ASIAN JOURNAL OF PHARMACEUTICAL AND CLINICAL RESEARCH

INNOVARE ACADEMIC SCIENCES
Knowledge to Innovation

Vol 18, Issue 2, 2025

Online - 2455-3891
Print - 0974-2441

Research Article

# ASSESSMENT OF BRAIN PERFUSION WITH MAGNETIC RESONANCE IMAGING AND ITS APPLICATION IN ACUTE ISCHEMIC STROKE

**NADEEM LIYAKAT[1], SURESH CHANDRA BASER[2], UMMED SINGH[3]*, KETAN BHATNAGAR[4], AMBREEN LIYAKAT[5], LIYAKAT ALI GAURI[4]**

**[1]Department of Radio Diagnosis, Sardar Patel Medical College, Bikaner, Rajasthan India. [2]Department of Radio Diagnosis, Geetanjali Medical College, Udaipur, Rajasthan India. [3]Department of General Medicine, Shri Kalyan Government Medical College, Sikar, Rajasthan India. [4]Department of Medicine, Sardar Patel Medical College, Bikaner, Rajasthan, India. [5]The Galaxy Ultrasound and Diagnostic Centre, Jaipur, Rajasthan, India.**

***Corresponding author: Ummed Singh; Email: drummedsingh04@gmail.com**

***Received: 10 October 2023, Revised and Accepted: 25 January 2025***

**ABSTRACT**

**Objective:** The purpose of this study was to evaluate the role of magnetic resonance imaging (MRI), with a particular emphasis on various MRI sequences, in the identification and control of acute ischemic cerebral stroke.

**Methods:** A cross-sectional research design was employed on the patients who had been clinically diagnosed with acute stroke at Sardar Patel Medical College, Bikaner. The study included patients of all age groups and sexes. All patients with acute stroke were evaluated on the basis of history and clinical examinations. A 3 Tesla GE SIGNA Architect machine was used to do MRI scans, including diffusion-weighted imaging (DWI) and conventional sequences, to determine the presence of acute infarcts.

**Results:** The majority of patients were from rural areas, and there was a notable male predominance (male-to-female ratio of 8.06:1). DWI outperformed conventional MRI sequences in terms of sensitivity for detecting acute infarcts; DWI hyperintensity with corresponding apparent diffusion coefficient hypointensity was observed in all 31 cases of acute infarcts, while conventional sequences detected altered signal intensities in only 58.06% of cases.

**Conclusion:** MRI is a powerful way of assessing the macroscopic and microscopic aspects of brain vascularization. The combination of magnetic resonance angiography (MRA), DWI, and perfusion imaging is probably the best way to select patients for thrombolytic therapy. Further work is needed to improve the accuracy of cerebral blood flow (CBF) and cerebral blood volume measurements and to develop a multivariate model integrating MRA, DWI, perfusion imaging, and clinical data to enhance stroke therapy strategies.

**Keywords:** Magnetic resonance imaging, Diffusion-weighted imaging, Cerebral blood flow, Cerebral blood volume, Acute stoke, Thrombolytic therapy.

 DOI: http://dx.doi.org/10.22159/ajpcr.2025v18i2.49280. Journal homepage: https://innovareacademics.in/journals/index.php/ajpcr

## INTRODUCTION

Acute stroke changes in cerebral perfusion pressure (CPP) were fundamentally driven by global [1]. It is the difference between mean arterial pressure, which is often equivalent to intracranial pressure, and venous pressure. Cerebrovascular resistance is decreased and normal cerebral blood flow (CBF) is successfully maintained over a wide range of perfusion pressures by the cerebral vasculature in response to minor reductions in CPP [2].

