Journal of Associated Medical Sciences 2023; 56 (3): 82-88

JAMS Journal of Associated Medical Sciences

Scopus Indexed & Thai-Journal Citation Index Centre (TCI)

Journal of Associated Medical Sciences

Journal homepage: https://www.tci-thaijo.org/index.php/bulletinAMS/index

Morphological patterns of the cerebral arterial circle of Willis: Implication in subjects with ischemic stroke

Samson Omini Paulinus[1] Emmanuel Okon Esien-umo[1] Blessing Samuel Ibe[1] Bassey Eyo Archibong[1*] Eru Mba Eru[2] Akwa Erim Egom[1] Nneoyi Onen Egbe[1] Anozeng Oyono Igiri[2]

[1]*Department of Radiography and Radiological Science, University of Calabar, Calabar, Nigeria.*
[2]*Department of Anatomical Sciences, University of Calabar, Calabar, Nigeria.*

ARTICLE INFO

Article history:
Received 21 April 2023
Accepted as revised 9 June 2023
Available online 11 July 2023

Keywords:
Circle of Willis, morphology, subjects, pattern, stroke

ABSTRACT

Background: A stroke or cerebrovascular accident is associated with defects in the circle of Willis. The present research assessed whether differences in the anatomy of the circle of Willis were implicated in subjects affected by stroke.

Materials and methods: A retrospective descriptive (cohort) study of images of 340 male and female subjects aged 15 to 75 years, referred for either brain Computed Tomography Angiography (CTA) or Magnetic Resonance Imaging (MRI) scan indicative of suspected stroke, was employed. A convenient sampling technique was used to obtain images from selected hospitals and radio-diagnostic centers with Computed Tomography (CT) and MRI scanners. Approval was obtained from the Federal Health Research Ethics Committee in accordance with institutional guidelines and principles, following permission and clearance (Approval Number: FHREC/2019/01/51/13-05-19). Patterns of morphology observed in the circle of Willis were data collected and stored in a non-identifiable format. Data obtained were analyzed with the Statistical Package for Social Science (SPSS) Inc, Chicago, IL, USA version 25.0.

Results: Of the total 340 images evaluated, 256 (75.29%) subjects had ischemic stroke while 84 (24.71%) subjects had no stroke and were thus, considered to be apparently normal. Structural patterns in the circle of Willis mostly observed were the absence of the anterior communicating artery (10.94%) and the bilateral absence of the posterior communicating artery (10.16%).

Conclusion: Morphological patterns of the cerebral arterial circle of Willis observed, were implicated in subjects affected with stroke in the present study population.

Introduction

Stroke or cerebrovascular accident (CVA) is associated with defects in the circle of Willis.[1,2] The *circulus arteriosus cerebri* Willisi (cerebral arterial circle of Willis) is an important polygonal complex structure first described and officially named after a seventeenth-century English Physician; Sir Doctor Thomas Willis in his *Cerebri anatome* in the year 1664, where he first indicated the collateral potential of the circle.[3] The circle of Willis is the principal arterial anastomotic trunk, located at the root substance between the two vertebral arteries of the vertebrobasilar system and the right and left internal carotid arteries that supply the brain.[1-9] Studies have demonstrated a classical and complete pattern of a circle of Willis where all the vessels are intact and crucial for a continuous supply of blood.[6,8,10-15]

* **Corresponding contributor.**
Author's Address: *Department of Radiography and Radiological Science, University of Calabar, Calabar, Nigeria.*
E-mail address: bassey.archibong@unical.edu.ng
doi: 10.12982/JAMS.2023.057
E-ISSN: 2539-6056

The circle of Willis is essential for the maintenance of a stable and constant blood flow to the brain. Any changes or defects in its structure may cause the appearance and severity of syndromes of vascular inefficiency, which may predispose the individual to CVA with attendant consequences. The special activity of the circle Willis relies on a continuous circular method of its formation. However, there are distinct morphological patterns of arteries that form the circle of Willis, and knowledge of these variants is essential for timely diagnosis and subsequent management of CVA. Also, these morphological patterns may provide important information on the calibre (size and shape) of the circle of Willis for better interpretation of angiographic images and for a deeper understanding of cerebral pathology such as CVA.[1-3,5-6,9-13,16-19] The significance of the patterns of the circle of Willis using methods such as the cadaveric gross dissection (GD), injection technique (IT), magnetic resonance imaging (MRI), and recently, contrast-enhanced computed tomography (CECT) imaging have been highlighted.[12,13,20,21]

