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Radiological Imaging of the Brain: Anatomy, Pathophysiology and Pathology – A Systematic Review

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ABSTRACT

Radiological imaging of the brain is central to the evaluation of neurological disorders, enabling non-invasive assessment of cerebral anatomy, pathophysiology, and pathology. Advances in computed tomography (CT) and magnetic resonance imaging (MRI) have improved diagnostic accuracy and clinical decision-making globally; however, evidence from low- and middle-income countries remains fragmented. This systematic review examined the role of radiological imaging modalities in the assessment of brain anatomy and in the identification and characterization of major neurological conditions, with particular focus on Nigeria.

The review was conducted in accordance with PRISMA 2021 guidelines. A comprehensive search of electronic databases and region-specific journals identified peer-reviewed studies published between 2015 and 2025 that investigated brain imaging using CT or MRI in Nigerian populations. Five eligible observational studies were included, comprising three CT-based and two MRI-based investigations conducted in tertiary or population settings. Data were synthesised narratively and thematically.

Findings showed that non-contrast CT remains the primary imaging modality for acute neurological presentations, particularly traumatic head injury and intracranial haemorrhage, due to its accessibility, speed, and sensitivity to acute blood products. CT was effective in identifying gross structural abnormalities but demonstrated limited ability to detect subtle or microstructural brain injury. In contrast, MRI provided superior anatomical detail and microstructural assessment, enabling improved characterization of non-acute, degenerative, and complex neurological conditions. Overall, CT and MRI play complementary roles in neuroimaging practice in Nigeria. Strengthening imaging infrastructure, expanding MRI availability, and optimizing referral pathways are essential to improve diagnostic accuracy, support evidence-based management, and advance neurological research in resource-limited settings.

Keywords
Neuroimaging, Computed tomography, Magnetic resonance imaging.

Background
Radiological imaging of the brain plays a fundamental role in modern neuroscience by enabling non-invasive visualization of cerebral anatomy, physiological processes, and pathological alterations associated with neurological disease [1]. Advances in neuroimaging have significantly improved diagnostic accuracy, disease classification, and prognostic assessment across a wide range of brain disorders [2].

Radiological imaging refers to the use of ionizing and non-ionizing radiation techniques to produce images of internal body structures for diagnostic and research purposes [3]. Computed Tomography (CT) is an imaging modality that uses X-rays to generate cross-sectional images of the brain, particularly useful in detecting acute hemorrhage and trauma [4]. Magnetic Resonance Imaging (MRI) utilizes strong magnetic fields and radiofrequency pulses to provide high-resolution images of brain anatomy and pathology [1]. Positron Emission Tomography (PET) is a functional imaging technique that measures cerebral metabolism and molecular processes using radiotracers [5].

Globally, epilepsy affects approximately 50 million people, with an age-standardized prevalence of approximately 650 per 100,000 population, and the majority residing in low- and middle-income countries [6]. Dementia affects over 55 million people worldwide, with nearly 10 million new cases annually, and prevalence increasing sharply with age, affecting approximately 7% of individuals aged 65 years and above [7,8]. Approximately 60% of people with dementia live in LMICs, highlighting the global burden of disease [7]. In Nigeria, pooled community-based surveys report an epilepsy prevalence of 8 per 1,000 population [9], while dementia prevalence is estimated at approximately 4.9% among adults aged 60 years and above, with Alzheimer's disease accounting for about 2% [10].

Risk factors for epilepsy include perinatal brain injury, central nervous system infections, traumatic brain injury, and genetic predisposition [11]. Dementia risk factors include advanced age, cardiovascular disease, diabetes mellitus, low educational attainment, and genetic susceptibility [8]. Environmental and socioeconomic factors further modify disease risk in LMICs by influencing access to preventive and diagnostic healthcare services [12]. Epilepsy arises from abnormal neuronal excitability caused by structural, genetic, metabolic, immune, or unknown etiologies [13]. Dementia is most commonly caused by neurodegenerative processes such as Alzheimer's disease, vascular brain injury, and mixed pathologies [14]. Neuroimaging provides critical evidence linking these causes to structural and functional brain changes [1].

