Evaluation of Anatomical Variants of the Circle of Willis in a Nigerian Population Using Contrast Enhanced Computed Tomography (CECT) Scan.

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Abstract

Observations from different races have demonstrated the importance of variants of the major arterial supply to the brain, these are lacking in the Nigerian population. This anatomic-imaging study was carried out to identify, evaluate and document the distributions of variants of the Willis' circle using Contrast Enhanced Computed Tomography (CECT) scan. A retrospective and prospective study was conducted on 512 apparently normal brain CT images consisting of 286 (55.86%) males and 226 (44.14%) females with a Bright speed 4-slice CT scanner in the Radiology Department of a Nigerian healthcare institution. The images were reviewed using proportionate random sampling probability technique. Data collected showed that 39.84% had complete circle of Willis while the rest (60.16%) had wide morphological variants. These include absence of bilateral Posterior Communicating Artery (PCoA) (39.26%), presence of double Anterior Communicating Artery (ACoA) (1.56%), absence of one A1 segment (1.37%), absence of ACoA (5.47%), absence of P1 segment and PCoA (5.08%) and the absence of unilateral PCoA (7.42%). The distribution of the variants was gender dependent at $p<0.001$ but age group dependent at $p<0.05$, as a significant correlation exist between gender and age groups at $p<0.05$ and $p<0.01$ in relation to the variants noted. The CECT scan method has established for the first time the occurrence and availability of morphological variants of the Willis' circle in a Nigerian population with 39.84% complete circle and 39.26% bilateral absence of PCoA observed as the most common while 1.37% absence of one A1 segment was the least among other variants noted.

Keywords: CECT Scan, Circle of Willis, Morphological, Variants.

1. Introduction:

The circle of Willis is a complex structure first described and named after a seventeenth century English Physician "Dr. Thomas Willis" in 1664 ''[1]'', it is an important polygonal complex channel located at the root of the substance of the brain between the two vertebral arteries of the vertebrobasilar system and the right and left internal carotid arteries that supply the brain ''[2]''. It special activity relies on the continuous circular method of arrangement (often called structural completeness) which is known to be different among individuals ''[3]''. Configuration of the brain arteries into the Willis' circle provides collateral in the distribution of blood such that if a portion of it becomes occluded or if one of its arterial supply is narrowed, the flow of blood from other arteries can maintain adequate cerebral distribution thereby preventing symptoms from conditions like ischaemia ''[4]''. The study of embryology forms the basis of development in anatomical variants of the circle of Willis which can be demonstrated ultrasonographically ''[5]''. Some of these variants represent the mainstream of evolution while others occur as a result of alteration in the vascular construction programme by some factors, during vasculogenesis ''[6]''. Morphological variants in the circle of Willis are very common, for example, the Posterior Communicating Arteries (PCoAs) are absent in some individuals, in others, the Anterior Communicating Arteries (ACoAs) may be double. In approximately one in three persons, one of the posterior cerebral arteries is a major branch of the Internal Carotid Artery (ICA), this variant is usually unilateral ''[7]''. In some cases in the proximal part of its course, one of the anterior cerebral arteries is often small while the Anterior Communicating Artery ((ACoA) is larger than normal in these subjects ''[8]''. In some individuals, the proximal part of the Posterior Cerebral Artery (PCA) is narrowed and its ipsilateral Posterior Communicating Artery (PCoA) is large, so the ICA supplies the posterior cerebrum in one common variation. The ACoA is a large vessel, such that a single ICA supplies both the right and left anterior cerebral hemispheres in another variation ‘’[7],[8]’’. A greater number of these variations also exist as stipulated by the work of ‘’[9]’’ on “circle of Willis in cerebrovascular disorder”. Some of these variants are different from the original description put forward by Dr. Thomas Willis (1621-1675). The works of ‘’[10],[11]’’ carried out in Athens, have equally shown that variants in the Willis’ polygon contribute importantly to cerebrovascular disease development. Meanwhile, these variants are clinically significant in cerebral haemodynamics, where they act as collateral anastomotic network ‘’[12],[13],[14]’’. Study by ‘’[15]’’ on the recently deceased 102 Iranian males showed that about 50.00% of the subjects were characterized with a kind of variant in the circle of Willis congenitally. Also, studies by ‘’[16],[17],[18],[19]’’ have investigated variants of the difference in each segment of the circle of Willis, while comparative studies by ‘’[15]’’and ‘’[20]’’ have equally shown a range of anatomical variants of the cerebral arterial circle of Willis in the Iranian and the Egyptian populations respectively. Studies on anatomical variants of the Willis’ circle across the different races based on the Magnetic Resonance Imaging (MRI), the cadaveric Gross Dissection (GD) and also with the injection techniques have been reported, meanwhile the occurrence of anatomical variants and presentation of the circle of Willis in the Nigerian population have not been recorded at all. Therefore, this anatomic-imaging study was aimed at identifying, evaluating and documenting the morphological variants and presentation of the circle of Willis in a Nigerian population using contrast enhanced brain Computed Tomography (CT) images and to also determine the distribution and predominance of these variants among the different age groups correlated with gender and age