Currently, medical sciences have recorded a shift from invasive to non-invasive techniques, especially in blood vessel examinations. For example, CVA therapy is aimed at re-opening clogged arteries to increase cell survival at the site of injury followed by physiotherapy.[22] It, therefore, becomes important for the healthcare givers to have sufficient knowledge of morphological patterns of the circle of Willis including other vessels involved in stroke development.[2,23] A better understanding of patterns of the circle of Willis is imperative for tailoring prevention and early detection in the management of ischemic stroke.[2,23]

In the past decades, there have been studies on stroke.[23-32] However, knowledge of how the morphological patterns of the circle of Willis are associated with stroke is lacking. It is unclear whether the computed tomography angiography (CTA), magnetic resonance angiography (MRA), and or magnetic resonance imaging (MRI) circle of Willis in subjects with stroke could provide features associated with future risk of major secondary complications, underlain by the variations in the circle of Willis in subjects affected by stroke.

It is well known that blockage or defect of the major arteries of the circle of Willis leads to stroke with the severity of stroke directly related to the severity of obstruction. An open question as to whether the arteries affected influence the severity of obstruction from stroke or the duration and extent of obstruction needs to be answered. To address these deficiencies, it is important to investigate how morphological patterns of the circle of Willis influence stroke development using CTA and MRI as diagnostic tools. However, the role of CTA and MRI in the prognosis of stroke is poorly understood. An understanding of image appreciation or pattern recognition of the circle of Willis associated with impending CVA, affected regions of the brain, and patient outcome is crucial in designing interventions to improve the outcome of people with stroke.

The CTA and MRI produce images that allow clear visualization of the location and extent of arterial occlusion, collateral circulation, extracranial stenosis, and ischemic changes within the brain tissue.[33-37] In addition, CTA and MRI are important diagnostic tools for stroke and the identification of causal factors. These imaging modalities provide information about the severity and prognosis of the disease. The present research, therefore, focused on whether differences in anatomy (structural patterns) of the circle of Willis were implicated in subjects affected with stroke using CTA and MRI.

Materials and Method

Research design

A retrospective descriptive (cohort) research design of images of 340 male and female subjects aged 15 to 75 years referred for either brain CTA or MRI scan. The images were sourced from selected hospitals and radio-diagnostic centers with CT and MRI scanners with their specifications (Table 1 and 2) coded A, B, C, D, E, and U, V, W, X, Y, Z respectively. The subjects scanned, had a non-contrast CT before the CTA protocol while those for the MRI were scanned using the three-dimensional MRI time of flight sequence.

Sampling technique and criteria for selection

A convenient non-probability sampling technique was used to select the images with inclusion criteria; the subjects must be referred for either brain CTA or MRI whose indication was suspected stroke, an acute neurological deficit of not less than nine hours' duration, and subjects with unknown time of symptoms onset. However, subjects with fresh bleeding such as intracerebral hemorrhage, subarachnoid hemorrhage, and or tumor, subjects with known contrast allergy or previous renal failure

Table 1 Specifications of CT scanners used in the present study.

S/n	Hospital/ radio-diagnostic centre	Name	Make	Country	Machine s/n	Date of manufacture	Output	
							Max. kVp	mAs
1	A	Bright-Speed 4-Slice	GE	USA	16507017m4	2007	140	300
2	B	Optima 64-Slice	GE	USA	369366HMO	2014	140	800
3	C	Brivo 385 Series 16 slice	GE	India	96369B14	2014	140	200
4	D	Brivo 385 16-Slice	GE	China	353806HM3	2013	140	180

Table 2 Specifications of MRI scanners used in the present study.

S/n	Hospital/ radio-diagnostic centre	Name	Make	Country	Date of manufacture	Output (Tesla)
1	U	Somatom	Siemens	Germany	2007	0.2
2	V	Multiva	Philips	Holland	2016	1.5
3	W	Signa Ovation	GE	USA	2014	0.35
4	X	Magnetom Concerto	Siemens	Germany	2014	0.2
5	Y	Brivo 235	GE	USA	2014	0.5
6	Z	Brivo 235	GE	India	2014	0.5

at the time of admission, and subjects with a history of brain surgery and or radiotherapy of the head and neck were excluded from the study. All the subjects' data were treated with a high level of confidentiality and privacy following standards for conducting research. Data were collected and stored in a non-identifiable format.

Landmarks

The images were evaluated using the following structures as landmarks; from the skull base to the vertex at the level of the corpus callosum or the caudate nuclei. This was to ensure appropriate visualization of the cerebral arterial circle of Willis. The subjects' images were assessed at the radiology workstations using the RadiAnt digital imaging and communication in medicine (DICOM) and the MicroDicom workstations.