Neuroimaging is central to the diagnostic evaluation of epilepsy by identifying epileptogenic lesions and guiding surgical planning [15]. MRI is the preferred modality for detecting hippocampal sclerosis, cortical malformations, and neurodegenerative changes [1]. CT remains essential in emergency settings for rapid assessment of acute hemorrhage and trauma [4]. PET imaging supports differential diagnosis in dementia by identifying disease-specific metabolic patterns [5].

Figure 1: A Computed tomography of a patient with epilepsy [14].

Radiological imaging informs treatment decisions by enabling accurate disease classification and monitoring response to therapy [2]. In epilepsy, imaging guides medical therapy and selection of candidates for surgical intervention [15]. In dementia, neuroimaging assists in prognostication and emerging disease-modifying treatment eligibility [14].

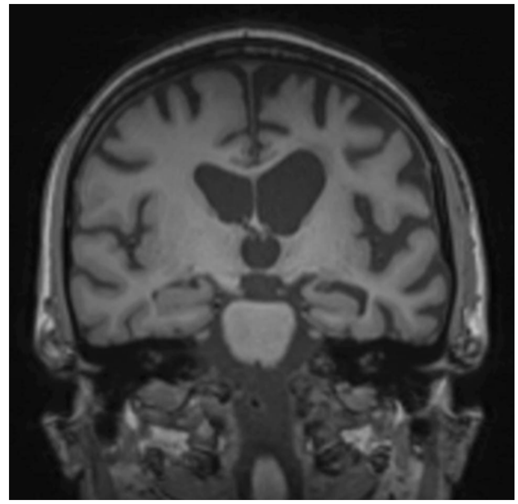


Figure 2: Magnetic resonance imaging of a dementia patient [15].

Figure 3: Magnetic resonance imaging of an epilepsy patient [15].

Rationale

Despite the growing importance of neuroimaging, there is fragmented evidence on the epidemiology and imaging characteristics of major brain pathologies in Africa and Nigeria [16]. Limited access to advanced imaging technologies further exacerbates diagnostic delays and misclassification in LMICs [12].

Understanding the radiological correlates of brain anatomy, pathophysiology, and pathology is essential for improving neurological outcomes and advancing precision medicine [1]. A systematic review provides a rigorous method to evaluate imaging modalities across diverse populations and disease contexts [17].

Figure 4: A Computed tomography of a patient with Dementia [14].

Aim

To systematically review the role of radiological imaging modalities in the assessment of brain anatomy, pathophysiology, and pathology in major neurological disorders.

Research question

"What is the role of radiological imaging modalities in the evaluation of brain anatomy and in the identification and characterization of brain pathophysiology and pathology?"

Methodology

This study was conducted as a systematic review in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2021 guidelines, which provide contemporary standards for transparent reporting and methodological rigor in systematic reviews [18]. The review synthesised evidence from radiological imaging studies of the brain, focusing on anatomical structures, pathophysiological processes, and pathological conditions. Particular emphasis was placed on studies conducted in Nigeria, reflecting regional contributions to neuroimaging research.

A comprehensive and reproducible literature search was undertaken across multiple electronic databases and region-specific journals to identify eligible studies. The databases searched included PubMed, Scopus, and Google Scholar, alongside targeted searches of the West African Journal of Radiology, the Indian Journal of Radiology and Imaging, and the Journal of Neurosciences in Rural Practice. The search covered publications from 1 January 2015 to 13 June 2025 and was restricted to peer-reviewed articles published in English involving human subjects. Search terms were developed using free-text keywords related to brain imaging, disease mechanisms, and radiological modalities. Boolean operators (AND, OR) were applied to combine concepts in a structured manner to optimise sensitivity and specificity of retrieval [19].

