Role of Advanced Neuroimaging in Acute Ischemic Stroke Management: A Review

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ABSTRACT

Acute ischemic stroke (AIS), a leading cause of death and long-term disability globally, which must be promptly diagnosed and treated in order to improve clinical results. The "Time is Brain" theory highlights how urgent early reperfusion is because postponing treatment causes irreversible neuronal loss and the growth of infarcted brain tissue. While crucial for ruling out cerebral hemorrhage, conventional non-contrast computed tomography (NCCT) offers little insight into the infarct core, ischemic penumbra, collateral circulation, and major vascular blockage. Acute stroke evaluation and treatment selection have been greatly enhanced by the development of advanced neuroimaging modalities such as computed tomography angiography (CTA), computed tomography perfusion (CTP), diffusion-weighted magnetic resonance imaging (DWI-MRI), perfusion-weighted imaging (PWI), and magnetic resonance angiography (MRA). Even outside of conventional therapeutic windows, these imaging methods allow precise identification of brain tissue that can be saved, evaluation of arterial blockage, and selection of appropriate candidates for mechanical thrombectomy and intravenous thrombolysis. The significance of perfusion-based imaging in extending the thrombectomy window up to 24 hours in certain patients has been shown by landmark clinical trials including DAWN and DEFUSE 3. As a result, advanced neuroimaging is now an essential part of individualized stroke care rather than merely a helpful diagnostic tool. The relevance of sophisticated neuroimaging in acute ischemic stroke, its influence on treatment choices, its present clinical uses, its drawbacks, and potential future paths to better patient outcomes are all covered in this study.

Keywords: Acute Ischemic Stroke, Advanced Neuroimaging, CT Perfusion, Mechanical Thrombectomy, Ischemic Penumbra.

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Introduction

Acute ischemic stroke (AIS), which accounts for around 62% of all stroke occurrences worldwide and places a significant financial strain on healthcare systems, continues to be one of the major causes of death and long-term disability.[1] According to the Global Burden of Disease Study 2023, stroke remains the third most common cause of disability-adjusted life years (DALYs) and the second most common cause of death globally, with the biggest burden falling on low- and middle-income nations.[2]

AIS is caused by an abrupt stoppage of cerebral blood flow, which, if reperfusion is delayed, can cause irreparable brain tissue destruction and fast neuronal impairment.[3]

Therefore, to enhance neurological outcomes and lower mortality, early detection and prompt intervention are essential. Increased dependency in survivors, poor functional recovery, and infarct core extension can result from delayed diagnosis.[4]

Since undetected major artery ischemic stroke results in the loss of almost 1.9 million neurons every minute, the idea that "Time is Brain" has become essential to contemporary stroke care.[5] This idea emphasizes how critical it is to make quick decisions about diagnosis, treatment, and evaluation, especially when it comes to reperfusion treatments like mechanical thrombectomy and intravenous thrombolysis.[6]

Prior to thrombolysis, non-contrast computed tomography (NCCT) was the primary imaging modality utilized to rule out cerebral bleeding. However, infarct core, salvageable penumbra, collateral circulation, and the state of major vessel blockage are only partially revealed by

NCCT alone.[7] The growing use of sophisticated neuroimaging methods in the assessment of acute stroke has been prompted by these constraints.

Patient selection for reperfusion therapy has been greatly enhanced by advanced neuroimaging modalities including as CT angiography (CTA), CT perfusion (CTP), diffusion-weighted magnetic resonance imaging (DWI-MRI), perfusion-weighted imaging (PWI), and MR angiography (MRA).[8] These methods enable medical professionals to detect artery blockage, evaluate infarct progression, locate viable penumbral tissue, and direct therapy choices outside of traditional therapeutic windows.[9] The treatment of acute ischemic stroke has been completely transformed by recent landmark trials like DAWN and DEFUSE 3, which have shown that imaging-based patient selection employing perfusion imaging can safely extend the thrombectomy window up to 24 hours in chosen patients.[10] As a result, sophisticated neuroimaging has developed into a key element of evidence-based stroke care pathways from a helpful diagnostic tool.

