Anatomical variation of circle of Willis in computed tomographic angiography study

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ABSTRACT

Introduction: The circle of Willis (CW) is located at the base of the brain, connecting the carotid and vertebral-basilar arterial systems. Cerebral computed tomographic angiography (CTA) has high sensitivity and specificity in detecting intracranial vascular variations. The aim of this study was to identify anatomic variations in the CW using cerebral CTA and to compare these variations based on age and gender. **Methods:** A cross-sectional study was conducted among total of 54 patients referred for CTA who met the inclusion criteria were evaluated. Data on age, gender, and the presence of anatomical variations in the CW were collected and analyzed using SPSS version 26.0. **Results:** The study included 54 participants, with a male-to-female ratio of 1.45:1 and ages ranging from 3 to 87 years. The most common anatomical configuration was Type A anterior CW (75.9%), followed by hypoplasia of the bilateral posterior communicating arteries / Type E posterior CW (38.9%). Complete anterior and posterior circulation was observed in 16.6% of participants, and the proportions of complete CW configuration were similar in males and females (p = 0.501 and 0.391 for anterior and posterior CW, respectively) as well as in younger (under forty) and adult (forty or older) participants (p=1 for both anterior and posterior CW), without statistically significant differences. Fetal PCA was observed in 24.1% of participants, with the unilateral type being more common (61.5%), and there was no correlation with the participants' gender. **Conclusions:** This study identified common anatomical variations in the Circle of Willis using cerebral CTA. Type A anterior CW and Type E posterior CW were most prevalent, with no significant differences in completeness based on gender or age. Fetal PCA was observed in 24.1% of participants, primarily in the unilateral form, without gender correlation. These findings highlight the importance of recognizing anatomical variations in the Circle of Willis for improved clinical decision-making and diagnostic accuracy in neurovascular assessments.

Keywords: Circle of Willis, computed tomographic angiography, posterior communicating arteries.

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INTRODUCTION

The circle of Willis (CW) is an anastomotic arterial polygon located at the base of the brain. It serves as an important circulatory pathway by connecting the carotid and vertebral-basilar systems. The CW was first elucidated by Thomas Willis approximately 400 years ago.[1] It is an essential route for collateral blood supply to the brain in cases of occlusion in either system.[2]

The complete CW consists of 10 components: two internal carotid arteries (ICAs), two A1 segments of the anterior cerebral arteries (ACAs), two P1 segments of the posterior cerebral arteries (PCAs), the anterior communicating artery (ACom), two posterior communicating arteries (PComs), and the tip of the basilar artery (BA). The prevalence of this "typical" or "classic" circle ranges from 4.6% to 72.2%.[3] Studies have shown considerable variability in the CW, with less than half of individuals possessing a complete CW.[4] Variations in the CW influence cerebral blood flow hemodynamics, affecting vascular territories, the pathophysiology of cerebral

arterial remodeling, aneurysm formation or rupture, and stroke development.[5] Moreover, the CW is the main route for collateral blood flow in severe occlusive diseases of the ICA. Patients with CW variants that allow efficient collateral circulation have a lower risk of transient ischemic attacks and stroke than those without such collaterals.

Computed tomographic angiography (CTA) allows reliable, non-invasive evaluation of the intracranial arteries. In addition, CTA provides useful information about anatomical variations in cerebral circulation, with reported high sensitivity and specificity (81–90% and 93%, respectively), approaching the diagnostic accuracy of digital subtraction angiography and comparable to the gold standard, catheter angiography.[7]

Various studies conducted abroad have linked anatomical variations in the CW to the development of stroke, migraine, cerebral aneurysms, and mental illness.[7] However, there are very few studies demonstrating the various configurations of the CW in the Nepalese population.[8] The aim of this study was to identify anatomic variations in CW configuration as seen on cerebral CTA in the Nepalese population, thereby helping to fill the literature gap in this field.