The search strategy combined neuroimaging-related terms such as "brain imaging", "neuroimaging", "brain MRI", "computed tomography", "diffusion tensor imaging" and "functional MRI" with disease-related terms including "anatomy", "pathophysiology", "pathology", "brain tumour", "stroke", "epilepsy" and "neurodegeneration". Geographic restrictions limiting studies to Nigeria or India were applied where database functionality allowed. Reference lists of included articles were manually screened to identify additional relevant studies.

Category	Inclusion Criteria	Exclusion criteria
	Original, peer-reviewed research articles	Non-original publications such as review articles, editorials, letters, conference abstracts, and case reports
	Studies involving human participants	Animal studies
	Use of radiological imaging modalities including MRI, CT, DTI, fMRI, PET, or MRS	Studies not primarily involving radiological imaging of the brain
	Focus on brain anatomy, pathophysiology, or pathology	Studies limited to histopathological, molecular, or genetic analyses without imaging correlation
	Studies conducted exclusively in Nigeria	Studies conducted outside Nigeria
	Publications between 2015 and 2025	Studies below 2015
	Articles published in the English language	Articles published in languages other than English

The primary information sources for this review were established biomedical databases and radiology-focused journals with strong coverage of neuroimaging research. PubMed was utilised for its extensive indexing of biomedical and clinical imaging literature, while Scopus provided broader multidisciplinary coverage. Google Scholar served as a supplementary source to capture regionally indexed publications and relevant grey literature. To ensure representation of local research output, region-specific journals, including the West African Journal of Radiology, the Indian Journal of Radiology and Imaging, and the Journal of Neurosciences in Rural Practice, were systematically searched. Manual screening of reference lists from included studies was performed to enhance search completeness, in line with current systematic review practices [18].

This systematic review examines existing literature on radiological imaging of the brain, with particular focus on anatomical structures, pathophysiological mechanisms, and common brain pathologies as visualised through imaging modalities such as CT, MRI, and PET. Study selection was guided by established systematic review principles outlined by the Centre for Reviews and Dissemination. Eligible studies were those that directly addressed brain imaging in relation to normal anatomy, disease processes, or diagnostic interpretation.

A comprehensive literature search was conducted using multiple electronic databases, with references managed using Mendeley software. Duplicate records were removed prior to screening. The initial screening stage involved reviewing titles and abstracts to exclude studies that did not meet the inclusion criteria. Full-text screening was subsequently undertaken to identify studies relevant to the review objectives.

The review process was reported using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, which ensures transparency and reproducibility in study selection and reporting. Data extraction followed a standardized template adapted from the National Institute for Health and Care Excellence (NICE) guidelines. Extracted data included publication details, study design, imaging modality, key findings, and specific information related to brain anatomy, pathophysiology, or pathology. The PICO framework informed the structure of data extraction.

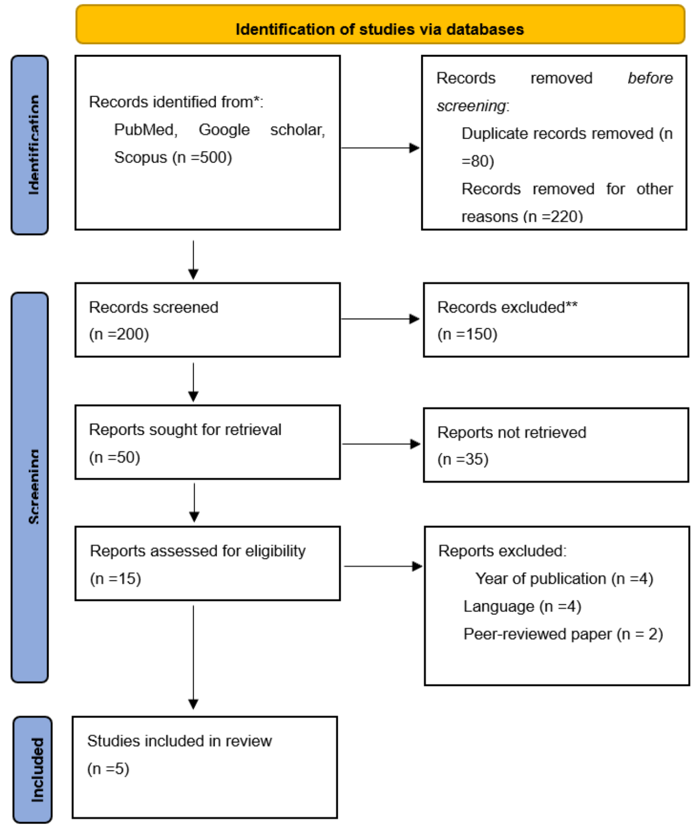
Quality appraisal of included studies was conducted using the Critical Appraisal Skills Programme (CASP) checklist, which assesses validity, relevance, and methodological rigor. This approach was applied consistently across all studies to minimize bias.

