Radiological Imaging in Acute Stroke: Current Concepts and Clinical Applications

Mr. Aadil Rashid Malik[1], Mr Jasar Hassan[2], Ms Zeenat Nazir, Ms Fiza Khan[4]

[1]*Assistant Professor Department of Medical Radiology & imaging Technology, CT University-Ludhiana, India3*

[2]*Assistant Professor Department of Medical Radiology & imaging Technology, Swami Vivekananda Institute of Engineering and Technology, India*

[3]*Assistant Professor Department of Medical Radiology & imaging Technology, SSM College, Dinanagar, India*

[4]*Assistant Professor Department of Medical Radiology and Imaging Technology, CGC University-Chandigarh, India*

***Abstract*—Acute stroke is a neurological emergency and a leading cause of mortality and long-term disability worldwide. Early diagnosis and timely intervention are critical for improving clinical outcomes. Radiological imaging plays a central role in the acute evaluation of stroke by differentiating ischemic from hemorrhagic events, identifying vascular occlusions, estimating infarct core and salvageable penumbra and guiding reperfusion therapies. The advent of multimodal imaging techniques, including non-contrast computed tomography (NCCT), CT angiography (CTA), CT perfusion (CTP)and magnetic resonance imaging (MRI), has significantly transformed stroke management. This comprehensive review discusses the principles, imaging findings, clinical applications, advantagesand limitations of various radiological modalities used in acute stroke, with emphasis on imaging-based treatment selection and emerging technological advances.**

***Index Terms*—Acute stroke, CT, MRI, CT perfusion, CT angiography, diffusion-weighted imaging, thrombolysis, thrombectomy.**

I. INTRODUCTION

Stroke is defined as a sudden onset of focal neurological deficit resulting from an interruption in cerebral blood supply, either due to vascular occlusion or hemorrhage. It remains one of the leading causes of mortality and long-term disability worldwide and poses a significant public health challenge, particularly in low- and middle-income countries. The burden of stroke is compounded by rising life expectancy, increasing prevalence of vascular risk factors such as hypertension, diabetes mellitusand dyslipidemia and limited access to timely specialized care. Beyond its clinical consequences, stroke carries a substantial socioeconomic impact due to prolonged hospitalization, rehabilitation requirements, loss of productivityand long-term dependency.

Acute stroke management is critically time-sensitive, encapsulated by the principle "time is brain." It is estimated that approximately 1.9 million neurons are lost each minute during an untreated ischemic stroke, underscoring the urgency of rapid diagnosis and intervention. Delays in diagnosis directly correlate with increased infarct size, worsened neurological outcomes and higher mortality rates. Consequently, early and accurate differentiation between ischemic and hemorrhagic stroke is essential to guide appropriate therapy and prevent potentially catastrophic complications.

Radiological imaging has emerged as the cornerstone of acute stroke evaluation and management. Historically, imaging was primarily used to exclude intracranial hemorrhage; however, advances in neuroimaging technology have dramatically expanded its role. Contemporary stroke imaging provides comprehensive information regarding stroke subtype, vascular anatomy, collateral circulation, infarct core size and the presence of potentially salvageable brain tissue (ischemic penumbra). This shift has transformed imaging from a purely diagnostic modality into a critical determinant of therapeutic decision-making.

The development of multimodal imaging techniques including non-contrast computed tomography (NCCT), CT angiography (CTA), CT perfusion (CTP)and magnetic resonance imaging (MRI) has revolutionized acute stroke care. These modalities enable precise patient selection for reperfusion therapies such as intravenous thrombolysis and mechanical thrombectomy, even in extended or unknown time windows. Imaging-guided treatment strategies have significantly improved functional outcomes and reduced disability, particularly in patients with large vessel occlusion and favorable perfusion profiles.

Given the expanding indications and evolving imaging protocols in acute stroke, a thorough understanding of radiological techniques and their clinical applications is essential for radiologists and clinicians involved in stroke care. This review aims to provide a comprehensive overview of the role of radiological imaging in acute stroke, highlighting the strengths and limitations of various imaging modalities, key imaging findings and their impact on modern stroke management.