METHODS

A cross-sectional observational hospital-based study was conducted in the Department of Radiodiagnosis at the National Academy of Medical Sciences (NAMS), Bir Hospital, Kathmandu, over a period of 16 months from August 2019 to December 2020. All patients attending the Radiology Department for cerebral CTA who provided informed written consent were included. Participants with skull base tumors, congenital brain abnormalities, and hemorrhagic stroke were excluded from the study. Ethical approval was obtained from the Institutional Review Board of NAMS (Ref. No. 547/77-78). Data collection was done by convenience sampling technique till sample size was obtained.

The examination was performed on a 128-slice CT scanner (Philips). Patients were positioned supine, with the scanogram covering the area from the skull base to the vertex. Low osmolar contrast media was injected via a pump injector. Arteries with cross-sectional diameters of less than 0.8 mm were considered hypoplastic.

Variables such as complete/incomplete CW, type of variant anatomy of the anterior/posterior CW, presence or absence of aneurysms, other vascular pathologies, age, and gender were recorded. Data were entered into MS Excel 2016, and statistical analyses were conducted using Statistical Package for the Social Sciences (SPSS) version 26.0. The chi-square (χ^2) test was used when appropriate. The p-values (using Fischer's exact test) were calculated with a predetermined level of significance of 0.05, and a 95% confidence interval (CI) was constructed. The results were expressed as percentages, mean ± standard deviation, and median for the variables. Appropriate tables and diagrams were used during data analysis.

RESULTS

Our study group included CTA studies of 54 patients. Thirty-two patients (59.3%) were male and 22(40.7%) were female, resulting in a male-to-female ratio of 1.45:1. The mean age of the patients was 52.65 ± 19.6 years, with ages ranging from 3 to 87 years.

The most common indication for CTA was suspected CVA 25(46.3%), followed by suspected aneurysm 13(24.1%). (Table 1)

Table 1: Indications of CTA among participants

Indication	Frequency(n)	Percent(%)
Suspected CVA	25	46.3%
Suspected Aneurysm	13	24.1%
Headache	3	5.6%
Seizure	2	3.7%
Suspected AV Malformations	2	3.7%
Tumour	2	3.7%
Trauma	5	9.3%
Unspecified	2	3.7%
Total	54	100%

Regarding anatomical variations, the proportion of patients with a complete anterior Circle of Willis (CW) was 81.5% (n=44), with a prevalence of 78.1% (n=25) in males and 86.4% (n=19) in females. Similarly, 18.5% (10/54) of patients had an incomplete anterior CW, with a prevalence of 21.9% in males (n=7) and 13.6% in females (n=3), respectively. (Table 2)

Table 2: Genderwise proportion of complete and incomplete anterior/posterior CW

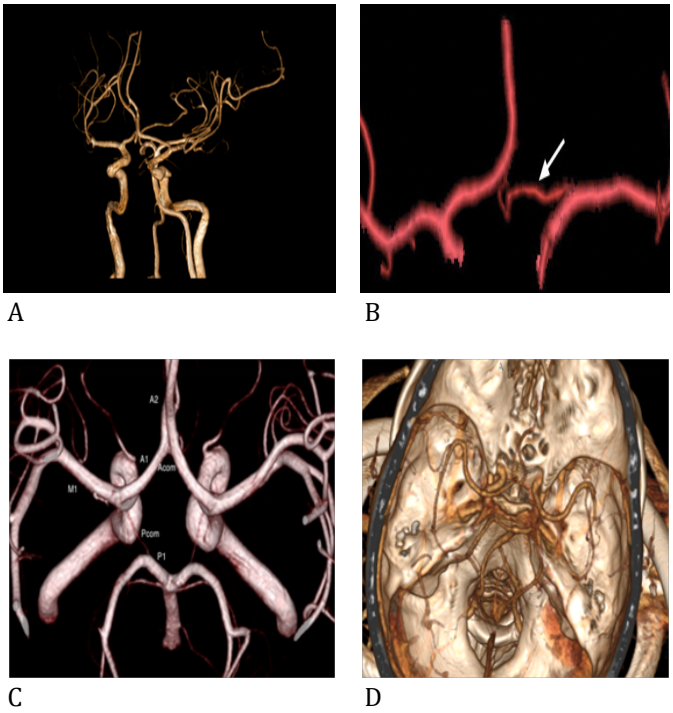
Parameter	Male (n=32)	Female (n=22)	Total (n=54)	p-value
Anterior CW				
Complete	25 (78.1%)	19 (86.4%)	44 (81.5%)	0.501
Incomplete	7 (21.9%)	3 (13.6%)	10 (18.5%)	
Posterior CW				
Complete	13 (40.6%)	6 (27.3%)	19 (35.2%)	0.391
Incomplete	19 (59.4%)	16 (72.7%)	35 (64.8%)	

