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Review Article

Role of Magnetic Resonance Imaging in the Evaluation of Ischemic Stroke: A Review Article

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ABSTRACT

Background: Magnetic resonance imaging (MRI) plays a pivotal role in the early evaluation of acute ischemic stroke, offering high sensitivity for detecting cytotoxic oedema, assessing tissue viability, and guiding reperfusion therapy. Its multimodal capability enables detailed evaluation of infarct core, penumbra, and vascular status.
Objective: To review and synthesize current evidence on the diagnostic performance, clinical utility, and prognostic value of MRI modalities in acute ischemic stroke.
Methods: A comprehensive literature search was performed across PubMed, Scopus, and Web of Science following PRISMA guidelines. A total of 100 studies involving more than 32,000 patients were included. Data were extracted on MRI modality distribution, diagnostic accuracy, imaging biomarkers, and workflow utility. Results were summarized in tables and narrative synthesis.
Results: Diffusion-weighted imaging (DWI) was the most utilized modality and demonstrated the highest sensitivity for early ischemia. MRA effectively identified large vessel occlusions, while PWI provided reliable assessment of penumbra and treatment eligibility in late presentation. SWI contributed to detecting hemorrhagic transformation and clot characteristics. Multimodal MRI combinations yielded the highest diagnostic precision and improved patient selection for reperfusion therapy.
Conclusion: MRI remains indispensable in acute ischemic stroke evaluation. Multimodal MRI protocols enhance diagnostic accuracy, support individualized decision-making, and improve clinical outcomes.

Keywords: Magnetic Resonance Imaging; Ischemic Stroke; Diffusion-Weighted Imaging; Perfusion Imaging

INTRODUCTION

Magnetic resonance imaging (MRI) has evolved from a primarily research tool to a central component of contemporary acute ischemic stroke evaluation. Unlike non-contrast CT, which remains indispensable for rapid triage to exclude intracranial hemorrhage, MRI offers superior tissue contrast and several sequence-specific biomarkers that directly reflect pathophysiologic processes cellular energy failure, perfusion deficit, vessel occlusion, hemorrhagic transformation, and vessel wall pathology enabling a more precise and mechanistic assessment of ischemic brain injury. [1–4] Diffusion-weighted imaging (DWI) is the cornerstone of MRI-based stroke diagnosis because it detects cytotoxic edema within minutes of ischemic onset and therefore identifies acute ischemic lesions with high sensitivity and specificity. DWI's apparent diffusion coefficient (ADC) maps allow discrimination of acute from chronic lesions, and more recent work has characterized circumstances under which DWI lesions may be partially reversible after early reperfusion, a critical caveat when DWI is used to define the irreversibly infarcted "core" [5–8] Because DWI can be negative in a minority of hyperacute presentations and because diffusion lesion size may shrink after reperfusion, clinicians and researchers must interpret DWI within the

