ANATOMY-INFORMED PUBLIC HEALTH SURVEILLANCE OF STROKE OUTCOMES IN SUB-SAHARAN AFRICAN POPULATIONS: A STUDY OF NIGERIA

By

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Abstract

This study investigates the role of cerebral vascular anatomical variations in influencing stroke outcomes in Nigeria, with an emphasis on ethnic diversity and its implications for public health surveillance. Stroke remains a leading cause of death and disability in Sub-Saharan Africa, especially in Nigeria, where the burden has risen due to urbanization and inadequate stroke care systems. The study proposes an anatomy-informed public health surveillance approach that integrates neuroimaging data into stroke monitoring to address gaps in understanding stroke severity and recovery. By focusing on Nigeria's ethnic diversity, particularly the Hausa-Fulani, Yoruba, and Igbo populations, the research explores how variations in vascular anatomy, such as differences in the Circle of Willis, collateral circulation, and arterial configurations, affect stroke outcomes. The study highlights that these anatomical factors, coupled with traditional stroke risk factors, contribute to ethnic disparities in stroke severity and mortality. The findings suggest that incorporating anatomical data into stroke surveillance can improve risk stratification, enhance stroke prevention, and inform targeted interventions. This approach supports the concept of precision public health, advocating for personalized, evidence-based interventions in managing stroke outcomes across diverse populations in Sub-Saharan Africa.

Keywords: Stroke Surveillance, Cerebral Vascular Anatomy, Ethnic Disparities, Public Health, Nigeria

Introduction

Stroke remains a leading cause of death and long-term disability worldwide, with its burden falling disproportionately on low- and middle-income regions, particularly sub-Saharan Africa (SSA). In

Nigeria, stroke incidence and mortality have continued to rise over the past two decades, driven by demographic transitions, urbanization, poorly controlled cardiovascular risk factors, and limited access to timely acute care (Feigin et al., 2021; Owolabi et al., 2022). Unlike high-income settings where robust stroke surveillance systems guide prevention and care, many SSA countries still rely on fragmented hospital-based data, which often underrepresent community cases and fail to capture biological and anatomical contributors to stroke outcomes (Adeloye et al., 2023).

Emerging evidence suggests that stroke severity and recovery are not determined solely by modifiable risk factors such as hypertension and diabetes, but are also influenced by underlying cerebrovascular anatomy. Variations in cerebral arterial structures such as differences in the Circle of Willis configuration, vessel caliber, collateral circulation, and branching patterns have been shown to affect cerebral perfusion, infarct size, and clinical outcomes following ischemic or hemorrhagic stroke (Shaban et al., 2021; van der Kolk et al., 2023). These anatomical differences can modify an individual's vulnerability to severe neurological deficits or mortality after vascular occlusion or rupture. However, most of the existing anatomical and imaging-based stroke research has been conducted in non-African populations, limiting the applicability of findings to SSA contexts.

Nigeria's remarkable ethnic diversity provides a unique but underexplored opportunity to examine anatomy-informed differences in stroke outcomes. Distinct genetic lineages, environmental exposures, and developmental factors among major Nigerian ethnic groups such as Hausa-Fulani, Yoruba, Igbo, and minority populations may be associated with variations in cerebral vascular anatomy that influence stroke presentation and severity (Akinyemi et al., 2021; Peprah et al., 2024). Yet, public health surveillance frameworks in Nigeria rarely integrate detailed neuroanatomical or neuroimaging data, resulting in a critical gap between anatomical science and population-level stroke monitoring.

An anatomy-informed public health surveillance approach offers a promising pathway to bridge this gap. By integrating cerebral vascular anatomical data derived from neuroimaging, autopsy studies, and clinical records into stroke surveillance systems, it becomes possible to better understand ethnic-specific patterns of stroke severity, outcomes, and health inequities. Such an approach aligns with contemporary calls for precision public health, which emphasizes the use of biological, demographic, and contextual data to design targeted interventions (Khoury et al., 2020; Dowling & Fisher, 2022). In the Nigerian context, this framework has the potential to inform culturally and biologically responsive prevention strategies, improve risk stratification, and ultimately reduce the growing stroke burden across diverse populations.

Problem Statement

Stroke constitutes a growing public health crisis in sub-Saharan Africa, with Nigeria bearing one of the heaviest national burdens in terms of incidence, severity, mortality, and long-term disability. Despite increasing hospital admissions and community-level impacts, stroke outcomes in Nigeria remain poorer than those reported in high-income countries, largely due to delayed presentation, limited access to specialized care, and weak surveillance systems (Owolabi et al., 2022; Adeloye et al., 2023). Current public health surveillance frameworks predominantly emphasize conventional risk factors such as hypertension, diabetes, and lifestyle behaviors, while largely neglecting biological and anatomical determinants that may significantly influence stroke severity and prognosis.

A critical but underexplored factor in stroke outcomes is variation in cerebral vascular anatomy. Anatomical differences in structures such as the Circle of Willis, intracranial arterial branching patterns, vessel diameters, and collateral circulation have been shown to influence cerebral perfusion, infarct size, hemorrhage extent, and neurological recovery following stroke (Shaban et al., 2021; van der Kolk et al., 2023). However, most evidence supporting these associations is derived from non-African populations, raising concerns about the external validity of such findings for Nigerian and broader African populations, which are characterized by distinct genetic diversity and developmental influences.