1. CT vs MRI in Acute Stroke

Since early detection of infarcted tissue, salvageable penumbra, and arterial occlusion is crucial for treatment decisions involving intravenous thrombolysis and mechanical thrombectomy, rapid and precise neuroimaging is the cornerstone of acute ischemic stroke (AIS) care.[3] In order to identify patients who are most likely to benefit from reperfusion therapy, modern stroke imaging has moved from a strictly time-based approach to a tissue-based technique.[8]

1.1 Non-contrast CT

Due to its widespread availability, quick acquisition, and superior capacity to rule out cerebral bleeding, non-contrast computed tomography (NCCT) continues to be the first-line imaging modality in suspected AIS.[4] Since administering thrombolysis in hemorrhagic stroke can be disastrous, the main function of NCCT is to distinguish between ischemic and hemorrhagic stroke before beginning thrombolytic therapy.[7]

NCCT can show indications like loss of gray-white matter distinction, the insular ribbon sign, sulcal effacement, and the hyperdense middle cerebral artery (MCA) sign, even if early ischemic changes may be mild during the hyperacute phase.[11]

A typical tool for measuring early ischemic alterations in anterior circulation stroke and predicting reperfusion therapy eligibility is the Alberta Stroke Program Early CT Score (ASPECTS). Lower ASPECTS scores are associated with larger infarct cores and poorer functionaloutcomes.[12]

However, NCCT cannot accurately evaluate ischemic penumbra or collateral circulation and has a low sensitivity for identifying hyperacute infarction within the first few hours.[13] Therefore, NCCT alone is insufficient for advanced treatment selection in many patients, despite being crucial for early triage.

1.2 CTA

The major reason for mechanical thrombectomy is large vascular occlusion (LVO), which can be quickly assessed by CT angiography (CTA).[14] Because early diagnosis of LVO greatly enhances triage and treatment planning, CTA is now frequently integrated into acute stroke pathways.[15]

Vessel patency, thrombus location, arterial stenosis, dissection, tandem lesions, and collateral circulation status can all be seen with CTA.[16] Because improved collateral flow is linked to slower infarct progression, a wider recoverable penumbra, and better results following reperfusion therapy, assessment of collateral circulation is especially crucial.[17]

Research has demonstrated that applying CTA in conjunction with NCCT greatly enhances patient selection for thrombectomy without significantly delaying treatment.[18] Multiphase CTA has also become a useful technique for dynamic collateral assessment and could replace perfusion imaging in some situations.[19]

1.3 CT Perfusion(CTP)

CT perfusion (CTP) has emerged as one of the most significant advanced imaging techniques in AIS because it allows for functional evaluation of cerebral blood flow and aids in differentiating possibly salvageable tissue (ischemic penumbra) from permanently infarcted tissue (ischemic core),.[20]

Cerebral blood flow (CBF), cerebral blood volume (CBV), mean transit time (MTT), and time-to-maximum (Tmax) are among the quantitative measures produced by CTP. While delayed Tmax with relatively maintained CBV indicates penumbral tissue that might still benefit from reperfusion, reduced CBV and significantly reduced CBF imply infarct core.[21]

Patients who report after the traditional 4.5-hour thrombolysis window or 6-hour thrombectomy window benefit most from this approach. Perfusion-based selection criteria were utilized in landmark trials like DAWN and DEFUSE 3, which showed that certain patients could safely have thrombectomy up to 24 hours following the beginning of symptoms.[9] The use of multimodal CT (NCCT + CTA + CTP) is further supported by recent systematic studies, which demonstrate enhanced detection of infarct core, vascular occlusion, and salvageable tissue within a brief acquisition time of roughly 10–15 minutes.[10] Nevertheless, there are certain drawbacks, including as radiation exposure, the possibility of contrast nephropathy, and differences in post-processing software platforms.[21]

1.4 MRI (DWI, FLAIR, MRA)

When it comes to diagnosing acute ischemic stroke, magnetic resonance imaging (MRI) is more sensitive than NCCT, especially in the hyperacute period when early changes might not be apparent.[22] By displaying reduced diffusion brought on by cytotoxic edema, diffusion-weighted imaging (DWI), which is thought to be the most sensitive MRI sequence for early ischemia diagnosis, can detect infarction within minutes after symptom onset.[23]

With a sensitivity of over 90% for hyperacute infarction, DWI is particularly useful for posterior circulation strokes, brainstem infarcts, and tiny cortical infarcts that CT may miss.[24] Additionally, the DWI lesion volume aids in predicting the functional outcome following reperfusion therapy and estimating the infarct core.[25]

