



Saint Paul's Hospital Millennium Medical College

Graduate Study Program

Anatomic study and variants of circle of Willis and associated factors in adult population undergo CT angiography of the brain From April 2024 to Jun 2024in Saint Paul's Hospital Millennium Medical College, Addis Ababa Ethiopia.

Hashime Meketa (MD, Radiology Resident)

July 2024.

Addis Ababa Ethiopia

Saint Paul's Hospital Millennium Medical College

Graduate Study Program

Anatomic study and variants of circle of Willis and associated factors in adult population undergo CT angiography of the brain in Saint Paul's Hospital Millennium Medical College From April 2024 to Jun 2024, Addis Ababa Ethiopia.

A Thesis Paper Submitted to the Department of Clinical Radiology, Presented in Partial Fulfillment in Requirement of the Certificate of Clinical Radiology Speciality in St. Paul's Hospital Millennium Medical College.

Investigator: Hashime Meketa. MD, Radiology Resident.

Saint Paul's Hospital Millennium Medical College

Graduate Study Program

Title:

Anatomic study and variants of circle of Willis and associated factors in adult population undergo CT angiography of the brain in Saint Paul's Hospital Millennium Medical College, Addis Ababa Ethiopia.

Principal Investigator:

Hashime Meketa. MD, Radiology Resident.

Advisors:

Dr Hanan Tofik. MD, Neuroradiology fellow.

Mrs. Hanna Feleke. MPH.

July 2024.

Addis Ababa Ethiopia

ACADEMIC RESEARCH PROPOSAL SUBMISSION GUIDE

Name of investigator	Hashime Meketa. MD, Radiology resident.
Full title of the research project	Title: Anatomic study and variants of circle of Willis and associated factors in adult population undergo CT angiography of the brain in Saint Paul Hospital Millennium Medical College, Addis Ababa, Ethiopia, 2024.
Duration of the project	Between April to Jun 2024
Study Area	St Paul's hospital millennium medical college
Total Cost of the project	26,240 Ethiopian Birr
Source(s) of Funding	St Paul's Hospital Millennium Medical College
Address of investigator	Tel:
	Cell phone: +251913137272
	Fax:
	P.O. Box:
	Email: meketahashim@gmail.com
Name of Advisor(s)	1) Dr Hanan tofik.MD, neuroradiology fellow. 2) Mrs. Hanna Feleke. MPH.

ACKNOWLEDGEMENT

I'm grateful to the department of radiology and medical radiology technology for giving me the chance to do research on this topic and I would like to thank my advisors' Dr Hanan Tofik and Mrs. Hanna Feleke for the advice they gave me during my research.

Table of Contents

Acknowledgment	v
Table of content	vi
List of table	viii
List of figures	ix
Acronyms and abbreviations.....	x
Abstract	xi
1.Introduction.....	1
1.1.Background of the study	1
1.2.Statement of the problem	3
1.3.Significance of the study.....	4
2. Literature review	6
3. Objectives	10
3.1. General objectives.....	10
3.2. Specific objectives..	10
4.Materials	11
4.1.Study setting/area and period.....	11
4.2.Study design and Population.....	11
4.3.Eligibility criteria.....	11
4.3.1.Inclusion Criteria	11
4.3.2.Exclusion criteria:	11

4.4.Sample Size determination and Sampling technique.....	12
4.4.1.Sample size determination	112
4.4.2.Sampling technique and procedures	112
4.5.Study variables.....	112
4.5.1.Dependent variable	112
4.5.2.Independent variables.....	113
4.6.Operational definitions.....	13
4.7.Data collection tool, methods and Procedure	114
4.8.Data quality control.....	14
4.9.Data processing and analysis	14
4.10.Ethical clearance	15
4.11. Plan for dissemination of Results	15
5.Result.....	116
6.Discussion.....	24
7.Conclusions.....	27
8.Recommendations.....	28
Reference	30
Annexes.....	32

List of table

Table 1: Sociodemographic factors of study participants undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College	16
Table 2: Clinical presentation of study participants who undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College	117
Table 3: Proportion and location of abnormal vessels among study participants who undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College	18
Table 4: factors associated with variants of circle of among study participants who had undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College	22

List of figures

Figure 1: completeness of circle of Willis among study participants who undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College.....	17
Figure 1: axial CT angiography image at the level of COW from a study sample image showing hypoplastic right posterior communication artery (PCOM)	19
Figure 3: Feature of stroke among study participants who undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College	19
Figure 4: axial CT angiography image at the level of COW from a study sample image showing large homogeneously hyperdense lesion at the level of the right PCOM -PCA junction abutting both arteries (arrow) suggestive of acute hemorrhagic stroke.....	20
Figure 5: location of aneurysms among study participants who had undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College.....	21
Figure 6: axial CT angiography image at the level of COW from a study sample image showing well defined round homogeneously hyperdense lesion (similar density to adjacent vessel) at anterior communicating artery (ACOM) (arrow) suggestive of ACOM aneurysm.....	21

Acronyms and abbreviations

ACAs- anterior cerebral arteries

ACoAs - anterior communicating arteries

BA - Basilar artery

CECT- contrast enhanced Computed tomography

COW - circle of Willis.

CT - Computed tomography.

CT angiography - Computed tomography angiography.

ICAs - Internal carotid arteries.

MRI - Magnetic resonance imaging.

PCAs - Posterior cerebral arteries.

PCoAs - Posterior communicating arteries.

WHO - World health organization.

CDC - Center for disease control.

Abstract

Background: The Circle of Willis is an important vascular structure in the brain that has important role in cerebral blood flow; there is a considerable individual variation in the pattern and caliber of vessels that make up the Circle of Willis. The anatomical variations of Circle of Willis have important factor in clinical presentation, morbidity & mortality (1).

Objectives: The primary aim of this study is to assess the anatomy and variations of the Circle of Willis and associated factors in adult population undergo brain CT angiography at St. Paul's Hospital Millennium Medical College, Ethiopia during study period.

Methods: This is a facility based cross-sectional study conducted among adult patients with CT angiography of the brain at St. Paul's Hospital Millennium Medical College. Simple random sampling technique was carried out to select study participants. Bi-variate and multivariate binary logistic regression was conducted to identify the relationship between dependant and independent variables. Finally, a statistical test with a p-value <0.05 was considered the cutoff point to assess the significance of associations.

Result: Out of the total 86 individuals, 52 (60.5%) were found to have a complete Circle of Willis, while 34 (39.5%) exhibited incomplete Circle, Hypoplastic arteries were present in 30% of participants, the most involved artery being the right and left Posterior communicating artery accounting 14% and 8.1% respectively, double right Posterior communicating artery & anterior communicating artery accounts 5.8% each. Arterial aneurysm were seen in 13 (15%), while 10 (12%) have acute hemorrhagic stroke.

Conclusions and recommendation: hypoplastic arteries in the posterior Circle of Willis are more common than the anterior portion. This study suggested that sex, age, presence of Hypoplastic arteries, stroke and aneurysm are important factors associated with the completeness of the Circle of Willis. The observed associations between completeness of Circle of Willis and the reduced likelihood of stroke and aneurysms warrant further investigation. Elucidating the underlying mechanisms may have important implications for the prevention and management of these cerebrovascular conditions.

Keywords: Circle of Willis, Anatomical Variations, Hypoplastic arteries.