The diagnosis and imaging of acute ischemic cerebral stroke can be challenging, particularly when time-critical decisions need to be made for stroke treatment. Furthermore, approximately 30% of patients evaluated by an acute stroke team have a stroke mimic; 15% of those receiving IV tissue plasminogen activator (IVtPA) are diagnosed with a stroke mimic [3]. Ultimately, the early diagnosis of acute ischemic cerebral stroke is based on clinical assessment, but magnetic resonance imaging (MRI) is important to exclude intracranial hemorrhage, aid in the diagnosis of ischemic stroke, and aid in triage for treatment of acute major ischemic stroke. The second leading cause of death in the world is stroke [4]. In 2010, 16.9 million deaths were observed, and out of them 5.9 million stroke deaths were observed [4]. In every 40 s, a stroke case occurred in the United States, with every 4 min a stroke death [5]. There has been a stroke reduction rate in the past two decades, even though stroke is increasing, causing the number of stroke survivors and disability-adjusted life years to be lost [4]. Seventy percentages of work capacity is reduced in stroke survivors, with 30% requiring assistance with self-care [6]. Seventy million stroke survivors were estimated globally by 2030 [4].

For the first time in 1970, the WHO defined stroke as "rapidly developing clinical signs of focal (or global) disturbance of cerebral function lasting more than 24 h with no apparent cause other than of vascular origin [7]." Over the past 45 years since this definition was proposed, there have been advances in clinical assessment, imaging, and treatment of stroke. Thus, while the term stroke can be used broadly to include ischemic stroke, cerebral hemorrhage, subarachnoid hemorrhage, and cerebral venous thrombosis, we will focus on imaging (MRI) of ischemic cerebral stroke, which can be defined as neurological dysfunction caused by focal cerebral arterial ischemia" [3].

In the late 1980s and early 1990s, when MRI-based techniques for studying brain perfusion were developed [8], ischemic stroke was one of the first pathologic conditions to which they were applied, fundamentally a disease caused by impaired perfusion. Before the development of new techniques such as PET and SPECT, magnetic resonance perfusion imaging of AS patients provided a window into a fast-changing disease process where variations in tissue perfusion could have a significant impact on patient outcomes. It allowed perfusion measurements to be taken more quickly than PET or SPECT.

Interest in imaging perfusion surged after the U.S. Food and Drug Administration approved the intravenous tissue plasminogen activator (tPA) in 1996. It has other potential roles in predicting prognosis and ischemic cerebrovascular disease, including establishing diagnosis and guiding non-thrombolytic therapies designed to maintain cerebral perfusion. Understanding these methods is crucial to integrating the findings of earlier studies on MR perfusion imaging and applying perfusion imaging in patient care. The specifics of these techniques and the artifacts they may produce are frequently ignored in discussions about perfusion imaging.

There is also emerging literature to support the greater use of imaging in minor stroke and transient ischemic stroke (TIA), and imaging is important in the diagnosis of alternate mechanisms of stroke. Moreover, with the increasing complexity of care for ischemic stroke patients, radiologists are integral members of the modern multidisciplinary acute stroke team. Therefore, the focus of study was to examine evolving role of MRI for acute ischemic stroke using various sequences.

## METHODS

### Participants

The required sample size to conduct the study was estimated using a statistical equation;

$$n = \frac{(Z_{\alpha} + Z_{1-\beta})^2 P(1-P)}{E^2}$$

The study design variables included $Z_{\infty}$ = 1.96 at 95% confidence level; $Z_{1-\beta}$ = 0.8413 at 80% power of study; P = 2% (prevalence of stroke in India); and E = 5% be absolute error. This analysis indicated that a minimum of 62 participants were required to achieve statistical significance. Therefore, a total of 62 patients clinically diagnosed with acute stroke by the Department of Radio-diagnosis at Sardar Patel Medical College, Bikaner, were recruited as the participants for the study. Patients of all age groups were included irrespective of the gender. The exclusion criteria were as follows: (1) Patients who need artificial respiration and those who could not undergo the MR examinations, (2) patients with prior H/O intracranial hemorrhage, (3) claustrophobic patients, (4) patients who have a heart pacemaker, and (5) patients who had a metallic foreign body (metal silver) in their eye or who have an aneurysmal clip in their brain cannot have an MRI since the magnetic field may dislodge the metal. An informed consent form was obtained from all the participants or their next of kin after explaining the procedures, potential risks, and benefits associated with the study. The study was approved by the Institution's Local Ethics Committee and conducted in accordance with the latest Declaration of Helsinki.