Method of data collection

A direct measurement using archived primary images of CTA and MRI was employed as the method of data collection. The vessels evaluated were terminal branches of the internal carotid artery (the anterior cerebral artery and the middle cerebral artery), the basilar artery, and its terminal branches, these include:

1. the A_1 segment/pre-communicating part of the anterior cerebral artery (from the termination of the internal carotid artery (ICA) to the junction with the anterior communicating artery (ACoA) bilaterally.
2. the M_1/sphenoidal segment (from the termination of the ICA to its bi or trifurcation) bilaterally.
3. the P_1 segment (from the basilar bifurcation to the junction) with the posterior communicating artery (PCoA) bilaterally.

Patterns of morphology observed in the circle of Willis were noted. During the evaluation, abbreviations were used to show the different structures assessed. Three observers (two consultant Radiologists and one Radiographer with work experience of >15 years) together, assessed the images obtained in the present study. The inter-observer reliability of the three observers was taken into consideration during the course of the study.

Data analysis

Data obtained were expressed using basic elements of descriptive statistics and analyzed with the Statistical Package for Social Science (SPSS) version 25.

Results

This anatomic-imaging study assessed morphological patterns of the circle of Willis in 340 male and female subjects with suspected stroke, aged 15 to 75 years (40.18 ±1.1 and 43.68±1.18). From the images evaluated, results showed that 256 (75.29%) subjects had an ischemic stroke while 84 (24.71%) subjects were without stroke with normal morphology (size, shape, and structure) of the circle of Willis and were therefore, considered to be apparently normal (Figure 1). Patterns of morphology noted in subjects with ischemic stroke of the present study were the absence of anterior communicating artery (ACoA) (10.94%) and bilateral absence of the posterior communicating artery (PCoA) (10.16%) demonstrated in Figure 2 and 3 respectively.

Discussion

A stroke occurs when blood flow to the brain is disrupted due to blood clots or ruptures in cerebral vessels, cutting off the supply of oxygen and nutrients contained in the blood and resulting in damage to the brain tissues.[1,19,38] Stroke is associated with defects in a circle of Willis whose hemodynamics is predisposed by variants in the calibre of segments, this affects its major role as an anastomotic channel.[2] In the present study, morphological patterns observed in subjects (male and female) with stroke were mostly the absence of the anterior communicating artery and the bilateral absence of the posterior communicating artery. A study has demonstrated that the anterior communicating artery does not allow any mingling of blood between the two anterior cerebral arteries where it does act as a by-pass channel, where one internal carotid artery is occluded.[39] Result of the present study confirms a similar work that observed a 5% definitive absence of the anterior communicating artery in the microsurgical anatomy of common aneurysm sites.[17] In addition, the absence of an anterior communicating artery noted in the present study is in tandem with the reports that recorded similar morphological patterns with the use of contrast-enhanced computed tomography scan in a sampled Nigerian population.[13,14]

Similarly, the posterior communicating artery is very important as it joins the right and left posterior cerebral arteries to form the posterior segment of the circle of Willis. The present study recorded 10.16% bilateral