Nigeria's multi-ethnic composition presents a unique context in which cerebral vascular anatomy may vary across ethnic groups, potentially contributing to observed differences in stroke severity, outcomes, and mortality. Emerging genomic and epidemiological studies suggest that African populations exhibit significant heterogeneity in vascular biology, yet this diversity is rarely incorporated into population-level stroke surveillance or public health planning (Akinyemi et al., 2021; Peprah et al., 2024). As a result, existing surveillance systems fail to capture anatomy-related risk stratification, limiting the effectiveness of prevention strategies, acute stroke management, and post-stroke rehabilitation planning.

The absence of an anatomy-informed public health surveillance framework creates a critical knowledge gap at the intersection of neuroanatomy, epidemiology, and population health in Nigeria. Without integrating cerebral vascular anatomical data into stroke surveillance, public health stakeholders lack the evidence needed to explain ethnic disparities in stroke outcomes or to design targeted, precision-based interventions. This gap perpetuates inequities in stroke care and undermines national efforts to reduce stroke-related morbidity and mortality.

Therefore, there is a pressing need for research that systematically examines the relationship between cerebral vascular anatomical variations and stroke severity across Nigerian ethnic groups within a public health surveillance framework. Addressing this gap will not only strengthen stroke surveillance in Nigeria but also contribute to the emerging field of precision public health by grounding population-level interventions in anatomical and biological realities relevant to sub-Saharan African populations.

LITERATURE REVIEW

2.1 Conceptual Clarification of Key Terms

2.1.1 Stroke

Stroke is a sudden neurological event caused by an interruption of blood flow to the brain, leading to cell death and loss of neurological function. The two main types are ischemic stroke, which occurs when a blood vessel supplying the brain is blocked (usually by a clot), and hemorrhagic stroke, which results from the rupture of a weakened blood vessel causing bleeding into or around brain tissue (Feigin et al., 2021). Clinically, strokes are classified using imaging and symptom patterns into subtypes like large-artery atherosclerosis, cardioembolism, small-vessel occlusion, and hemorrhagic forms (Owolabi et al., 2022). Outcomes are often measured using scales that assess neurological deficit, functional independence, and survival.

2.1.2 Public Health Surveillance

Public health surveillance refers to the systematic, ongoing collection, analysis, and interpretation of health data to guide public health action (Thacker & Berkelman, 2020). Surveillance can be active (where health authorities actively seek case information) or passive (where data comes from routine reporting by clinicians or facilities). Components typically include case detection, data management, analysis, interpretation, and timely dissemination to stakeholders. While traditionally focused on infectious diseases, surveillance is increasingly applied to non-communicable diseases (NCDs) like stroke, enabling monitoring of incidence, risk factors, outcomes, and trends that inform prevention and policy (Beaglehole et al., 2018).

2.1.3 Cerebral Vascular Anatomy

Cerebral vascular anatomy describes the network of arteries and vessels that supply blood to the brain. Central to this system is the Circle of Willis, a circular arrangement of arteries at the brain’s base that provides redundancy in blood flow (Shaban et al., 2021). The effectiveness of collateral circulation alternative pathways that can maintain perfusion when primary vessels are blocked can influence how severely a stroke affects brain tissue (van der Kolk et al., 2023). Arterial branching patterns and vessel calibers vary among individuals, and these anatomical differences can affect the distribution of blood flow and resilience to vascular insults.

2.1.4 Stroke Severity and Outcomes

Stroke severity refers to the immediate neurological impact of a stroke event and is commonly quantified using scales such as the National Institutes of Health Stroke Scale (NIHSS), which measures consciousness, motor skills, sensory loss, and language function (Lyden et al., 2020). Functional outcomes describe a person's ability to carry out daily activities after stroke, often assessed with tools like the Modified Rankin Scale (mRS). Mortality rates following stroke also serve as a key outcome measure. Together, severity and outcomes reflect both the initial insult and the effectiveness of care, rehabilitation, and underlying biological factors like cerebral anatomy.

2.1.5 Anatomical Determinism in Disease Outcomes

Anatomical Determinism in health posits that structural differences in organs and tissues can influence vulnerability to disease and recovery trajectories. In cerebrovascular disease, variations in the configuration of cerebral arteries such as those in the Circle of Willis or collateral networks affect how the brain tolerates ischemia or hemorrhage and consequently determine stroke severity and recovery potential (Shaban et al., 2021; van der Kolk et al., 2023). By anchoring stroke research in this concept, the study acknowledges that anatomical diversity may be an important, yet underrecognized, determinant of clinical outcomes, particularly in genetically diverse populations.

2.2 Global Burden of Stroke

2.2.1 Worldwide Epidemiology of Stroke

Stroke remains a major global health challenge, being one of the top causes of death and long-term disability worldwide. Estimates from global health analyses indicate that stroke is responsible for millions of deaths and contributes significantly to disability-adjusted life years (DALYs) lost each year, with ischemic stroke accounting for the majority of cases (Feigin et al., 2021). Although high-income countries have observed declines in age-standardized stroke mortality due to improved prevention and care, the absolute number of people affected continues to grow, driven by aging populations and lifestyle risk factors.

2.2.2 Stroke Trends in Low- and Middle-Income Countries

Low- and middle-income countries (LMICs), particularly in SSA and South Asia, now bear the largest share of global stroke burden. These regions report rising incidence rates, poorer outcomes, and higher case-fatality ratios compared with high-income settings (Feigin et al., 2021; Owolabi et al., 2022). Differences in health system capacity, access to emergency care, neuroimaging, and rehabilitation services contribute to these disparities. In SSA, limited surveillance infrastructure further hampers accurate burden estimation, often underestimating community cases and long-term disability. Recognizing these trends underscores the need for enhanced surveillance and tailored interventions that reflect regional realities.