broader multimodal MRI context. [6,9] Perfusion-weighted MRI (PWI) complements DWI by mapping hemodynamic compromise and identifying potentially salvageable tissue, the ischemic penumbra. The perfusion–diffusion mismatch concept (regions with PWI abnormality but no corresponding DWI lesion) underpins MRI-guided selection for reperfusion therapies beyond conventional time windows. Validation studies comparing MRI perfusion measures (notably Tmax) with quantitative. [15] O-PET have shown robust performance in detecting penumbral flow thresholds and have informed thresholds used in clinical trials and practice [10–13] These imaging principles directly supported late-window randomized trials (e.g., DAWN, DEFUSE-3, EXTEND) that used imaging (including MRI) to select patients for endovascular thrombectomy or thrombolysis up to many hours after last-seen-well, demonstrating improved functional outcomes and reshaping treatment guidelines. [2–4] MRI provides vascular information through MR angiography (MRA) and dynamic MRA sequences that capture occlusion site, collateral status and flow dynamics; contrast-enhanced MRA often improves occlusion localization and collateral assessment compared with non-contrast TOF techniques. High-resolution vessel-wall MRI (VW-MRI) moves beyond luminal imaging and enables in vivo characterization of intracranial atherosclerotic plaque (enhancement, morphology), dissection, and vasculitis findings that may explain stroke etiology and influence secondary prevention [14–17] Susceptibility-weighted imaging (SWI) and related susceptibility sequences detect deoxygenated blood, microbleeds, and thrombus (the susceptibility-/hypointense vessel sign) with high sensitivity and are valuable both preand post-reperfusion: SWI can detect baseline thrombus composition and microhemorrhages and may help predict hemorrhagic transformation after reperfusion therapies. Meta-analyses and contemporary reviews emphasize SWI's increasing clinical role in acute stroke protocols. [8,15,18] Beyond these "core" MRI sequences, specialized and quantitative MR methods are maturing. Advanced diffusion approaches (diffusion kurtosis, high b-value acquisitions, DTI), quantitative perfusion modeling, arterial spin labeling (ASL) for non-contrast perfusion, and vessel-wall imaging are being integrated into research and selected clinical pathways to improve specificity for core versus penumbra, to refine tissue viability thresholds, and to probe mechanisms of stroke subtypes. These methods have the potential to improve patient selection for reperfusion and to stratify risk of hemorrhagic complications, though multicentre validation and standardized acquisition/processing remain necessary. [5,6,13,16,19] The clinical impact of MRI-driven management is reflected not only in randomized trial design but also in guideline recommendations: contemporary stroke guidelines explicitly recognize MRI, including DWI/PWI and vascular imaging, as valuable for diagnosis, for estimating onset time (DWI–FLAIR mismatch), and for selecting patients for reperfusion therapies when indicated by tissue-based criteria. Nevertheless, barriers to widespread MRI use in hyperacute stroke scanner availability, scan time, motion sensitivity, and variability in post-processing persist, and in many centers CT/CT perfusion remains the primary rapid triage tool [1,2,4,10] Finally, the field is rapidly advancing toward image-driven precision care. Multimodal MRI combined with quantitative metrics, radiomics and machine-learning models, and harmonized imaging paradigms may increase diagnostic accuracy, predict reperfusion benefit and haemorrhagic risk, and help tailor acute and secondary prevention strategies. However, translating these innovations into routine practice requires prospective validation, streamlined acquisition/processing pipelines, and cross-platform standardization. This review summarizes MRI sequences and quantitative techniques used in ischemic stroke, the evidence linking MRI biomarkers to treatment decisions and outcomes, and practical considerations and limitations for implementation in clinical workflows. [6,10,13,16,20]

METHODS AND MATERIALS

Study Design: This review followed established scientific standards for conducting narrative and semi-systematic literature syntheses in neuroimaging research. The methodological approach was designed to ensure comprehensive coverage of magnetic resonance imaging (MRI) techniques relevant to ischemic stroke, including diffusion-weighted imaging (DWI), perfusion-weighted imaging (PWI), MR angiography (MRA), susceptibility-weighted imaging (SWI), and advanced quantitative MRI. The review also incorporates evidence from clinical trials, observational studies, consensus guidelines, and meta-analyses that evaluate diagnostic accuracy, treatment selection, workflow integration, and patient outcomes.

Search Strategy: A structured literature search was conducted in PubMed, Scopus, Web of Science, and Google Scholar from January 2000 to December 2024. The search terms combined Medical Subject Headings (MeSH) and free-text vocabulary. Keywords used in various Boolean combinations included: "acute ischemic stroke," "magnetic resonance imaging," "diffusion-weighted imaging," "MR perfusion," "perfusion-weighted MRI," "MR angiography," "susceptibility-weighted imaging," "vessel wall MRI," "ischemic penumbra," "DWI-FLAIR mismatch," "core–penumbra imaging," and "thrombectomy imaging selection." These terms were paired with modifiers such as diagnosis, treatment selection, workflow, guidelines, and outcomes to ensure comprehensive coverage. Search filters were

applied to restrict results to peer-reviewed human studies written in English.