1. Introduction

1.1. Background of the study

The human brain is composed of billions of specialized cells and circuits which make it the most vital organ in the human body. It is richly supplied with blood vessels which provide oxygen and other essential nutrients. Circle of Willis (COW), named after Thomas Willis who first described it in 1664, is polygonal, intracranial collateral circulation formed between the carotid and vertebrobasilar arterial system. It is formed by two (right & left) internal carotids as well as two vertebral arteries, connected by central COW which lie in the interpeduncular fossa at the base of brain. Anteriorly ICA divides into anterior and middle cerebral arteries. The two anterior cerebral arteries are joined together by anterior communicating artery. Posteriorly two vertebral arteries unit to form basilar artery which branches into two posterior cerebral arteries. The posterior communicating artery, a branch of internal carotid completes the arterial polygon by joining with the posterior cerebral artery. Classical (textbook) arterial circle is bilaterally symmetrical and a complete ring of vessels(1, 2).

There may however be variations in this typical configuration with vessels generally vary in caliber; often they are hypoplastic, duplicated or even absent. Several studies have shown that these variations play an important role in the development of cerebrovascular diseases. Any change in the normal morphology of the circle may condition the appearance and severity of symptoms of cerebrovascular disorders, such as aneurysms, infarcts and other vascular anomalies. It has been shown that in more than 50% of healthy brains and in more than 80% of dysfunctional brains the COW contains at least one artery that is absent or underdeveloped(1).A complete configuration of the COW on the other hand is present in 42–52% of healthy individuals and there is evidence suggesting that a well-functioning complete COW is protective against cerebral ischemia in patients with carotid artery occlusive disease (2).

A thorough knowledge of the variations of vessels is useful to surgeons & interventional radiologists in planning their shunt operations. Understanding the specific anatomy & variations of COW through CECT of the brain imaging can enhance the accuracy of diagnosis and treatment planning for patients presenting with cerebrovascular related diseases. The study will also contribute to the existing body of knowledge in the field of neuro imaging, particularly the COW anatomy & variations and associated abnormalities. The findings of the study can be utilized for educational purposes, including training programs for healthcare providers and medical students and Insights gained from the study can inform healthcare planning and policy-making at St. Paul Millennium Medical College and beyond (3).

1.2. Statement of the problem

The human brain accounts for two percent of the total body weight. Despite its weight, it needs one-sixth of the total cardiac output as well as one-fourth of the body's oxygen demand in every single breath. It also needs a continuous and uninterrupted blood and oxygen supply. The COW is the main structure that provides constant and regular arterial blood flow into the brain and protect the brain from ischemia and infarction (3,5).

In the year 2023, a total of 60.7million people died across the globe. Out of this group, 11.67 million deaths were reported from Africa. According to center for disease control Stroke (cerebrovascular diseases) is the 5th most common cause of death in USA accounting 5% of the cases (34). even if we don't have reliable data to estimate the prevalence of cerebrovascular diseases in Ethiopia, The personal, social, and economic costs of stroke and associated cerebrovascular diseases are paramount important.

In cerebrovascular disease patients COW can maintain adequate blood flow and reduce the damage of the affected areas because of the presence of the collateral circulations, providing alternate routes for blood and this compensation lies on the anatomical morphology of COW (2, 4, and 5).

The normal anatomy and variations of circle of Willis play an important role in the development of CVD as well, Any change in the normal morphology may condition the appearance & severity of symptoms of CVD, such as aneurysms and infarcts(2).

Despite variations play an important role in the development of Cerebral Vascular Diseases, as well as surgical & interventional radiology planning & clinical follow-up of patients, up-to date limited data are available in developing countries and there is no published date about COW in Ethiopian population. limited access to advanced diagnostic technologies and specialized healthcare services further exacerbates the burden of CVD related conditions, leading to delayed diagnosis, sub-optimal treatment, and compromised patient outcomes(3).

This research aims to fill the above mentioned gaps seen in our hospital and enhance the quality of clinical & surgical treatment of patient with cerebrovascular diseases by clearly stating the prevalence and variation of the COW.

1.3. Significance of the study

The state of the COW becomes important in determining the adequacy of the brain circulation in operations for cerebral aneurysm and in ligation of the carotid artery. The possibility of bypassing or shunting effects in occlusion of one of the cerebral vessels and the adequacy of recovery or lack of recovery after vascular occlusion might be explained in part by variations in the anatomy of the circle of Willis. The failure in some instances of vascular occlusion to recover at all, and the recovery in others over a long period of time, these outcomes might be associated in part with anatomical variations of the circle these, and other related, problems make a study of the circle of Willis in the normal brain essential(4).

The study will provide information regarding the importance of knowing the variations in the anatomizing and branching pattern of the COW in a selected group of study population at st Paul hospital millennium medical college, Addis Ababa, Ethiopia. The association between aneurysms and anomalies of the COW suggesting structural malformations may provide a mechanical basis for the development of aneurysm in congenitally weak portions of the vascular wall(5). The knowledge about variations of the COW is clinically important as it plays an important role in cerebral hemodynamic. It also provides relevant data on these variations for their possible clinical implications(6). Meta-analysis of 2,718 participants in Ethiopia shows presence of any variation in COW was 1.38 times more likely to develop ischemic stroke as compared to the patent COW. The presence of hypoplasia/incompleteness PCoAs & ACoA were contributing factor for the development of ischemic stroke(7). To this effect, knowing the state of the circle pattern & its variants become vital in determining the adequacy of the brain circulation as well as in selected cases which needs operations like cerebral aneurysms and internal carotid artery ligation(8, 9). patients with effective collateral circulations have a lower risk of transient ischemic attack and stroke than those with ineffective collateral's(2). Furthermore, the possibility of by-passing or shunting effects in occlusion of one of the cerebral vessels and the adequacy of recovery or lack of recovery after vascular occlusions may be explained in part by variations in the anatomy of the Cow (10).

Additionally, this may have paramount importance to neurosurgeons as well as those who perform advanced procedures while maintaining constant blood supply to the brain. These problems make it necessary to have a wide knowledge of the variations in the anatomy of the COW.

It is therefore important to try and correlate COW pattern & variants to the occurrence of certain common clinical conditions such as stroke, aneurysms & arterio-venous malformations. Therefore, based on these scientific reports, it has been argued that it is essential to properly assess the anomalies in the vessels that form the CW in the general population. This is to determine the capacity of the brain circulation in operations for cerebral aneurysms as well as in interventions involving the internal carotid artery(11).

There is no well established reporting format used in the radiology department clearly stating the status and possible variants of COW. the study will recommended to incorporate institutional based reporting format which explains the COW anatomy and variants on daily report of CT angiography of the brain to radiology residents, radiologists and neuroradiologist so that treating physicians will have a clear understanding and will help in choosing possible better treatment options for individual patient with CVD present in the hospital.

Lastly, the inferences that were obtained from this study will also be useful to neurosurgeons, neuroradiologist and other health practitioners in enhancing their knowledge in teaching and research purposes.

2. Literature review

The circle of Willis is a crucial structure in the brain, forming an arterial polygon composed of the basilar artery (BA), the anterior communicating artery (ACoA), and pair each- of anterior cerebral arteries (ACAs), posterior cerebral arteries (PCAs), internal carotid arteries (ICAs) and posterior communicating arteries (PCoAs) that facilitates blood flow between the brain's two sides and allows for anastomotic circulation if part of the circulation is pathologically occluded and has considerable importance in clinical teaching and practice. Several Studies have described angiographic anatomical variations in COW in populations diverse in age, gender, race and geographical region by using different research methodologies.

