Submitted: 05 September, 2025 Accepted: 16 October, 2025 Published: 08 December, 2025 DOI:10.22514/sv.2025.193

Open Access
Signa Vitae

ORIGINAL RESEARCH

3D-ASL imaging of cerebral blood flow in predicting early poor prognosis of intravenous thrombolysis in acute ischemic stroke

Li He[1], Liu Wang[2,*], Shengli Hu[3], Daobing Zeng[4], Wen Chen[1], Xiaoqin Peng[5]

[1]Department of Radiology, Taihe Hospital, Hubei University of Medicine, 442000 Shiyan, Hubei, China
[2]Department of Ultrasound Medicine, Sinopharm Dongfeng General Hospital, Hubei University of Medicine, 442008 Shiyan, Hubei, China
[3]Department of Neurosurgery, Taihe Hospital, Hubei University of Medicine, 442000 Shiyan, Hubei, China
[4]Department of Nuclear Medicine, Taihe Hospital, Hubei University of Medicine, 442000 Shiyan, Hubei, China
[5]Department of Neurology, Taihe Hospital, Hubei University of Medicine, 442000 Shiyan, Hubei, China

***Correspondence**
wangl_dr@163.com
(Liu Wang)

Abstract

Background: Early prediction of poor prognosis after intravenous thrombolysis in acute ischemic stroke (AIS) is critical for clinical management. Three-dimensional arterial spin labeling (3D-ASL) allows non-invasive quantification of cerebral blood flow (CBF), but its value in predicting early outcomes remains unclear. **Methods**: This single-center retrospective study assessed the data of 60 patients with AIS who received intravenous thrombolysis between January 2022 and January 2023. Patients with a reduction of $\leq$5 points in their National Institutes of Health Stroke Scale (NIHSS) score at discharge were defined as having a poor early outcome and were classified into a poor prognosis group (n = 30) or a good prognosis group (n = 30) if otherwise. CBF values, derived from 3D-ASL imaging, were compared between the two groups across different post-labeling delay (PLD) times and brain regions. Receiver operating characteristic (ROC) curve analysis was used to evaluate the predictive value of CBF for early poor prognosis, and the sensitivity, specificity, and area under the curve (AUC) were calculated. **Results**: At a PLD of 2500 ms, CBF values in both the infarct core and ischemic penumbra (IP) regions were significantly lower in the poor prognosis group compared with the good prognosis group ($p < 0.05$). ROC analysis showed AUCs of 0.757 (IP, sensitivity 90%, specificity 63.3%) and 0.800 (infarct core, sensitivity 70%, specificity 86.7%). Combined CBF improved AUC to 0.882 (sensitivity 80%, specificity 80%). **Conclusions**: CBF values from 3D-ASL (PLD 2500 ms) in the infarct core and IP may predict early poor prognosis after thrombolysis in AIS, with combined assessment showing optimal performance. Findings require validation in larger cohorts.

Keywords

Acute ischemic stroke; Magnetic resonance imaging; 3D-ASL; Cerebral blood flow; Adverse prognosis

1. Introduction

Early intravenous thrombolysis is a well-established and evidence-based therapeutic approach for acute ischemic stroke (AIS). Although many patients achieve satisfactory reperfusion of ischemic tissue and exhibit rapid neurological improvement following thrombolytic therapy, a subset of patients experiences neurological deterioration manifested by expansion of cerebral infarction, secondary hemorrhage, or cerebral edema. These complications can severely affect prognosis and, in some cases, become life-threatening [1, 2]. Therefore, the ability to accurately predict adverse outcomes after intravenous thrombolysis in AIS is of great clinical importance, as it enables the formulation of individualized treatment strategies, optimization of medical resource allocation, and improvement of patients' overall quality of life [3].

Conventional imaging modalities, such as Computed Tomography (CT) angiography, Magnetic Resonance Imaging (MRI) angiography, and digital subtraction angiography, primarily assess the degree of large-vessel stenosis or occlusion but provide limited information regarding microcirculatory perfusion within ischemic brain tissue [4]. In contrast, three-dimensional arterial spin labeling (3D-ASL) perfusion imaging employs magnetically labeled protons in arterial blood as endogenous tracers, eliminating the need for exogenous contrast agents or exposure to ionizing radiation. This technique allows for non-invasive and quantitative assessment of cerebral blood flow (CBF), thereby providing a more comprehensive understanding of cerebral perfusion status [5]. In addition, previous investigations have demonstrated a strong concordance between 3D-ASL and dynamic susceptibility contrast (DSC) perfusion imaging in evaluating cerebral perfusion in patients with AIS [6].