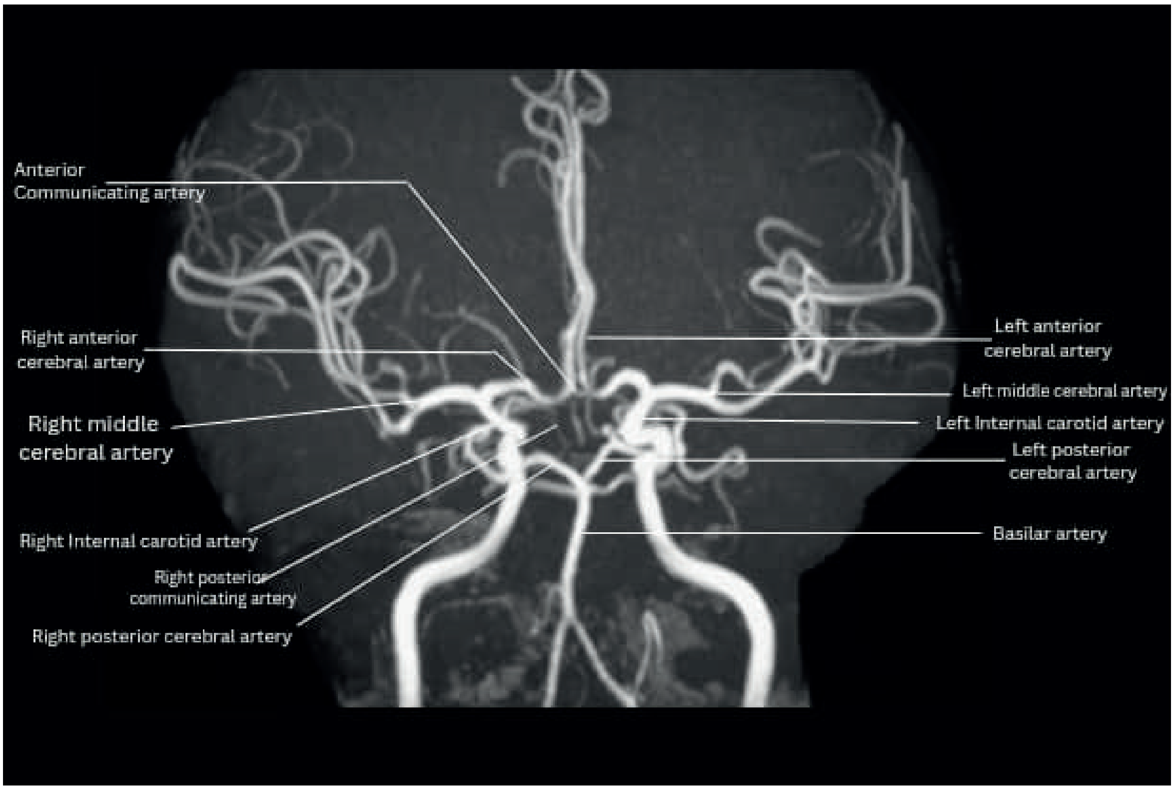

Figure 1. *Magnetic Resonance Angiogram of the circle of Willis in the present study.*

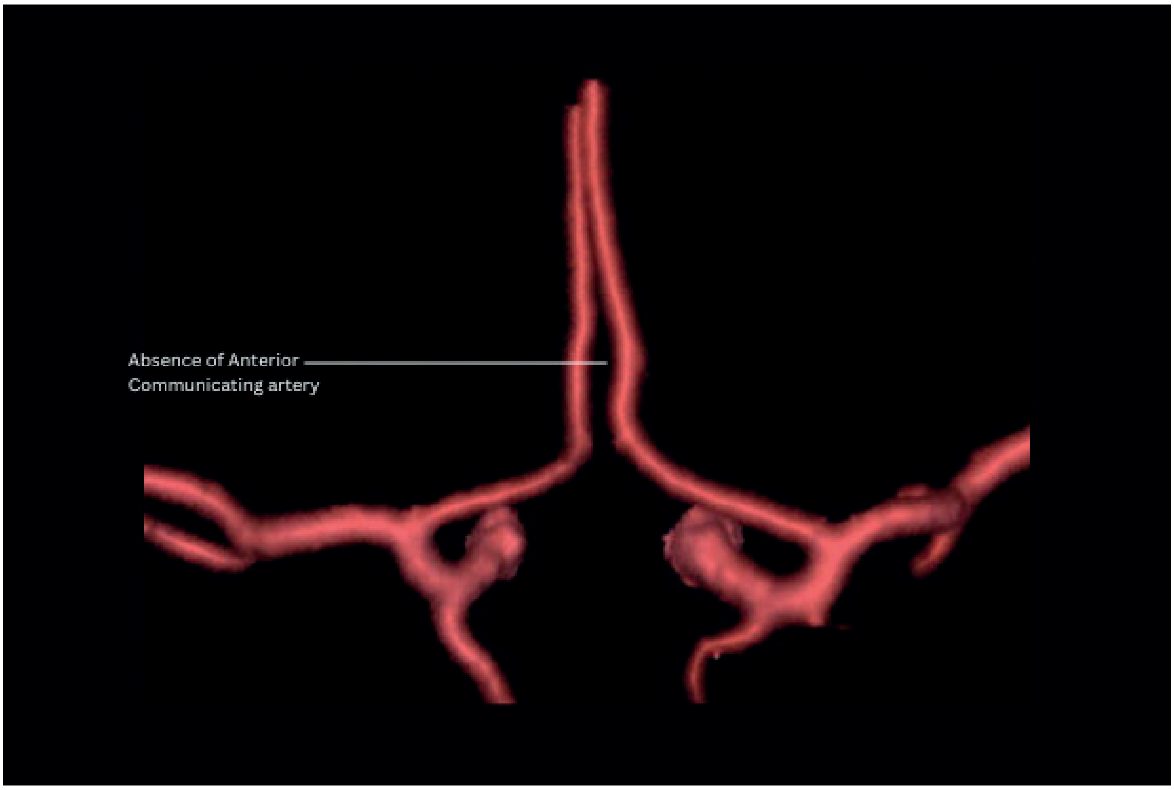

Figure 2. *Volume Rendering CTA showing absence of ACoA of the circle of Willis in subjects with stroke.*