There is a range of variations in the anatomy of the COW reported on several studies However; it is not clear whether the frequency of manifestation of the different variations of the COW is similar in the studies done in different racial populations(11, 12). Meta-analysis of 2,718 participants in Ethiopia shows presence of any variation in COW was 1.38 times more likely to develop ischemic stroke as compared to the patent COW. The presence of hypoplasia/incompleteness PCoAs & ACoA were contributing factor for the development of ischemic stroke (7). The complete COW in seen in 20.9% of healthy Iranian adults with no relationship between gender and the presence of anatomical variations (8).The complete COW in 12.24% of normal Chinese male individuals, among whom 4.67% had developmental variations, including hypoplasia of either posterior or anterior circulation, even as 7.75% had normal complete development of the COW.

In Africa, a study in the Egyptian population found the completes COW in 46.7% of the subjects, most of whom were female (52.8%)(13). Similar study in Pakistan and observed an incomplete anterior &posterior circle in 20% & 77% of the study participants respectively. a complete COW was more likely to be observed in younger and female participants(14, 15). Among patients with carotid stenosis, complete anterior and posterior circles were seen in 60% and 70% of the participants respectively, which is higher than the prevalence in normal subjects .In another similar studies observed the

complete COW in 55%, complete anterior circle in 88%, and complete posterior circle in 63% of the patients (16)

Posterior Circulation

The posterior circulation of the caudal division of the ICA develops to form the PCoAs. The caudal division of the ICA communicates with the PCA, even as the paired dorsal longitudinal arteries fuse to form the basilar artery (BA). The PCA joins the vertebrobasilar system. In the COW the most common anatomical variations are absence, hypoplasia, “infundibulum” PCoAs, and fetal type posterior communicating artery (FTP) with the hypoplastic P1 segment (14, 15). Anomalies of the posterior circulation were more common than the anterior, with PCoAs hypoplasia being the most frequent (38%). the posterior part of the COW was complete in 38.3% of individuals, The posterior part of the COW was observed to be complete in 40% of younger and 37.5% of older participants(17).

A Magnetic Resonance Angiography (MRA) imaging scan study was conducted on 250 Egyptian patients revealed complete COW in 46.7% cases. The prevalence of the circle completeness in the younger subjects was higher than the older ones (50% versus 45% respectively) and in females (52.8%) more than males (42.6%). Furthermore, the anterior part of circle was complete in 75% (younger subjects) and 65% (older subjects) while the posterior part was complete in 40% (younger subjects) and 37.5% (older subjects)(18). statistically significant differences data between the mean vessel diameters between males and females in the vessels forming the COW were also found(13). Additionally, the average diameters of the proximal vessels supplying the CW were larger in the older subjects. On the contrary, the distal branches of the circle had smaller mean diameters in the older subjects. The study illustrated that there were statistically significant differences in some vessel diameters according to age and gender, and concluded that some of the variations could be related to aneurysmal development and significantly correlate with relative contributions of the flow rates of the proximal arteries(13).

A study conducted on 50 brain specimens showed that the majority of the circles (52%) had different type of anomalies. Cerebrovascular hypoplasia involving some vessels in

the COW was the most frequent anomaly and was found in 24% of the brains whereas accessory vessels in the form of duplication/triplications of the anterior communicating artery were seen in 12% of the circles. On the other hand, the embryonic origin of the posterior cerebral arteries from the internal carotid persisted in 10% of the circles. Lastly, an incomplete circle due to the absence of one or the other posterior communicating arteries was found in 6% of the specimens. Variations were also seen to be more frequent in the posterior half of the circle (11).

Anterior Circulation

The ICA has two parts: cranial and caudal. The cranial part forms primitive olfactory arteries that give rise to the ACA, the middle cerebral artery (MCA), and the anterior choroidal artery. The ACoA originates from the plexiform vascular network.

The anterior part of the COW was complete in 80.95% of the subjects. The most common type of anatomical variation in this part involved the origin of the MCA (71.42%)(19). magnetic resonance angiography (MRA) images of 2246 healthy Chinese male individuals, and found that among those with complete anterior circulation, the most common anatomical variation was the presence of the window pattern of ACoA (55.77%). Asymmetrical and unilateral hypoplasia of the ACA was more common in subjects with complete anterior circulation (29.92%) than in those with incomplete circulation (21.42%), even as anatomical variations in the A1 segment of the ACA were more frequent in the right side than in the left ($Z = 9.944$, $p < 0.001$). Furthermore, they observed four distinct ACoA morphologies: absent, single, double, and multi branch. In contrast, the ACA showed six possible patterns: normal, double tubular, Y-shaped, ampulla, circle, and window. Though the ACoA was absent in 11 (17.05%) participants, a single tubular root was found in 72.61% of them, even as the ACoA was obscured in 29 participants due to closeness to the bilateral A2 segment of the ACA. In addition, the authors found that patency of the ACoA are related to the development of the A1 segment of the ACA in 28.22% of the individuals.

The prevalence of a typical COW and the variation in the anterior communicating artery in the Sri Lankan population revealed a high incidence of hypoplastic vessels (193 of 225;

86%) and with multiple anomalies (127 of 225; 56.4%). The most frequent site of abnormal diameters was seen in the posterior half of the circle. The assumption was that this could be related to the embryological development of the posterior half of the CW, where the basilar and the internal carotid arteries anastomosis during development of the cerebral arteries. Furthermore, the findings of the anomalies of the anterior communicating artery in their study were similar to the studies conducted in India. There was a wide range in the prevalence of typical configuration between Indian and Sri Lankan studies and this was attributed to the belief that Sri Lankans have a common origin from India. Additionally, the results warranted further studies to ascertain influence of genetic, racial, regional, environmental, hemodynamics factors, or a combination of any of the above(3, 13).

Arterial fenestration involves duplication of the segmental artery or separation of the arterial lumen into separate luminal by the endothelium that may or may not share the same adventitia. There is a relationship between fenestration and aneurysm, which is caused by weakening of the tunica media that subsequently involves all three layers of the vessel wall. It is caused by trebling the tunica media. The embryological basis for fenestration of ACA, MCA, and PCA is still unclear in the Osborn textbook (20).

3. Objectives

3.1. General objectives

- To assess the anatomy and variants of the circle of Willis and associated factors on CT angiography of adult brain from April 2024 to Jun 2024 at SPHMMC, Ethiopia.

3.2. Specific objectives

- To assess the completeness of circle of Willis during study period.
- To determine variants of circle of Willis during study period.
- To determine the associated factors of circle of Willis during study period.

4. Materials

4.1. Study setting/area and period

The study was conducted from April to Jun 2024 at St. Paul's Hospital Millennium Medical College (SPHMMC) which is one of the tertiary referral hospitals directly under the Federal Ministry of Health located in the capital Addis Ababa Ethiopia. It is a teaching hospital for the health science students enrolled in various undergraduate and postgraduate programs at Millennium Medical College. The hospital undergoes around 380 brain CT angiography images annually and 95 study populations over the study period, there is no well established reporting format used in the radiology department stating the anatomy and variants of COW.

4.2. Study design and Population

The study is a facility based sectional study of adult patients who undergoes CT angiography of the brain at St. Paul's Millennium Medical College hospital b/n April 2024 to Jun 2024. Data collection template was prepared to collect data based on a review of literature.

4.2.1. Source of populations

All adult patients who undergone CT angiography of the brain at St. Paul's Millennium Medical College hospital during the study period.

4.2.2. Study Population

All selected adult patients who undergo CT angiography of the brain at St. Paul's Millennium Medical College hospital during the study period.

4.3. Eligibility criteria

4.3.1. Inclusion Criteria

All adult patients who undergone CT angiography of the brain at St. Paul's Millennium Medical College hospital b/n April to Jun 2024.