Herein, the present study utilized 3D-ASL imaging to evaluate microcirculatory reperfusion in brain tissue following intravenous thrombolysis in AIS patients and examine its association with early poor prognosis for identifying effective imaging markers that could assist in the clinical assessment and prediction of thrombolytic outcomes.

2. Materials and methods

2.1 General information

A retrospective analysis was performed on the data of 60 patients with ischemic stroke who underwent intravenous thrombolytic therapy at our hospital between January 2022 and January 2023. The study inclusion criteria were as follows: (1) diagnosis confirmed by MRI and CT based on the Diagnosis and Management of Acute Ischaemic Stroke guidelines [7]; (2) symptom onset within 5 hours before admission; (3) receipt of intravenous thrombolytic therapy; and (4) first episode of acute ischemic stroke. Exclusion criteria included: (1) non-ischemic stroke; (2) recent history of intracranial surgery, trauma, cerebral hemorrhage, severe hepatic or renal dysfunction, or coagulation disorders; (3) incomplete or poor-quality imaging data; and (4) presence of hematologic diseases.

The National Institutes of Health Stroke Scale (NIHSS) scores at admission and discharge were recorded by neurologists with associate senior professional titles or higher. The difference between the NIHSS scores at discharge and admission was used to evaluate the patients' short-term prognosis. Patients with a reduction in NIHSS score of $\leq$5 points at discharge were defined as having a poor early prognosis [8]. Accordingly, the study population was divided into a poor prognosis group (n = 30) and a good prognosis group (n = 30), and our preliminary analyses showed that there were no significant differences in baseline characteristics between the two groups ($p > 0.05$), indicating good comparability. The detailed baseline data are presented in Table 1.

This study was approved by the Ethics Committee of Shiyan Taihe Hospital (Approval No.: 2025KS115), and written informed consent was obtained from all participants.

2.2 Methods

2.2.1 Scanning method

All imaging examinations were performed using a 3.0 T MRI system (Magnetom Prisma, Siemens Healthcare, Erlangen, BY, Germany) equipped with a 16-channel head coil. Each patient underwent conventional MRI, diffusion-weighted imaging (DWI; b = 1000 s/mm^2), and three-dimensional arterial spin labeling (3D-ASL) imaging with dual post-labeling delays (PLD = 1500 ms and 2500 ms). Before the examination, the patients and their families were instructed to remove all metal objects and were informed about the precautions required during the procedure. The patients were placed in the supine position, with the head placed at the isocenter of the coil, and the scanning line was carefully aligned with the midpoint of the eyebrows to ensure accurate positioning. The scanning range extended from the vertex to the foramen magnum.

All included patients completed a standardized MRI protocol consisting of conventional MRI, DWI, and ASL sequences. For DWI acquisition, a single-shot echo-planar imaging (EPI) sequence was used to ensure high spatial resolution and signal-to-noise ratio, thereby improving the clarity and diagnostic reliability of the images. The DWI parameters were as follows: repetition time (TR) = 6000 ms, echo time (TE) = 75 ms, and b-value = 1000 s/mm^2, which allowed for sensitive detection of water molecule diffusion within brain tissue. For ASL imaging, two PLD settings were applied (1500 ms and 2500 ms) to comprehensively evaluate cerebral perfusion under different hemodynamic conditions. The scanning parameters for the ASL sequence with a PLD of 1500 ms were TR = 4521 ms and TE = 9.5 ms, whereas for the PLD of 2500 ms, TR = 5216 ms and TE = 9.8 ms. Both ASL sequences employed identical geometric parameters, including a slice thickness of 4 mm with no interslice gap, a field of view of 240 mm $\times$ 240 mm, and a matrix size of 512 $\times$ 512, ensuring consistency across the perfusion acquisitions.

TABLE 1. Comparison of baseline data between the two study groups.