DWI is frequently utilized in conjunction with fluid-attenuated inversion recovery (FLAIR) imaging to ascertain the date of stroke onset, especially in patients with wake-up stroke or unclear symptom onset. According to the DWI-FLAIR mismatch idea, if FLAIR is negative but DWI indicates acute infarction, the stroke is probably inside the thrombolysis window, supporting intravenous thrombolysis eligibility.[7]

Large vessel occlusion, arterial stenosis, aneurysms, and vascular abnormalities can all be detected with MR angiography (MRA), which enables non-invasive assessment of intracranial and extracranial vessels without the use of ionizing radiation.[26] Time-of-flight (TOF) MRA and contrast-enhanced MRA are often employed methods in the assessment of acute stroke.[14]

Longer acquisition times, restricted emergency availability, contraindications in patients with metallic implants or severe instability, and challenges in monitoring critically sick patients while scanning are some of the drawbacks of MRI, despite its exceptional diagnostic accuracy.[27] Therefore, rather than being the standard first-line imaging modality, MRI is frequently preferred in certain individuals.

2. Comparative advantages and limitations

Clinical urgency, patient stability, institutional resources, and therapeutic objectives all influence the choice of imaging modalities for acute ischemic stroke. Each method has unique benefits and drawbacks.[28]

NCCT is essential for emergency stroke triage since it is still the quickest and easiest initial imaging method. Rapid exclusion of cerebral bleeding is its main benefit, but its usefulness in advanced treatment decisions is limited by its low sensitivity for early ischemic alterations and incapacity to determine penumbra.[29]

CTA is crucial for thrombectomy planning because it offers superior vascular assessment and quick diagnosis of major vessel blockage. Additionally, it provides collateral evaluation, which has a big impact on prognosis. However, CTA offers no direct information about tissue viability, necessitates iodinated contrast, and entails a risk of contrast nephropathy.[30]
CTP is especially helpful when choosing a late-window thrombectomy because it provides comprehensive functional information on the ischemic penumbra and infarct core. However, it necessitates the use of contrast, increased radiation exposure, and sophisticated post-processing software, all of which could limit availability in smaller centers.[31]

When it comes to posterior circulation stroke and wake-up stroke assessment, MRI with DWI offers the highest sensitivity for early infarct detection. For the treatment of unknown-onset stroke, DWI-FLAIR mismatch is quite beneficial. However, due to lengthier scan times, greater costs, restricted accessibility, and patient-related contraindications, MRI is less useful in hyperacute crises.[32]
Instead of a single, uniform methodology, recent stroke guidelines suggest a customized imaging approach. While CTP or MRI are only used for specific patients who need extended-window thrombectomy evaluation or diagnostic clarification, the majority of centers use NCCT with CTA as the typical initial technique.[3]

In order to attain the greatest neurological results, sophisticated neuroimaging should be included into a patient-centered decision-making process that balances quick diagnosis, treatment eligibility, and resource optimization.[6]

Table 1: Comparison of Imaging Modalities in Acute Ischemic Stroke

S. No	**Imaging Modality**	**Main Purpose**	**Key Advantages**	**Limitations**	**Common Clinical Use**
1.	NCCT	Rule out hemorrhage, initial screening	Fast, widely available, low cost	Poor early ischemia detection, no penumbra assessment	First-line emergency imaging
2.	CTA	Detect vessel occlusion, collateral status	Rapid LVO detection, thrombectomy planning	Contrast use, nephrotoxicity risk	Mechanical thrombectomy selection
	CTP	Assess infarct core and penumbra	Tissue-based decision making, extended window selection	Radiation + contrast exposure, software dependency	Late-window thrombectomy
	DWI-MRI	Detect hyperacute infarction	Highest sensitivity for early infarct	Longer scan time, limited availability	Posterior circulation stroke, wake-up stroke
	FLAIR MRI	Estimate stroke timing	Useful for DWI-FLAIR mismatch	Less useful alone	Unknown onset stroke
	MRA	Vascular assessment with	No ionizing radiation	Longer acquisition, less availa	Selected vascular evaluatio

		out radia tion		ble in emer gency	n

3. Perfusion Imaging

Since perfusion imaging makes it possible to distinguish between possibly salvageable brain tissue (ischemic penumbra) and irreversibly infarcted tissue (infarct core), it has become an essential part of the assessment of acute ischemic stroke (AIS).[29] Modern tissue-based stroke care is predicated on this distinction, which enables physicians to choose patients for reperfusion therapies outside of conventional time windows.[4]