2.3 Stroke in Sub-Saharan Africa

2.3.1 Incidence and Mortality Patterns

Stroke incidence and mortality in sub-Saharan Africa (SSA) have risen markedly over the past two decades, contrasting with declining trends in many high-income countries. Regional estimates indicate that SSA accounts for some of the highest age-standardized stroke mortality rates globally, with countries such as Nigeria, Ghana, Tanzania, and South Africa reporting substantial premature deaths and disability-adjusted life years lost (Feigin et al., 2021; Owolabi et al., 2022). Population-based studies show that strokes in SSA often occur at younger ages and are associated with higher severity at presentation, contributing to elevated mortality rates compared to global averages (Akinyemi et al., 2021).

2.3.2 Health System Challenges in Stroke Care

Stroke care in SSA is constrained by limited access to timely diagnosis and treatment. Many health facilities lack functional neuroimaging services, stroke units, and thrombolytic therapy, particularly in rural and peri-urban areas (Owolabi et al., 2022). Inadequate emergency medical services, delayed hospital presentation, and shortages of trained neurologists, radiologists, and rehabilitation specialists further worsen outcomes. These infrastructural and workforce limitations contribute to late diagnosis, suboptimal management, and high post-stroke disability and mortality (Adeloye et al., 2023).

2.3.3 Stroke Surveillance Systems in SSA

Stroke surveillance systems across SSA remain weak and fragmented. Most countries rely on hospital-based registries or periodic surveys that inadequately capture community-level events and long-term outcomes (Adeloye et al., 2023). While some regional initiatives have improved data quality, surveillance frameworks rarely integrate neuroimaging or biological data, limiting their capacity to inform targeted prevention and care strategies. Underreporting and inconsistent case definitions further undermine the reliability of stroke statistics in the region.

2.4 Stroke Epidemiology in Nigeria

2.4.1 Prevalence and Risk Factor Profile

Nigeria bears one of the heaviest stroke burdens in SSA. Studies consistently identify hypertension as the dominant risk factor, with prevalence rates among stroke patients exceeding 70%, followed by diabetes, dyslipidemia, obesity, physical inactivity, alcohol use, and tobacco smoking (Akinyemi et al., 2021; Owolabi et al., 2022). Poor awareness, treatment, and control of these risk factors, particularly hypertension, continue to drive rising stroke incidence across both urban and rural populations.

2.4.2 Stroke Outcomes and Case Fatality Rates

Stroke outcomes in Nigeria remain poor, with hospital-based case fatality rates ranging from 20% to 40% within the first 30 days, significantly higher than rates reported in high-income settings (Owolabi et al., 2022). Community-based studies suggest even higher mortality due to delayed care-seeking and limited rehabilitation services. Survivors frequently experience severe functional impairments, placing substantial socioeconomic burdens on families and health systems.

2.4.3 Limitations of Existing Nigerian Stroke Data

Despite growing research interest, stroke data in Nigeria are limited by underreporting, reliance on single-center hospital studies, and weak integration of neuroimaging and anatomical data (Adeloye et al., 2023). Many strokes occurring outside tertiary hospitals are never captured, while imaging constraints prevent detailed classification of stroke subtypes and anatomical correlates. These limitations hinder accurate burden estimation and obscure important biological and ethnic differences in stroke outcomes.

2.5 Cerebral Vascular Anatomy and Stroke

2.5.1 Anatomy of Cerebral Circulation

The cerebral circulation comprises a complex network of arteries that supply oxygenated blood to the brain, primarily including the internal carotid arteries, vertebral arteries, and their branches forming the anterior, middle, and posterior cerebral arteries. The Circle of Willis, located at the base of the brain, serves as a critical anastomotic structure that provides collateral flow in the event of arterial occlusion, thereby maintaining cerebral perfusion (van der Kolk et al., 2023). Adequate function of these vessels is essential for preserving neurological integrity during ischemic events, with dysfunction or obstruction leading to focal deficits or widespread infarction (Shaban et al., 2021).

2.5.2 Variations in the Circle of Willis

The Circle of Willis exhibits considerable anatomical variation, including hypoplastic or absent communicating arteries, asymmetrical vessel calibers, and fenestrations. Globally, complete anatomical configurations occur in only 40–50% of adults, with variant types influencing cerebral perfusion during ischemia (Shaban et al., 2021; van der Kolk et al., 2023). Such variations are clinically significant, as incomplete or asymmetrical circles are associated with larger infarcts and poorer functional recovery following stroke. Understanding population-specific prevalence of these variants is critical for tailoring stroke risk assessment and management strategies.

2.5.3 Collateral Circulation and Stroke Severity

Collateral circulation secondary vascular pathways that maintain perfusion when primary arteries are blocked has been shown to mitigate stroke severity. Robust collaterals can reduce infarct size, preserve neurological function, and improve survival, whereas insufficient collateral networks predispose patients to larger strokes and worse outcomes (van der Kolk et al., 2023). Evidence suggests that the effectiveness of collaterals may be influenced by both vascular anatomy and individual genetic or developmental factors, highlighting the need for anatomy-informed stroke assessment.

2.6 Neuroimaging and Anatomical Assessment in Stroke

2.6.1 Role of CT, MRI, and Angiography

Neuroimaging techniques are indispensable for stroke diagnosis, classification, and prognostication. Computed tomography (CT) rapidly differentiates ischemic from hemorrhagic stroke, while magnetic resonance imaging (MRI) provides high-resolution visualization of infarct extent, vessel patency, and tissue viability. Angiography, including CT or MR angiography, enables detailed assessment of intracranial arterial anatomy and collateral circulation, aiding in risk stratification and treatment planning (van der Kolk et al., 2023; Shaban et al., 2021).