Baseline data	Poor prognosis group (n = 30)	Good prognosis group (n = 30)	p value
Gender (Male/Female)	14/16	15/15	0.796
Age (yr)	61.67 $\pm$ 4.87	62.37 $\pm$ 4.17	0.552
Weight (kg)	55.37 $\pm$ 6.49	53.64 $\pm$ 6.08	0.291
Time from onset to admission (h)	3.23 $\pm$ 1.5	3.43 $\pm$ 1.5	0.608
Distribution of subtypes in ischemic stroke, n (%)			
Great atherosclerosis	10 (33.33)	12 (40.00)	0.592
Cardiac embolism	9 (30.00)	9 (30.00)	
Small vessel occlusion	8 (26.67)	7 (23.33)	
Other	3 (10.00)	2 (6.67)	
Complications, n (%)	26 (86.67)	24 (80.00)	0.488
Use of antithrombotic drugs, n (%)	28 (93.33)	29 (96.67)	0.554

2.2.2 Image post-processing and imaging evaluation

After DWI and 3D-ASL scanning, all raw imaging data were transferred to the ADW 4.6 advanced workstation (GE Healthcare, Milwaukee, WI, USA) for professional post-processing. For DWI image analysis, Functool software (Python 3.8, GE Healthcare, Milwaukee, WI, USA) was used for image reconstruction to generate apparent diffusion coefficient (ADC) maps. On DWI images, the infarcted regions demonstrating restricted diffusion appeared as hyperintense signals, whereas the corresponding areas on ADC maps appeared hypointense, consistent with cytotoxic edema and reduced water molecule diffusivity.

For the 3D-ASL datasets, reconstruction was similarly performed using Functool software to obtain quantitative cerebral blood flow (CBF) maps. To provide a more comprehensive assessment of cerebral perfusion, DWI and ASL images were subsequently fused to visualize both diffusion restriction and perfusion changes simultaneously. Careful evaluation of these fused images enabled the determination of whether the hyperintense regions on DWI corresponded to hypoperfused regions on ASL. When the area of lowperfusion visualized on ASL exceeded the extent of the DWI hyperintensity, the region was considered to represent the ischemic penumbra (IP).

To achieve a more precise evaluation of patients' prognostic outcomes, quantitative measurements of CBF were obtained from three regions: the IP, the infarct core, and their corresponding contralateral mirror regions. The infarct core was defined as the hyperintense area on DWI with a matching hypointense signal on the ADC map, whereas the IP was identified as the hypoperfused region on ASL demonstrating a CBF reduction of more than 30% relative to the contralateral mirror region and extending beyond the DWI hyperintensity.

All CBF measurements were independently performed by two radiologists with 5 and 8 years of experience in neuroimaging. The inter-rater reliability for CBF quantification was excellent, with an intraclass correlation coefficient (ICC) of 0.92 ($p < 0.001$). Both raters were blinded to patients' clinical outcomes to ensure objectivity of the imaging evaluation.

2.3 Statistical analysis

Data analysis was conducted using SPSS 25.0 statistical software (IBM, Armonk, NY, USA). The Shapiro-Wilk test was employed to assess the normality of continuous variables. Continuous variables conforming to a normal distribution are presented as mean ± standard deviation ($\bar{x} \pm s$), and comparisons between groups were made using the independent samples t-test. For continuous variables not following a normal distribution, median (interquartile range) (M (IQR)) is presented, and the Mann-Whitney U test was applied for intergroup comparisons. Categorical variables are expressed as counts (percentages) (n (%)), and comparisons between groups were performed using the χ^2 test or Fisher's exact probability method.

To evaluate the predictive value of cerebral blood flow (CBF) in different brain regions (such as the infarct core, ischemic penumbra, and contralateral mirror region) for early poor prognosis in patients, receiver operating characteristic (ROC) curve analysis was conducted. The area under the curve (AUC), optimal cutoff value, sensitivity, and specificity were calculated. The Youden index was computed to determine the optimal diagnostic threshold. The DeLong test was utilized to compare differences in AUCs among different ROC curves. All statistical analyses were two-tailed, and a p-value < 0.05 was considered statistically significant.