2. Materials and method:

A retrospective and prospective research design conducted on 512 apparently normal brain CT images consisting of 286 (55.86%) males and 226 (44.14%) females with their ages graded from <1 year to >91 years, reviewed between January 2013 to July 2015 using a Bright speed 4-slice CT scanner with the equipment standardized according to the manufacturer’s specifications as obtained from the Radiology Department, Jos University Teaching Hospital (JUTH). Axial sections of the brain (Plate 1) were obtained from the base of the skull to its vertex with slice thicknesses of 2.5mm following the intravenous administration of 10 – 40mls Ultravist (contrast medium) through the anti-cubital vein for enhancement of the vessels (circle of Willis). Images were carefully observed with the component vessels noted. A proportionate random probability method was employed. Data were obtained in accordance with the institutional guidelines following ethical permission, approval and clearance granted by the Committee on Research Ethics, JUTH.

3. Results:

Table 1 shows the distribution of cerebral arterial circle of Willis pattern observed in the study population.

Table 1
Distribution of variants of the cerebral arterial circle of Willis pattern observed amongst a Nigerian population.

Code	Variants	No. of Cases	Percentage (%)
CP	Complete circle of Willis	204	39.84
V_1	Presence of double ACoA	8	1.56
V_2	Absence of A1 segment	7	1.37
V_3	Absence of ACoA	28	5.47
V_4	Absent ICA	0	0.00
V_5	Absence of bilateral PCoAs	201	39.26
V_6	Absence of both P1 segments	0	0.00
V_7	Absence of P1 segment and a PCoA	26	5.08
V_8	Absence of a P1 segment	0	0.00
V_9	Absence of a unilateral PCoA	38	7.42
	Total	512	100

One-Sample Kolmogorov-Smirnov Z = 10.846 at p<0.001, showed a normal distribution of the variants in the study population.

Table 2
Age group distribution of variants of cerebral arterial circle of Willis pattern amongst a Nigerian population

Age-group (years)	CP	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	Total
<1- 10	13	0	1	2	0	9	0	1	0	2	28
11-20	26	1	0	2	0	16	0	3	0	5	53
21-30	34	1	2	5	0	47	0	1	0	3	93
31-40	34	1	2	11	0	52	0	13	0	6	119
41-50	51	4	1	3	0	31	0	2	0	16	108
51-60	24	0	1	1	0	21	0	4	0	6	57
61-70	8	0	0	1	0	13	0	1	0	0	23
71-80	4	0	0	2	0	3	0	1	0	0	10
81-90	7	1	0	1	0	7	0	0	0	1	16
>91	3	0	0	0	0	2	0	0	0	0	5
Total	204	8	7	28	0	201	0	26	0	38	512

The distribution of the variants was not age group dependent (chi cal. = 69.277; df = 45; $p<0.05$)

Plate 1 shows axial CECT scan of the brain at the level of posterior cliniods demonstrating a hyperdense (enhanced) brain arteries which include a single ACoA that connects the right and left anterior cerebral with a paired internal carotid. Originating from the ICA are the right and left PCoAs that join the right and left posterior cerebral arteries, and a single basilar artery as indicated by the arrows. This description, defines a complete circle of Willis with all the vessels intact. Plate 2 shows an additional hyperdense vessel parallel to the single ACoA with the adjoining paired anterior cerebral arteries, this represents the presence of double ACoA (V_1) as indicated by the two arrows. Plate 3 shows axial CECT scan image of the brain characterised with the absence of an A1 segment (V_2) (the vessel that begins from the end of the ICA to the junction with the ACoA) as shown by the arrow. Plate 4 shows total absence of a vessel (ACoA) communicating with the right and left anterior cerebral arteries; this represents the complete absence of an ACoA (V_3), as indicated by the arrow. The preterminal branch that begins from the ICA close to its end division to connect with the Posterior Cerebral Artery (PCA) is the PCoA. Axial CECT scan image of the brain shows complete absence of the PCoA bilaterally (V_5) in Plate 5 as shown by the arrows. Plate 6 demonstrates the absence of a vessel that begins from the basilar division to the junction with the PCoA (P1 segment) and also the absence of a connection of another vessel between the PCA and the ICA, this represents the absence of a P1 segment and a PCoA (V_7) as indicated by the arrows. Plate 7 shows total absence of a unilateral connection between the PCA and the ICA which represents the absence of a unilateral PCoA (V_9).