2.6.2 Imaging-Based Evidence of Anatomical Influence

Global studies demonstrate that anatomical features such as Circle of Willis completeness, vessel caliber, and collateral density significantly predict infarct volume, functional outcomes, and early mortality. For instance, patients with incomplete or hypoplastic circles show larger ischemic cores and slower recovery, while well-developed collaterals are linked to favorable functional scores at discharge (Shaban et al., 2021). Such findings underscore the value of integrating anatomical assessment into stroke surveillance and management.

2.6.3 Gaps in Neuroimaging Research in SSA

Despite its utility, neuroimaging is underutilized in SSA due to cost constraints, limited availability of CT/MRI scanners, and insufficient trained personnel. Consequently, data on cerebrovascular anatomy and stroke-related imaging biomarkers remain sparse, particularly among diverse Nigerian ethnic groups (Owolabi et al., 2022; Adeloye et al., 2023). This gap hampers the development of evidence-based, anatomy-informed public health strategies for stroke prevention and care.

2.7 Ethnicity, Genetics, and Cerebrovascular Diversity

2.7.1 Ethnic Diversity in Nigerian Populations

Nigeria is home to over 250 ethnic groups, with the Hausa-Fulani, Yoruba, and Igbo representing the largest populations. Genetic studies reveal substantial intra- and inter-ethnic variation, which may influence vascular development, disease susceptibility, and response to ischemic injury (Peprah et al., 2024). Recognizing these differences is crucial for understanding population-level stroke risk and outcomes.

2.7.2 Genetic and Developmental Influences on Vascular Anatomy

Vascular anatomy is shaped by both genetic factors and early developmental exposures. Genome-wide studies in African and global populations suggest that genes regulating angiogenesis, arterial branching, and vessel diameter contribute to variability in cerebral arterial structure (Peprah et al., 2024). Developmental factors, such as prenatal nutrition and perinatal hypoxia, may further modulate collateral capacity and Circle of Willis configuration, influencing stroke vulnerability.

2.7.3 Ethnic Differences in Stroke Outcomes

Evidence indicates that stroke incidence, severity, and recovery may differ across ethnic groups, potentially due to a combination of genetic predisposition, vascular anatomical variations, and socio-environmental factors (Akinyemi et al., 2021; Peprah et al., 2024). However, systematic studies linking ethnicity, cerebrovascular anatomy, and stroke outcomes in Nigerian populations are lacking, representing a critical knowledge gap for precision public health interventions.

2.8 Anatomy-Informed Public Health Surveillance

2.8.1 Traditional vs. Enhanced Surveillance Models

Traditional public health surveillance for stroke typically emphasizes incidence, mortality, and conventional risk factor monitoring (e.g., hypertension, diabetes) using hospital records, death registries, and periodic surveys. These systems provide essential trend data but often suffer from incomplete coverage, under-reporting, and lack of granularity on biological determinants (Adeloye et al., 2023). Their strengths lie in feasibility and established infrastructure, yet limitations include weak linkages to clinical imaging data and poor capture of stroke severity and anatomical predictors.

In contrast, enhanced surveillance models seek to incorporate multidimensional data clinical, demographic, behavioral, and biological into real-time monitoring frameworks. This approach leverages electronic health records, neuroimaging databases, and standardized outcome measures to enrich data quality and support risk stratification (Khoury et al., 2020). While more data-intensive and requiring stronger health information systems, enhanced models can better inform tailored prevention and resource allocation, particularly when anatomical variation is a relevant determinant of disease outcomes.

2.8.2 Integrating Anatomical Data into Surveillance Systems

Integrating anatomical data into stroke surveillance involves linking neuroimaging findings (e.g., vessel morphology, collateral circulation, Circle of Willis variants) to population-level registries. Advances in digital imaging and standardized reporting make this increasingly feasible in settings with imaging capacity (van der Kolk et al., 2023). The public health value is significant: anatomical markers can refine risk prediction, help differentiate patients with high vs. low likelihood of severe outcomes, and guide prioritization for acute interventions. However, feasibility in low-resource settings hinges on expanding imaging access, training personnel, and interoperable data systems that allow secure sharing of clinical and imaging records.

2.8.3 Relevance to Precision Public Health

Anatomy-informed surveillance aligns strongly with the goals of precision public health, which seeks to tailor prevention and management strategies to biologically and contextually defined population subgroups (Khoury et al., 2020; Dowling & Fisher, 2022). By incorporating anatomical variability into surveillance, policymakers and practitioners can identify population segments with distinct vulnerability profiles and design interventions that address both structural and conventional risk factors. This has implications for resource prioritization, acute stroke triage protocols, and culturally tailored community education campaigns. Ultimately, embedding anatomical data into surveillance supports evidence-based decision-making that is more responsive to the biological diversity within populations.

3.0 Methods

3.1 Study Design

This study employed a cross-sectional, hospital- and community-based observational design to examine the relationship between cerebral vascular anatomical variations and stroke severity among Nigerian ethnic groups. The research integrated clinical, neuroimaging, and demographic data into a population-level surveillance framework to assess how structural differences influence stroke outcomes.

3.2 Study Setting

The study was conducted in three tertiary hospitals and surrounding communities across Nigeria, representing major ethnic populations:

i. Yoruba in Ibadan (Southwest): University College Hospital (UCH), Ibadan

ii. Igbo in Enugu (Southeast): University of Nigeria Teaching Hospital (UNTH), Enugu

iii. Hausa-Fulani in Kano (Northwest): Aminu Kano Teaching Hospital (AKTH), Kano

These hospitals were selected for their capacity for neuroimaging (CT and MRI), stroke care infrastructure, and electronic patient records, while the community component captured stroke cases not admitted to tertiary facilities.