3. Results

3.1 Comparison of CBF values in the infarct core and the healthy mirror region

When PLD was 2500 ms, the CBF values in both the infarct core area and the IP area of patients with poor prognosis were significantly lower than those of patients with good prognosis ($p < 0.05$). However, no significant difference in CBF values was observed in the contralateral mirror area between the two groups ($p > 0.05$) (Table 2).

In Fig. 1, panels A and B show the DWI and 3D-ASL images of a patient with poor prognosis, respectively. The DWI image (A) shows acute infarction lesions located near the left lateral ventricle, and the 3D-ASL image (B) demonstrates low perfusion in both the infarcted area and its surrounding regions following intravenous thrombolysis.

3.2 Diagnostic value of CBF values in the core infarct area and IP area for early adverse prognosis

ROC curves were plotted using CBF values of the core infarct area and IP area, as well as their combination, under a PLD of 2500 ms, to predict early adverse prognosis. The results indicated that when the CBF value in the IP area was 33.870 mL/(100 g·min), the sensitivity for diagnosing adverse prognosis in patients with acute ischemic stroke reached 90%. When the CBF value in the infarct core area was 23.045 mL/(100 g·min), the specificity for diagnosing adverse prognosis was 86.7%. The combined diagnostic efficiency of the two parameters was the highest, with an AUC of 0.882 (95% confidence interval (CI): 0.800–0.964), and both sensitivity and specificity reaching 80%. The detailed results are presented in Table 3 and Fig. 2.

4. Discussion

This study demonstrated that CBF values derived from 3D-ASL in both the infarct core and IP regions at a PLD of 2500 ms can effectively predict early poor prognosis after intravenous thrombolysis in AIS. The combined assessment of CBF in these two regions provided the highest diagnostic accuracy (AUC = 0.882, sensitivity = 80.0%, specificity = 80.0%), outperforming the predictive value of either region alone. These findings indicate that 3D-ASL may serve as a valuable, non-invasive imaging tool for evaluating cerebral microcirculatory perfusion and predicting early neurological outcomes in patients undergoing thrombolytic therapy.

The 3D-ASL technique has become an important approach for cerebral perfusion assessment because it provides quantitative blood flow measurements without the use of contrast

TABLE 2. Comparison of CBF values under different PLD conditions ($\bar{x} \pm s$).

Group	n	Infarct core area CBF (mL/(100 g·min))		IP area CBF (mL/(100 g·min))		Contralateral mirror area CBF (mL/(100 g·min))	
		PLD = 1500 ms	PLD = 2500 ms	PLD = 1500 ms	PLD = 2500 ms	PLD = 1500 ms	PLD = 2500 ms
Poor prognosis group	30	15.57 ± 2.58	20.46 ± 2.57	28.54 ± 5.65	33.43 ± 5.60	39.26 ± 8.82	54.31 ± 8.86
Good prognosis group	30	16.09 ± 2.81	23.91 ± 3.01	27.66 ± 4.79	38.33 ± 4.56	40.85 ± 7.71	56.14 ± 7.52
t		0.744	4.779	0.655	3.716	0.744	0.861
p		0.460	<0.001	0.515	<0.001	0.460	0.393

CBF: cerebral blood flow; IP: ischemic penumbra; PLD: post-labeling delay.