Methodology

This narrative review was conducted using a structured and methodical approach to comprehensively evaluate the role of radiological imaging in the diagnosis and management of acute stroke. The methodology was designed to ensure inclusion of clinically relevant, high-quality and up-to-date evidence while maintaining academic rigor and reproducibility.

Literature Search Strategy

A comprehensive literature search was performed using major electronic databases, including PubMed/MEDLINE, Scopus, Web of Science and Google Scholar. The search covered publications from January 2000 to December 2024, reflecting the period of significant advancements in acute stroke imaging. A combination of Medical Subject Headings (MeSH) terms and free-text keywords was used, including acute stroke, stroke imaging, non-contrast CT, CT angiography, CT perfusion, magnetic resonance imaging, diffusion-weighted imaging, intravenous thrombolysis and mechanical thrombectomy. Boolean operators (AND/OR) were applied to optimize search sensitivity and specificity. In addition, reference lists of selected articles and recent review papers were manually screened to identify relevant studies not captured in the initial search.

Eligibility Criteria

Studies were selected based on predefined inclusion and exclusion criteria.

Inclusion criteria encompassed original research articles, systematic reviews, meta-analysesand consensus guidelines that addressed the role of radiological imaging in acute ischemic or hemorrhagic stroke. Articles evaluating diagnostic accuracy, imaging-based treatment selection, perfusion imaging and vascular assessment using CT and MRI were included. Only studies published in the English language and involving human subjects were considered.

Exclusion criteria included case reports, conference abstracts, editorials, letters to the editor and studies lacking adequate methodological detail. Articles focused exclusively on chronic stroke, rehabilitation, or non-imaging aspects of stroke management were also excluded.

Data Extraction and Organization

Relevant data were extracted from the selected studies, including imaging modality, technical parameters, key radiological findings, clinical indications, advantages, limitations and impact on therapeutic decision-making. The extracted information was organized thematically according to imaging modality—non-contrast CT, CT angiography, CT perfusion and MRI—to facilitate a structured and comparative analysis. Particular emphasis was placed on imaging criteria used for patient selection for intravenous thrombolysis and mechanical thrombectomy.

Data Synthesis and Analysis

A qualitative synthesis of the extracted data was performed. Findings were critically analyzed and integrated to highlight established practices, recent advancements and emerging trends in acute stroke imaging. Landmark clinical trials and internationally accepted guidelines were given priority to ensure evidence-based interpretation and clinical relevance.

II. CLASSIFICATION OF ACUTE STROKE

Table 1: Classification of Acute Stroke and Imaging Correlates

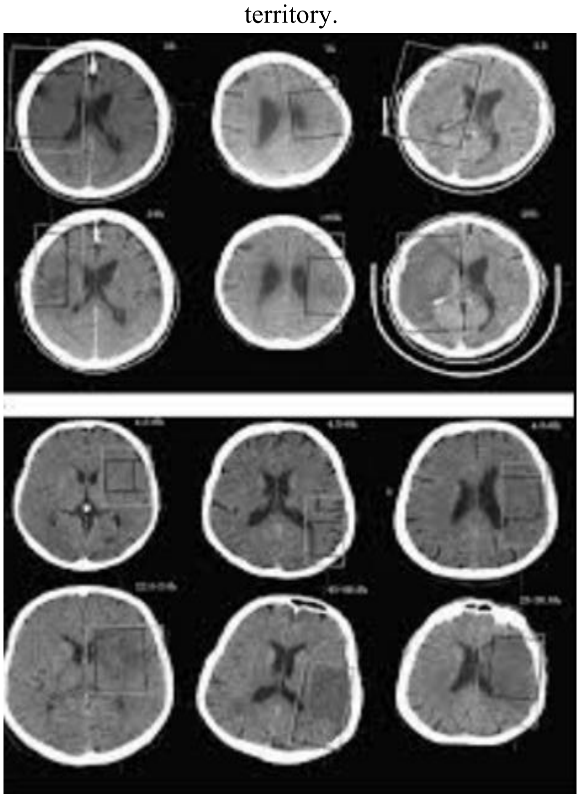
Stroke Type	Pathophysiology	First-Line Imaging	Key Imaging Findings
Ischemic stroke	Arterial occlusion causing cerebral infarction	NCCT	Subtle early ischemic changes, hyperdense vessel sign
Hemorrhagic stroke	Vessel rupture with bleeding	NCCT	Hyperdense intraparenchymal or subarachnoid blood
Large vessel occlusion (LVO)	ICA/MCA/basilar artery occlusion	CTA	Vessel cut-off, poor collaterals
Lacunar infarct	Small vessel disease	MRI (DWI)	Small deep infarcts
Cardioembolic stroke	Embolus from heart	CTA / MRI	Multiple territorial infarcts