4.3.2. Exclusion criteria:

Patient who had motion artifact and foreign body artifacts on brain CT images.

4.4. Sample Size determination and Sampling technique

4.4.1. Sample size determination

The sample size is estimated using sample size determination formula for a single population proportion. The annual average numbers of patients undergoes CT angiography of the brain are around 380 patient. Assuming the margin of error 5% the sample size is calculated by the following yamane's formula and is calculated to be

The sample size (n) were calculated using the formula $n = N / (1 + Ne^2)$ where

n = minimum sample size

N = population size, which is 95 during the study period (obtained from hospital quality unit) &

e = Margin of error = 0.05 (or 5%), therefore the calculated sample size will round to

$$n = 77$$

Since the total population size is 95 and the calculated sample size after 10% non-respondent is 86, a simple random sampling technique were used to select the 86 patients.

4.4.2. Sampling technique and procedures

The 86 patients were enrolled to the study during the study period by simple random sampling technique until the sample size is reached. This can be done by assigning a unique identifier (e.g., patient ID) to each of the 86 patients and then using a random number generator or a random number table to select 86 patients.

4.5. Study variables

4.5.1. Dependent variable

Completeness of Circle of Willis Anatomy

4.5.2. Independent variables

- Age
- Sex
- CT scan feature of stroke.
- CT scan feature of COW aneurysm.
- Clinical history at presentation.

4.6. Operational definitions

Circle of Willis (COW): circular arterial network having the following vessels on brain **angiography images:** two anterior cerebral arteries, one anterior communicating artery, two posterior cerebral arteries, and two posterior communicating arteries.

Anatomical Variants: Deviations from the typical anatomy of the COW, which may include hypoplasia (underdevelopment), aplasia (absence), or fenestration (splitting) of any component arteries on angiographic appearance.

Hypoplasia: an artery within the COW is present but underdeveloped which is diameter less than 50% of the expected size or less than 1mm in outer to outer diameter on brain angiographic imaging.

Aplasia: complete lack of visualization of the artery on angiographic imaging. Fenestration: the presence of an artery splits into two separate lumens and then rejoins visible on angiographic imaging.

Collateral Circulation: presence of blood flow in a compensatory artery during angiography when the primary artery is blocked.

Brain angiography: the successful injection of contrast material and subsequent capture of CT-scan images that delineate the vascular structures of the brain (6)(18)(23).

4.7. Data collection tool, methods and Procedure

A structured checklist was used to collect important data from patient which fulfill inclusion criteria. The data including socio-demographic as well as pre and post contrast CT images of the brain both on brain and angiographic windows were first collected by trained first year radiology residents with supervision by senior radiologist and neuroradiologist sub-specialist, the collected data were carefully visualized and evaluated with special attention given to the COW and were studied in detail in each CT scan image with reference to parameters such as completeness, hypoplasia or absence of components of COW and presence of aneurysm with senior radiologist supervision. The diameter were measured using a digital measurement caliper with a cutoff point for hypoplasia at less than 1mm chosen based on earlier reports from other studies (16)(18) Spot Photographic images at the level of COW were captured and stored by exporting from the CT-scan images for later use to study the COW in detail. Finally, the data were recorded in a data collecting sheet, coded and entered in Microsoft excel.

4.8. Data quality control

Before and after data processing and analyses the data were checked & re-checked for possible errors and it were presented in contingency tables and numerical descriptions to show the relationships of variables so as to make the data more meaningful.

4.9. Data processing and analysis

The data were entered to epi info version 7.2 and exported to SPSS software version 27. Data cleaning were performed to identify outliers or inconsistencies, errors, and missing values. Both descriptive and analytical statistics were executed. The result was presented in table, graph and text. Both binary and multivariate logistic regression models were used to determine the association between the independent and the dependent (outcome) variables. The model fitness (goodness of fit) was checked using the Hosmer Lemeshow test. Multicollinearity was also checked using variance inflation to see the correlation between independent variables and also checking the no extreme outlier. All variables that had an association with the outcome variable at a p-value of 0.25 or less in binary analysis were entered into the multivariable analysis. Finally, a statistical test with a p-value of 0.05 was considered the cutoff point to assess the significance of associations

using adjusted odds ratio (AOR) with 95% confidence intervals (CI) in the multivariable analysis.

4.10. Ethical clearance

An official written letter of ethical clearance was obtained from the SPHMMC Institutional Review Board and submitted to the responsible hospital administration office. During the data collection procedure, patient privacy and confidentiality were kept to the maximum by collecting data anonymously. Confidentiality of data collected were kept and names of the patients wasn't included during data collection. The research paper were submitted and will be presented to SPHMMC. The findings will also be presented in different seminars, meetings and workshops and may be published in scientific journals.

4.11. Plan for dissemination of Results

The result of the study will be documented and submitted to departments of radiology, departments of neurology and department of neurosurgery and all relevant bodies in SPHMMC and other health facilities. Publications will be made in the Ethiopian Journal of Health Sciences.

5. Result

5.1 Socio-demographic factors

The study examined 86 study participants with 100% response rate focused on the normal anatomy and variants of COW. The age distribution were classified by 10 year based on previous literature (13,14). The age ranged from 20 to 60 years and above. Specifically, 16(18.6%) were aged 20-29, 15(17.4%) were aged 30-39, 15(17.4%) were aged 40-49, another 11 (12.8%) were aged 50-59, and the largest group, comprising 29(33.7%) were aged 60 and above. The mean age of the participants was 48.3 years, with a standard deviation of 18.1 years. In terms of sex distribution, about 46 participants (53%) were male and 40 participants (47%) were female (table1).

Table 1: Socio-demographic factors of study participants undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College from April 2024 to Jun 2024.

Variable	Category	Frequency	Percentage
Age	20-29	16	18.6
	30-39	15	17.4
	40-49	15	17.4
	50-59	11	12.8
	>=60	29	33.7
Mean age	Mean $\pm$ SD=48.3 $\pm$ 18.1		
Sex	Female	40	47
	Male	46	53

5.2. Clinical presentation

The data revealed a variety of symptoms prompting the need for brain CT-angiography imaging. The most common clinical presentation was headache, reported by 39 participants, accounting for 45.3% of the total cases. This was followed by left body weakness, observed in 15 participants (17.4%), and right body weakness, noted in 14 participants (16.3%). Additionally, 10 participants (11.6%) experienced hearing and visual disturbances, while 8 participants (9.3%) presented with loss of consciousness (Table 2).

Table 2: Clinical presentation of study participants who undergone CT angiography of the brain in Saint Paul’s Hospital Millennium Medical College from April 2024 to Jun 2024.

Variable	Category	Frequency	Percentage
Clinical presentations	Headache	39	45.3
	Right body weakness	14	16.3
	Left body weakness	15	17.4
	Hearing and visual Disturbance	10	11.6
	Loss of consciousness	8	9.3
	Total	86	100.0

5.3. Circle of Willis Anatomy

The following figure illustrates the distribution of participants based on the completeness of the Circle of Willis. Out of the total participants, majority comprising 52 individuals (60.5%), were found to have a complete Circle of Willis. In contrast 34 participants (39.5%) exhibited an incomplete Circle of Willis (figure 1).