Due to time constraints and single-researcher involvement, a narrative synthesis was employed. Both qualitative and quantitative data were synthesised through thematic analysis, tables, and descriptive summaries. Concept mapping was used to identify relationships between imaging findings and disease processes, allowing for a coherent synthesis aligned with the objectives of this review.

Result

All five studies included in this systematic review were conducted in Nigeria and were hospital- or population-based investigations of neuroimaging practice within the Nigerian healthcare context. Three studies were carried out in tertiary hospital settings using computed tomography, including a multicenter study across tertiary hospitals in the Niger Delta region [20], a single tertiary hospital-based study [21], and a tertiary hospital study in South-South Nigeria [22]. The magnetic resonance imaging studies were also conducted in Nigeria, comprising a hospital-based MRI study reported in the Nigerian Journal of Medicine [23] and a population-based MRI dataset involving adult Nigerian participants [24]. The included studies employed observational designs reflecting real-world clinical imaging practice. Onwuchekwa and Alazigha [20] utilized a prospective multicenter observational design, while Ugwuanyi et al. [21] and the Spectrum of Brain MRI Study [23] adopted cross-sectional descriptive designs. Jacob et al. [22] conducted a retrospective observational study based on previously acquired CT examinations. Wogu et al. [24] differed methodologically by employing a data descriptor study design, focusing on standardized MRI data acquisition for anatomical and microstructural analysis rather than clinical outcome assessment.

PRISMA CHART



Sample sizes across the studies varied considerably. The largest CT-based study included 310 patients with traumatic head injury [20], followed closely by Ugwuanyi et al. [21], which evaluated 300 patients undergoing cranial CT for neurological indications. Jacob et al. [22] analyzed CT images from 139 patients referred for suspected intracranial pathology. The MRI studies had comparatively smaller sample sizes, with 93 patients included in the hospital-based MRI study [23] and 88 adult participants included in the population-based MRI dataset described by Wogu et al. [24]. The populations studied reflected both acute and non-acute neurological presentations. Onwuchekwa and Alazigha [20] focused exclusively on patients presenting with traumatic head injury across all age groups, with a clear male predominance. Ugwuanyi et al. [21] included patients referred for CT for a broad range of neurological indications, including trauma, headache, and seizures. Similarly, Jacob et al. [22] examined patients referred for cranial CT due to suspected intracranial pathology, encompassing both traumatic and non-traumatic conditions. The MRI-based studies predominantly evaluated non-acute and complex neurological conditions, with the Spectrum of Brain MRI Study [23] involving patients referred for MRI assessment of diverse neurological disorders, while Wogu et al. [24] included adult Nigerian participants comprising both healthy individuals and patients for anatomical and microstructural brain mapping.

Computed tomography was the primary imaging modality in three studies, all of which utilized non-contrast cranial CT protocols.

