 years and a standard deviation of 17.9 years. Fifty-five patients were under 40 and the remainder were 40 and over.

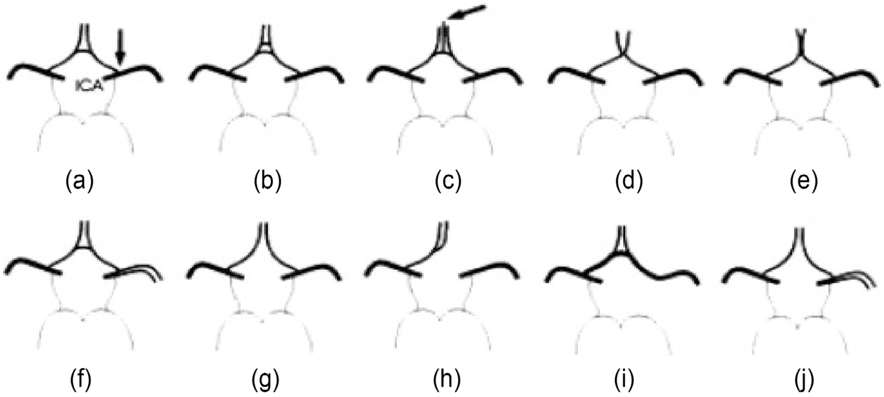

Figure 1. Schematic representation of the anatomical variants of the anterior part of the polygon of Willis (5). (a): Single anterior communicating artery, the internal carotid divides into the anterior and middle cerebral; (b): Two or more anterior communicating arteries; (c): Medial artery of the corpus callosum originating from the anterior communicating artery; (d): Fusion of the anterior cerebral arteries over a short distance; (e): The anterior cerebral arteries form a common trunk and divide distally into two post-communicating segments; (f): Division of the internal carotid artery into two separate trunks; (g): Hypoplasia or absence of the anterior communicating artery; (h): A pre-communicating segment of an anterior cerebral artery is absent or hypoplastic; (i): Hypoplasia or absence of the internal carotid; (j): Absence or hypoplasia of the anterior communicating artery with division of the internal carotid into two separate trunks.

3.2. Radio-Anatomical Data

a) Anatomical variants of the anterior part of Willis' polygon as a function of sex and age

The anterior configuration of the polygon of Willis was complete in 69 patients (57.5%), representing 50% of men and 65.5% of women (Table 1); in 56% of subjects under 40 years of age and 58% of subjects over 40 years of age (Table 2).

Among the anatomical forms of the anterior aspect of Willis's polygon, type a was the most frequent, found in 47% of patients, followed by type g in 35% (tables and Figure 2 and Figure 3).

b) Mean vessel diameters by sex and age

The mean internal carotid diameter was 3.71 ± 0.9 mm in men and 3.31 ± 0.8 mm in women with a significant difference (P = 0.016). The other diameters of the vessels measured did not show significant differences according to sex (Table 3 and Table 4).

4. Discussion

4.1. Demographics

In our study the average age was 43 years, it was advanced and could be

Table 1. Prevalence of anterior Willis polygon variants according to sex.

Variante / Sexe	a	b	c	d	e	f	g	h	i	j
Hommes	22 (18.33%)	0 (0%)	1 (0.83%)	6 (5%)	2 (1.66%)	0 (0%)	24 (20%)	7 (5.84%)	0 (0%)	0 (0%)
Femmes	34 (28.33%)	0 (0%)	1 (0.83%)	2 (1.66%)	1 (0.83%)	0 (0%)	18 (15%)	2 (1.66%)	0 (0%)	0 (0%)
Total	N = 56 (46.68%)	N = 0 (0%)	N = 2 (1.66%)	N = 8 (6.66%)	N = 3 (2.5%)	N = 0 (0%)	N = 42 (35%)	N = 9 (7.5%)	N = 0 (0%)	N = 0 (0%)
Valeur de P	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096	0.096

P > 0.05 (not significant); P < 0.05 (significant); P < 0.01 (very weak); P < 0.001 (very highly significant).

Table 2. Prevalence of anterior Willis polygon variants as a function of age.

Variante / Age	a	b	c	d	e	f	g	h	i	j
Age < 40 ans	26 (21.68%)	0 (0%)	1 (0.83%)	4 (3.33%)	0 (0%)	0 (0%)	19 (15.83%)	5 (4.17)	0 (0%)	0 (0%)
Age >ou= 40 ans	30 (25%)	0 (0%)	1 (0.83%)	4 (3.33%)	3 (2.5%)	0 (0%)	23 (19.17%)	4 (3.33%)	0 (0%)	0 (0%)
Total	N = 56 (46.68%)	N = 0 (0%)	N = 2 (1.66%)	N = 8 (6.66%)	N = 3 (2.5%)	N = 0 (0%)	N = 42 (35%)	N = 9 (7.5%)	N = 0 (0%)	N = 0 (0%)
Valeur de P	0.766	0.766	0.766	0.766	0.766	0.766	0.766	0.766	0.766	0.766

P > 0.05 (not significant); P < 0.05 (significant); P < 0.01 (very weak); P < 0.001 (very highly significant).