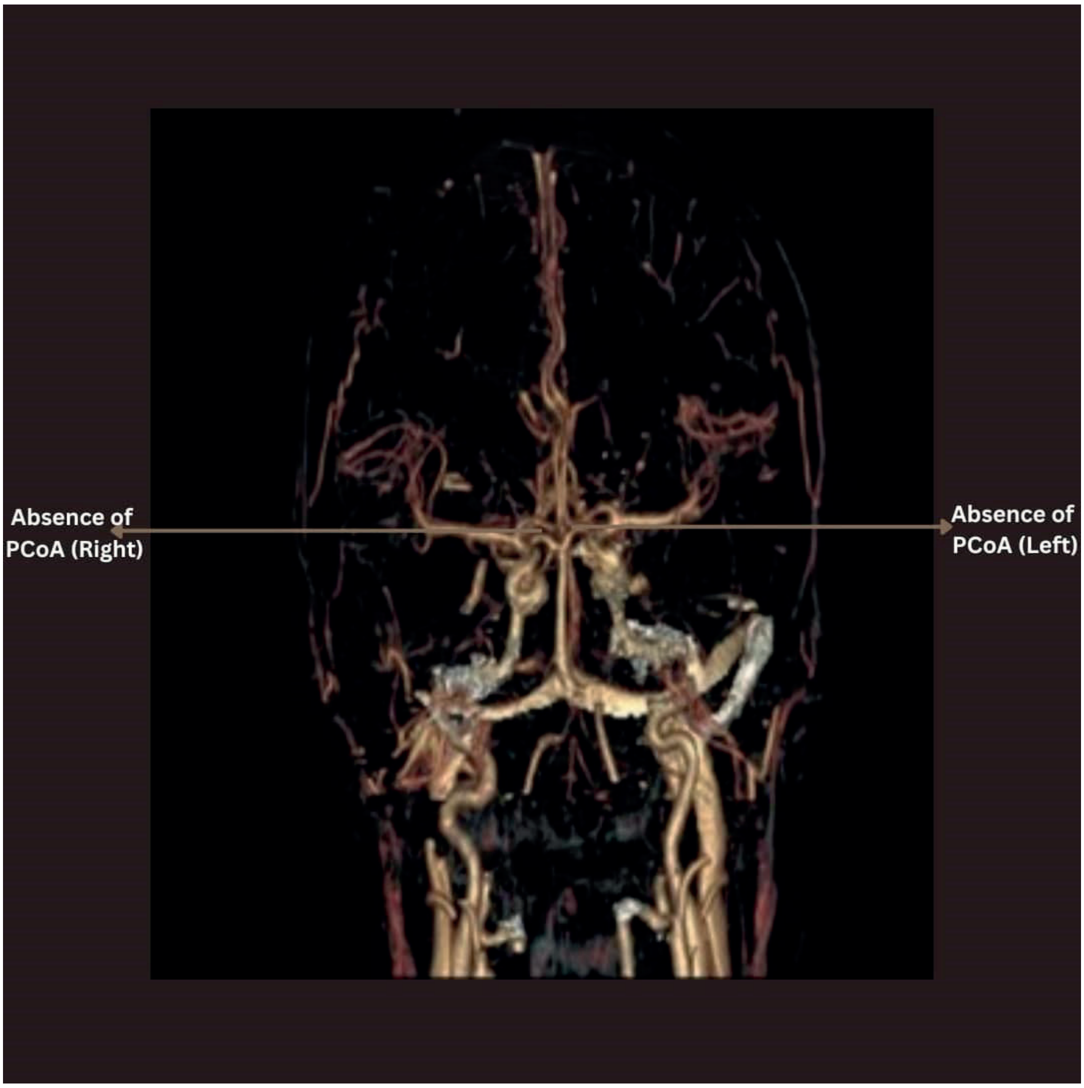

Figure 3. *Volume Rendered (VR) CTA image of the circle of Willis showing bilateral absence of PCoA.*

absence of a posterior communicating artery, which supports similar studies where the absence of a bilateral posterior communicating artery was the most common pattern noted in the circle of Willis.[14,40-41] Also, the result of the present study supports work that stipulates that the incomplete circle of Willis was mostly due to the absence of a posterior communicating artery.[8]