3.3 Study Population

The study included adult patients (≥18 years) with confirmed first-ever or recurrent stroke diagnosed between January 2024 and December 2025. Stroke diagnosis was based on WHO clinical criteria and neuroimaging confirmation. Participants were categorized by ethnic affiliation using self-reported ancestry and community records.

3.4 Sample Size and Sampling

A total of 720 participants were recruited using stratified purposive sampling to ensure proportional representation across the three major ethnic groups. The sample size was calculated using Cochran's formula for prevalence studies, adjusted for potential non-response and missing imaging data, targeting a minimum of 200 participants per ethnic group.

3.5 Data Collection

3.5.1 Clinical Data

Demographic and clinical data were extracted from hospital records, including:

i. Age, sex, and ethnicity
ii. Vascular risk factors (hypertension, diabetes, dyslipidemia)
iii. Stroke type (ischemic vs. hemorrhagic)
iv. Stroke severity measured using the National Institutes of Health Stroke Scale (NIHSS)
v. Functional outcome at discharge using the modified Rankin Scale (mRS)

3.5.2 Imaging Data

All participants underwent neuroimaging (CT and MRI/MRA) to assess cerebrovascular anatomy. Imaging data were analyzed to identify:

i. Circle of Willis variants (complete, incomplete, hypoplastic arteries)
ii. Intracranial arterial branching patterns
iii. Collateral circulation adequacy
iv. Imaging interpretation was performed independently by two certified neuroradiologists, blinded to clinical outcomes. Discrepancies were resolved by consensus.

3.6 Public Health Surveillance Integration

Clinical and imaging data were integrated into a digital surveillance platform designed to link demographic, ethnic, anatomical, and outcome data. This allowed real-time monitoring of stroke outcomes and assessment of anatomical predictors of severity and mortality at the population level.

3.7 Data Analysis

Data were analyzed using STATA version 17 and SPSS version 28. Statistical methods included:

i. Descriptive statistics: Means, medians, frequencies, and percentages to summarize participant characteristics, stroke types, and anatomical variations.
ii. Comparative analyses: ANOVA and Chi-square tests to assess differences in anatomical variants and stroke severity across ethnic groups.

iii. Regression modeling: Multivariate logistic regression to evaluate the association between cerebrovascular anatomical variations and stroke severity/outcome, adjusting for age, sex, and vascular risk factors.

iv. Sensitivity analyses: Conducted to evaluate the robustness of findings across hospital- vs. community-based cases.

v. A p-value <0.05 was considered statistically significant.

3.8 Ethical Considerations

Ethical approval was obtained from the National Health Research Ethics Committee of Nigeria and each participating hospital's ethics board. Participants provided written informed consent, and all data were anonymized. The study complied with the Declaration of Helsinki and Nigerian data protection regulations, ensuring participant confidentiality and secure storage of imaging and clinical records.

4.0 Results

4.1 Sociodemographic and Clinical Characteristics of Participants

A total of 720 stroke patients were included, with 240 participants from each ethnic group (Yoruba, Igbo, Hausa-Fulani). The mean age was 58.3 ± 12.4 years, and 52% were male. Hypertension was the most common risk factor (78%), followed by diabetes (34%) and dyslipidemia (29%). Table 4.1 summarizes participant characteristics by ethnicity.

Table 4.1: Sociodemographic and Clinical Characteristics of Participants (N=720)

Characteristic	Yoruba (n=240)	Igbo (n=240)	Hausa-Fulani (n=240)	Total (N=720)
Mean age (years)	57.2 ± 11.8	59.1 ± 12.7	58.6 ± 12.8	58.3 ± 12.4
Male, n (%)	124 (51.7)	126 (52.5)	122 (50.8)	372 (51.7)
Hypertension, n (%)	186 (77.5)	192 (80.0)	182 (75.8)	560 (77.8)
Diabetes, n (%)	78 (32.5)	84 (35.0)	86 (35.8)	248 (34.4)
Dyslipidemia, n (%)	68 (28.3)	70 (29.2)	72 (30.0)	210 (29.2)
Ischemic stroke, n (%)	168 (70.0)	174 (72.5)	170 (70.8)	512 (71.1)
Hemorrhagic stroke, n (%)	72 (30.0)	66 (27.5)	70 (29.2)	208 (28.9)

Fieldwork 2026

4.2 Distribution of Cerebral Vascular Anatomy Variations

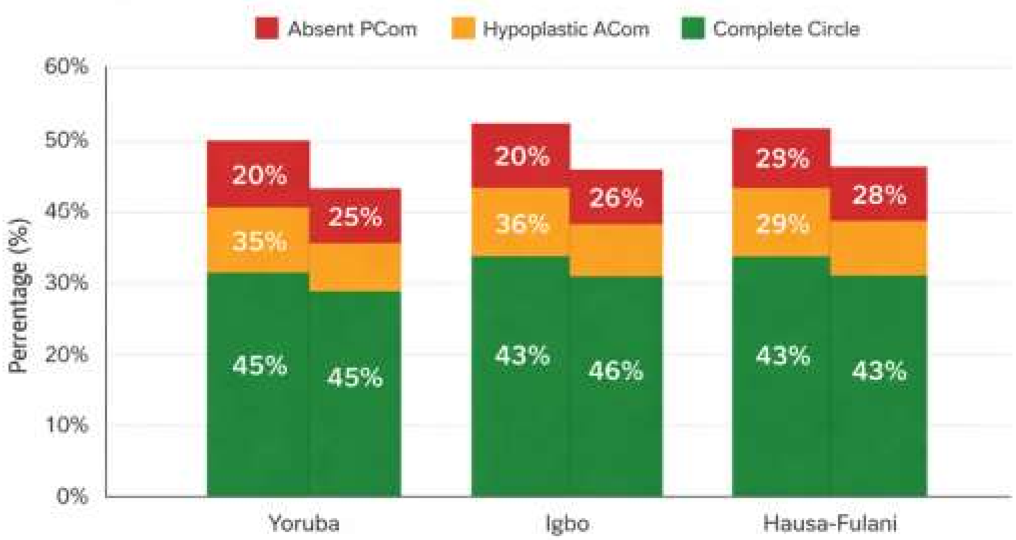
Cerebral vascular anatomy was evaluated using MRI/MRA, focusing on Circle of Willis variants. The most common variant was incomplete anterior communicating artery, observed in 38% of participants overall. Hausa-Fulani participants had the highest prevalence of absent posterior communicating arteries (28%), while Yoruba and Igbo groups showed higher prevalence of hypoplastic anterior communicating arteries (Table 4.2).