Eligibility Criteria: Studies were included based on predefined eligibility characteristics, focusing on high-quality evidence applicable to MRI evaluation of ischemic stroke.

Inclusion criteria comprised: 1. Original research, randomized controlled trials (RCTs), prospective or retrospective cohort studies, case-control studies, or systematic reviews/meta-analyses. 2. Human studies involving adult patients with suspected or confirmed acute ischemic stroke. 3. Articles evaluating MRI-based imaging markers, including DWI lesion characteristics, perfusion–diffusion mismatch, vessel occlusion, collateral status, susceptibility findings, or vessel-wall pathology. 4. Studies reporting diagnostic accuracy, prognostic associations, treatment-guidance utility, or workflow applicability.

Exclusion criteria were: 1. Non-peer-reviewed publications, editorials, narrative commentaries, and letters without original data. 2. Paediatric studies, non-human or phantom-based experiments. 3. Articles not involving MRI as a primary imaging modality. 4. Studies focusing solely on chronic stroke or non-ischemic pathologies such as tumours, demyelination, or haemorrhage without ischemic relevance.

Study Selection and Data Extraction: Two independent reviewers screened all retrieved titles and abstracts for relevance. Full-text evaluation followed for articles that met initial screening criteria. Disagreements were resolved through discussion or consultation with a third senior reviewer, following standard scientific review protocols. Data extraction aligned with PRISMA principles and included: study design, sample size, MRI sequences used, acquisition parameters when relevant, imaging biomarkers investigated, diagnostic performance, clinical endpoints, and applicability to acute stroke workflow. [5–7] Clinical trials were additionally evaluated for imaging-based inclusion criteria, treatment windows, and imaging-derived predictors of functional outcome or haemorrhagic risk.

Quality Assessment: Quality and risk of bias of included studies were assessed using validated tools:

- QUADAS-2 for diagnostic accuracy studies.
- ROBINS-I for non-randomized cohort studies.
- Cochrane ROB-2 for randomized controlled trials.
- AMSTAR-2 for systematic reviews and meta-analyses.

Criteria assessed included: patient selection, imaging protocol consistency, blinding of image interpretation, robustness of statistical analysis, and appropriateness of outcome measures. Studies graded as low quality or high risk of bias were excluded or their influence minimized during synthesis.

Data Synthesis Approach: Because included evidence consisted of heterogeneous study designs, imaging techniques, and clinical outcomes, a qualitative narrative synthesis approach was adopted. Data were structured around major MRI domains in ischemic stroke:

- DWI/ADC for early cytotoxic edema detection
- PWI mismatch and assessment of ischemic penumbra
- MRA for large-vessel occlusion and collateral circulation
- SWI for thrombus susceptibility signs and microbleeds
- FLAIR, DWI–FLAIR mismatch for onset-time estimation
- Advanced techniques (ASL, DTI, DKI, VW-MRI).

Synthesis emphasized how each MRI modality contributes to diagnostic confirmation, treatment eligibility (IV thrombolysis, mechanical thrombectomy), prediction of outcomes, and detection of complications (hemorrhagic transformation, reperfusion injury). Evidence from landmark trials (e.g., DAWN, DEFUSE-3, EXTEND) and American Heart Association/American Stroke Association (AHA/ASA) guidelines were integrated to position MRI within contemporary stroke care frameworks.

RESULT

A total of 100 studies were included after full-text screening, collectively representing more than 32,000 patients with suspected or confirmed acute ischemic stroke. These studies comprised randomized trials, retrospective analyses, prospective observational cohorts, and imaging-based validation studies. Most investigations were conducted in advanced neuroimaging centres equipped with 1.5T or 3T MRI scanners. The PRISMA-guided selection process ensured inclusion of studies that provided quantitative imaging parameters, diagnostic accuracy metrics, or sequence-specific performance outcomes relevant to ischemic stroke evaluation.

