Original Article

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Internal Medicine Section

Association of Vessel Wall MRI Findings with Clinical Outcomes in Atherosclerotic Ischaemic Stroke: A Systematic Review

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ABSTRACT

Introduction: Vessel wall Magnetic Resonance Imaging (MRI) is a promising modality for identifying and characterising the atherosclerotic plaque and the vascular pathology. However, the prognostic value of vessel wall characteristics has not been established and is undefined.

Aim: To assess the association between plaque characteristics on vessel wall MRI with clinical outcomes in patients with ischaemic stroke.

Materials and Methods: The present systematic review was conducted at the Department of Neurology, Super Speciality Hospital and Government Medical College, Nagpur, and Datta Meghe Institute of Higher Education and Research, Wardha,Maharashtra,India between January 2026 and April 2026. The present systematic review was registered in Prospective Register of Systematic REviews (PROSPERO) (Reg no. CRD420261357174) and was conducted according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Studies involving adult patients (>18 years) with atherosclerotic ischaemic stroke who underwent 3-Tesla vessel wall MRI were included. Prospective and retrospective cohort studies with more than 20 participants and full-text articles published in English from 2016 onwards were included, while case reports, case series, reviews, randomised controlled trials, and studies involving non atherosclerotic stroke aetiologies were excluded. A comprehensive literature search was performed in PubMed, Embase, ScienceDirect, Cochrane Library, and Google Scholar upto January 2026 using predefined MeSH terms and Boolean operators. A total of seven studies meeting the inclusion and exclusion criteria were included in the review including 766 patients. Risk of bias in included studies was assessed independently by two reviewers using the Newcastle Ottawa Scale (NOS), and the strength of evidence was evaluated using the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) framework.

Results: The included studies were of high methodological quality; however, the certainty of evidence ranged from very low to moderate as per GRADE assessment due to observational nature of studies and heterogeneity in outcome definitions. The plaque characteristics included Intraplaque Haemorrhage (IPH), plaque enhancement and permeability, plaque burden and plaque composition showed significant association with poor functional outcomes. Plaque enhancement also independently predicted stroke recurrence (Hazard ratio: 2.17, 95% Confidence interval: 1.27-3.70). These were also associated with high National Institutes of Health Stroke Scale (NIHSS) score at admission.

Conclusion: Plaque characteristics on vessel wall MRI, particularly IPH and plaque enhancement, show consistent associations with adverse functional outcomes and recurrence of stroke. These findings suggest a potential role of vessel wall MRI in risk stratification and prognostic assessment in patients with ischaemic stroke; however, larger multicentric prospective studies are required to establish generalisability and prognostic utility.

Keywords: Atherosclerosis, Intraplaque haemorrhage, Magnetic resonance imaging, Plaque enhancement, Plaque imaging, Prognosis, Stroke recurrence, Vessel wall imaging

INTRODUCTION

Stroke is associated with high morbidity and mortality burden. It has global annual case burden of 12.20 million cases and is associated with a 12-year recurrence rate of 39.70% [1,2]. In 2019, the stroke burden was 11.60% of global mortality [3]. It is the second leading cause of death and disability globally [1]. Amongst the various aetiologies, atherosclerotic disease is the commonest cause of ischaemic stroke and may be responsible for almost 30 to 50% cases of ischaemic strokes in Asian population [4,5].

Despite advances in the diagnostic and treatment modalities, ischaemic stroke has been associated with poor functional recovery or recurrence [1]. This has led to the search for accurate risk stratification methods to guide the treatment protocols.

The conventional imaging modalities, including Computed Tomography Angiography (CTA), Magnetic Resonance Angiography (MRA), and Digital Subtraction Angiography (DSA), provide limited information regarding the composition of culprit plaque. High-resolution vessel wall MRI has emerged as a complementary technique enabling direct visualisation of arterial wall architecture and atherosclerotic plaque characteristics [6]. Vessel wall MRI can identify features associated with plaque vulnerability, including IPH, composition of necrotic core, disruption of the fibrous cap and plaque enhancement and permeability [7,8].

The evidence to establish the prognostic utility of plaque characteristics is limited by the unavailability and scarcity of randomised controlled trials and systematic reviews and meta-analysis. Therefore, the present review was conducted to assess the association between the plaque characteristics on vessel wall MRI and outcome in patients suffering from ischaemic stroke.