4. Discussion

Results of the present study show that subjects with complete circle of Willis (plate 1), accounted for about 39.84% while the rest (plates 2, 3, 4, 5, 6 and 7) recorded 60.16% wide (incomplete) morphological variants. This observation is in line with the report of ''[11]'' who studied 1,000 brains using the GD technique to record 45.20% complete Willis' circle with 54.80% variants noted. The result of this study also agrees with ''[17]'' who conducted a research on 150 Netherland subjects using the MRI technique and ''[8]'' who also carried out a composite review of about 1,413 human brains of the Japanese population using the GD technique to obtain 42.00% and 35.50% complete circle of Willis with 58.00% and 64.50% variants noted respectively. The bilateral absence of PCoA (V_5) (Plate 5) 39.26% was the most variant (incomplete) recorded in our study population. This finding asserts ''[21]'' who in his anatomical variations of the *circulus arteriosus* in cadaveric human brains, put it that "incomplete circle of Willis was mostly due to the absence of PCoA". The result of the present study also support ''[22], [23]''. Absence of a unilateral PCoA (V_9) (Plate 7) 7.42% is closely related to the result of ''[22]''. Also, the absence of ACoA (V_3) (Plate 4), was observed to be 5.47% which is in keeping with ‘’[24]’’ who recorded a definitive absence of ACoA to be 5.00% of surgical dissections in his “microsurgical anatomy of common aneurysm sites”. However, the result of 5.47% observed from the present study is relatively high compared to ‘’[11], [17]’’ who reported similar findings on the absence of an ACoA to be 0.80-1.00% cases. The absence of P1 segment and a PCoA (V_7) (plate 6) 5.08% recorded from our study disagrees with ‘’[25]’’ who observed that the P1 segment may be absent developmentally from the PCA but the absent of it (P1 segment) is an uncommon finding. Cases of presence of double ACoA (V_1) 1.56% recorded from our study justifies ‘’[26]’’who observed double ACoA in 22 out of 200 subjects. This observation also support ‘’[27], [28]’’who reported that the frequency of a double ACoA appears to be racial; this was later observed by almost all authors working on the circle of Willis. The result of absent A1 segment (V_2) (Plate 3) 1.37% obtained from our study agrees with the observation of ‘’[29]’’who reported 1.00-2.00% of the absence of an A1 segment in their “microsurgical anatomy of the anterior cerebral-anterior communicating-recurrent artery complex”. Absence of an ACoA (V_3) and a PCoA (V_7) 3.15% each (Table 1) was recorded in our study while the absence of an A1 segment (V_2) was 0.70%. Interestingly, no cases of absent ICA (V_4), absence of both P1 segments (V_6) and the absence of one P1 segment (V_8) were noted in our study. These findings are thus in line with the observations of ‘’[15]’’ who studied 102 brains of recently deceased Iranian male population. The result on gender distribution of the circle of Willis obtained from our study population shows 55.86% males and 44.14% females which justifies the report of ‘’[30]’’who studied 100 male and female Moroccan subjects using the injection technique. Similarly, studies such as those of ‘’[20],[31],[32]’’ reported similar observations but did not mention the gender distribution of their cases. However, the distribution of variants in the present study was gender dependent at $p<0.001$. On the relationship between gender and age groups (Table 2) of the variants, Pearson correlation coefficient (r), revealed a significant correlation exist at $p<0.01$ and $p<0.05$ between gender and age groups in relation to the variants noted. The findings therefore validate similar works by ‘’[15],[33]’’.

Postulations as to the underlying reasons for the occurrence of these variants noted in our study may not have been accounted for in this research, but may probably be attributed to factors that could be embryological (developmental), racial, or any combination of the aforementioned. However, results of the present study have established for the first time the occurrence, presence and availability of morphological variants of the circle of Willis in a Nigerian population. Thus, familiarization of these variants may contribute significantly to pattern recognition and interpretation of cranial vessels in relation to diagnosis and even during neurosurgical interventions (if need be) which will be helpful in enhancing the calibre of patient care.

5. Conclusion

From the results of this research, it could be concluded that the CECT scan has revealed some morphological variants of the circle of Willis in a Nigerian population with 39.84% complete circle of Willis and 39.26% bilateral absence of PCoA observed as the most common while the absence of one A1 segment (1.37%) was the least among other variants noted.