Onwuchekwa and Alazigha [20] employed dual-slice and multislice CT scanners with axial acquisition from the skull base to the vertex using 5 mm slice thickness, assessed in bone and soft-tissue windows with multiplanar reformats when required. Ugwuanyi et al. [21] and Jacob et al. [22] also used non-contrast axial CT imaging with systematic evaluation of cranial bones and intracranial structures using bone and soft-tissue windows. Magnetic resonance imaging was used in two studies. The Spectrum of Brain MRI Study [23] utilized conventional MRI sequences, including T1-weighted, T2-weighted, fluid-attenuated inversion recovery, and diffusion-weighted imaging. Wogu et al. [24] applied a standardized MRI protocol incorporating multiple sequences to achieve high-resolution anatomical and microstructural brain assessment.

Four major themes were identified from the synthesis of the included studies, reflecting the roles of computed tomography (CT) and magnetic resonance imaging (MRI) in the evaluation of brain anatomy, pathophysiology, and pathology within Nigerian clinical settings.

Role of Computed Tomography in the Identification of Hemorrhagic and Traumatic Head Injuries

Computed tomography was consistently identified as the primary imaging modality for the detection and characterization of hemorrhagic and traumatic brain injuries across the CT-based studies [20-22].

Onwuchekwa and Alazigha [20] demonstrated that CT reliably identifies a wide spectrum of traumatic intracranial lesions, with intracranial hemorrhage representing the most frequent abnormal finding. Intra-axial hemorrhages, particularly intracerebral hematomas, were most prevalent, followed by extra-axial hemorrhages including subdural, epidural, and subarachnoid hemorrhages. CT also enabled simultaneous detection of associated skull fractures and pneumocranium, facilitating comprehensive trauma assessment.

Similarly, Ugwuanyi et al. [21] reported a high diagnostic yield of CT in patients presenting with head trauma and other neurological complaints, highlighting its sensitivity to acute blood products and traumatic lesions. Jacob et al. [22] further reinforced CT's role in acute neurological evaluation, demonstrating its effectiveness in identifying traumatic brain injuries that require urgent clinical intervention.

Across these studies, CT imaging was central to early diagnosis, triage, and management of traumatic and hemorrhagic brain pathology, particularly in emergency settings.

Role of Computed Tomography in Structural and Microstructural Evaluation of Brain Pathologies

Beyond trauma, CT was shown to play a role in evaluating structural brain abnormalities and providing limited insight into microstructural pathology [20,21].

Onwuchekwa and Alazigha [20] demonstrated that CT effectively delineates gross structural changes such as cerebral edema, mass effect, midline shift, ventricular distortion, and skull fractures. However, the study also highlighted that a proportion of patients with clinical features of severe head injury had normal CT findings, suggesting underlying microstructural injuries such as diffuse axonal injury that are not readily detectable on CT.

Ugwuanyi et al. [21] similarly showed that CT provides valuable structural information in a variety of brain pathologies but has limited sensitivity for subtle parenchymal and microstructural abnormalities. While CT can suggest microstructural injury indirectly through secondary signs such as edema or unexplained neurological deficits, direct visualization of microstructural damage remains limited.

Together, these findings indicate that CT is effective for assessing macroscopic structural brain pathology but offers only indirect or limited evaluation of microstructural brain injury.

Advantages of Magnetic Resonance Imaging in Detailed Anatomical and Microstructural Evaluation

The MRI-based studies consistently demonstrated the superiority of MRI in providing detailed anatomical and microstructural evaluation of the brain [23,24].

The Spectrum of Brain MRI study showed that MRI offers high-resolution visualization of cortical and subcortical anatomy, white matter, and deep gray matter structures using conventional sequences such as T1-weighted, T2-weighted, FLAIR, and diffusion-weighted imaging. This allowed for improved detection of subtle parenchymal abnormalities not visible on CT.

Wogu et al. [24] further demonstrated MRI's strength in detailed anatomical and microstructural characterization through the development of a standardized Nigerian brain MRI dataset. The use of multiple MRI sequences enabled precise tissue contrast and enhanced assessment of brain microstructure, supporting both clinical evaluation and research applications.