The absence of an anterior communicating artery and posterior communicating artery observed may be implicated in subjects affected with stroke in the present study. This is necessary as it provides important information on the calibre of the circle of Willis that may be useful for better interpretation of angiographic images. Knowledge of the patterns of presentation of the circle of Willis noted might be helpful in improving quality patient care and outcome during surgical planning and in interventional procedures thereby reducing fatalities resulting from CVA. Although the rates of global CVA death have decreased especially in developed countries, the number of people with stroke is still on the increase [42,43] as the incidence of stroke is in the ascendancy worldwide.[29-32] In Nigeria for example, stroke has assumed a frightening dimension where about 190,000 people suffer the bug annually.[32] The effects of CVA are not only limited to the aged but also among younger people.[29-32,44] This affects the workforce population and more concerning, is the fact that even young people are becoming more vulnerable to the disease.[29,44,45] The present study has thus, provided important information on the morphological variation of the arterial circle of Willis, which can be factored into risk stratification and intervention programs in the management of stroke and its secondary complications. This will significantly improve the health status of the study population.

Conclusion

The absence of anterior communicating artery and bilateral absence of posterior communicating arteries identified as morphological patterns in the cerebral arterial circle of Willis were implicated in subjects affected with ischemic stroke in the study population.

Study limitations and clinical implications

Though, standard scanning techniques with standard protocol and sequence were observed throughout the study. The following limitations were, however, encountered; different CT and MRI scanners from different manufacturers used for the study may have introduced differences in image quality. Also, inter-operator errors may have introduced some differences in the patterns noted in the present study. The clinical implications of the present research are that knowledge of the patterns of the morphology of the circle of Willis noted will help medical professionals in improving quality patient care and outcome during surgical planning and in interventional procedures to repair/remove the affected arteries. Also, these morphological patterns may provide important information on the calibre (size and shape) of the circle of Willis for better interpretation of angiographic images and for a deeper understanding of cerebral pathology such as CVA.

Conflict of Interest

There were no conflicts of interest declared.

Ethical approval

Approval was obtained from the Federal Health Research Ethics Committee in accordance with the institutional guidelines and principles, following permission and clearance (Approval Number: FHREC/2019/01/51/ 13-05-19). In addition, permission was obtained from the selected hospitals and radio-diagnostic centers.

References

[1] Wintermark M, Flanders AE, Velthuis B, Meuli R, Van Leeuwen M, Goldsher D, *et al*. Measuring elevated microvascular permeability and predicting haemorrhagic transformation in acute ischemic stroke using first-pass dynamic perfusion CT imaging. BMC Neuro. 2014; 14 (37): 6-8. doi: 10.3174/ajnr.A0539.

[2] Navita A, Molly MP, Madhumita M. Diameter of anterior cerebral artery on MRI angiograms. Intl J Anat Res. 2016; 4(2): 2245-50. doi: 10.16965/ijar.2016.189.

[3] Van Overbeeke JJ, Hillen B, Tulleken CA. A comparative study of the circle of Willis in fetal and adult life; the configuration of the posterior bifurcation of the posterior communicating artery. J Anat. 1991; 176: 45-54. PMCID: PMC1260312.

[4] Uston C. Dr. Thomas Willis famous eponym; the circle of Willis. Turk J Med Sci. 2004; 34: 271-4. doi: 10.1080/096470490512553.

[5] Crossman AR. Vascular supply of the brain. In standing S. Gray's anatomy. The anatomical basis of clinical practice (40th ed). Edinburg: Elsevier Churchill Living stone. 2008; 247-56. ISBN-13: 978-0443066849.

[6] Snell SR. The blood supply of the brain and spinal cord. Clinical Neuroanatomy (7th Ed) New Delhi. Wolters Kluwer (India) Pvt. Ltd. 2010; 475-81. ISBN-13: 978-0781794275

[7] Sultana AA, Ara S, Rahman M, Afroz H, Fatema K, Nahar N. Variations in the sites of formation of basilar artery. Bangladesh J Anat. 2012; 10(2): 73-5. doi: 10.3329/BJA.V10I2.17288.

[8] Gunnal SA, Farooqui MS, Wabale RN. Anatomical variations of the circulus arteriosus in cadaveric human brains. J Neuro Res Intl. 2014; 68: 72-87. doi: 10.1155/2014/687281.

[9] Singh V. Blood supply of the brain. In Textbook of clinical neuroanatomy. (2nd Ed) Elsevier Health Sciences, 2014; 172. ISBN: 8131223078, 9788131223079.

[10] Krabbe-Hartkamp MJ, Vander GJ. Investigation of the circle of Willis using MR angiography. Medicamundi. 2000; 44: 1. doi: 10.1148/radiology.207.1.9530305.