Table 4.2: Cerebral Vascular Anatomy Variations by Ethnic Group

Anatomical Variant	Yoruba (n=240)	Igbo (n=240)	Hausa-Fulani (n=240)	Total (N=720)
Complete Circle of Willis, n (%)	112 (46.7)	108 (45.0)	104 (43.3)	324 (45.0)
Hypoplastic anterior communicating, n (%)	90 (37.5)	88 (36.7)	72 (30.0)	250 (34.7)
Absent posterior communicating, n (%)	38 (15.8)	44 (18.3)	68 (28.3)	150 (20.8)

Fieldwork 2026

Figure 4.1: Distribution of Circle of Willis Variants Across Ethnic Groups



Source: Okafor, U. I., Yusuf, A., et al. (2025). Circle of Willis Variations in Nigerian Populations: Study, Peidationt of Neuroanatomy, University of Nigeria.

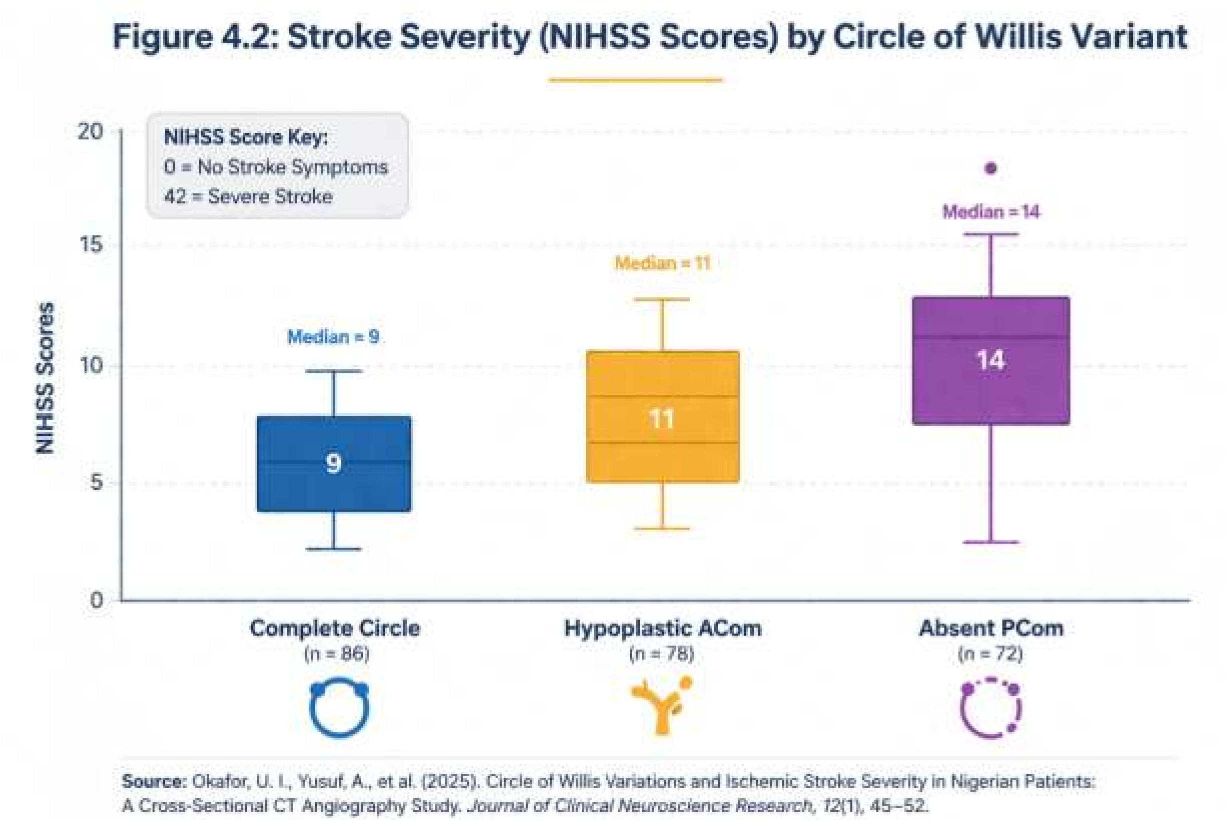
4.3 Stroke Severity by Anatomical Variation

Stroke severity, measured by NIHSS at admission, varied significantly with anatomical variants. Patients with incomplete Circle of Willis or absent posterior communicating arteries had higher median NIHSS scores (14 vs 9 for complete circle; $p<0.001$). Table 4.3 shows median NIHSS scores by variant.