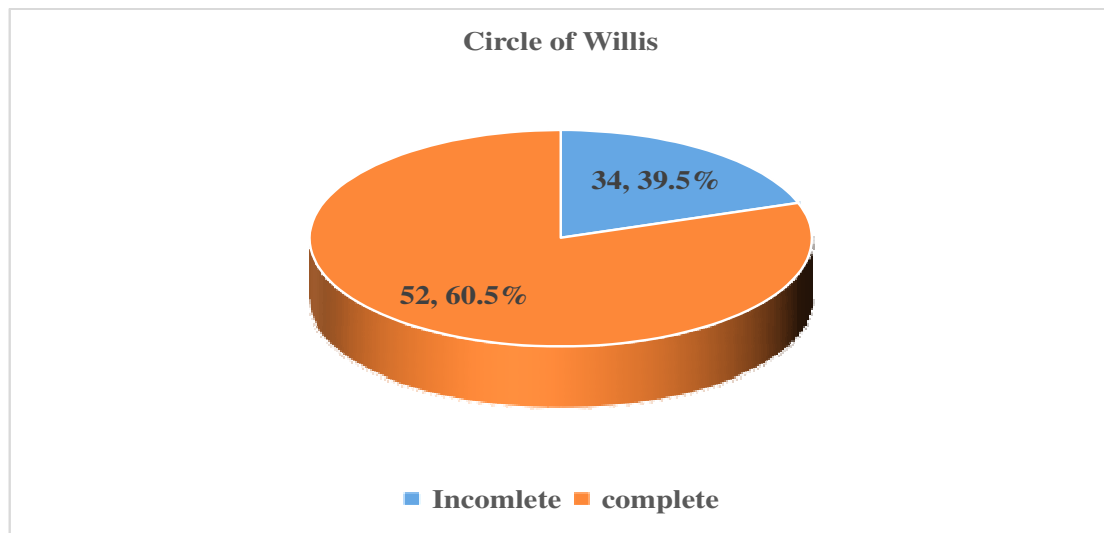


Figure 2: completeness of circle of Willis among study participants who undergone CT angiography of the brain in Saint Paul’s Hospital Millennium Medical College from April 2024 to Jun 2024.

5.4. Proportion and location of abnormal vessels of COW

The study investigated various anatomical variants of the Circle of Willis among the participants, revealing significant findings. Hypoplastic arteries were present in 30% of the participants, with specific locations being the right PCoA (14%), left PCoA (8.1%), double right PCoA (2.3%), and hypoplastic ACoA (5.8%). The majority, 70%, did not exhibit Hypoplastic arteries. Arterial agenesis and arterial fenestration were both notably rare, observed in only 1.2% of the participants for each variant, with 98.8% of the participants showing no signs of these conditions.

Table 3: Proportion and location of abnormal vessels among study participants who undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College from April 2024 to Jun 2024.

Variable	Variant	Frequency	Percentage
Hypoplastic Artery	No	60	70
	Yes	26	30
Hypoplastic Artery location	Right PCoA	12	14.0
	Left PCoA	7	8.1
	Double right PCoA	2	2.3
	ACoA	5	5.8
Arterial agenesis	No	85	98.8
	Yes	1	1.2
Arterial fenestration	No	85	98.8
	Yes	1	1.2
Aneurysms	No	73	84.9
	Yes	13	15.1
Location of Aneurysms	Right PCoA	5	5.8
	ACoA	5	5.8
	Left PCoA	3	3.5

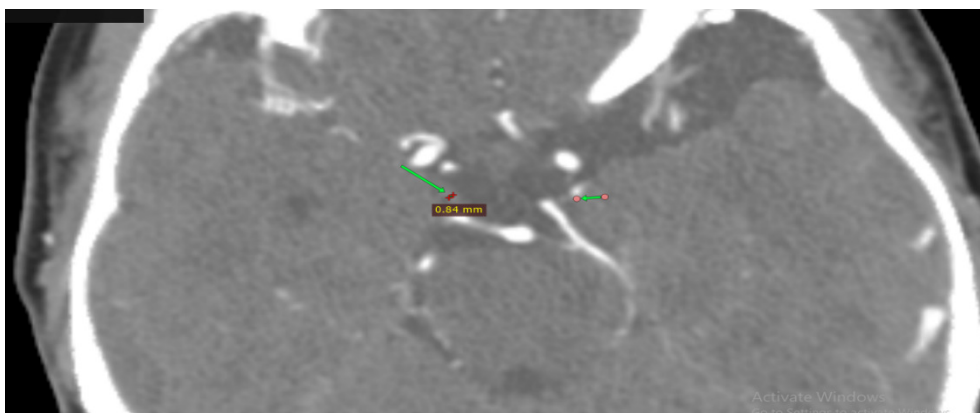


Figure 3: axial CT angiography image at the level of COW from a study sample image showing hypoplastic right posterior communication artery (PCOM) measuring 0.8mm in diameter (arrow).

5.5 Feature of stroke

The following figure presents the research findings on the incidence of stroke as evidenced by CT scans among the study participants. According to the data, a substantial majority of the participants, 76 individuals (88%), did not show stroke on their CT scans. In contrast, 10 participants (12%) had CT scan findings indicative of acute hemorrhagic stroke. The following pie chart vividly depicts the relative proportions of participants with and without CT-evidenced stroke, emphasizing that the vast majority did not exhibit stroke evidence (Figure 2).

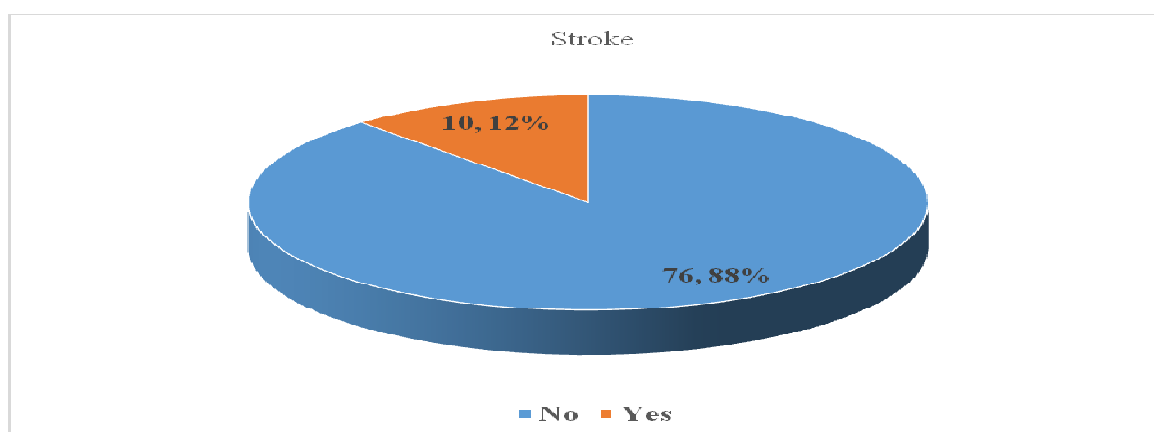


Figure 3: Feature of stroke among study participants who undergone CT angiography of brain in Saint Paul's Hospital Millennium Medical College from April 2024 to Jun 2024.

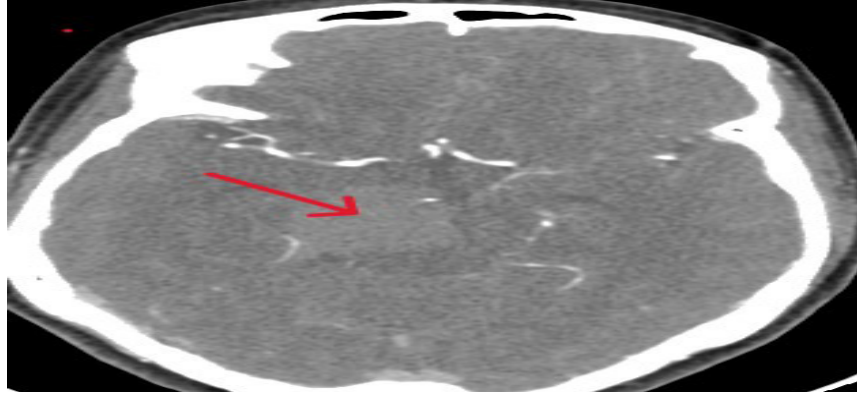


Figure 4: axial CT angiography image at the level of COW from a study sample image showing large homogeneously hyperdense lesion at the level of the right PCOM -PCA junction abutting both arteries (arrow) suggestive of acute hemorrhagic stroke.