2.1 CT Perfusion (CTP)

In addition to its quick acquisition, accessibility, and compatibility with regular CT methods, CT perfusion (CTP) is commonly used in emergency stroke settings.[22] It offers a quantitative evaluation of cerebral hemodynamics using metrics including time-to-maximum (Tmax), mean transit time (MTT), cerebral blood flow (CBF), and cerebral blood volume (CBV).[20]

In CTP imaging, penumbral tissue is characterized by prolonged Tmax or MTT with somewhat maintained CBV, suggesting hypoperfused but alive tissue, while infarct core is usually described as regions with considerably reduced CBF and CBV, indicating irreversible tissue damage.[21]

By standardizing thresholds for infarct core and penumbra estimation, automated perfusion software (such as RAPID) has further increased the precision and repeatability of CTP, improving decision-making in acute stroke care.[33] Major clinical trials have shown that CTP is very useful in identifying patients for mechanical thrombectomy in prolonged time periods.[10]

However, CTP's drawbacks include ionizing radiation exposure, the requirement for iodinated contrast, and platform-to-platform heterogeneity that could impact interpretation.[34]

2.2 MR Perfusion (PWI)

With the benefit of avoiding ionizing radiation, MR perfusion imaging, also known as perfusion-weighted imaging (PWI), provides an alternative to CTP.[35] PWI uses dynamic susceptibility contrast techniques to assess cerebral perfusion, producing metrics like Tmax, cerebral blood flow, and cerebral blood volume that are comparable to CTP.[36]

PWI is frequently used in conjunction with diffusion-weighted imaging (DWI) to evaluate the ischemia penumbra, or diffusion-perfusion mismatch.[37] The existence of salvageable tissue that could benefit from reperfusion therapy is indicated by the mismatch between a larger PWI-defined hypo perfused region and a small DWI-defined infarct core.[38]

Longer acquisition times, higher costs, restricted availability, and contraindications like implanted metallic devices or patient instability limit the use of MR perfusion in acute settings, despite the fact that it offers high-quality functional and anatomical information.[39]

2.3 Infarct core vs penumbra

Understanding the pathogenesis of stroke and making treatment decisions depend heavily on the concepts of infarct core and ischemia penumbra. The penumbra is made up of hypo perfused but potentially viable brain tissue that can be saved if prompt reperfusion is accomplished, whereas the infarct core reflects brain tissue that has experienced irreversible ischemia injury.(40)

Clinicians can estimate the volume of salvageable tissue and forecast therapy benefit by accurately quantifying these regions using advanced perfusion imaging.[41] Positive results after reperfusion therapy are linked to a big penumbra with a small infarct core, while a large core with a minimum penumbra suggests limited benefit and increased risk of problems.[42]

2.4 Clinical importance in treatment planning

Since perfusion imaging allows for customized, imaging-based decision-making, it has greatly changed AIS treatment approaches.[8] It is important when choosing patients for mechanical thrombectomy and intravenous thrombolysis, especially when the onset time is unknown or the presentation is delayed.[3]

Perfusion imaging criteria were used in landmark trials like DAWN and DEFUSE 3 to show that thrombectomy can be beneficial for certain individuals with favorable core-penumbra mismatch up to 24 hours following symptom onset.[15] A paradigm change from strict time-based criteria to adaptable, tissue-based therapeutic approaches has resulted from these findings.

Furthermore, by identifying patients who are more likely to experience hemorrhagic transformation or needless recanalization, perfusion imaging helps with risk stratification and enhances safety and results.[43] Consequently, a crucial component of contemporary stroke care pathways is the incorporation of perfusion imaging into acute stroke workflows.