MATERIALS AND METHODS

The PRISMA statement was followed during the study. The present systematic review was conducted at the Department of Neurology, Super Speciality Hospital and Government Medical College, Nagpur, and Datta Meghe Institute of Higher Education and Research, Wardha, Maharashtra, India between January 2026 and April

2026. As this systematic review did not include human participants directly, therefore the approval of Institutional Ethics Committee was not required. This review was registered at PROSPERO (Reg no. CRD420261357174).

Search strategy: Thorough search was performed in all the relevant electronic databases: PubMed, Embase, ScienceDirect and Cochrane Library. Google search was also performed. The Medical Subject Headings (MeSH) keywords were used for ischaemic stroke, plaque, prognosis, outcome, vessel wall imaging. Boolean operators: "AND" and "OR" were used. The filters were used for publication year from 2016 to 2026. The detailed search strategy for PubMed is as follow: (("Stroke"[Mesh] OR "Brain Ischemia"[Mesh] OR "Ischaemic Stroke" OR "Cerebral Infarction" OR "Acute Ischaemic Stroke") AND ("Magnetic Resonance Imaging"[Mesh] OR "Vascular Imaging Techniques"[Mesh] OR "Vessel Wall MRI" OR "High-Resolution MRI" OR "Intracranial Vessel Wall Imaging" OR "Plaque Imaging") AND ("Atherosclerosis"[Mesh] OR "Carotid Stenosis"[Mesh] OR "Atherosclerotic Plaque" OR "Plaque Characteristics" OR "Intraplaque Haemorrhage" OR" Plaque Enhancement" OR "Plaque Burden" OR "Vulnerable Plaque") AND ("Prognosis"[Mesh] OR "Treatment Outcome"[Mesh] OR "Recurrence"[Mesh] OR "Outcome Assessment, Health Care"[Mesh] OR "Stroke Recurrence" OR "Functional Outcome" OR "NIHSS" OR "Modified Rankin Scale" OR "mRS")).

The review was conducted according to the Population, Intervention, Comparison, Outcome, and Study Design (PICOS) framework. Population (P) included adult patients (>18 years) with atherosclerotic ischaemic stroke. Intervention/Exposure (I) comprised vessel wall MRI assessment of plaque characteristics including IPH, plaque enhancement, plaque burden, plaque permeability, ulceration, and plaque composition. Comparator (C) included patients without high risk plaque characteristics or comparison between different plaque features wherever applicable. Outcomes (O) included functional outcome measured by modified Rankin Scale, stroke severity measured by NIHSS, stroke recurrence, infarct volume, and prognosis. Study design (S) included prospective and retrospective cohort studies and cross sectional studies. Data extracted included participant demographics, study design, MRI characteristics, plaque features, follow-up duration, and clinical outcome measures.

The search strategy retrieved 223 records from PubMed, 248 records from Embase, 176 records from ScienceDirect, 58 records from the Cochrane Library, and 120 records from Google Scholar, resulting in a total of 825 records identified for screening.

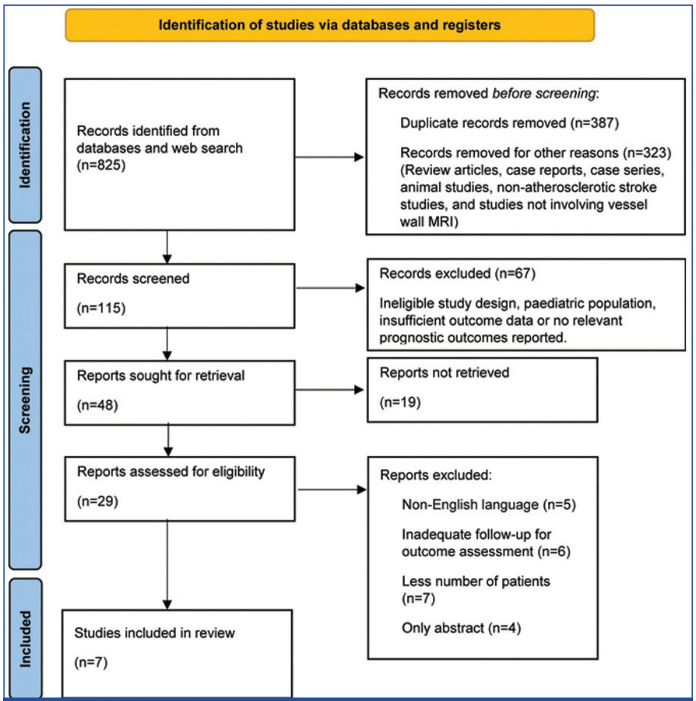
The process of manual selection is as per flowchart in [Table/Fig-1].