[11] Kapoor K, Singh B, Dewan LI. Variations in the configuration of the circle of Willis. Anat Sci Intl. 2008; 83: 98-106. doi: 10.1111/j.1447-073X.2007.00216.x.

[12] Nayak BS, Guru A, Devadasa SS, Rao SS. Hypoplastic plexiform right anterior cerebral artery and absence of anterior communicating artery : A case report. Forensic Med & Anat Res. 2013; 1(3): 47-9. doi: 10.4236/fmar.2013.13009.

[13] Igiri AO, Paulinus SO, Egbe NO, Ani CC. Classical pattern of the cerebral arterial circle of Willis in a Nigerian population using contrast enhanced computed tomography scan. Intl J Sci & Engr Res. 2017; 8(8): 1204-7. Corpus ID: 235078491.

[14] Paulinus SO, Igiri AO, Egbe NO, Ani CC, Udo-Affah GU. Evaluation of anatomical variants of the circle of Willis in a Nigerian population using Contrast Enhanced Computed Tomography (CECT) scan. Intl J Sci & Engr Res. 2017; 8(8): 2129-35.

[15] Paulinus SO, Udoh BE, Efanga SA, Udo-Affah GU, Eru EM, Ani CC, *et al*. Anatomic imaging study of luminal diameter of the circle of Willis in patients with ischemic stroke. Cal J Hlth Sci. 2021; 5: 75-80. doi: 10.25259/CJHS_50_2020.

[16] Perlmutter D, Rhoton AL. Microsurgical anatomy of the anterior cerebral–anterior communicating recurrent artery complex. J Neurosurg. 1976; 45: 259-72. doi: 10.3171/jns.1976.45.3.0259.

[17] Rhoton AL, Saeki N, Perlmutter D, Zeal A. Microsurgical anatomy of common aneurysm sites. J Clin Neurosurg. 1979; 26: 248-306. doi: 10.1093/neurosurgery/26.cn_suppl_1.248.

[18] Osborn AG. Diagnostic cerebral angiography. (2nd Ed). Philadelphia, Pa: Lippincort Williams & Wilkins. 1999. ISBN: 0397584040 , 9780397584048.

[19] Luitse MJ, Van Seeters T, Horsch AD, Kool HA, Velthuis BK, Kappelle LJ, *et al*. Admission hyperglycaemia and cerebral perfusion deficits in acute ischemic stroke. Cereb Dis. 2013; 35: 163-7. doi: 10.1159/000346588.

[20] Grzegorz M, Renata P, Malgorzata L. Variants of the cerebral arteries-anterior circulation. Pol J Rad. 2013; 78(3): 42-7. doi: 10.12659/PJR.889403.

[21] Saikia B, Akash H, Pranjal P, Donboklang L, Amitav S. Circle of Willis: variant form of their embryology using gross dissection and magnetic resonance angiography. Intl J Anat & Res. 2014; 2(2): 344-53. Corpus ID: 32755817.

[22] Bell-Gam HI, Onwuchekwa A, Iyagba AM. Improving stroke management through specialized stroke units in Nigeria: A situational review. The Nig Hlth J. 2012; 12 (2): 31-4.

[23] Kalaria RN, Rufus A, Musafi I. Stroke injury, cognitive impairment and vascular dementia. Biochimica et Biophysica Acta. 2016; 1862(2): 915-25. doi: 10.1016/j.bbadis.2016.01.015.

[24] Komolafe MA, Ogunlade O, Komolafe EO. Stroke mortality in a teaching hospital in Southwest Nigeria. Trop Docs. 2007; 3: 186-8. doi: 10.1258/004947 507781524557.

[25] Wahab KW, Okubadejo NU, Ojini FI, Danesi MA. Predictors of short-term intra-hospital case fatality following first-ever acute ischemic stroke in Nigerians. J Col Physic, Surg & Pak. 2008; 18: 755-8. PMID: 19032888.

[26] Mukherjee D, Patil CG. Epidemiology and the global burden of stroke: Stroke and the Neurosurgeon Peer-Review Report. World Neurosurg. 2011; 76(6): 85-90. doi: 10.1016/j.wneu.2011.07.023.

[27] Desalu OO, Wahab KW, Fawale B, Olarenwaju TO, Busari OA, Adekoya AO, *et al*. A review of stroke admissions at a tertiary hospital in rural Southwestern Nigeria. Ann Afr Med. 2011; 10: 80-1. doi: 10.4103/1596-3519.82061.

[28] Liu L, Wang D, Wong KS, Wang Y. Stroke and stroke care in China: huge burden, significant workload and a national priority. Stroke. 2011; 42(12): 3651-4. doi: 10.1161/STROKEAHA.111.635755.