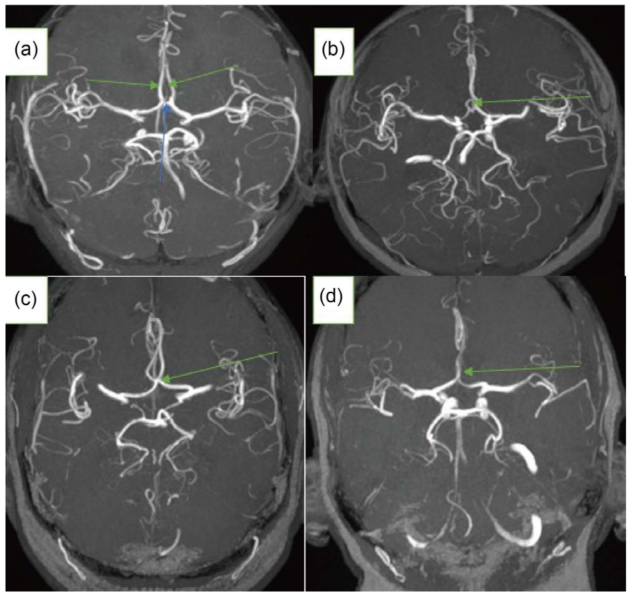

Figure 2. MRA with MIP reconstructions in axial sections showing; (a): Anterior variant of type a: two anterior cerebral arteries (green arrow) joined by an anterior communicating one (blue arrow); (b): Anterior type c variant: medial artery of the corpus callosum arising from the anterior communicating artery (green arrow); (c): Anterior variant of type d: fusion of the two anterior cerebral arteries over a short distance (green arrow); (d): Anterior variant of type e: fusion of the two anterior cerebral arteries over a long distance (green arrow).

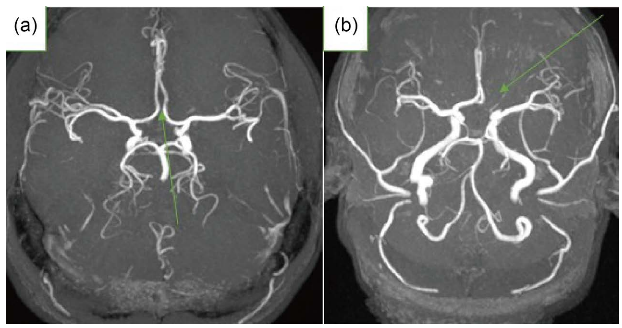

Figure 3. ARM avec reconstructions MIP en coupes axiales montrant; (a): variante antérieure de type g: absence de l'artère communicante antérieure (green arrow); (b): Variante antérieure de type h: absence d'un segment pré-communicant d'une artère cérébrale antérieure (green arrow).

Table 3. Mean vessel diameters according to gender.

arteries	Average diameter in men	Average diameter in women	P-value
ACI	3.71 ± 0.9	3.31 ± 0.8	**0.016**
A1	1.99 ± 0.36	1.89 ± 0.35	0.11
ACoA	1.34 ± 0.17	1.29 ± 0.22	0.15

$P > 0.05$ (not significant); $P < 0.05$ (significant); $P < 0.01$ (very weak); $P < 0.001$ (very highly significant); ICA: Internal carotid artery; A1: Precommunicating segment of the anterior cerebral artery; ACoA: Anterior communicating artery.

Table 4. Mean vessel diameters according to age.

Arteries	Age < 40 years	Age ≥ 40 years	P-value
ACI	3.43 ± 1.01	3.60 ± 0.82	0.31
A1	1.96 ± 0.33	1.92 ± 0.35	0.60
ACoA	1.32 ± 0.18	1.30 ± 0.22	0.72

P > 0.05 (non significant); P < 0.05 (significant); P < 0.01 (very weak); P < 0.001 (very highly significant); ICA: Internal carotid artery; A1: Precommunicating segment of the anterior cerebral artery; ACoA: Anterior communicating artery.

explained by the fact that the MRI unit of the department receives almost only adult patients due to the unavailability of anesthesia equipment, necessary to ensure sedation of pediatric patients. The average of 43 years was in the interval found 42 - 51 years by some authors such as Maaly *et al*., Keeranghat *et al*., Hadhri *et al*.; Yeniceri *et al*. and Stefani *et al*., who, like us, had adult samples [11]-[17]. Krabbe-Hartkamp *et al*., found an average age of 70 years much higher than that of the latter [9].