### Imaging protocol

All patients with acute stroke were clinically evaluated on the basis of history and clinical examination, which included neurological assessments such as cranial nerve involvement, motor function, and tone. The primary scanning was done with: MRI performed on a 3 Tesla GE SIGNA Architect machine involving different MRI sequences:

1. T1-Weighted imaging (T1): To provide detailed anatomical information and assess structural changes.
2. T2-Weighted imaging (T2): To visualize edema and identify abnormal tissue signals.
3. Fluid-attenuated inversion recovery (FLAIR): To highlight sub-acute changes and differentiate between infarcted tissue and edema.
4. Diffusion-weighted imaging (DWI): To detect areas of restricted diffusion indicating acute infarct.
5. Gradient echo imaging: To identify hemorrhagic changes and microhemorrhages.
6. Magnetic resonance angiography (MRA): To assess cerebral vessel patency and identify large vessel occlusions or stenosis (neck and brain)
7. Arterial spin labeling (ASL): To measure CBF and assess perfusion deficits without contrast. (Non-contrast perfusion imaging)

### Image processing

For image processing, open-source tools statistical parameter mapping (SPM) was used. Images were initially pre-processed to correct for artifacts, align sequences, and standardize data formats. This included correcting for motion artifacts, and normalizing intensity values across different sequences. T1 and T2 images were used for visualizing brain anatomy and identifying gross lesions or abnormalities. Diffusion data from DWI were processed to generate apparent diffusion coefficient (ADC) maps using the formula: $ADC=-\ln(S_{b1000}/S_{b0})/(b1000-b0)$, where S denotes DWI signal intensities. Low ADC values indicated areas of restricted diffusion corresponding to acute infarcts, and the core infarct regions were identified. ASL images were used to measure CBF. The processing involved quantifying perfusion metrics to assess regions with reduced perfusion and differentiate between ischemic penumbra and infarcted tissue. The DWI-PWI mismatch was calculated to identify the ischemic penumbra. The mismatch was determined by comparing regions of abnormal perfusion on PWI with areas of diffusion restriction on DWI. This allowed for the assessment of salvageable brain tissue.

### Statistical analysis

The data were initially recorded in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) and subsequently imported into IBM SPSS version 23.0.0 (IBM, New York, USA) for formal statistical analysis. Nominal data are presented in frequencies and proportions. The Pearson Chi-square test was utilized to determine the differences in proportions. The level of significance was kept at 95% for all statistical analyses. $p < 0.05$ was taken as significant.

## RESULTS

### Demographic distribution

Out of the 62 patients included in the study, the majority were aged between 71 and 80 years (37.1%, n=23). This was followed by the 61–70 age group (25.8%, n=16). Fewer cases were observed in the <40 years (14.5%, n=9), 41–50 years (12.9%, n=8), and 51-60 years (9.7%, n=6) age groups. There was a notable gender disparity with 57 male patients (91.9%) and only 5 female patients (8.1%). In addition, 39 patients (62.9%) resided in rural areas, while 23 patients (37.1%) were from urban areas (Table 1).

### Neurological examination findings

In the neurological assessment, 7 patients (11.3%) exhibited left-sided involvement of the V cranial nerve. Motor deficits were most commonly observed as right-sided weakness in 19 patients (30.6%). Other motor findings included involvement of the left-sided IX, X, and XI nerves in 7 patients (11.3%), with power reduced to 0 and tone decreased in 7 patients (11.3%). Lower limb weakness with power 1 and decreased tone was noted in 5 patients (8.1%), and 2 patients (3.2%) each had left-sided weakness and right hemiparesis fever. Sensory abnormalities included decreased sensation and touch pain on the right side in 13 patients (21.0%), tingling sensation and fine touch in 8 patients (12.9%), and pain and temperature loss over the right side in 7 patients (11.3%). Cerebellar assessment revealed left ataxia in 8 patients (12.9%), with 15 patients (24.2%) not assessed in this domain (Table 2).