Inclusion criteria:

- Studies involving patients more than 18 years of age;
- Studies involving patients of both the genders;
- Prospective or retrospective cohort studies;
- Studies where MRI was performed using 3-Tesla MRI;
- Studies with more than 20 patients;
- Studies published after 2016 (in the last 10 years);
- Studies with full-text publications;
- Studies having full-text article in English language.

Exclusion criteria:

- Studies older than 10 years;
- Studies with stroke of other or uncertain aetiology;
- Case reports, case series, randomised controlled trials and reviews;
- Randomised controlled trials evaluating therapeutic interventions were excluded because the review focused on prognostic imaging associations rather than treatment efficacy.



[Table/Fig-1]: PRISMA 2020 flow diagram.

Study Procedure

Data extraction: The data was organised in table including author name, publication year, study design, follow-up period, sample size and findings. Data was extracted and entered in Microsoft excel by two authors. In case of any disagreement, it was resolved by consensus or by the third senior author if consensus could not be achieved.

Risk of bias analysis: The risk of bias for cohort and registry-based studies was done by the NOS with grading for the selection of cohorts (maximum 4 stars), comparability (2 stars) and outcome (3 stars) [9]. Selection domain evaluated representativeness, selection of non-exposed cohort, ascertainment of exposure, and demonstration that outcome was not present at baseline. Comparability domain evaluated adjustment for age/sex and additional confounders. Outcome domain evaluated assessment method, follow-up duration, and adequacy of follow-up. Study quality was categorised according to the AHRQ recommended NOS conversion criteria [10].

Grade assessment: The overall quality of evidence for primary outcome was assessed by the GRADE framework [11]. The final rating of the evidence was documented as high, moderate, low or very low.

RESULTS

Study selection: A total of 825 records were retrieved after extensive search of the databases. 115 records were screened. Finally, 29 records were assessed for eligibility. Upon reviewing for the inclusion and exclusion criteria, a total of seven studies were included in the systematic review [12-18]. All the studies were published from 2017 onwards.

Characteristics of included studies: There were two retrospective studies, four prospective studies and one cross-sectional study. A total number of 766 patients were included. All the studies had used 3-Tesla MRI for vessel wall imaging.

Findings of the different studies: The findings of the studies are being summarised in the [Table/Fig-2] [12-18].

IPH: Five studies evaluated the association between IPH and clinical outcomes [12,14-17]. IPH was reported to be the predictor of adverse outcomes in ischaemic stroke in all the studies.

Plaque enhancement and permeability: These was either reported to be a predictor of recurrence or associated with higher