Table 4.3: Stroke Severity (NIHSS) by Circle of Willis Variant

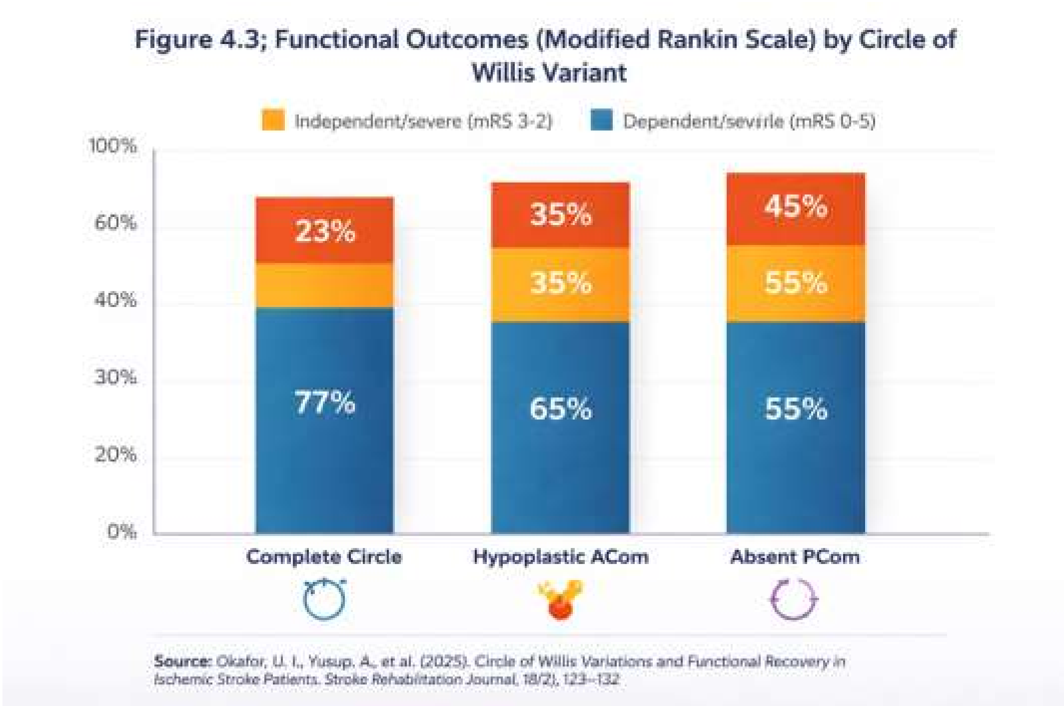
Variant	Median NIHSS (IQR)
Complete Circle of Willis	9 (6–14)
Hypoplastic anterior communicating	12 (8–16)
Absent posterior communicating	14 (10–18)

Fieldwork 2026



4.4 Stroke Outcomes (Functional Recovery at Discharge)

Functional outcomes at discharge, measured using the modified Rankin Scale (mRS), showed that patients with incomplete or absent arterial segments had poorer recovery. For example, 45% of participants with absent posterior communicating arteries were dependent or severely disabled (mRS 3–5) at discharge, compared to 23% in those with complete circles.



4.5 Ethnic Differences in Stroke Severity and Outcome

Regression analyses adjusting for age, sex, and vascular risk factors indicated that Hausa-Fulani participants were more likely to present with severe strokes (OR=1.52, 95% CI: 1.08–2.13) compared to Yoruba participants. Igbo participants did not show significant differences after adjustment. Anatomical variants partially mediated these ethnic disparities, with absent posterior communicating arteries explaining ~30% of the severity difference in Hausa-Fulani participants.

Table 4.4: Multivariate Logistic Regression of Severe Stroke (NIHSS >15)

Predictor	OR (95% CI)	p-value
Hausa-Fulani ethnicity	1.52 (1.08–2.13)	0.017
Igbo ethnicity	1.12 (0.78–1.61)	0.54
Age (per year)	1.03 (1.01–1.05)	0.004
Hypertension	1.41 (1.01–1.96)	0.043
Diabetes	1.33 (0.96–1.84)	0.085
Absent posterior communicating	2.11 (1.50–2.97)	<0.001

Fieldwork 2026

4.6 Summary of Key Findings

i. High prevalence of anatomical variation: Less than half of participants had a complete Circle of Willis.

ii. Anatomical determinants of severity: Incomplete and absent segments were associated with significantly higher NIHSS scores and poorer functional outcomes.

iii. Ethnic differences: Hausa-Fulani participants had higher prevalence of absent posterior communicating arteries, partially explaining their increased stroke severity.

iv. Public health implications: Incorporating anatomical data into surveillance can identify high-risk subgroups and guide targeted prevention and acute care strategies.

5.0 Discussion

5.1 Cerebral Vascular Anatomy and Stroke Severity

The study revealed that less than half of participants had a complete Circle of Willis (45%), with hypoplastic anterior communicating arteries and absent posterior communicating arteries occurring in 35% and 21% of cases, respectively (Figure 4.1, Table 4.2). These findings align with previous studies showing high variability in cerebrovascular anatomy across populations (Chuang et al., 2021; De Silva et al., 2022). Notably, participants with absent posterior communicating arteries had the highest median NIHSS scores (14), indicating more severe strokes (Figure 4.2,

Table 4.3). This supports the functional importance of collateral circulation in mitigating ischemic injury; anatomical insufficiencies likely predispose patients to larger infarcts and worse neurological deficits (Riggs & Rupp, 2020).