**Table 1: Distribution of cases according to demographics**

| Demographic variable | Demographic profile | Number of patients (n=62) (%) |
|---|---|---|
| Age (years) | ≤40 | 9 (14.5) |
| | 41–50 | 8 (12.9) |
| | 51–60 | 6 (9.7) |
| | 61–70 | 16 (25.8) |
| | 71–80 | 23 (37.1) |
| Gender | Female | 5 (8.1) |
| | Male | 57 (91.9) |
| Residence | Rural | 39 (62.9 |
| | Urban | 23 (37.1 |

**Table 2: Distribution of cases according to neurological examination**

| Neurological examination | Total, n (%) |
|---|---|
| Cranial nerve | |
| Right-sided IX, X, XI nerve affected | 8 (12.9) |
| Left-sided V nerve involved | 7 (11.3) |
| Normal | 47 (75.8) |
| Motor | |
| Right-sided weakness | 19 (30.65) |
| Left-sided IX, X, XI nerve involve | 7 (11.3) |
| Power 0, tone decreased | 7 (11.3) |
| Lower tone | 6 (9.7) |
| Right lower limb weakness, Power 1, tone decreased | 5 (8.1) |
| Left-sided weakness | 2 (3.2) |
| Right hemiparesis fever | 2 (3.2) |
| Normal | 14 (22.6) |
| Sensory | |
| Decrease sensation on right side, touch pain | 13 (21.0) |
| Tingling sensation, fine touch | 8 (12.9) |
| Pain and temperature loss over the right side | 7 (11.3) |
| Not assessed | 6 (9.7) |
| Normal | 28 (45.1) |
| Cerebellar | |
| Not checked | 15 (24.2) |
| Left ataxia | 8 (12.9) |
| Normal | 39 (62.9) |

**Table 3: Distribution of cases according to area of the brain involved**

| Area of the brain involved | Total, n (%) |
|---|---|
| Cerebellum posterioinferiority | 8 (12.9) |
| Temporoparietal frontal lobe | 7 (11.3) |
| B/L cerebellar hemisphere, vermis, left occipital cortex | 6 (9.7) |
| Left frontal lobe | 6 (9.7) |
| Left insula, left frontoparietal cortex | 5 (8.1) |
| Left parietal posteriofrontal cortex | 5 (8.1) |
| Frontoparietal lobe involving cortex | 3 (4.8) |
| Left occipital | 1 (1.6) |
| Normal | 12 (19.4) |

**Table 4 : Distribution of cases according to ASL MR perfusion-diffusion mismatch**

| Duration of stroke (h) | Diffusion-perfusion mismatch present | Diffusion-perfusion mismatch absent | $\chi^2$ | p |
|---|---|---|---|---|
| <12 | 24 | 7 | 9.5385 | 0.002 |
| 12–24 | 12 | 19 | | i.e. <0.05 |

**Table 5: Distribution of cases according to T2 flair mismatch**

| Duration of stroke | T2 flair mismatch present | T2 flair mismatch absent | $\chi^2$ | p |
|---|---|---|---|---|
| <12 | 23 | 8 | 9.5385 | 0.002 i.e. |
| 12–24 | 13 | 18 | | <0.05 |

**Table 6: Comparison of imaging characteristics between DWI and T2 WI in acute infarcts**

| Imaging characteristics | Total, n (%) |
|---|---|
| T2 and diffusion positive cases | 36 (58.06) |
| T2 negative and diffusion positive cases | 26 41.94 |

**Imaging findings**

Imaging results revealed the following distributions of brain involvement: bilateral cerebellar posterioinferiority was present in 8 cases (12.9%), temporoparietal frontal lobe involvement in 7 cases (11.3%), and bilateral cerebellar hemisphere, vermis, and left occipital cortex in 6 cases (9.7%) each. Left frontal lobe involvement was observed in 6 cases (9.7%), while left insula, left frontoparietal cortex, and left parietal posteriofrontal cortex were each affected in 5 cases (8.1%). Frontoparietal lobe involvement was seen in 3 cases (4.8%), and left occipital cortex was involved in only 1 case (1.6%). Twelve cases (19.4%) had normal imaging findings (Table 3).