Similarly, the proportion of patients with a complete posterior Circle of Willis (CW) was 35.2% (n=19), with a prevalence of 40.6% (n=13) in males and 27.3% (n=6) in females. In contrast, 64.8% (n=35/54) of patients had an incomplete posterior CW, including 59.4% (n=19) of males and 72.7% (n=16) of females. No significant statistical difference was found between males and females regarding

the proportion of complete and incomplete anterior/ posterior CW. (Table 2)

Isolated incomplete anterior CW was observed in 9 out of 10 participants (90%), while isolated incomplete posterior CW was noted in 34 out of 35 participants (97%). Only one participant exhibited incomplete circulation in both the anterior and posterior CW. An incomplete configuration in either the anterior or posterior circulation was found in 45 participants (83.3%), whereas nine participants (16.6%) had a complete CW in both circulations.

Similarly, Type A complete anterior circulation variant with a single anterior communicating artery (ACom) was the most common variant, observed in 41 participants (75.9%) among anterior circulation variants. This variant was seen in 17 females (41.4% of anterior circulation variants, 77.2% of overall female participants) and 24 males (59.6% of anterior circulation variants, 70.6% of overall male participants). The Type H complete anterior circulation variant, characterized by a distally split common anterior cerebral artery (ACA trunk), was the second most common variant, found in 6 participants (11.1%). (Figure 1)



A B C D

Figure 1: A: 3-D image showing classical Circle of Willis (Type A anterior circulation). B: VRT image showing hypoplastic left A1 segment of ACA (Type H anterior circulation. C: 3-D labelled CTA: Bilateral hypoplastic PCA (Type E posterior circulation). D: MDCTA showing Type E posterior circulation variant

Similarly, for posterior CW variants, the Type E incomplete posterior circulation variant, characterized by bilateral hypoplasia of the posterior communicating arteries (PComs), was the most common variant, observed in 21 participants (38.9%). This variant was present in nine female participants (42.8% of posterior circulation variants, 40.9% of overall female participants) and 12 male participants (57.2% of posterior circulation variants, 37.5% of overall male participants).

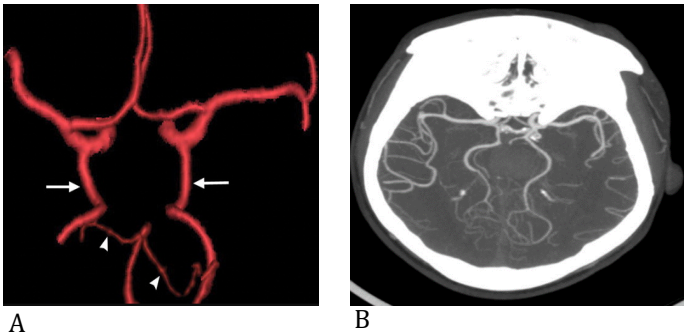
The Type A complete posterior circulation variant, characterized by the presence of both posterior communicating arteries (PComs), was the second most common variant, observed in 15 participants (27.8%). It was noted in 12 male participants (80%) and 3 female participants (20%). (Figure 1C, 1D)

The Type G variant was found in six participants (11.1%), Type J in four participants (7.4%), and Type B in three participants (5.6%). Type D and Type F were each observed in two participants (3.7% each), while Type H and Type I variants were not detected.