Author and Year	Study population with follow-up period	Type of study	Study parameters assessed and Intervention or treatment	Findings
Cai J et al., [12] 2025	A total of 171 patients were included in the study, comprising 129 patients with acute cerebral infarction or Transient Ischaemic Attack (TIA) and 42 asymptomatic patients, with a follow-up period of one year.	Prospective cohort	Plaque enhancement grade, Intraplaque Haemorrhage (IPH), degree of stenosis, and other plaque characteristics were assessed, and all patients received standard medical management.	The favourable prognosis group included patients with mRS score less than 3 at one year and poor prognosis group had patients with mRS score 3 to 6 at one year. The NIHSS score at admission was significantly higher in poor prognosis group as compared to favourable prognosis group (5.90±4.84 vs 2.24±2.75, respectively; p=0.003). On the basis of findings of vessel wall MRI, the incidence of IPH was more in patients with poor prognosis as compared to those with favourable prognosis group (31.82% vs 14.29%; p=0.048).
Lv Y et al., [13] 2023	132 patients with intracranial atherosclerotic disease with 1.3-3.8 years follow-up period.	Prospective cohort	Plaque burden, IPH, degree of stenosis, surface irregularities, remodeling ratio, and plaque enhancement ratio were assessed, and all patients received standard secondary stroke prevention therapy.	High resolution-vessel wall MRI findings showed recurrence of stroke was independently associated with plaque burden {Hazard ratio: 3.15 per 10% increase (95% CI: 1.34-7.42); p=0.009} and enhancement ratio {Hazard ratio: 2.17 (95% CI: 1.27-3.70); p=0.004}. They further reported that AUC for plaque burden was 0.725 (95% CI: 0.629 to 0.822) and for enhancement burden was 0.692 (95% CI: 0.593-0.792) as compared to Essen stroke risk wherein AUC was 0.595 (95% CI: 0.492-0.699).
Kumar A et al., [14] 2023	A total of 83 patients with acute ischaemic stroke were included, and no follow-up period was reported.	Cross-sectional	Calcification, fibrous cap rupture, IPH, lipid-rich necrotic core was assessed with no specific intervention.	They reported that the NIHSS score were significantly different in patients with calcified plaques (6±3.3), with fibrous capsular rupture (6.6±1.8), with IPH (12.7±3.7) and with lipid rich necrotic core (8.8±3.7); p=less than 0.001. NIHSS score showed significant correlation with ICA luminal stenosis (r=0.603; p=less than 0.001) and with lumen area (r=0.666; p=less than 0.001). They concluded there was significant correlation between plaque characteristics and stroke severity.
Liu S et al., [15] 2021	67 stroke patients with no follow-up period.	Retrospective cohort	Plaque length, IPH, plaque enhancement, AnS, Tmax >6 s volume were assessed with no specific intervention.	They included 45 patients in the stroke group and 22 in the TIA group. They reported higher plaque length, IPH, plaque enhancement, AnS and Tmax more than 6 s volumes were significantly higher in stroke group (p=less than 0.05). They also reported that IPH (p=0.020) and AnS (p=0.034) were independent predictors for patients with stroke. They further reported significant association of NIHSS with Tmax > 6.0-s volume, IPH, hypertension and AnS (p=less than 0.05).
Che F et al., [16] 2021	156 patients with acute ischaemic stroke with 3 months follow-up period	Prospective cohort	Extracranial carotid IPH, stenosis degree, lipid rich necrotic core was assessed with Standard stroke management.	They considered poor outcome for mRS 3 or more. They reported that 20.5% patients had poor functional outcome. They further reported that extracranial carotid IPH was a significantly strong predictor of poor functional recovery at 3 month follow-up {Adjusted odds ratio: 3.66 (95% CI: 1.68-7.94); p=0.001}
Cao X et al., [17] 2020	97 patients with ischaemic stroke with no follow-up period.	Prospective study	IPH, ulceration, wall thickness, normalised wall index were assessed with No specific intervention.	They reported that patients with NIHSS >1 had higher prevalence of IPH {Odds ratio: 5.654 (95% CI: 2.272-14.070); p <0.01} and ulceration {Odds ratio: 2.891 (95% CI: 1.090-7.667); p=0.033}. NIHSS showed significantly positive correlations with maximum wall thickness (r=0.24; p=0.018), normalised wall index (r=0.22; p=0.032). IPH (r=0.27; p=0.007), IPH volume (r=0.35; p=less than 0.01), IPH proportion (r=0.28; p=0.005) and ulceration (r=0.35; p=less than 0.01).
Renu A et al., [18] 2017	60 patients with acute ischaemic stroke with 90 days follow-up period.	Prospective cohort	Gadolinium Vessel wall Enhancement (GVE), vessel wall permeability were assessed with standard stroke management with mechanical thrombectomy intervention	They measured the impairment of vessel wall permeability (measured as GVE) after treatment with alteplase. They reported that GVE was associated with higher proportion of patients having mRS score>2 at day 90 (68% with GVE and 39% without GVE; p=0.024) and with higher final infarct volume {44 mL (IQR: 14 to 90 mL) with GVE and 16 mL (IQR: 4 to 34 mL) without GVE; p=0.014}.