**Perfusion-diffusion mismatch (ASL MR perfusion-diffusion)**

In our study, among patients who presented with a stroke within 12 h of onset, a significant proportion (24 out of 31) exhibited a perfusion-diffusion mismatch. This suggests that a majority of these patients had brain tissue that was at risk but not yet irreversibly damaged, highlighting a critical window for intervention. The statistically significant p-value (0.002) supports the robustness of this finding, indicating that the presence of a perfusion-diffusion mismatch is more likely within the first 12 h post-stroke (Table 4).

For patients with a stroke duration between 12 and 24 h, fewer cases showed a mismatch (12 out of 31), suggesting that as time progresses, the window for identifying salvageable tissue narrows, with more brain tissue likely progressing to infarction. This underscores the importance of early imaging and intervention in acute stroke management.

**T2 FLAIR mismatch**

In our study, for strokes occurring within 12 h, 23 out of 31 cases showed a T2 FLAIR mismatch, in the 12–24-h stroke duration group, the number of cases with a T2 FLAIR mismatch decreased (13 out of 31), reflecting the progression of ischemic changes over time, which become more apparent on T2 FLAIR imaging. The significant p-value (0.002) further supports the conclusion that DWI is more sensitive in the early detection of ischemic changes, while T2 FLAIR imaging may lag in identifying these changes (Table 5).

**Sensitivity of DWI in acute infarcts**

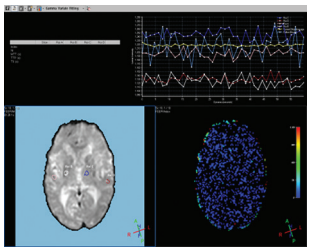
It was found that 36 out of the total cases (58.06%) were positive on both T2 and DWI, while 26 cases (41.94%) were T2 negative but diffusion positive. This significant percentage of diffusion-positive but T2-negative cases highlights the superior sensitivity of DWI in detecting acute infarcts, even when conventional T2-weighted imaging fails to show altered signal intensity areas (Table 6).

The study found that diffusion-weighted imaging (DWI) was more sensitive than conventional MRI sequences in identifying acute infarcts. DWI hyperintensity, with corresponding ADC hypointensity, was observed in all 31 cases of acute infarction, underscoring the robustness of DWI in acute stroke detection (Fig. 1).

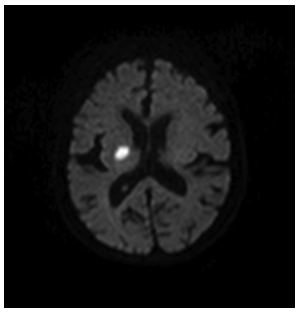
These results emphasize the crucial role of DWI in the early detection and accurate assessment of acute ischemic strokes, especially within the critical early hours post-stroke onset. The findings justify the clinical utility of DWI as a superior imaging modality compared to conventional MRI sequences, particularly in the acute setting.

## DISCUSSION

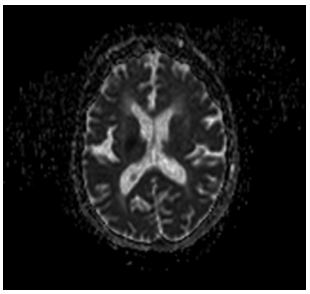
Perfusion-weighted imaging (PWI) has become a pivotal tool in the management of acute ischemic stroke, particularly when combined with DWI. PWI primarily reveals areas of hypoperfusion, while DWI identifies regions of irreversible infarction. The discrepancy between the volumes on PWI and DWI, termed the "diffusion-perfusion mismatch," is crucial in distinguishing salvageable penumbral tissue from already infarcted brain regions. This mismatch is critical in determining which patients are likely to benefit from reperfusion therapies, as a significant mismatch suggests the presence of at-risk but viable tissue that could potentially recover with prompt intervention.