These studies collectively highlight MRI's advantage in anatomical precision and microstructural assessment compared to CT.

Role of Magnetic Resonance Imaging in the Diagnosis of Non-Acute and Complex Neurological Conditions

MRI emerged as the preferred imaging modality for the evaluation of non-acute and complex neurological conditions in both MRI-based studies [23,24].

The Spectrum of Brain MRI study demonstrated MRI's utility in diagnosing a broad range of non-acute neurological disorders, including degenerative, inflammatory, and chronic structural brain conditions. MRI provided improved lesion characterization and anatomical localization in these cases.

Wogu et al. [24] further highlighted MRI's role in characterizing complex neurological conditions through population-level imaging data, supporting longitudinal assessment and detailed brain phenotyping. MRI's sensitivity to subtle tissue changes made it particularly valuable for evaluating complex brain pathology beyond the acute phase. Although limitations related to cost and availability were noted, MRI remained essential for comprehensive evaluation of non-acute and complex neurological disorders.

Discussion

This systematic review highlights the central role of neuroimaging, particularly computed tomography (CT) and magnetic resonance imaging (MRI), in the evaluation of brain anatomy, pathophysiology, and pathology within the Nigerian healthcare context. The findings demonstrate that imaging practices in Nigeria largely mirror global patterns, while also reflecting contextual constraints such as resource availability, cost, and access. All included studies were observational and conducted in real-world clinical settings, emphasizing the pragmatic role of neuroimaging in routine neurological care in low- and middle-income countries.

Computed tomography emerged as the predominant imaging modality for acute neurological presentations, particularly traumatic head injury and intracranial hemorrhage. Across the CT-based studies, CT consistently demonstrated high diagnostic utility in identifying intra-axial and extra-axial hemorrhages, skull fractures, pneumocranium, and secondary effects such as cerebral edema and mass effect [20-22]. These findings are consistent with earlier studies from both high- and low-resource settings, which have established non-contrast CT as the first-line imaging modality in acute neurotrauma due to its speed, accessibility, and sensitivity to acute blood products. The male predominance and high burden of traumatic injuries observed in the Nigerian studies also align with global epidemiological trends linking head injury to road traffic accidents and occupational hazards.

However, this review also underscores the limitations of CT in detecting subtle and microstructural brain injuries. Both Onwuchekwa and Alazigha [20] and Ugwuanyi et al. [21] reported instances where patients with significant neurological deficits had normal CT findings, suggesting underlying diffuse axonal injury or microscopic parenchymal damage. This observation is consistent with previous international studies that have demonstrated CT's limited sensitivity for non-hemorrhagic axonal injuries and early ischemic changes. As such, while CT remains indispensable for acute evaluation and triage, it cannot fully characterize all forms of brain injury, particularly at the microstructural level.

Magnetic resonance imaging was shown to provide superior anatomical detail and microstructural assessment in the reviewed MRI-based studies. The Spectrum of Brain MRI Study [23] demonstrated MRI's ability to detect subtle parenchymal abnormalities using conventional sequences such as T1-weighted, T2-weighted, FLAIR, and diffusion-weighted imaging. Similarly, Wogu et al. [24] illustrated the value of standardized MRI protocols in generating high-resolution anatomical and microstructural brain data suitable for both clinical and research purposes. These findings are consistent with global evidence that MRI outperforms CT in evaluating white matter disease, inflammatory conditions, degenerative disorders, and subtle ischemic changes.

MRI also emerged as the preferred modality for non-acute and complex neurological conditions. Both MRI-based studies highlighted its diagnostic advantage in chronic, degenerative, and inflammatory brain disorders, where precise lesion characterization and anatomical localization are essential [23,24]. This mirrors international practice, where MRI is regarded as the gold standard for comprehensive neuroimaging beyond the acute phase. However, the Nigerian context presents notable challenges, including limited availability, high cost, and longer acquisition times, which restrict widespread MRI utilization. These constraints likely explain the smaller sample sizes observed in MRI studies compared to CT-based investigations.