Table 2: CT/MR Perfusion Parameters and Their Clinical Interpretation

S. No	Parameter	Meaning	Infarct Core	Penumbra
1	Cerebral Blood Flow (CBF)	Blood flow per unit brain tissue	Significantly markedly reduced	mildly reduced
2	Cerebral Blood Volume (CBV)	Volume of blood in tissue	reduced	Normal or mildly reduced
3	Mean Transit Time (MTT)	Time taken for blood to pass	increased	increased
4	Time to Maximum (Tmax)	Delay in contrast arrival	↑ significantly delayed	↑ prolonged (key marker)

3. Imaging in Thrombolysis and Thrombectomy Decisions

In acute ischemic stroke (AIS), advanced neuroimaging is essential for choosing suitable patients for reperfusion treatments. Imaging-guided, tissue-based decision-making has replaced strict time-based criteria in modern stroke management, allowing for treatment in a larger patient population with better results.[38]

3.1 IV thrombolysis selection

For qualified AIS patients who present inside the therapeutic window, intravenous thrombolysis with alteplase continues to be the recommended first-line treatment. Before starting thrombolysis, imaging, especially non-contrast CT (NCCT), is necessary to rule out cerebral hemorrhage.[4] Additionally, the Alberta Stroke Program Early CT Score (ASPECTS) is frequently used to evaluate early ischemic alterations and infarct extent; higher scores (≥6) are linked to improved outcomes and decreased hemorrhagic risk.[12]

According to recent guidelines, IV thrombolysis should be started within 4.5 hours of the beginning of symptoms. Early therapy has been shown to significantly increase functional independence.[44] However, by finding individuals with recoverable brain tissue, even in delayed presentations, imaging has extended eligibility beyond stringent time constraints.[8]

3.2 Wake-up stroke and DWI-FLAIR mismatch

Approximately to 20–25% of stroke patients have wake-up stroke or an unclear time of onset, which has historically prevented them from receiving thrombolysis.[45] The care of this group has been transformed by MRI-based imaging, especially the diffusion-weighted imaging (DWI) and fluid-attenuated inversion recovery (FLAIR) mismatch concept.

The patient is suitable for thrombolysis since the existence of a DWI-positive lesion without concomitant FLAIR hyperintensity indicates that the stroke was probably recent (within ~4.5 hours).[26] The WAKE-UP trial showed that alteplase significantly improved functional outcomes in patients chosen based on DWI-FLAIR mismatch when compared to placebo, without significantly increasing mortality.[46]

Modern stroke guidelines now include this imaging-based strategy, which permits the safe extension of thrombolysis to certain patients whose onset time is unclear.[47]

3.3 Large vessel occlusion detection

Large vascular occlusion (LVO) detection is essential because it recognizes patients who may benefit from mechanical thrombectomy. To observe intracranial arterial occlusions, especially in the internal carotid artery (ICA), middle cerebral artery (MCA), and basilar artery, CT angiography (CTA) and MR angiography (MRA) are frequently utilized.[15]

Although LVOs make about 20–40% of all ischemic strokes, their burden of disability and mortality is disproportionately large.[48] Early detection with vascular imaging improves clinical outcomes and drastically shortens the time to intervention.[14]

Additionally, as excellent collaterals are linked to slower infarct progression and better response to reperfusion therapy, collateral circulation assessment with multiphase CTA gives prognostic information.[17]

4.4 Mechanical thrombectomy selection

Large artery blockage in the anterior circulation has made mechanical thrombectomy the standard of therapy for patients with AIS. By evaluating the size of the infarct core, penumbra, and vascular condition, imaging plays a crucial part in choosing qualified individuals.[18]

While sophisticated imaging, such as CT perfusion (CTP) or MR perfusion (PWI), is used in the late window (6–24 hours) to identify patients with favorable core-penumbra mismatch, selection in the early temporal window (within 6 hours) is mostly based on NCCT/CTA findings and ASPECTS score.[10]

Thrombectomy dramatically increases functional independence, according to clinical research, with approximately 46% of treated patients seeing positive outcomes as opposed to 26% with medical therapy alone.[9] The benefit is greatest when imaging shows significant salvageable tissue and a small infarct core.[49]

4.5 DAWN and DEFUSE 3 relevance

By proving the effectiveness of thrombectomy outside of the conventional 6-hour window using imaging-based selection criteria, the DAWN and DEFUSE 3 trials represented a significant paradigm change in the treatment of stroke.