Regarding the configuration of the posterior cerebral arteries (PCAs), the adult configuration was observed in 41 participants (75.9%), including 24 males (58.5%) and 17 females (41.5%). The difference in the proportion of adult PCA configuration between males and females was not statistically significant ($p = 0.63$).

Similarly, the fetal configuration of the PCAs was seen in 13 participants (24.1%), comprising six males (46.1%) and seven females (53.9%). The difference in the proportion of fetal PCA configuration between males and females was also not statistically significant ($p=0.59$).

Among the 13 participants with fetal posterior circulation, eight had unilateral fetal posterior circulation, while five exhibited bilateral fetal configuration. (Figure 2A, 2B)



A B

Figure 2: A: VRT CTA showing Bilateral Fetal PCA (Type C Posterior circulation) (Arrows- Fetal PCA, Arrowheads- Superior cerebellar arteries). B: Axial cerebral CTA image showing bilateral fetal PCA with right P1 segment aplasia.

When comparing the completeness of the anterior CW based on age groups (<40 years vs ≥40 years), a complete anterior CW was more commonly observed in the ≥40 years group (n=34, out of a total of 44 cases of complete anterior CW). Similarly, incomplete anterior CW variants were also more frequent in this age group (n=8, out of a total of ten cases of incomplete anterior CW).

In the <40 years group, complete anterior CW was found in 83.3% (n=10), while incomplete anterior CW was observed in 16.7% (n=2). In the ≥40 years group, complete anterior CW was found in 80.9% (n=34), while incomplete anterior CW was observed in 19.1% (n=8). However, there was no significant statistical difference in the completeness of the anterior CW between the <40 years and ≥40 years groups (p = 1.0, Fisher's exact test). (Table 3)

Similarly, when comparing the completeness of the posterior CW, a complete posterior CW was more frequently observed in the ≥40 years group (n=15, out of a total of 19 cases of complete posterior CW). Incomplete posterior CW variants were also more common in this group (n=27, out of a total of 35 cases of incomplete posterior CW). In the <40 years group, complete posterior CW was found in 33.3% (n=4), while incomplete posterior CW was observed in 66.7% (n=8).

In the ≥40 years group, complete posterior CW was found in 35.7% (n=15), while incomplete posterior CW was observed in 64.3% (n=27). Again, no significant statistical difference was found in the completeness of the posterior CW between the <40 years and ≥40 years groups (p=1.0, Fisher's exact test). (Table 3)

Table 3: Age wise proportion of complete and incomplete anterior/posterior CW

Parameter	<40 years (n=12)	≥40 years (n=42)	Total (n=54)	p-value
Anterior CW				
Complete	10(83.3)	34(80.9)	44 (81.5%)	1.0
Incomplete	2(16.7)	8(19.1)	10 (18.5%)	
Posterior CW				
Complete	4(33.3)	15(35.7)	19 (35.2%)	0.391
Incomplete	8(66.7)	27(64.3)	35 (64.8%)	

DISCUSSION

The CW is an important anastomotic arterial polygon located at the base of the brain, connecting the carotid and vertebral-basillar arterial systems. It is an essential route for collateral supply of blood to the brain in cases of occlusion in either system.[2] Classical C is bilaterally symmetrical and with complete ring of vessels but variations in this typical configuration is often seen.[3,4,9] Status of this circle is crucial for determining the adequacy of brain circulation during management of cerebral aneurysms and other vascular diseases.[9,10] Though DSA is considered gold standard in detection and characterization of aneurysms and vascular variants, cerebral CTA being cheaper, non-invasive and with less radiation exposure is considered equally sensitive and specific.[11]