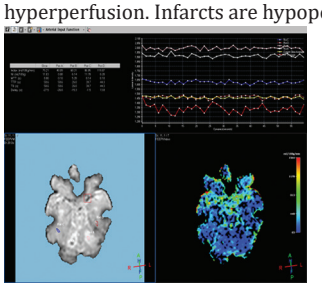


Case 1: Perfusion Image: No evidence of hyperperfusion. Infarcts are hypoperfused

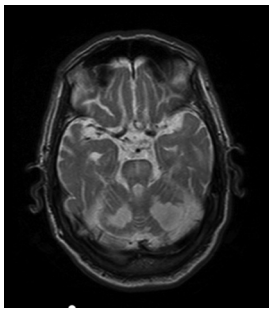


Case 1: An area of diffusion restriction in the right ganglio-capsular region with low ADC due to acute infarct

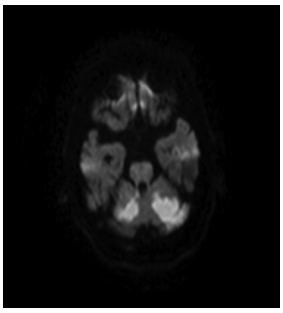




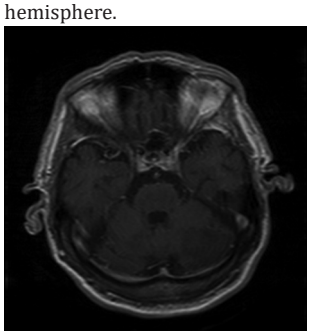
Case 2: Perfusion Image: No evidence of hyperperfusion. Infarcts are hypoperfused



Case 2: T2 IMAGE showing hyperintensity in bilateral cerebellar hemisphere.



Case 2: Diffusion restriction in B/L cerebellar hemisphere s/o of acute infarct along vertebrobasillar territory.



Case 2: Lesion appearing mild hypointense in $T_1$W image

**Fig. 1: Magnetic resonance imaging comparison of perfusion and diffusion in acute ischemic stroke cases**

Our study demonstrated that most patients presenting within 12 h of stroke onset exhibited a significant diffusion-perfusion mismatch, aligning with literature that emphasizes the importance of early identification and intervention. As time from symptom onset increases, the presence of this mismatch decreases, underscoring the narrowing window for effective treatment. This observation is consistent with prior studies suggesting that patients with a PWI-DWI mismatch are more likely to benefit from reperfusion therapies, such as endovascular thrombectomy (EVT).

Perfusion imaging allows for the assessment of various parameters, including cerebral blood volume (CBV), CBF, time to peak, and mean transit time. These parameters progressively deteriorate as ischemia advances to infarction, offering critical insights into the stroke's extent and severity. Recent studies indicate that collateral-based imaging paradigms, such as multiphase CT angiography (mCTA), are as effective as perfusion-based paradigms in selecting patients for EVT, especially those who present beyond the 6-h window. Our findings support the use of imaging criteria from studies like the DEFUSE-3 trial, which have shown superior predictive validity in specific contexts compared to the DAWN trial criteria [9].

Interestingly, while the American Heart Association (AHA) guidelines suggest that both patients who meet and those who do not meet the DAWN criteria may benefit from EVT, the role of perfusion imaging remains significant [9]. However, challenges associated with perfusion imaging – such as delays in acquisition, motion sensitivity, and the need for contrast agents – continue to limit its widespread adoption. In addition, some evidence suggests that perfusion-based selection criteria may disqualify certain patients from EVT without necessarily improving outcomes, highlighting the need for further refinement of these protocols [10].