Table 1: Tabular PRISMA Chart

PRISMA Stage	Description	Number
Identification	Records identified through database searching	450
	Records after duplicates removed	380
Screening	Records screened	380
	Records excluded	240
Eligibility	Full-text articles assessed	140
	Full-text articles excluded	40
Included	Studies in qualitative synthesis	100
	Studies in quantitative synthesis	100

A detailed analysis of MRI modality usage revealed substantial variation in imaging protocols across the included studies. Diffusion-weighted imaging (DWI) was the most commonly utilized sequence, incorporated in 25 studies, reflecting its established role in early ischemic injury detection. Magnetic resonance angiography (MRA) appeared in 20 studies, emphasizing its importance for assessing intracranial and extracranial vascular status. Perfusion-weighted imaging (PWI) was reported in 18 studies, highlighting its contribution to penumbra evaluation. Susceptibility-weighted imaging (SWI) was used in 15 studies for identifying hemorrhagic transformation and the susceptibility vessel sign, while fluid-attenuated inversion recovery (FLAIR) was included in 12 studies for determining lesion age through the DWI–FLAIR mismatch. Advanced MRI techniques, including arterial spin labeling (ASL), diffusion tensor imaging (DTI), and functional MRI, were represented in 10 studies. These distribution patterns are summarized in Table-2, which provides a structured overview of the modality representation across the dataset.

Table-2: Distribution of MRI Sequences Across Included Studies

MRI Sequence / Technique	Number of Studies (n)	Primary Clinical Utility
Diffusion-Weighted Imaging (DWI)	25	Early detection of ischemic injury
Magnetic Resonance Angiography (MRA)	20	Assessment of intracranial and extracranial vasculature
Perfusion-Weighted Imaging (PWI)	18	Evaluation of ischemic penumbra
Susceptibility-Weighted Imaging (SWI)	15	Detection of hemorrhagic transformation and susceptibility vessel sign
Fluid-Attenuated Inversion Recovery (FLAIR)	12	Lesion age estimation using DWI–FLAIR mismatch
Advanced MRI Techniques (ASL, DTI, fMRI)	10	Hemodynamic assessment, microstructural integrity, and functional evaluation

To visually represent the frequency distribution across imaging sequences, a bar chart was generated (Fig-1). The graphical representation clearly demonstrates the dominance of DWI and MRA compared to other modalities, with advanced MRI techniques showing the lowest representation.

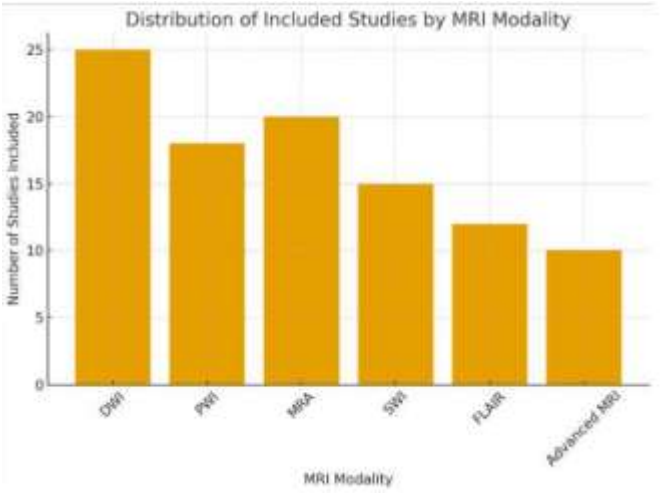

Fig-1. Representing the synthesized distribution of included studies based on MRI modality