In our series the sex ratio was 1.06, it was the same with the work of Maaly *et al*., Keeranghat *et al*., and Stefani al., whose results were between 1 and 1.5 [13] [14] [15] [16] [17]. However, in the studies of Hadhri *et al*., and Yeniçeri *et al*., there was a female predominance with a sex ratio which was respectively 0.94 and 0.64 [15] [16]. These noted differences could be explained by the choice of study populations.

4.2. Radio-Anatomical Data

a) The variants of the anterior territory of the Polygon of Willis and their correlation with sex and age

In our study, the anterior part of the polygon of Willis was complete in 69 patients, *i.e.* 57.5%. The Krabbe-Hartkamp and Keeranghat results exceeded ours with, respectively, 74% and 52.9% of the study population [5]-[14].

By sex, the anterior configuration of the polygon was complete in 50% of men and 65.5% of women. However Hafez and Horikoshi found a complete anterior configuration in 70% and 66.8% of men and 75% and 57% of women respectively [18] [19] [20]. In an exclusively male population Qiu had found 78% complete anterior configuration [20] confirming the male trend.

Regarding age, in our series the anterior part of the polygon was complete in 56% of subjects under 40 years old and 58% in subjects over 40 years old, contrary to the work of Maaly *et al*., who found a complete anterior portion in 75% of under 40s and 65% of older subjects [13].

About the earlier variants of the polygon of Willis, we encountered 6 such as Hafez while Keeranghat and his collaborators found 8 [14] [18]. However, Chen found 10. This could be explained by the large size of their sample: 507 cases [10].

In our study, the anterior type a variant was the most frequent (47%) regardless of age or sex (35% of men, 58% of women, 47% of young people and 46% of elderly subjects). It was also the most frequent variant in studies by Maaly, Keeranghat, and Hafez [13] [14] [18]. For our series, it was followed by type g (35%) regardless of age or sex with 38% of men and 31% of women. These results exceeded those of Hafez who found 15% in men and 20% in women [18]. Moreover, in Maaly's study, the second most frequent variant was type b in the youngest and type g in the elderly [13].

We did not find in our study the earlier variants of type b, f, i and j. It was the same with the results of Keeranghat and Hafez [14] [18] [21].

These differences observed in the number of earlier variants found in these studies could be explained on the one hand by the size of the study populations (Keeranghat 503; Chen 507 cases; Hafez 120 cases, our study 120 cases) but also by the prevalence of each type of variant in the general population.

In our study, men and older subjects were more likely to have variants of the anterior part of the Polygon of Willis even though there was no statistically significant difference (P = 0.096 according to sex and P = 0.766 depending on age).

b) The diameters of the anterior vessels of the polygon of Willis according to sex and age

All the vessels constituting the anterior part of the polygon of Willis were evaluated by measuring their diameter on the native sections. Therefore, those that were visualized as continuous segments of at least 0.8 mm in diameter were considered present; those less than 0.8 mm in diameter were considered hypoplastic.

In our study, mean vessel diameters were higher in men than in women. These results were similar with those of Krabbe, Hartkamp, Maaly, Hafez, and Horikoshi [5] [13] [18] [19].

However in our study, only the average caliber of the internal carotid arteries presented a statistically significant difference according to sex with a value of P = 0.016 while Maaly., had found statistically significant differences according to sex on the average caliber of the arteries internal carotid arteries, anterior cerebral arteries and anterior communicating artery [13]. It was the same with the work of Keeranghat which had found statistically significant differences on the average caliber of the internal carotid arteries [14].

In our series, the mean caliber of the internal carotid arteries was higher in elderly subjects than in young subjects without statistically significant difference. These results were similar to those of Keeranghat [14] while in Maaly's study, the average caliber of the internal carotid arteries was higher in elderly subjects with statistically significant differences [13] [21] [22] [23].

In most studies, the average caliber of centripetal vessels (internal carotid arteries) is higher in older subjects [13] [14] [23]. This could be explained by the compensatory widening of these vessels in the elderly due to reduced cardiac output, decreased elasticity or atherosclerosis whose prevalence increases with age.

5. Conclusions

The anterior part of the polygon of Willis plays an anastomotic role between the carotid territories, thus ensuring adequate cerebral blood flow in the event of occlusion in this territory. Its ability to redistribute blood flow depends on its morphology, the presence and size of the vessels that constitute it.

Its morphology depends on its variants, some of which have greater hemodynamic importance than others depending on whether or not they are continuous with the rest of the polygon.

Knowledge of the capacity of the anterior vessels of the polygon to ensure their role of replacement is essential for the management of vascular diseases of the brain.

Other studies should be carried out on a larger number of patients in order to create a Senegalese database for the diameters of the posterior vessels of the polygon of Willis in angio-MRI.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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