[Table/Fig-2]: Summary of study findings [12-18].
*IPH: Intraplaque haemorrhage; GVE: Gadolinium vessel wall enhancement; MRI: Magnetic resonance imaging; mRS: Modified rankin scale; NIHSS: National institutes of health stroke scale; TIA: Transient ischaemic attack

NIHSS score. Renu A et al., showed that GVE in post-thrombectomy patients was associated with higher proportion of poor functional outcome (Modified Rankin Scale/mRS: >2) [18].

Plaque burden and vessel wall thickness: It was either reported to be an independent predictor of stroke recurrence or had positive correlation with NIHSS score.

Plaque composition and other features: Kumar A et al., evaluated plaque composition, reporting significant differences in NIHSS scores according to plaque characteristics [14]: calcified plaques (6±3.3), fibrous capsular rupture (6.6±1.8), IPH (12.7±3.7), and lipid-rich necrotic core (8.8±3.7; p=less than 0.001). Liu S et al., found that plaque length and Tmax >6.0-second volumes were significantly associated with stroke versus TIA classification and higher NIHSS scores [15]. Cao X et al., identified ulceration as significantly more prevalent in patients with higher NIHSS scores (OR: 2.89, 95% CI: 1.09-7.67; p=0.033) and reported positive correlations between ulceration and NIHSS (r=0.35; p<=less than 0.01) [17].

Quality of the studies: The quality of the non randomised studies was assessed by the Newcastle-Ottawa Scale (NOS) [Table/Fig-3] [12-18].

All studies were of high quality (NOS of 7 or more), except Renu A et al., [18]. It was rated as moderate rating due to limited adjustment for confounders and a follow-up adequacy concern.

Author and year	Selection (max 4)	Comparability (max 2)	Outcome (max 3)	Total (max 9)	Quality
Cai J et al., 2025 [12]	3	2	3	8/9	High
Lv Y et al., 2023 [13]	4	2	3	9/9	High
Kumar A et al., 2023 [14]	3	1	3	7/9	High
Liu S et al., 2021 [15]	3	2	3	8/9	High
Che F et al, 2021 [16]	4	2	3	9/9	High
Cao X et al., 2020 [17]	3	1	3	7/9	High
Renu A et al., 2017 [18]	3	1	2	6/9	Fair

[Table/Fig-3]: NOS for non randomised studies [12-18].

GRADE assessment: The overall GRADE assessment of the evidence was rated as Low to Moderate across all outcome domains. [Table/Fig-4,5].

Risk of bias: All included studies were observational, with inherent susceptibility to selection bias and confounding. Although NOS scores were predominantly high, the observational nature of the evidence warrants downgrading by one level.

Outcome	Study	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision
IPH and mRS>2	3	Observational	Serious	Not serious	Not serious	Serious
Plaque enhancement and stroke recurrence	1	Observational	Serious	Not serious	Not serious	Serious
Plaque characteristics and NIHSS	4	Observational	Serious	Not serious	Not serious	Not serious
GVE with poor functional outcome	1	Observational	Serious	Not serious	Serious	Serious

[Table/Fig-4]: GRADE Assessment (Part 1).
*IPH: Intraplaque haemorrhage; GVE: Gadolinium vessel wall enhancement; mRS: Modified Rankin Scale; NIHSS: National institutes of health stroke scale

Outcome	Publication bias	Overall certainty
IPH and mRS>2	Undetected	Low
Plaque enhancement and stroke recurrence	Undetected	Low
Plaque characteristics and NIHSS	Undetected	Moderate
GVE with poor functional outcome	Undetected	Very low

[Table/Fig-5]: GRADE Assessment (Part 2).
*IPH: Intraplaque haemorrhage; GVE: Gadolinium vessel wall enhancement; mRS: Modified rankin scale; NIHSS: National institutes of health stroke scale

The study by Renu A et al., evaluated Gadolinium Vessel wall Enhancement (GVE) specifically in post-thrombectomy patients, limiting generalisability to broader stroke populations [18]. This warranted downgrading for indirectness in this specific outcome domain. Several studies had relatively wide confidence intervals, particularly for secondary and subgroup analyses. Small sample sizes in some studies contributed to imprecision concerns.

DISCUSSION

The present systematic review demonstrates that various characteristics of the plaque of vessel wall MRI, including IPH, plaque enhancement and permeability, plaque burden and vessel wall thickness and plaque composition show significant association with poor outcomes or recurrence or positive correlation with NIHSS score or poor functional outcome.