III. NON-CONTRAST COMPUTED TOMOGRAPHY (NCCT)

Role and Importance

NCCT is the first-line imaging modality in acute stroke due to its wide availability, rapid acquisition and high sensitivity for hemorrhage. The primary objective is to exclude intracranial hemorrhage before initiating thrombolytic therapy.

Figure 1. Non-contrast CT brain showing early ischemic changes including loss of gray–white matter differentiation and sulcal effacement in the MCA territory.



IV. EARLY ISCHEMIC CHANGES

Table 2: Early Ischemic Signs on Non-Contrast CT

CT Sign	Description	Clinical Significance
Loss of gray–white differentiation	Cortical blurring	Early ischemia
Insular ribbon sign	Loss of insular cortex clarity	MCA territory infarction
Lentiform nucleus obscuration	Poor visualization of basal ganglia	Deep ischemia
Hyperdense artery sign	Dense thrombus in artery	Acute vessel occlusion
Sulcal effacement	Loss of cortical sulci	Cerebral edema

Although early ischemic changes on non-contrast computed tomography may be subtle, careful evaluation can reveal characteristic findings such as loss of normal gray–white matter differentiation, the insular ribbon sign, obscuration of the lentiform nucleus, sulcal effacement due to developing cerebral edema and the presence of a hyperdense vessel sign, most commonly involving the middle cerebral artery, which indicates acute intraluminal thrombus

V. ASPECTS (ALBERTA STROKE PROGRAM EARLY CT SCORE)

Table 3: ASPECTS Scoring System

Aspects Score	Infarct Extent	Prognosis
10	No infarction	Excellent
8–9	Minimal ischemia	Good
6–7	Moderate infarction	Fair
≤5	Large infarct core	Poor (higher hemorrhage risk)

ASPECTS is a 10-point scoring system used to quantify early ischemic changes in the MCA territory. Lower scores correlate with larger infarct size and poorer prognosis. An ASPECTS ≥6 is generally considered favorable for reperfusion therapy

VI. CT ANGIOGRAPHY (CTA)

CTA provides rapid evaluation of intracranial and extracranial arterial anatomy following contrast administration.

CT angiography plays a crucial role in the acute evaluation of stroke by providing rapid and detailed assessment of the intracranial and extracranial arterial system. Its primary clinical application is the detection of large vessel occlusion, particularly involving the internal carotid artery, middle cerebral artery and basilar artery, which directly influences eligibility for mechanical thrombectomy. In addition, CT angiography enables accurate identification of arterial stenosis, occlusion, or dissection, helping to determine the underlying etiology of ischemic stroke. Evaluation of collateral circulation using CTA is essential, as robust collateral flow is associated with smaller infarct core size and better clinical outcomes. Furthermore, CTA findings assist in procedural planning for endovascular therapy by delineating vascular anatomy, thrombus location and the presence of tandem lesions, thereby facilitating timely and effective mechanical thrombectomy.

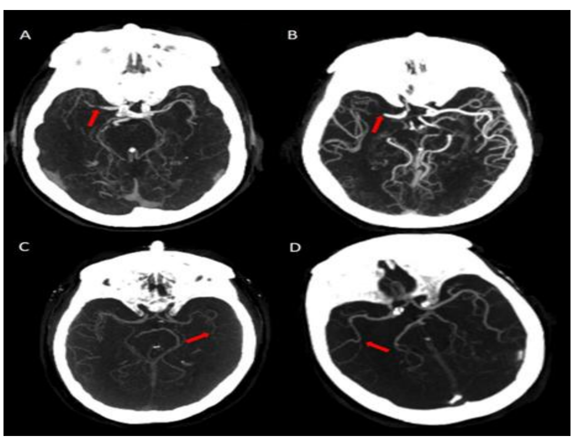


Figure 2; CT angiography demonstrating abrupt cut-off of the middle cerebral artery consistent with large vessel occlusion.