The DAWN experiment demonstrated that thrombectomy up to 24 hours after symptom onset dramatically improved functional results by using a clinical–imaging mismatch method to select individuals with severe neurological impairments but relatively small infarct core.[3]

Similar to this, the DEFUSE 3 trial showed that thrombectomy carried out within 6–16 hours produced noticeably better results than usual medical therapy by using perfusion imaging to identify individuals with a target mismatch profile (small core and large penumbra).[6]

The notion of "tissue window" over "time window" was created by these seminal investigations, which significantly altered stroke treatment practices globally.[43]

Therefore, in order to ensure the best possible patient selection and better clinical outcomes, current recommendations strongly advise using advanced imaging tools to guide reperfusion decisions, especially in late-presenting or unknown-onset stroke patients.[39]

Table 3: Imaging Criteria for Reperfusion Therapy Selection in AIS

S. NO	Imaging Modality	Key Finding	Clinical Decision
1	NCCT	No hemorrhage, ASPECTS ≥6	Eligible for IV thrombolysis (within window)
2	DWI–FLAIR MRI	DWI (+) / FLAIR (−) mismatch	Thrombolysis in wake-up stroke
3	CTA / MRA	Large vessel occlus	Candidate for thromb

		ion (ICA/ MCA)	ectomy
4	CTP / PWI	Small core + large penu mbra	Extend ed windo w thromb ectomy (6–24 hrs)
5	Collateral imaging (CTA)	Good collat eral circul ation	Better progno sis, support s interve ntion

4. Emerging Advances

The diagnosis, evaluation, and treatment of acute ischemic stroke (AIS) have been greatly improved by recent developments in neuroimaging. Particularly in complicated or late-presenting situations, these improvements aim to increase speed, accuracy, and customized therapy selection.[4]

4.1 AI in stroke imaging

By facilitating quick image interpretation, automated anomaly detection, and workflow optimization, artificial intelligence (AI) has become a game-changing tool in acute stroke imaging.[50-51] AI-based software tools like RAPID[54], Viz.ai[52], and e-ASPECTS help identify large vascular occlusions (LVOs), calculate ASPECTS scores with excellent consistency, and estimate infarct core and penumbra.[52]

Door-to-needle and door-to-groin puncture times are important factors that determine functional outcomes in stroke therapy, and studies have shown that AI-assisted imaging shortens these times.[52]

Additionally, especially in environments with limited resources, AI increases diagnostic accuracy by identifying early ischemia changes that non-expert readers would overlook.[53]

AI integration with stroke networks also makes it possible for stroke teams to get automated notifications, which speeds up decision-making and allows thrombectomy candidates to be transferred across hospitals.[54] Notwithstanding these benefits, there are still significant obstacles like cost, governmental approval, data privacy issues, and platform variability.[55]

4.2 Automated perfusion software (RAPID)

The accuracy and consistency of infarct core and penumbra estimation have been greatly enhanced by developments in perfusion imaging software. Automated platforms create quick, repeatable maps that inform treatment choices based on predetermined thresholds (e.g., relative cerebral blood flow <30% for core and Tmax>6 seconds for penumbra).[56]

Particularly crucial in multicenter stroke studies and tele-stroke services, these techniques reduce interobserver variability and allow consistent interpretation across sites.[46] Automated mismatch calculation is now extensively incorporated into clinical processes for patient selection for extended-window thrombectomy, and it has played a key role in important trials.[10]

Variability in volume estimation might still result from variations in software algorithms and processing methods, underscoring the necessity of cross-platform standardization and validation.[57]

4.3 Mobile stroke units (MSUs)

By providing imaging capabilities right to the patient, mobile stroke units (MSUs) mark a significant leap in prehospital stroke care. With telemedicine connectivity, point-of-care labs, and portable CT scanners, MSUs allow for early diagnosis and thrombolysis commencement prior to hospital admission.[58]

MSUs dramatically shorten treatment delays, according to clinical research, and faster thrombolysis improves functional results and lessens disability.[59] By avoiding the delays involved in secondary transfers, prehospital imaging also enables direct triage of patients with suspected major artery blockage to comprehensive stroke clinics.[60]

Despite the clinical advantages of MSUs, their broad use is constrained by high operating costs, infrastructural needs, and logistical difficulties, especially in areas with limited resources.[61]

4.4 Future directions

It is anticipated that new technologies like molecular imaging, sophisticated collateral imaging methods, and ultra-fast MRI protocols would improve stroke diagnostic and treatment choices.[7] Methods that concentrate on oxygen extraction fraction, metabolic imaging, and blood–brain barrier permeability may offer more profound understanding of tissue viability than traditional perfusion metrics.[40]