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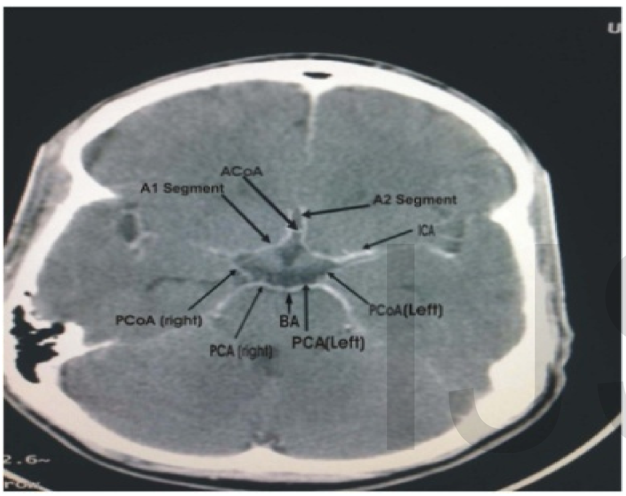

Plate 1: Axial CECT scan image of the brain demonstrating a complete pattern (CP) of the circle of Willis as shown by the arrows

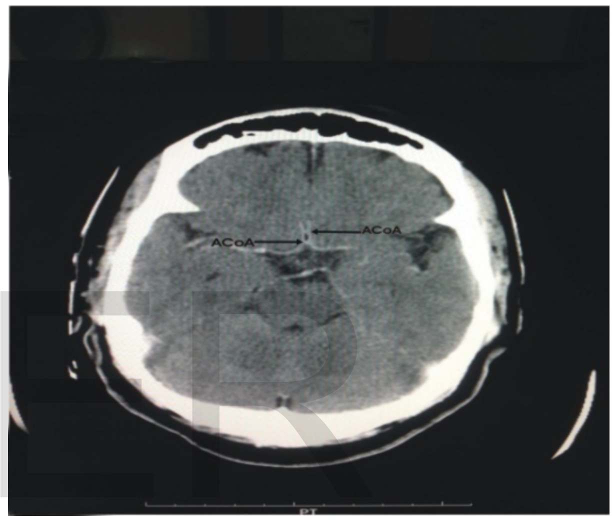

Plate 2: Axial CECT scan image of the brain illustrating the presence of double ACoA (V_1) as shown by the arrows

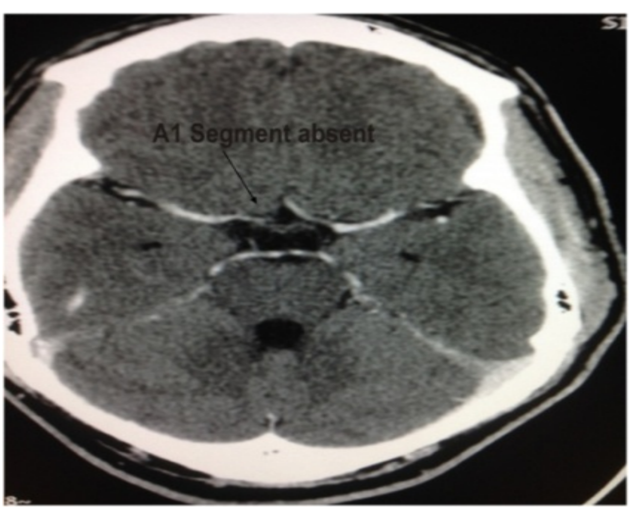

Plate 3: Axial CECT scan image of the brain demonstrating the absence of one A1 segment (V_2) as indicated by the arrow

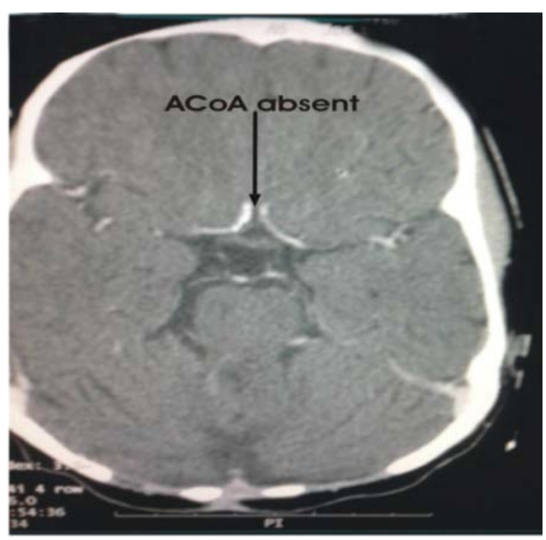

Plate 4: Axial CECT scan image of the brain demonstrating absence of an ACoA (V_3) as shown by the arrow