IPH was consistently reported and most robustly associated parameter with poor outcomes in patients with ischaemic stroke. Study by Zhao XQ et al., reported significant association between IPH and volume of lipid core [19]. It may also increase the plaque vulnerability, which in turn lead to increase the chances of rupture and erosion of the plaque. This may be the underlying factor for the poor outcomes and recurrence of stroke.

It has been hypothesised that the plaque cap is the core component isolating the thrombogenic core from the blood. The plaque cap is made of type I and type III fibrillary collagens. These have low thrombogenic potential [20,21]. Thus, it acts as an effective barrier preventing thrombosis. However, once the cap is eroded, the necrotic core is exposed which has high thrombogenic potential. This leads to local thrombus formation, which gradually increases in size and occludes the artery, leading to stroke. Thus, IPH may lead to poor outcomes and recurrence.

The rapid expansion of the plaque and the increased risk of distal embolisation may lead to association of IPH and higher NIHSS score on admission. The analysis of ruptured carotid plaques has also revealed the presence of activated pro-inflammatory genes, including Matrix Metalloproteinases (MMP) (MMP1, MMP7, MMP8, MMP9, MMP12, MMP13) and cytokines Interleukin 6 (IL 6) C-X-C Motif Chemokine Ligand (CXCL) 1 CXCL5, CXCL8) [22,23]. These may additionally contribute to the increased vulnerability of the plaque and thromboembolic potential. These factors also account for association of IPH with poor functional outcome (mRS: 3 or more) [22,23].

Apart from IPH, plaque enhancement and vulnerability were found to be important predictors of poor outcome. Histopathological studies have demonstrated that plaque enhancement corresponds to neovascularisation, infiltration of the inflammatory infiltrates and expanded extracellular matrix. These make the plaque more prone to rupture [24]. Studies have demonstrated association of these parameters with higher NIHSS score and as a predictor of recurrence. Cao X et al., directly reported ulceration to be more prevalent in patients with higher NIHSS score [17]. It has also been hypothesised that the matric metalloproteinases degrade collagen and elastin [25]. The ulceration predisposes the plaque to rupture under shear stress. The ulcerated surface further promotes thrombus formation, producing large territorial infarcts corresponding to the high NIHSS score. The ulcerated surface of the vulnerable plaque is also the source of continuous microemboli leading to higher risk of recurrence [26].

The association between plaque characteristics and stroke severity (NIHSS) at the time of admission as reported by studies [16,17] supports the pathophysiological linkage between adverse plaque features and clinical presentation. The graded relationship as reported by Kumar A et al., further provides biological gradient and establishes causality [14].

Limitation(s)

There are certain limitations. The sample size was modest in all the studies (60 to 171). Most of the studies were single centre studies limited generalisability in broader population. Furthermore, the evidence regarding GVE was derived from the study by Renu A et al., involving post-thrombectomy patients, limiting applicability to the broader ischaemic stroke population [18]. Several studies also reported wide confidence intervals, particularly in secondary and subgroup analyses, reflecting imprecision in effect estimates. Finally, heterogeneity in study design, plaque characteristics assessed, outcome definitions, and follow-up durations precluded quantitative meta-analysis.

CONCLUSION(S)

The present systematic review shows very low to moderate quality of evidence indicative of association of plaque characteristics on vessel wall MRI with poor functional outcome, NIHSS score or recurrence of stroke. The consistency of evidence across the studies suggests a possible role of vessel wall MRI findings in risk stratification of patients with ischaemic stroke. The presence of high-risk plaque characteristics may warrant for intensive secondary prevention strategies or consideration for revascularisation process. Most of the available studies are retrospective and prospective cohort studies, indicating the need for randomised controlled trials with long-term follow-up period to establish the prognostic significance. Further multicentric studies might be required to establish prognosis with generalisability. It is also recommended that cost-effectiveness analysis may be done to justify the resource utilisation for prognostic purposes.

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PLAGIARISM CHECKING METHODS: [Jain H et al.]
- Plagiarism X-checker: May 06, 2026
- Manual Googling: Jul 01, 2026
- iThenticate Software: Jul 03, 2026 (4%)

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