Key Imaging Findings

On CT angiography, acute ischemic stroke commonly manifests as occlusion of major intracranial vessels, including the internal carotid artery, the M1 or M2 segments of the middle cerebral artery and the basilar artery. CTA also allows identification of tandem lesions, characterized by simultaneous involvement of cervical and intracranial arterial segments, which have important therapeutic implications. Assessment of collateral circulation is another critical component of CTA interpretation, as the presence of robust collaterals is associated with smaller infarct volumes and favorable clinical outcomes, whereas poor collateral flow predicts worse prognosis. Owing to its rapid acquisition, wide availability and high diagnostic accuracy, CT angiography has become an indispensable component of contemporary acute stroke imaging protocols.

VII. CT PERFUSION (CTP)

Perfusion Parameters

Table 4: CT Perfusion Parameters and Interpretation

Parameter	Normal	Ischemic Core	Penumbra
CBF	Normal	↓↓↓	↓
CBV	Normal	↓	Normal or mildly ↓
MTT	Normal	↑	↑↑
Tmax	< 6 sec	↑	> 6 sec

CT perfusion evaluates cerebral hemodynamics by generating quantitative parametric maps that reflect regional cerebral blood flow characteristics. Cerebral blood flow is markedly reduced within the ischemic core, indicating severely compromised perfusion, while cerebral blood volume is decreased in areas of irreversible infarction due to loss of autoregulatory capacity. In contrast, parameters such as mean transit time and Tmax are typically prolonged in regions of ischemic penumbra, representing hypoperfused yet potentially salvageable brain tissue surrounding the infarct core

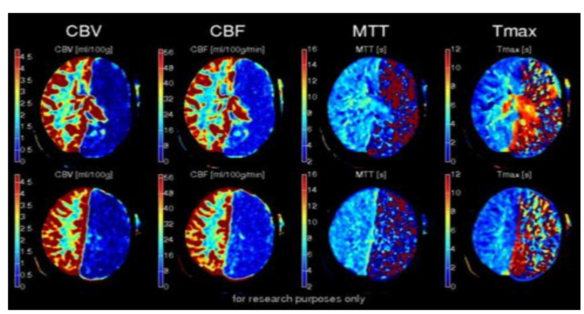


Figure 3; CT perfusion maps showing reduced cerebral blood flow and prolonged Tmax indicating ischemic penumbra surrounding the infarct core

Clinical Significance

CTP differentiates irreversibly infarcted tissue from potentially salvageable penumbra. This distinction allows patient selection for reperfusion therapies beyond the traditional 4.5-hour window, extending up to 24 hours in selected cases.

VIII. MAGNETIC RESONANCE IMAGING (MRI)

MRI offers superior sensitivity and specificity in detecting acute ischemia.
Key MRI Sequences

- Diffusion-Weighted Imaging (DWI): Detects ischemia within minutes of onset
- Apparent Diffusion Coefficient (ADC): Confirms restricted diffusion
- Fluid-Attenuated Inversion Recovery (FLAIR): Helps estimate lesion age
- Susceptibility-Weighted Imaging (SWI/GRE): Detects hemorrhage and microbleeds
- MR Angiography (MRA): Evaluates arterial occlusion

DWI–FLAIR Mismatch
The absence of FLAIR hyperintensity with DWI restriction suggests stroke onset within 4.5 hours, aiding thrombolysis decisions in wake-up strokes.

IX. IMAGING IN HEMORRHAGIC STROKE

CT Findings
On non-contrast computed tomography, hemorrhagic stroke is characterized by the presence of a hyperdense intraparenchymal bleed, which may vary in size and location depending on the underlying etiology. Intraventricular extension of hemorrhage is commonly observed and is associated with increased morbidity and poorer prognosis. Associated mass effect, manifested as compression of adjacent brain structures and midline shift, reflects the severity of intracranial hypertension. Obstructive hydrocephalus may also develop due to ventricular outflow obstruction by intraventricular blood, further complicating the clinical course and necessitating urgent management

RI Role
MRI helps identify underlying etiologies such as vascular malformations, tumors, or cerebral amyloid angiopathy. SWI is particularly useful for detecting cerebral microbleeds.