5.6. Site of aneurysm

Aneurysms were found in 15.1% of the participants, with the remaining 84.9% were free of aneurysms. The aneurysms were located in the right PCoA (5.8%), ACoA (5.8%), and left PCoA (3.5%). The figure illustrates the distribution of aneurysms in various locations within the Circle of Willis among the study participants. It highlights three specific sites where aneurysms were identified. Both the Right Posterior Communicating Artery (PCoA) and the Anterior Communicating Artery (ACoA) each had an equal number of aneurysms, with five cases reported in each location. Meanwhile, the left PCoA exhibited three cases of aneurysms. This visual representation underscores the prevalence of aneurysms in these critical arterial junctions, with the PCoA being the most common site followed by the ACoA . Understanding the specific locations of aneurysms is vital for targeted diagnostic and therapeutic approaches in managing cerebrovascular conditions (figure 3).

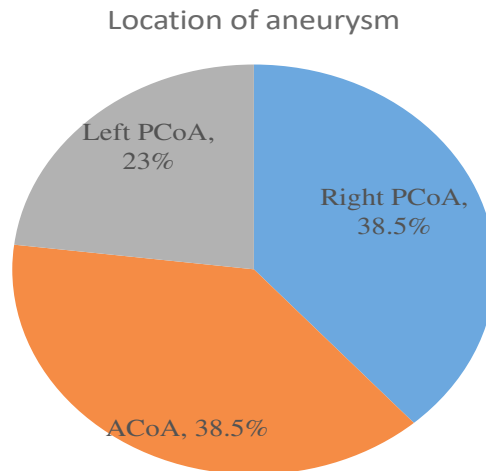


Figure 5: location of aneurysms among study participants who had undergone CT angiography of the brain in Saint Paul's Hospital Millennium Medical College from April 2024 to Jun 2024.

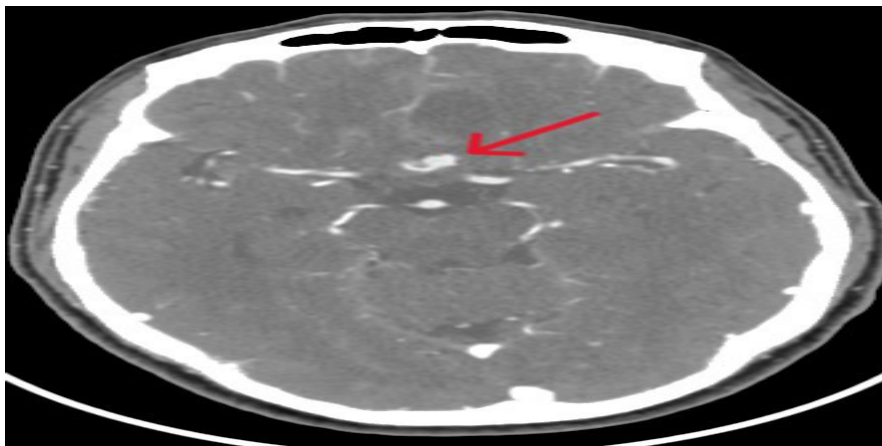


Figure 6: axial CT angiography image at the level of COW from a study sample image showing well defined round homogeneously hyperdense lesion (similar density to adjacent vessel) at anterior communicating artery (ACoA) (arrow) suggestive of ACoA aneurysm.

5.7 Factors associated with variant of circle of Willis

The research findings indicate significant associations between various variables and the completeness of the Circle of Willis. Males were more likely to have a complete Circle of Willis compared to females, with an adjusted odds ratio (AOR) of 48 (95% CI: 3.8-618, $p=0.003$).

Among different age groups, individuals aged 30-39 had the highest likelihood of having a complete Circle of Willis, with an AOR of 15.3 (95% CI: 5.4-32.5, p=0.023). Presence of Hypoplastic arteries was associated with a lower likelihood of a complete Circle of Willis, with an AOR of 63.5 (95% CI: 5.5-735, p=0.001). Individuals without stroke were more likely to have a complete Circle of Willis compared to those patients with stroke, with an AOR of 17.2 (95% CI: 5.4-55.4, p=0.004). Similarly, individuals without an aneurysm were more likely to have a complete Circle of Willis compared to those with an aneurysm, with an AOR of 6.2 (95% CI: 1.78-24.6, p=0.012). These findings suggest that sex, age, presence of Hypoplastic arteries, CT scan evidence of stroke, and aneurysm are important factors associated with the completeness of the Circle of Willis (table 4).

Variable	Category	Circle of Willis		COR, 95% CI	AOR, 95% CI	P value
		Incomplete	Complete			
Sex	Female	24(70.5%)	21(40.5%)	1	1	0.003
	Male	10(29.5%)	31(59.5%)	13.2(2.78-62.4)	48(3.8-618)	
Age	20-29	1(0.34)	12(23.0%)	1	1	0.023
	30-39	10(29.4%)	8(15.4%)	63.3(5.4-732)	15.3(5.4-32.5)	
	40-49	6(17.6%)	9(17.3%)	10(1.26-79.3)	8.7(7.2-27.5)	
	50-59	4(11.8%)	7(13.5%)	4.58(0.73-28.6)	5.8(0.46-32.3)	
	>=60	13(38.2%)	16(30.8%)	1.66(0.25-11.1)	6.8(0.25-11.1)	
Hypoplast	No	4(23.5%)	56(81.2%)	14(3.92-	63.5(5.5-	0.001

Tic arteries a				49.9)	735)	
	Yes	13(76.5%)	13(18.8%)	1	1	
Evidence d Stroke	No	10(58.8%)	66(95.7%)	15.4(3.4- 69.5)	17.2(5.4- 55.4)	0.004
	Yes	7(41.2%)	3(4.3%)	1	1	
T Aneurys a m b	No	12(70.6%)	61(88.4%)	3.1(0.88- 11.4)	6.2(1.78- 24.6)	0.012
	Yes	5(29.4%)	8(11.6%)	1	1	

Table 4, Factors associated with variants of COW among study participants who had undergone CT angiography of the brain in SPHMMC from April 2024 to Jun 2024.

6. Discussion

The Circle of Willis is crucial anastomosis and collateral channel for nourishing the brain. The purpose of this study was to determine the proportion of normal anatomy and variant of the circle of Willis and associated COW anomalies in patient who undergo CT angiography of the brain at Saint Paul's Hospital Millennium Medical College during the study period.

The study examined 86 study participants with the mean age of the participants were 48.3 years, with a standard deviation of 18.1 years. There was a difference on the sex with male accounting slightly higher percentage of 53% while female accounts 47%, the largest age group were aged 60 and above comprising of 33.7%.

The most common clinical presentation was headaches accounting for 45.3% of the total cases. This was followed by the left and right body weakness accounting 17.4% and 16.3% respectively. These varied symptoms reflect the diverse ways in which clinical presentation for undergoing CT angiography of the brain associated with COW anatomy & variants which possibly can manifest clinically. This data is crucial for healthcare professionals in identifying and prioritizing symptoms that may warrant further investigation through imaging techniques.