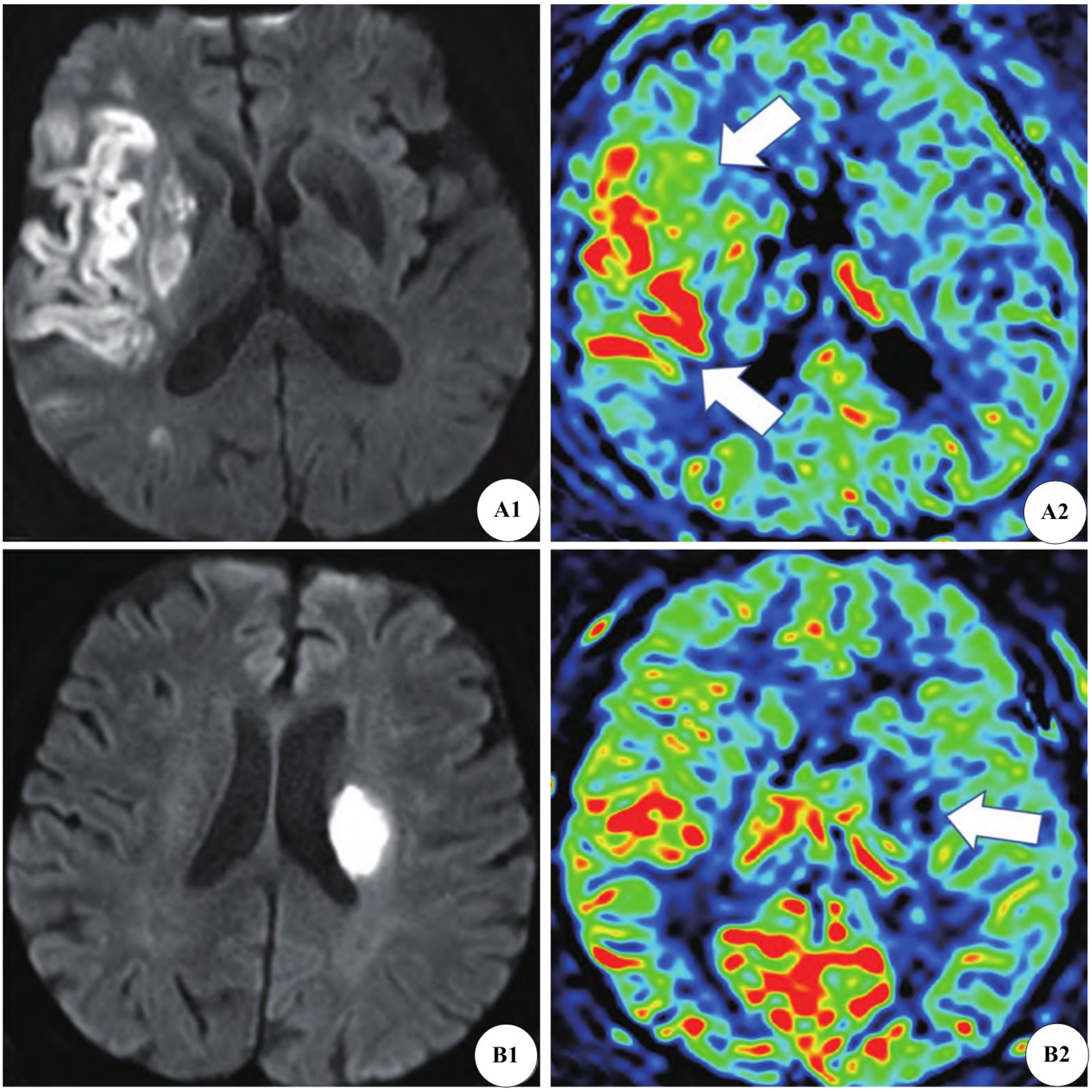

FIGURE 1. 3D-ASL perfusion status (PLD = 2500 ms) under different prognostic conditions. (A1) DWI image of a patient with poor prognosis. (A2) DWI image of a patient with good prognosis. (B1) 3D-ASL image (PLD = 2500 ms) of a patient with poor prognosis (after intravenous thrombolysis). (B2) 3D-ASL image (PLD = 2500 ms) of a patient with good prognosis.

TABLE 3. Diagnostic efficiency of CBF values in the core infarct area and IP area for early adverse prognosis.

Variables	Best truncation value	AUC	Standard error	*p* value	95% CI	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Diagnostic accuracy (%)
IP area CBF (mL/(100 g·min))	33.870	0.757	0.063	0.001	0.633–0.880	90.0	63.3	70.6	84.6	76.7
Infarct core area CBF (mL/(100 g·min))	23.045	0.800	0.058	<0.001	0.687–0.913	70.0	86.7	83.3	73.3	78.3
Combined Diagnosis	0.517	0.882	0.042	<0.001	0.800–0.964	80.0	80.0	80.0	80.0	80.0

AUC: area under the curve; 95% CI: 95% confidence interval; CBF: cerebral blood flow; IP: ischemic penumbra; PPV: positive predictive value; NPV: negative predictive value.