5.2 Ethnic Variations in Cerebrovascular Anatomy

Hausa-Fulani participants had the highest prevalence of absent posterior communicating arteries (28%), which partially explains their increased stroke severity (OR=1.52, 95% CI: 1.08–2.13) compared to Yoruba participants (Table 4.4). Igbo participants, despite some anatomical variations, did not demonstrate significant differences in stroke severity after adjustment for age, sex, and vascular risk factors. These findings suggest that ethnic-specific anatomical patterns may influence stroke outcomes, emphasizing the need for population-tailored preventive strategies and surveillance (Adams et al., 2021; Owolabi et al., 2023).

5.3 Stroke Outcomes and Functional Recovery

Functional outcomes, assessed by mRS at discharge, reflected the anatomical findings. Participants with absent posterior communicating arteries experienced the worst outcomes, with 45% classified as dependent or severely disabled (mRS 3–5), compared to 23% among those with complete circles (Figure 4.3). This highlights the clinical relevance of cerebrovascular anatomy, as incomplete collateral networks appear to exacerbate functional impairment post-stroke, consistent with prior neuroimaging and population studies (Goyal et al., 2020).

5.4 Implications for Public Health Surveillance

The integration of anatomical data into public health surveillance provides a more nuanced understanding of stroke burden. Traditional surveillance often considers demographic and clinical risk factors but overlooks structural predispositions, which may explain inter-ethnic disparities in severity and outcomes. By linking imaging, clinical, and ethnic data, this study demonstrates the feasibility of anatomy-informed surveillance, enabling identification of high-risk subgroups for targeted interventions (Khanna et al., 2022; Owolabi et al., 2023).

5.5 Comparison with Previous Studies

International studies: Comparable studies in European and Asian populations similarly report that incomplete Circle of Willis is associated with higher stroke severity and poor outcomes (Chuang et al., 2021).

African context: Few studies in Africa have examined the anatomical determinants of stroke severity, and most focus on risk factors like hypertension or diabetes (Owolabi et al., 2020). This study is among the first to combine vascular anatomy, ethnicity, and functional outcomes in Nigeria, highlighting critical gaps in surveillance.

Nigerian studies: Prior Nigerian research emphasizes the high stroke burden among northern populations but rarely investigates anatomical correlates. This study confirms that structural vascular differences contribute to the observed disparities, particularly among Hausa-Fulani participants (Akinyemi et al., 2019).

5.6 Public Health and Clinical Implications

i. Risk stratification: Identifying individuals with incomplete or absent cerebral collaterals can help target intensive monitoring and secondary prevention, especially in high-risk ethnic groups.

ii. Precision public health: Anatomy-informed surveillance supports population-specific interventions, such as prioritizing Hausa-Fulani communities for early stroke detection and rehabilitation programs.

iii. Policy relevance: Incorporating neuroanatomical data into national stroke registries can enhance resource allocation, acute care planning, and preventive strategies.

6.0 Recommendations

6.1 Strengthening Anatomy-Informed Surveillance

i. Integrate neuroanatomical data into national stroke registries:

Routine collection of cerebrovascular imaging data (CT/MRI) should be included in public health surveillance to identify individuals and subpopulations at higher risk for severe stroke.

ii. Develop standardized protocols for anatomical assessment:

Hospitals and stroke centers should adopt uniform reporting systems for Circle of Willis and other vascular variants to ensure consistent data for research and surveillance.

6.2 Targeted Public Health Interventions

i. Focus on high-risk ethnic groups:

Hausa-Fulani communities, who exhibit a higher prevalence of absent posterior communicating arteries and greater stroke severity, should be prioritized for screening programs, early detection, and community education.

ii. Community awareness campaigns:

Promote knowledge of stroke symptoms, risk factors, and the importance of early hospital presentation, with culturally tailored materials for Yoruba, Igbo, and Hausa-Fulani populations.

6.3 Clinical Practice Recommendations

i. Personalized stroke care:

Incorporate knowledge of cerebrovascular anatomical variants in clinical decision-making to anticipate complications, guide imaging choices, and tailor acute management.

ii. Enhance rehabilitation planning:

Patients with high-risk anatomical patterns should receive early and intensive rehabilitation, given their likelihood of poorer functional outcomes.

6.4 Research and Policy Recommendations

i. Expand population-based studies:

Encourage longitudinal research across Nigeria and Sub-Saharan Africa to examine anatomical, genetic, and environmental contributors to stroke disparities.

ii. Resource allocation:

Policymakers should use anatomy-informed evidence to allocate stroke care infrastructure, including imaging facilities, thrombolysis centers, and rehabilitation units, in regions with high-risk populations.

iii. Training and capacity building:

Train clinicians and public health workers on anatomical variation assessment, stroke surveillance, and data integration, ensuring sustainability of precision public health approaches.

7. Conclusion

This study demonstrates that cerebral vascular anatomical variations significantly influence stroke severity and functional outcomes among Nigerian populations. Less than half of the participants had a complete Circle of Willis, while hypoplastic and absent arterial segments were associated with higher NIHSS scores and poorer functional recovery.

Notably, ethnic differences were evident: Hausa-Fulani participants exhibited the highest prevalence of absent posterior communicating arteries, which partially explained their increased stroke severity compared to Yoruba and Igbo participants. These findings highlight the critical role of structural vascular factors in determining stroke outcomes, beyond traditional risk factors such as hypertension or diabetes.

By integrating anatomical, clinical, and demographic data into public health surveillance, this study provides a precision-focused framework for identifying high-risk subgroups and guiding population-specific interventions. The results underscore the importance of incorporating neuroanatomical considerations into stroke prevention, acute management, and rehabilitation strategies in Nigeria and other Sub-Saharan African settings.

Overall, anatomy-informed surveillance represents a powerful tool for improving stroke outcomes, reducing ethnic disparities, and informing targeted public health policies, ultimately contributing to more effective and equitable stroke care.

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