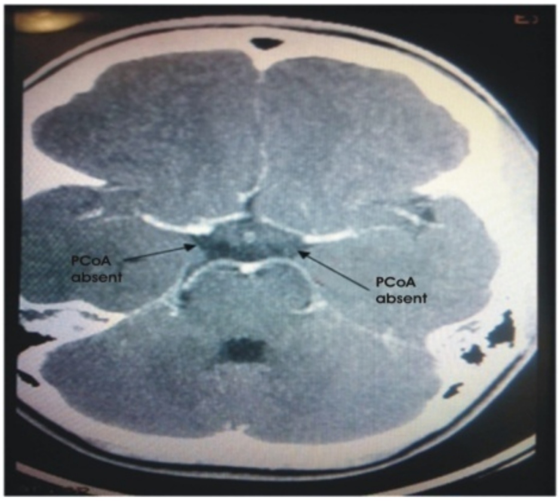

Plate 5: Axial CECT scan image of the brain demonstrating the bilateral absence of PCoA (V_5) shown by the arrows

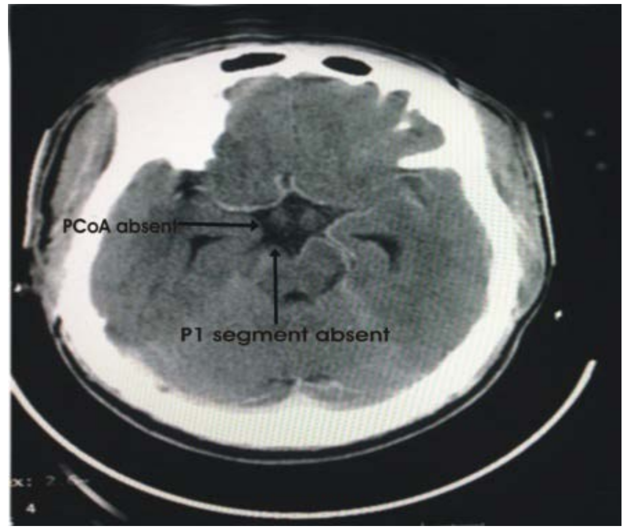

Plate 6: Axial CECT scan image of the brain illustrating the absence of a PCoA and a P1 segment (V_7) as shown by the two arrows

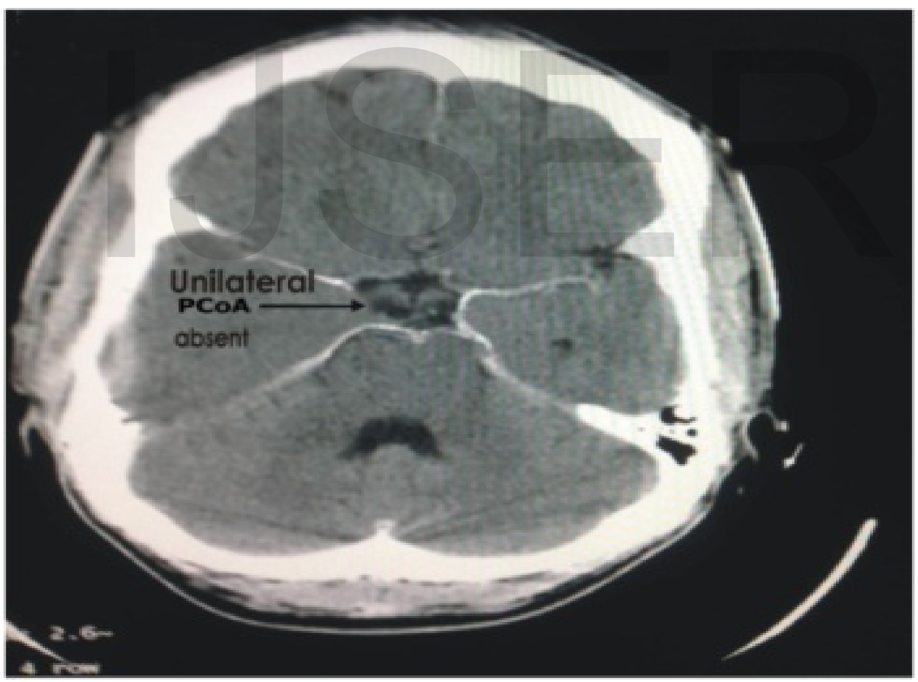

Plate 7: Axial CECT scan image of the brain demonstrating the absence of a unilateral PCoA (V_9) as indicated by the arrow.