Our study also underscores the ongoing importance of non-contrast CT (NCCT) and CTA in the acute stroke setting. These modalities remain the primary tools for stroke diagnosis and patient selection for EVT, particularly in centers where advanced perfusion imaging may not be readily available. The ESCAPE trial's *post hoc* analysis supports the effectiveness of an mCTA and NCCT-based imaging paradigm, which may simplify patient selection for EVT without compromising clinical outcomes [11-14].

Moreover, recent research suggests that collateral-based imaging paradigms, such as mCTA, are at least as effective as perfusion-based paradigms in selecting patients for EVT, particularly those presenting beyond the 6-h window [15]. The adoption of NCCT or mCTA-based imaging for the 6–24 h time window could also streamline stroke care by enabling Primary Stroke Centers to triage patients for EVT without the need for advanced perfusion imaging [16,17].

Furthermore, hyperperfusion following successful recanalization is another critical aspect of stroke management. Hyperperfusion, likely due

to a delayed autoregulatory response in maximally vasodilated tissue, can persist post-reperfusion and may correlate with better outcomes, as observed in our cohort. However, the risk of infarction in regions where reperfusion is not achieved remains a significant concern, reinforcing the need for timely intervention [18]. Interestingly, a study by Coutts *et al.* found a relatively low risk of recurrent stroke among patients with a classical definition of TIA, with a slightly higher event rate in patients presenting with an NIHSS of 0 in the emergency department [19]. This finding highlights the importance of careful assessment and monitoring of patients with mild or atypical stroke symptoms. Our findings also align with previous studies, such as those by Albers *et al.*, which suggest that early reperfusion significantly increases the likelihood of favorable clinical outcomes, particularly in patients with a diffusion-perfusion mismatch [20]. Arakawa *et al.* concluded that tissue-specific rather than whole-brain thresholds might be a more precise measure in predicting the likelihood of infarction, highlighting the importance of detailed imaging in patient management [21]. In addition, research by Thomalla *et al.* demonstrated that the DWI-FLAIR mismatch is a reliable indicator for selecting patients within a safe and effective time window for thrombolysis, even when the exact time of symptom onset is unknown [22].

Our study reinforces the critical role of advanced imaging techniques, particularly DWI and PWI, in the early and accurate assessment of acute ischemic stroke. These modalities, along with a deeper understanding of diffusion-perfusion mismatches and hyperperfusion phenomena, can guide more effective patient selection for reperfusion therapies, ultimately improving clinical outcomes. Zhu *et al.* [23] further emphasize the potential of the advanced technique Intravoxel Incoherent Motion (IVIM) in refining ischemic tissue assessment, showing significant differences in ischemic volumes that could enhance patient selection. Continued research and refinement of imaging protocols are essential to optimize stroke care, particularly in expanding access to advanced treatments like EVT.

## CONCLUSION

MRI is a powerful way of assessing the macroscopic and microscopic aspects of brain vascularization. The combination of MRA, DWI, and perfusion imaging is probably the best way to select patients who will benefit most from thrombolytic therapy. Thresholds based on absolute CBF can be used to identify IGR with good sensitivity and specificity. However, in a retrospective analysis, they did not work better than relative measures obtained without deconvolution, and a combination of relative MAX and TTP thresholds allowed the best prediction of IGR. Further work is necessary to improve the accuracy of absolute CBF and CBV measurements and to build a multivariate model integrating MRA, DWI, perfusion imaging, and clinical data to enable choice of the most useful strategy in stroke therapy.

## AUTHORS' CONTRIBUTIONS

Nadeem Liyakat conceived the idea for the study. Nadeem Liyakat, Ketan Bhatnagar, and Liyakat Ali Gauri were involved in the data collection procedures. Nadeem Liyakat and Suresh Chandra Baser conducted the formal analysis of the data. Nadeem Liyakat, Suresh Chandra Baser, Ummed Singh, and Ambreen Liyakat wrote/revised the drafts of the manuscript. All authors approved the final version of the manuscript for publication.

## CONFLICT OF INTEREST

None.

## AUTHORS FUNDING

None.

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