Furthermore, fully individualized stroke therapy may be made possible by combining multimodal imaging with AI-driven predictive models, where treatment choices are determined by the unique physiology of each patient rather than by broad standards.The potential of imaging biomarkers to predict therapeutic response, hemorrhagic transformation, and long-term neurological recovery is also being investigated.[62]

Accuracy, accessibility, affordability, and usability must all be balanced as these technologies develop further in order to be incorporated into clinical practice. However, it is anticipated that sophisticated imaging will continue to be essential to precise stroke care in the future.[6]

5. Challenges and Limitations

Despite tremendous progress, there are still a number of systemic and practical obstacles to the widespread use of sophisticated neuroimaging in the management of acute ischemic stroke (AIS), which may affect prompt diagnosis and treatment results.[63]

5.1 Cost

The high expense of sophisticated imaging modalities like CT perfusion (CTP) and MRI, which covers not only the purchase of equipment but also maintenance, software integration, and skilled staff, is one of their main drawbacks.Due to cost limitations, access to these technologies is frequently restricted in low- and middle-income countries, resulting in a dependence on simple imaging methods like non-contrast CT, which may not offer comprehensive information regarding tissue viability.[64] The financial strain on healthcare institutions is further increased by the price of AI-based software and license.[65]

5.2 Limited Availability

Not all healthcare settings have equal access to advanced imaging modalities, especially in rural or resource-constrained areas.[66] The lack of MRI facilities and perfusion imaging capabilities in many primary and secondary care facilities leads to discrepancies in the provision of stroke care. Because of this, patients who come to these centers might have a delayed diagnosis or need to be transferred to higher-level facilities, which would lengthen their time to treatment.

5.3 Interpretation Challenges

It may not always be possible to obtain the specialist knowledge needed for accurate interpretation of sophisticated imaging, particularly in non-tertiary facilities or after hours.[7] Clinical decision-making may be inconsistent because to variations in mismatch estimation, ASPECTS score, and perfusion map interpretation.[12] Treatment eligibility may be impacted by differences between various platforms and algorithms, despite the fact that automated software and AI tools have enhanced uniformity.[57]

5.4 Delays in emergency settings

Even though sophisticated imaging offers vital information, if it is not effectively integrated, it may cause delays in emergency processes.[5] Due to lengthier acquisition periods and logistical issues like patient monitoring and contraindications, MRI in particular could not be easily available in acute settings.[67] Despite being quicker, even CT perfusion necessitates more processing time and knowledge, which could cause choices about thrombolysis or thrombectomy to be delayed if workflows are not streamlined.[68]

One of the fundamental challenges in stroke management is striking a balance between the advantages of comprehensive imaging and the urgency of treatment. To overcome these constraints and guarantee fair and prompt stroke care, streamlined procedures, increased accessibility, and the incorporation of quick automated instruments are crucial.[69]

6. Conclusion:

By facilitating quick diagnosis, precise evaluation of tissue viability, and evidence-based reperfusion therapy selection, advanced neuroimaging has completely changed the field of managing acute ischemic stroke (AIS).[5] Methods like CT perfusion, MRI diffusion–perfusion imaging, and vascular imaging have changed the paradigm of stroke therapy from one that is solely time-based to one that is tissue-based, enabling customized treatment choices even over long time periods.[46]

Clinically speaking, the use of multimodal imaging into stroke protocols has greatly improved patient outcomes by lowering the likelihood of sequelae like hemorrhagic transformation and boosting eligibility for mechanical thrombectomy and thrombolysis.[15] The use of automated software and artificial intelligence to support imaging-guided decision-making has also improved workflow efficiency and decreased interobserver variability, resulting in more consistent and dependable stroke care across institutions.[70]
Cost, accessibility, and interpretation issues still exist despite these developments, especially in environments with limited resources.[65] To guarantee fair access to sophisticated stroke care worldwide, these obstacles must be addressed by better infrastructure, training, and the deployment of tele-stroke networks.[66]
Artificial intelligence, ultra-fast imaging procedures, and precision medicine techniques that integrate imaging biomarkers with clinical and genetic data are key components of the future of stroke imaging.[76] It is anticipated that new technologies that evaluate collateral circulation, metabolic function, and blood–brain barrier integrity would improve patient selection and prognosis.[7]
In summary, advanced neuroimaging is essential to the management of AIS today because it bridges the gap between quick diagnosis and focused treatment.

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