In our study of 54 participants, 32(59.7%) were males and 22(40.7%) were females with slightly higher proportion of male participants (male to female ratio of 1.45:1). Similar high male proportion was seen in another study by Dhakal et al.[12] with Male to Female ratio of 1.12.[12,13]

Most common indication for CTA in our study was suspected CVA (n=25, 46.3%) followed by suspected aneurysm (n=13, 24.1%). This was in contrast with the study done by Dhakal et al.[12] with most common indication as evaluation of Subarachnoid hemorrhage (n=23, 24.2%) Similarly in study by Prasad et al.[13] most common indication was suspected intracranial hemorrhage. The difference in the result can be due to referral of patient and sampling.

In our study incomplete configuration of CW in either of anterior or posterior circulation was noted in 45 participants (83.3%) while nine patients showed complete configuration (16.7 %). Similar findings were found in studies by Machasio et al.[16] and Dhakal et al.[13] with complete CW configuration in 37.2%. Meanwhile some studies show much higher proportion of complete CW configuration (77.5%).[17] The prevalence of this configuration is however higher than in study done by Chuanya et al.[2] with prevalence of 12.24%. The proportion of patients with complete anterior CW was 81.5% (n=44). The prevalence of complete anterior CW was 78.1% (n=25/32) in male participants and 86.4% (n=19/22) in female participants. Complete anterior CW configuration was seen in 78.58% (n=33) in a study by Naveen et al.[18], which was similar to our study. Similar findings were observed in a study done by Machasio et al.[16] where anterior circulation was complete in 84% cases.

In our study, Type A complete anterior circulation variant (single Acom) was the most common variant 75.9%). This variant was also the commonest variant in other studes as well[16,18,19] Type H complete anterior circulation was the second most common variant observed in 6 participants (11.1%). Each of Type D, Type G and Type I variants accounted for 2% cases while Type B, Type E, Type F and Type J variants were not observed. In study conducted by Keeranghat et al.[14] most common anterior circulation variant was Type A (52.9%) followed by Type H (12.7%) which is similar to our study. Similarly In another study, Type B, Type E, Type F, Type I and Type J variations were

not demonstrated.[16]

In this study, complete posterior CW was 35.2%. The prevalence of complete posterior CW was 40.6% (n=13) in male and 27.3% (n=6) in female . Around 64.8%(35/54) of patients had incomplete posterior CW. This prevalence of complete posterior CW configuration was similar to other studies.[12,16] In a study conducted by Ross et al.[20] the proportion of complete posterior circulation was much higher (96%, n=48/50)

Type E posterior variant has been linked to an increased risk of ischemic stroke.[18] In our study Type E incomplete posterior circulation variant (bilateral hypoplasia of Pcom) was the most common variant seen in 21 patients accounting for 38.9% of the posterior circulation variants. Type E variant was observed in nine female participants (42.8 % of posterior circulation variants and in 40.9% of overall female participants). The same variant was observed in 12 male participants (57.2% of posterior circulation variants and in 37.5% of overall male participants). Our study is similar with study done by other studies.[10,,14,16,18,19] Studies in Nepalese population as well, most common posterior circulation variant was Type E (26.2% of overall variation in study by Prasad et al.[13] and 34.7% (n=34) in study by Dhakal et al.[12] Cerebral CTA study done by Zhang et al.[21] showed dominance of type E posterior variant with a prevalence of 52.3%, which is higher than the our study. Meanwhile another study done by Singh et al.[10] reported prevalence of Type E posterior circulation variant to be 12%. This was much less compared to the findings on our study and was second most common overall variant (most common being Acom hypoplasia/ Type G anterior CW). These variations can be due to size of the sample and sampling technique. Apart from these studies, many studies done in various parts of world also suggest Pcom variant to be the most common variation in posterior circulation as well as in overall circle of Willis, which corroborates to the findings of our study.[21] Type A complete posterior circulation with both Pcom (classical complete posterior circulation) was the second most common posterior circulation variant observed in 15 participants (27.8%), which corroborates with the prevalence of 27.6% (n=26/94) in another similar study.[16] Type G variant was observed in 6 participants (11.1%), Type J in four participants (7.4%) and Type B in three participants (5.6%). Each of Type D and Type F were noted in two participants (3.7% each) while Type H and type I variants were not noted in our study. Variants that were not demonstrated in other studies included Type C and Type J and Type H and Type I variants.[10,14,16] Isolated incomplete anterior CW was seen in nine participants out of ten total incomplete anterior CW configuration (90%) and isolated incomplete posterior CW was seen in 34 patients out of 35 total incomplete posterior CW configuration (97%) compared to 3.4%(n=2) and 76% (n=45) respectively in another study.[16]