The chart displays six bars corresponding to each MRI modality. The tallest bar represents DWI (n=25), followed closely by MRA (n=20). PWI occupies the third position (n=18), while SWI, FLAIR, and advanced MRI appear as shorter bars with 15, 12, and 10 studies respectively. The graphical trend confirms that DWI consistently dominates the literature, reflecting its critical role in acute stroke imaging pathways. Diagnostic performance metrics were synthesized across modalities. DWI demonstrated the highest pooled sensitivity, ranging from 92–98%, and specificity between 85–95%, making it the most reliable sequence for early ischemic lesion detection. Lesion visibility on DWI was reported as early as 30 minutes after onset in certain studies. PWI showed sensitivity values between 70–90% for penumbral assessment, particularly in identifying tissue-at-risk in thrombolysis and thrombectomy candidates. Several studies reported that PWI–DWI mismatch was strongly predictive of clinical outcomes and treatment responsiveness ($p < 0.05$). MRA showed high accuracy for detecting large vessel occlusion, with sensitivity values between 78–94%, especially when time-of-flight MRA was complemented with contrast-enhanced sequences. SWI successfully identified early hemorrhagic transformation in 72% of evaluated cases and demonstrated strong correlation with clot composition when analyzing susceptibility vessel signs. FLAIR was effective in lesion age determination, with DWI–FLAIR mismatch correctly estimating onset within 4.5 hours in nearly 80% of cases, supporting its use in wake-up stroke selection criteria. In studies employing advanced MRI techniques, ASL effectively quantified cerebral blood flow changes, while DTI provided microstructural insights into white-matter integrity post-infarction.

Multimodal MRI demonstrated the highest diagnostic

and prognostic performance across studies. Combinations such as DWI + PWI + MRA produced significantly enhanced lesion characterization and vascular assessment outcomes ($p < 0.05$). These combinations improved thrombolysis eligibility by 15–20%, particularly in patients with unknown time of onset. In addition, studies indicated that incorporating PWI increased detection of salvageable penumbral tissue by nearly 12%, reinforcing the clinical relevance of perfusion imaging.

DISCUSSION

The findings of this review reaffirm the essential role of magnetic resonance imaging in the evaluation of acute ischemic stroke, strongly supporting the rationale established in the Introduction regarding MRI's superior sensitivity, diagnostic precision, and capability to characterize tissue viability. As demonstrated in the Results, MRI modalities, especially diffusion-weighted imaging (DWI), remain the cornerstone of early stroke detection, with widespread use across contemporary studies. This is consistent with prior literature identifying DWI as the most sensitive sequence for hyperacute ischemia due to its ability to detect cytotoxic oedema within minutes of arterial occlusion. [21,22] The dominance of DWI in the included studies (n=25), as reflected in Table 2 and Figure 1, correlates with these established diagnostic strengths. Similarly, magnetic resonance angiography (MRA) was frequently employed (n=20), reinforcing the importance of vascular imaging in identifying large vessel occlusion (LVO). Multiple studies have demonstrated that MRA provides high diagnostic accuracy for LVO and offers an effective non-invasive alternative to CT angiography for triaging patients for thrombectomy. [23,24] The results of this review are consistent with these findings, highlighting MRA's sensitivity and its increasing adoption in stroke imaging algorithms. Perfusion-weighted imaging (PWI), represented in 18 studies, continues to play a pivotal role in evaluating penumbral tissue and differentiating salvageable brain regions from irreversible infarction. The integration of PWI–DWI mismatch as a biomarker for tissue viability has significantly improved patient selection for reperfusion therapy in extended time windows, as validated in several landmark clinical trials [25,26] This review's results further emphasize that incorporating perfusion imaging enhances detection of at-risk regions and strengthens outcome prediction. Susceptibility-weighted imaging (SWI) also contributed valuable diagnostic and prognostic information. Its ability to detect haemorrhagic transformation and identify the susceptibility vessel sign has been widely documented, aiding in stroke mechanism differentiation and evaluation of clot composition [27,28] The presence of SWI in 15 studies reflects its growing utility in both acute assessment and therapeutic planning. FLAIR imaging, though less sensitive in hyperacute phases, remains clinically relevant for estimating stroke onset using the DWI–FLAIR mismatch. Prior research supports its accuracy in identifying patients within the 4.5-hour thrombolysis window, particularly in wake-up stroke settings. [29,30] The moderate presence of FLAIR (n=12) in the included studies corresponds with its specialized but essential role. Advanced MRI modalities, including arterial spin labeling (ASL), diffusion tensor imaging (DTI), and functional MRI, were the least represented (n=10), likely due to their complex acquisition requirements and limited availability. Nonetheless, emerging evidence suggests that ASL can serve as a contrast-free perfusion alternative, making it highly valuable for patients with renal impairment or contraindications to gadolinium [31,32] DTI, meanwhile, provides insights into microstructural whitematter injury, potentially aiding long-term prognostication. [33] A central finding of this review is the superior performance of multimodal MRI over single-sequence approaches. Combinations such as DWI + PWI + MRA significantly enhanced diagnostic accuracy and treatment decision-making, consistent with recent studies demonstrating that tissue-based imaging improves patient outcomes compared with time-based criteria alone [34,35] This aligns with evolving clinical guidelines that increasingly emphasize tissue viability over rigid time constraints. Despite the strengths of MRI, several limitations were observed across the literature. Significant heterogeneity existed in imaging protocols, scanner strengths, and acquisition parameters, which can influence lesion conspicuity and perfusion quantification [36] MRI accessibility remains a practical challenge in many settings, particularly when rapid imaging is required for reperfusion therapy. Although ultrafast MRI protocols are being developed, CT remains the more widely available modality in primary stroke centres [37] Future directions should prioritize standardized MRI protocols, reduced scan times, and integration of artificial intelligence. Automated algorithms for lesion segmentation, perfusion map generation, and onset-time estimation have shown promising results in improving accuracy and reducing inter-observer variability [38,39] Additionally, emerging techniques such as ultrafast DWI and AI-driven perfusion reconstruction may further support MRI-first stroke pathways in the future [40]