The study revealed that 39.5% exhibited an incomplete COW. Majority of incompleteness was found in 70.5% of females and a smaller percentage of males (29.5%). These findings offer valuable insights into the demographic characteristics of individuals in the study, potentially aiding in understanding how age and sex may influence anatomical variations of COW. This finding is lower as compared with a study done in Egypt (21) and Kenya(22) in which COW was incomplete in 51.3 % and 37.2% of the cases respectively. But, it is higher than a study done in Turkish (23) which is 14.6% of the COW was incomplete.

Similarly, The study also revealed that Hypoplastic arteries were present in 30% of the participants, with COW incompleteness being the right PCoA (14%), the most affected area followed by left PCoA (8.1%), double right and, ACoA (5.8%). This finding is in line with a study conducted in Turkey(23), Nepal (24) and Pakistan (25) in which, Hypoplastic posterior communicating artery being the most common variation.

But, this finding is different from a study done in turkey(23)and Egypt(21) in which the ACoA being the most affected site. The variation might be due to larger sample size could show more anatomical variations in COW and its incidence in other studies.

The current research finding also presented a significant association between demographic variables and the completeness of the COW. Therefore, this study revealed that a majority of participants had a complete COW, with females being more likely to have a incomplete COW compared to males. The association between sex and COW completeness were explored in different literature, with some studies suggesting differences in COW morphology between males and females. This finding is in line with different studies that complete COW more likely observed in younger and female participants (26).

Additionally, age-related changes in the COW have also documented, with variations in the structure and function of the cerebral vasculature observed across different age groups. The current study revealed that individuals in the 30-39 and 40-49 age group had the highest likelihood of having a complete COW. This finding is consistent with a study done in Egypt that the prevalence of the circle completeness in the younger subjects was higher than the older ones (50% versus 45% respectively) (18).

Similarly, these study revealed that Arterial agenesis and arterial fenestration were both notably rare, observed in only 1.2% of the participants for each variant. This finding is slightly higher than the previous publication by Dimmick SJ Faulder et al. and Roger M et al. have shown a low prevalence for fenestrations in angiographic studies of 0.058% and 0.48% respectively (27, 28).

Majority of the participants, 76 (88%), did not show stroke on their CT scans. In contrast, 10(12%) had CT scan findings of acute hemorrhagic stroke. These findings are crucial for understanding the prevalence of stroke among individuals undergoing CT scans in this study population and can guide future clinical assessments and interventions. Additionally, Hypoplastic arteries and stroke were significantly associated with the completeness of the COW. These findings align with existing literature done in Romania (29), Poland(30) and Nepal (31) on the COW and its variations reported that the presence of Hypoplastic arteries and stroke as factors influencing the completeness of the COW and highlighting the role of vascular abnormalities in cerebrovascular diseases.

In the current study, Aneurysms were found in 15.1% (n=13) of the participants. The aneurysms were located in the right PCoA (5.8%), ACoA (5.8%), and left PCoA (3.5%). These findings provide a detailed overview of the prevalence and specific locations of anatomical variants in the COW, which is crucial for understanding the implications for cerebral blood flow and the potential risk of cerebrovascular events. These finding is lower than that in an earlier Kenyan (32) study which showed a higher prevalence of aneurysms at 40.9% and anterior circulation aneurysms. Moreover, the current study showed that, significant association was found between the COW configuration and presence of aneurysms ($P=0.012$). This finding is contradicted with other study done by Brzegowy et al(33) that there is no significant association between the COW configuration and presence of aneurysms. This variation might be due to sample size difference between the studies.

7. Conclusions

This study revealed that majority of study participants was found to have a complete Circle of Willis. The study also investigated various anatomical variants of COW among the study population, revealing significant findings. Variations in the posterior portion of COW are more common than the anterior portion in most patients.

The current research finding also presented a significant association between demographic variables and the completeness of the COW. Therefore, this study revealed that a majority of participants had a complete Circle of Willis, with females being more likely to have an incomplete COW compared to males. The association between sex and COW completeness were explored in different literature, with some studies suggesting differences in COW morphology between males and females. This finding is in line with different studies that complete COW more likely observed in younger and male participants (26).

Additionally, age-related changes in the Circle of Willis have also documented, with variations in the structure and function of the cerebral vasculature observed across different age groups. The current study revealed that individuals in the 30-39 and 40-49 age group had the highest likelihood of having a complete COW. This finding is consistent with a study done in Egypt that the prevalence of the circle completeness in the younger subjects was higher than the older ones (50% versus 45% respectively) (18).

This study suggested that sex, age, presence of Hypoplastic arteries, stroke, and aneurysm are important factors associated with the completeness of COW, Such findings are critical as the completeness of the COW has implications for cerebral blood flow and the potential for collateral circulation in the event of arterial blockages or other cerebrovascular anomalies. Therefore, understanding the prevalence of complete versus incomplete COW can aid clinicians in better anticipating and managing potential cerebrovascular issues in their patients.

8. Limitation

This cross-sectional study design with repeated sampling only enabled us to establish point study of normal anatomy and variants of COW on patients with CT angiography of the brain but not the incidence of new events over time, which could be a focus for future research.

The analysis of many important subgroups was limited by the small numbers of patients in these groups, limiting our power to draw conclusions about many traditional risk factors

9. Recommendations

Based on the research findings provided, here are the key recommendations:

- Investigate sex-specific factors: The significant association between female sex and a higher likelihood of a incomplete Circle of Willis suggests the need to explore the underlying mechanisms, such as hormonal influences or anatomical variations that may contribute to this sex-based difference.
- Examine age-related changes: The finding that individuals aged 30-39 years have the highest odds of a complete Circle of Willis highlights the importance of understanding the longitudinal changes in the cerebrovascular anatomy across different age groups. Investigating the factors driving these age-related trends could provide valuable insights.
- Assess the impact of vascular variations: The strong association between the presence of Hypoplastic arteries and a lower likelihood of a complete Circle of Willis underscores the need to carefully evaluate vascular variations in clinical practice. This knowledge could inform risk assessment and guide targeted interventions for patient who present with COW aneurysm and arterial blockage .
- Explore the relationship with stroke and aneurysms: The observed associations between the completeness of the Circle of Willis and the reduced likelihood of stroke and aneurysms warrant further investigation. Elucidating the underlying

mechanisms may have important implications for the prevention and management of these cerebrovascular conditions.

Overall, these recommendations aim to guide future research and clinical practice in understanding the factors that contribute to the completeness of the Circle of Willis and their potential implications for patient care.