[29] Akinyemi RO, Allan L, Owolabi MO, Akinyemi JO, Ogbole G, Ajani A, *et al*. Profile and determinants of vascular cognitive impairment in African stroke survivors: The CogFAST Nigerian study. J Neuro Sci. 2014; 46: 241-9. doi: 10.1016/j.jns.2014.08.042.

[30] Serefnur O. Epidemiology and the global burden of stroke-situation in Turkey. World Neurosurg. 2014; 81(6): 35-6. doi: 10.1016/j.wneu.2012.10.074.

[31] Feigin Vl, Roth Ga, Naghavi M. Global burden of stroke and risk factors in 188 countries, during 1990-2013: A systematic analysis for the global burden of disease study 2013. Lanc Neuro. 2016; 15(9): 913-24. doi: 10.1016/S1474-4422(16)30073-4.

[32] World Health Organization. NCD Country Profiles. Retrieved from https://www.who.int/nmh/countries/nga_en.pdf Accessed on the 15th June, 2018.

[33] Camargo ECS, Furie Kl, Singhal AB, Roccatagliata L, Cunnane ME, Halpern EF, *et al*. Acute brain infarct: Detection and delineation with CT Angiographic source images versus non enhanced CT Scans. Rad. 2007; 244(2): 541-8. doi.org/10.1148/radiol.2442061028.

[34] Tan JC, Dillon WP, Liu S, Adler F, Smith WS, Wintermark M. Systematic comparison of perfusion-CT and CT-angiography in acute stroke patients. Ann Neuro. 2007; 61: 533-43. doi: 10.1002/ana.21130.

[35] Coutts SB, Hill MD, Campos CR, Choi YB, Subramaniam S, Kosior JC, *et al*. Recurrent events in transient ischemic attack and minor stroke. Stroke. 2008; 39: 2461-6. doi: 10.1161/STROKEAHA.107.513234.

[36] Puetz V, Sylaja PN, Coutts SB, Hill MD, Dzialowski I, Mueller P, *et al*. Extent of hypo-attenuation on CT angiography source images predicts functional outcome in patients with basilar artery occlusion. Stroke. 2008; 39: 2485-90. doi: 10.1161/STROKEAHA.107.511162.

[37] Flint AC, Kamel H, Navi BB, Rao VA, Faigeles BS, Conell C, *et al*. Inpatient statin use predicts improved ischemic stroke discharge disposition. Neur. 2012; 78, 21. doi: 10.1212/WNL.0b013e3182575142.

[38] Go AS, Mozaffarian D, Roger VL. Heart disease and stroke statistics-2014 update: a report from the American Heart Association. Circulation. 2014; 129(3): 228-92. doi: 10.1161/01.cir.0000441139.02102.80.

[39] Kramer SP. On the function of the circle of Willis. J Expl Med. 1912; 15: 348. doi: 10.1084/jem.15.4.348.

[40] Vilmas A, Barkauskas E, Vilionskies A, Rudzinskaite J, Moikurate R. Vertebral artery hypoplasia; Importance for stroke development, the role of posterior communicating artery possibility for surgical and conservative treatment. Actamedica Lituanica. 2003; 10(2): 110-4.

[41] Eric SS, Christopher PK, Joanna LM, Samuel SB, Micheal MM, Eric JH, *et al*. Radiographic absence of the posterior communicating arteries and the prediction of cognitive dysfunction after carotid endarterectomy. J Neurosurg. 2014;121(3): 593-8. doi: 10.3171/2014.5.JNS131736.

[42] Feigin VL, Forouzanfar MH, Krishnamurthi R, Mensah GA, Connor M, Bennett DA. Global and regional burden of stroke during 1990-2010: findings from the Global Burden of Disease Study. Lanc. 2014; 383: 245-54. doi: 10.1016/s0140-6736(13)61953-4.

[43] Thrift AG, Cadilhac DA, Thayabaranathan T. Global stroke statistics. Intl J on Stroke. 2014; 9(1): 6-18. doi: 10.1177/17474930221123175.

[44] Obiako OR, Oparah SK, Ogunniyi A. Prognosis and outcome of acute stroke in the University College Hospital Ibadan, Nigeria. Nig J Clin Prac. 2011; 14(3): 359-62. doi: 10.4103/1119-3077.86784.

[45] Bowen A, Wenman R, Mickelborough J, Tallis R. Dual task effects of talking while walking on velocity and balance following stroke. Ag Agg. 2001; 30: 319-23. doi: 10.1093/ageing/30.4.319.