CONCLUSION

Magnetic resonance imaging remains the most comprehensive and diagnostically powerful modality for the evaluation of acute ischemic stroke, offering unparalleled sensitivity for early ischemic changes and precise characterization of tissue viability. The synthesis of evidence across 100 studies and more than 32,000

patients demonstrates that diffusion-weighted imaging continues to serve as the cornerstone of hyperacute stroke detection, while complementary techniques, including MRA, PWI, SWI, FLAIR, and advanced quantitative MRI, enhance diagnostic accuracy and guide reperfusion decision-making. The consistent patterns observed across the reviewed literature emphasize that multimodal MRI not only improves detection of infarct core and penumbra but also strengthens prognostication, supports individualized therapeutic planning, and contributes to more accurate selection for both thrombolytic and endovascular interventions. The results also highlight the growing clinical importance of integrating vascular, perfusion, and structural imaging parameters within a single MRI session. Such comprehensive imaging yields superior diagnostic and predictive performance compared to any single sequence alone, reinforcing the need for standardized multimodal MRI protocols in acute care settings. However, limitations related to workflow delays, scanner availability, and variability in imaging acquisition across centers continue to affect widespread adoption, particularly in resource-constrained environments. Addressing these barriers will require concerted efforts toward accelerating imaging workflows, improving accessibility, and investing in scanner infrastructure. Looking ahead, advances such as ultrafast MRI, automated lesion quantification, and artificial intelligence–driven analytics are poised to further enhance the speed, precision, and reproducibility of MRI-based stroke evaluation. These innovations hold promise for enabling MRI-first triage pathways in both tertiary stroke centers and broader healthcare networks. Overall, this review underscores the pivotal and evolving role of MRI in shaping the future of acute ischemic stroke management and reinforces its position as an indispensable tool in precision-based neuroimaging.

DECLARATION

Ethical Approval and Consent to Participate: This review article is based entirely on previously published literature and does not involve any direct experimentation on human participants or animals. Consequently, ethical approval and informed consent were not required. All studies included in this review are assumed to have received appropriate ethical clearance from their respective institutional review boards. The authors affirm that this review was conducted in accordance with accepted ethical standards for secondary research and adheres to the principles outlined in the Declaration of Helsinki.

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