Fetal PCA is a frequent variant of the posterior circulation. Studies have shown predisposition of Fetal PCA to stroke mechanism.[1] Persistence of fetal PCA has been demonstrated in various anatomic and angiographic studies with variations ranging from 11-46%.[23]

Fetal configuration of the PCAs was seen in 13 participants (24.1%), of which 6(46.1%) were male and 7(53.9%) were female. Out of 13 participants with fetal posterior circulation, 8 participants (61.5%) demonstrated unilateral circulation while 5(38.5%) had bilateral fetal configuration. Furthermore, the proportion of male and female fetal PCA configuration was statistically not significant in our study (p=0.59). This prevalence was very much similar with the study done by Kovac et al.[16] However, in contrary to our study, fetal PCA configuration in males and females was statistically significant in that study. Various studies done in Nepalese population shows discrepancies in the prevalence of fetal PCA configuration.[12,13] Such discrepancies can be due to the differences in participants' number in multiple studies.

One of our objectives was to observe whether the incompleteness of anterior and posterior circulation was associated with age or not as few studies including that by Chen et al.[24] has shown more prevalence of complete CW configuration among younger age groups For comparison purpose as suggested by similar other studies, age demarcation of less than or more than/equal to forty years was used.[14] In our study, complete and incomplete anterior CW in both age groups were similar and had no statistically significant difference. However, the study done by Keeranghat et al.[14] showed a very strong statistically significant difference between completeness of anterior and posterior circulation with age of the participants. Some studies have put forward the association between gender and CW variations with more complete circulation in the female population.[24] However, in our study, no significant statistical difference was found between males and females. Regarding the complete posterior CW, no significant statistical difference was found between males and females. A similar CTA based study also failed to demonstrate the statistically significant difference of complete circulation in male and female.[18.] However, a study done by Keeranghat et al.[14] found a strong statistically significant difference between males and females. Slight differences can be due to the differences in sample size and techniques

We included only symptomatic patients advised for CTA. Participants with vascular pathologies like AV malformations and aneurysms in CTA would have increased the sample size. Follow-up of the patients with some variant anatomy (e.g. Type E posterior circulation) for development of aneurysms or CVA was not possible with our study. Different minor but common CW variations like azygous ACA, PTA, fenestrations, and duplications were not demonstrated. Lastly, the study was based in a single center and may not be representative of the population.

CONCLUSIONS

In this study, we identified common anatomical variations in the Circle of Willis using cerebral CTA, with Type A anterior CW and Type E posterior CW being the most prevalent. No significant differences were observed in the completeness of CW configurations based on gender or age. Fetal PCA was present in 24.1% of participants, predominantly in the unilateral form, without a gender correlation. These findings highlight the frequent occurrence of anatomical variations in the Circle of Willis and emphasize the importance of understanding these variations for clinical decision-making and diagnostic accuracy in neurovascular assessments.

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AUTHORS' CONTRIBUTIONS

AB designed the research, collected data, performed statistical analysis, and interpretation. SR and HK contributed to the literature review and manuscript preparation. All authors read and approved the manuscript.

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