Reference

1. Macchi C, Lova RM, Miniati B, Gulisano M. The circle of Willis in healthy older persons. *Journal of Cardiovascular Surgery*. 2002;43(6):887.
2. Hoksbergen A, Fulesdi B, Legemate D, Csiba L. Collateral configuration of the circle of Willis: transcranial color-coded duplex ultrasonography and comparison with postmortem anatomy. *Stroke*. 2000;31(6):1346-51.
3. De Silva KRD, Silva R, Gunasekera WL, Jayasekera R. Prevalence of typical circle of Willis and the variation in the anterior communicating artery: A study of a Sri Lankan population. *Annals of Indian Academy of Neurology*. 2009;12(3):157-61.
4. Hafez KA, Afifi NM, Saudi FZ. Anatomical variations of the circle of Willis in males and females on 3D MR angiograms. *The Egyptian Journal of Hospital Medicine*. 2007;26(1):106-21.
5. Alahmari AF. Cross-sectional angiographic imaging of anatomical variations in the circle of Willis: A literature review. *Eur j anat*. 2020;24(4):297-309.
6. Banerjee A. Pathology of cerebrovascular disease. *Neurology India*. 2000;48(4):305-7.
7. Oumer M, Alemayehu M, Muche A. Association between circle of Willis and ischemic stroke: a systematic review and meta-analysis. *BMC neuroscience*. 2021;22:1-12.
8. Ayre JR, Bazira PJ, Abumattar M, Makwana HN, Sanders KA. A new classification system for the anatomical variations of the human circle of Willis: A systematic review. *Journal of Anatomy*. 2022;240(6):1187-204.
9. Paulinus S, Igiri A, Egbe N, Ani C, Udo-Affah G. Evaluation of Anatomical Variants of the Circle of Willis in a Nigerian Population Using Contrast Enhanced Computed Tomography (CECT) Scan. 2017.
10. Miralles M, Dolz J, Cotillas J, Aldoma J, Santiso M, Gimenez A, et al. The role of the circle of Willis in carotid occlusion: assessment with phase contrast MR angiography and transcranial duplex. *European Journal of Vascular and Endovascular Surgery*. 1995;10(4):424-30.
11. Iqbal S. A comprehensive study of the anatomical variations of the circle of willis in adult human brains. *Journal of clinical and diagnostic research: JCDR*. 2013;7(11):2423.
12. Eftekhari B, Dadmehr M, Ansari S, Ghodsi M, Nazparvar B, Ketabchi E. Are the distributions of variations of circle of Willis different in different populations?—Results of an anatomical study and review of literature. *BMC neurology*. 2006;6:1-9.
13. Maaly MA, Ismail AA. Three dimensional magnetic resonance angiography of the circle of Willis: Anatomical variations in general Egyptian population. *The Egyptian journal of radiology and nuclear medicine*. 2011;42(3-4):405-12.
14. Krabbe-Hartkamp MJ, Van der Grond J, De Leeuw F, De Groot J, Algra A, Hillen B, et al. Circle of Willis: morphologic variation on three-dimensional time-of-flight MR angiograms. *Radiology*. 1998;207(1):103-11.
15. Hartkamp MJ, van der Grond J, van Everdingen KJ, Hillen B, Mali WP. Circle of Willis collateral flow investigated by magnetic resonance angiography. *Stroke*. 1999;30(12):2671-8.
16. Hafez KA AN, Saudi FZ. Anatomical Variations of the Circle of Willis in Males and Females on 3D MR Angiograms. *Egypt J Hosp Med*. 2007;26(1). . Egyptian hospital 2007(1):26.

17. Kondori BJ, Azemati F, Dadseresht S. Magnetic resonance angiographic study of anatomic variations of the circle of Willis in a population in Tehran. *Archives of Iranian medicine*. 2017;20(4):235-9.
18. Osborn AG. *Diagnostic cerebral angiography*: Lippincott Williams & Wilkins; 1999.
19. Tarek F.A. Ella MSEEZ, Ahmed G. Elsayaf*, Mahmoud M. Moawad. Circle of Willis Anatomical Variations: A Multidetector Computed Tomography Angiography Study. *Menoufia medical journal*. 2024(1).
20. Roy Munialo Machasio RN, and Timothy Musila Mutala. Proportion of Variant Anatomy of the Circle of Willis and Association with Vascular Anomalies on Cerebral CT Angiography. *Hindawi*. 2019.
21. Yeniçeri I ÇN, Deveer M, Yeniçeri EN. Circle of Willis variations and artery diameter measurements in the Turkish population. *Folia Morphol (Poland)* 2017(5).
22. Prajwal Dhakal PK, Sharma Paudel, Sundar Suwal, Mohan Raj Sharma, Ram Kumar Ghimire. Anatomical Variations in Circle of Willis in Patients Undergoing CT Cerebral Angiography in a Tertiary Hospital in Nepal: A Descriptive Cross-sectional Study. *Nepal Medical Association* 2020;58(232).
23. Shaikh R SS. MRA-based evaluation of anatomical variation of circle of Willis in adult Pakistanis. *J Pakistan* 2018.
24. S. J. Dimmick and K. C. Faulder. "Normal variants of the cerebral circulation at multidetector CT angiography. *Radio Graphics*. 2009(4).
25. R. M. Krzyzewski KAT, M. Kochana, M. Kopeć W. Klimek-Piotrowska, and J. A. Walocha,. Anatomical variations of the anterior communicating artery complex: gender relationship. *Surgical and Radiologic Anatomy*. 2014;37(1).
25. Ana-Maria Dumitrescu AS, Dana Mihaela Turliuc, et, al. Clinical Significance of Circle of Willis Anatomical Variants in Cerebrovascular Disease. 2020.
26. W. Klimek-Piotrowska MK, M. Kochana, et, al. Configurations of the circle of Willis: a computed tomography angiography based study on a Polish population. *Folia Morphol (Poland)*. 2013;72(4).
27. Prasad VN CP, Poudel A. . Normal Variants of the Circle of Willis in patients undergoing CT Angiography. *JCMS Nepal*. 2017;13(1):190-2. College of Medical Sciences. 2017;13(1):190-2.
28. D. K. Chepsiror. The pattern of radiological findings seen in four-vessel cerebral angiography done at the KNH and Nairobi Hospital , University of Nairobi, Nairobi, Kenya. 2006.
29. P. Brzegowy JP, J. Wnuk, B. Łasocha, J. Walocha, and T. J. Popiela,. "Middle cerebral artery anatomical variations and aneurysms: A retrospective study based on computed tomography angiography findings," *Folia Morphologica (Poland)*, . 2018;77(3).

Annexes

Annex I

Consent Form

I am a radiology resident and I have prepared this survey to assess the anatomic variations of the circle of Willis in adult brain CT angiography scans at SPHMMC and identify the factors affecting them. Participation is entirely voluntary and you have every right not to answer questions you don't want to. The response being collected is for a possible decision-making purpose only and there are neither any personal risks nor any benefits to your participation. Your name and address will not be recorded in the survey. Everything that you say were kept confidential and the only identifier on the questionnaire were a code, not your name. No one was told about the results of the imaging report and no one was given your name. There is no any consequence in refusing to be part of this survey.

Annex- 2

Questionnaire

Questionnaire format prepared in order to collect information on anatomic variations of the circle of Willis in CT angiography images of adult brain scans images adapted from different literature(11)(16)(18)(22).

DATA COLLECTION FORM

Socio-demographic data

Code number -

Age (years) -

Completeness of the COW -

Presenting compliant -

Current or previous diagnosed COW aneurysm - Yes ☐ No ☐

Current or previous diagnosed stroke - Yes ☐ No ☐

If your answer to the above question is yes, please specify

A, hemorrhagic stroke B, ischemic stroke

If your answer to the above question is hemorrhagic stroke, please specify

A, at COW B, other than COW.

Brain CT Angiography data

Artery	Diameter (mm)		Other finding
Anterior communicating artery			
Posterior cerebral arteries	Right		
	Left		
Anterior communicating arteries	Right		
	Left		
Posterior communicating arteries	Right		
	Left		
Middle cerebral	Right		
	Left		

Artery			
--------	--	--	--

Investigator name

signature

Hashime Meketa (MD, Radiology Resident)

_____.

Advisor's names

signature

1) Dr Hanan TofikMD, neuroradiology fellow.

_____.

2) Mrs. Hanna Feleke, MPH.

_____.