MRI Sequence	Purpose	Key Findings
DWI	Detects acute infarct	Hyperintensity within minutes
ADC	Confirms diffusion restriction	Low ADC values
FLAIR	Lesion age	Delayed hyperintensity
SWI/GRE	Hemorrhage detection	Blooming artifacts
MRA	Vessel assessment	Occlusion or stenosis

Table 5: MRI Sequences in Acute Stroke

Imaging-Based Treatment Selection

Therapy	Imaging Requirement	Time Window
IV thrombolysis	NCCT excludes hemorrhage	≤ 4.5 hours
Extended thrombolysis	DWI–FLAIR mismatch	Unknown onset
Mechanical thrombectomy	CTA-confirmed LVO + CTP/MRI penumbra	Up to 24 hours

Table 6: Imaging-Based Treatment Selection

X. IMAGING-BASED TREATMENT SELECTION

Intravenous Thrombolysis
Intravenous thrombolysis remains the cornerstone of early reperfusion therapy in acute ischemic stroke and is highly dependent on imaging findings. Non-contrast computed tomography is mandatory to exclude intracranial hemorrhage, as the presence of bleeding constitutes an absolute contraindication to thrombolytic therapy. In addition to hemorrhage exclusion, assessment of early ischemic changes using the Alberta Stroke Program Early CT Score (ASPECTS) is crucial, with a favorable score indicating limited infarct core and reduced risk of hemorrhagic transformation. While the conventional therapeutic window for intravenous thrombolysis is within 4.5 hours from symptom onset, advanced imaging techniques such as MRI with diffusion–FLAIR mismatch or CT perfusion have enabled safe extension of treatment in selected patients with unknown or delayed presentation by identifying viable brain tissue.

10.1. Mechanical Thrombectomy
Mechanical thrombectomy has emerged as a highly effective treatment modality for patients with acute

ischemic stroke caused by large vessel occlusion. CT angiography plays a pivotal role in confirming occlusion of major intracranial arteries, including the internal carotid artery and proximal segments of the middle cerebral artery or basilar artery. Further patient selection is refined using CT perfusion or MRI perfusion techniques, which demonstrate the presence of salvageable ischemic penumbra surrounding a limited infarct core. Imaging-guided selection has significantly expanded the therapeutic window for mechanical thrombectomy, allowing effective intervention up to 24 hours from symptom onset in carefully selected patients, thereby improving functional outcomes and reducing disability.

XI EMERGING ADVANCES IN STROKE IMAGING

Recent advances in stroke imaging have focused on improving speed, accuracy and reproducibility of image interpretation. Artificial intelligence–based algorithms are increasingly being integrated into stroke workflows to enable automated infarct core quantification, perfusion analysis and detection of large vessel occlusion. Automated ASPECTS scoring and perfusion software reduce inter-observer variability and facilitate rapid decision-making in emergency settings. Additionally, ultra-fast stroke imaging protocols have been developed to minimize door-to-needle and door-to-groin puncture times. The advent of mobile stroke units equipped with onboard CT scanners represents a significant innovation, enabling pre-hospital imaging, early diagnosisand initiation of thrombolysis, particularly in urban settings.

XII LIMITATIONS OF ACUTE STROKE IMAGING

Despite significant advancements, acute stroke imaging has several limitations. Motion artifacts may degrade image quality, particularly in uncooperative or critically ill patients, potentially affecting diagnostic accuracy. Limited availability of MRI in emergency settings, especially in resource-constrained regions, restricts its routine use in hyperacute stroke evaluation. The use of contrast agents in CTA and CT perfusion carries a risk of contrast-induced nephropathy and allergic reactions, necessitating careful patient selection. Furthermore, interpretation of stroke imaging may be subject to inter-observer variability, particularly in assessment of early ischemic changes and perfusion maps, underscoring the need for standardized protocols and automated analysis tools.

XIII. CONCLUSION

Radiological imaging is fundamental to modern acute stroke management. A multimodal imaging approach enables rapid diagnosis, accurate stroke characterizationand evidence-based treatment selection, leading to improved clinical outcomes. Ongoing advancements in imaging technology and artificial intelligence are expected to further refine stroke care and optimize patient prognosis.

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