An important contribution of this review is the inclusion of a population-based MRI dataset by Wogu et al. [24], which represents a shift from purely clinical imaging toward population-level neuroimaging research in Nigeria. Such datasets are scarce in sub-Saharan Africa and are critical for developing normative brain atlases, understanding population-specific anatomical variations, and advancing neuroepidemiological research. This approach aligns with global trends emphasizing standardized imaging protocols and large datasets to support translational neuroscience and precision medicine.

This systematic review has several limitations that should be considered when interpreting its findings. All included studies were conducted in Nigeria, which may limit the generalizability of the results to other settings with different healthcare infrastructures and imaging capacities. The predominance of observational study designs introduces potential selection and reporting biases and limits the ability to draw causal inferences between imaging findings and clinical outcomes. Considerable heterogeneity existed across studies in terms of sample size, patient populations, clinical indications, and imaging protocols, particularly between CT- and MRI-based investigations. This variability precluded direct quantitative comparison and meta-analysis. In addition, advanced neuroimaging techniques were not uniformly employed, restricting comprehensive assessment of microstructural brain pathology.

The findings of this review have important implications for clinical practice and research in neuroimaging. The continued reliance on computed tomography for acute neurological conditions highlights the need to sustain CT infrastructure, ensure timely access, and maintain skilled personnel in emergency and trauma settings. However, the demonstrated advantages of magnetic resonance imaging in detailed anatomical and microstructural evaluation underscore the need to expand MRI availability and capacity, particularly for non-acute and complex neurological disorders. Strengthening referral pathways and optimizing resource allocation may help maximize MRI utilization where access remains limited.

Conclusion

This systematic review highlights the central role of radiological imaging modalities in the evaluation of brain anatomy and in the identification and characterization of brain pathophysiology and pathology in Nigeria. Computed tomography remains the primary first-line imaging modality, particularly for acute and traumatic brain conditions, due to its speed, accessibility, and effectiveness in detecting hemorrhage, fractures, and gross structural abnormalities. Magnetic resonance imaging provides complementary value through superior anatomical resolution and sensitivity to microstructural and non-acute brain pathologies. Together, CT and MRI support accurate diagnosis and guide appropriate clinical management across a range of neurological conditions. However, disparities in access, delayed imaging, and limited availability of advanced modalities continue to constrain optimal neuroimaging practice.

Limitations

This review reflects constraints inherent to the Nigerian healthcare setting, where access to computed tomography and magnetic resonance imaging remains limited, unevenly distributed, and, in many regions, altogether unavailable, particularly outside tertiary centres. The scarcity of functional CT and MRI scanners, coupled with frequent equipment downtime and inadequate maintenance, significantly reduces availability even where these modalities nominally exist. High out-of-pocket costs further restrict utilisation of neuroimaging services, contributing to delayed presentation, late imaging, and selection bias toward patients who can afford imaging.

Recommendations

Improving neuroimaging outcomes in Nigeria requires strengthening both access and appropriate use of radiological modalities. Computed tomography should be consistently prioritized for early evaluation of acute neurological presentations, especially traumatic head injury, while magnetic resonance imaging should be increasingly utilized for detailed anatomical assessment and evaluation of complex or non-acute neurological conditions. Health system investment in imaging infrastructure, workforce training, and maintenance is essential to ensure timely and high-quality imaging services. In addition, standardized imaging protocols and referral pathways should be implemented to enhance diagnostic consistency and continuity of care. Future research should focus on outcome-oriented studies and the expanded application of advanced MRI techniques to better characterize brain microstructure and disease patterns within the local population. Collectively, these measures can improve diagnostic accuracy, support evidence-based clinical decision-making, and strengthen neurological care delivery in Nigeria.

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