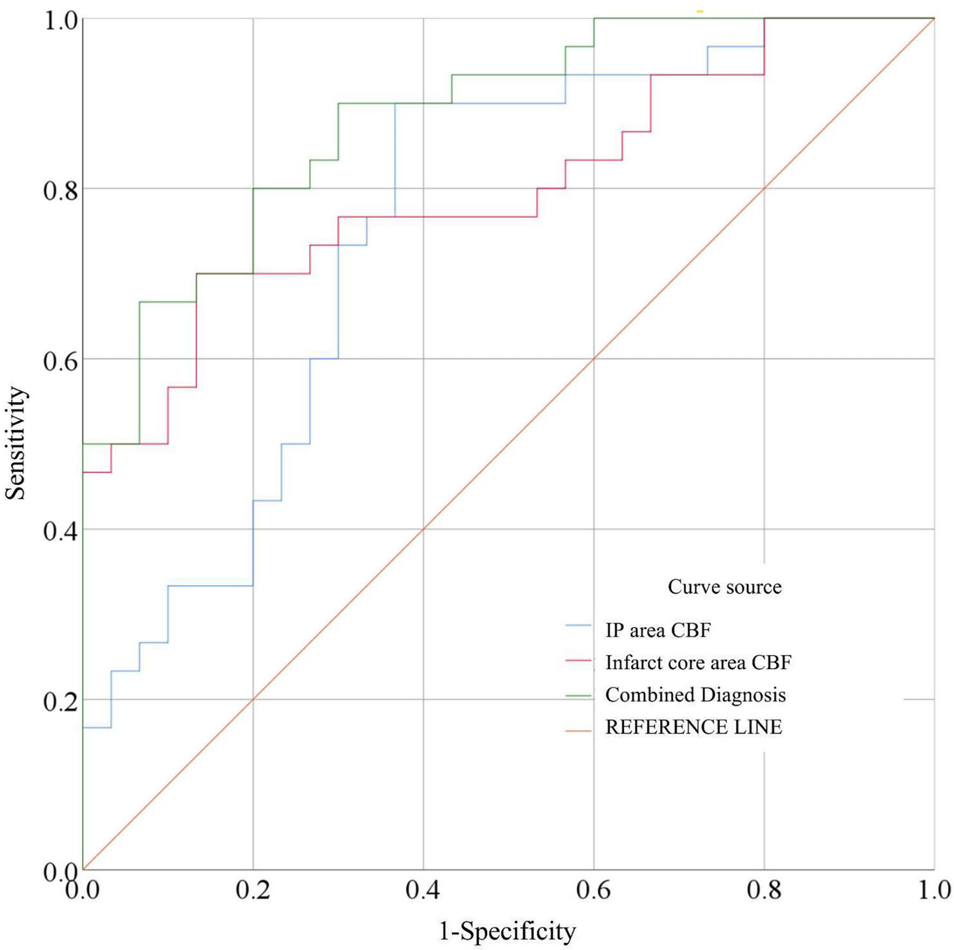

FIGURE 2. ROC curve for predicting poor prognosis using CBF values from 3D-ASL imaging. CBF: cerebral blood flow; IP: ischemic penumbra.

agents or exposure to ionizing radiation [9]. Its short acquisition time, typically around one minute, enables rapid and clinically practical visualization of ischemic regions in patients with cerebral infarction [10]. In addition, 3D-ASL allows repeated evaluation of cerebral perfusion over time, facilitating dynamic monitoring of tissue hemodynamics and offering a more comprehensive understanding of the cerebral blood flow status in ischemic tissue [11, 12]. Although 3D-ASL is a non-contrast method, several studies have confirmed its strong agreement with established perfusion techniques, including Positron Emission Tomography (PET), Computed Tomography Perfusion (CTP), and DSC. Vessel-encoded ASL has been shown to accurately delineate single-artery perfusion territories before and after revascularization procedures, demonstrating high concordance with Digital Subtraction Angiography (DSA) (κ = 0.899) [13]. Likewise, in ischemic stroke, there is no significant difference in hypoperfusion volume between ASL and DSC imaging when the PLD is set at 2500 ms (p = 0.435), with a concordance coefficient of κ = 0.773 [14]. Due to its non-invasive nature, reproducibility, and strong consistency with conventional perfusion techniques, 3D-ASL shows great promise as an alternative to DSC perfusion imaging in future stroke evaluation and follow-up [15].

3D-ASL can be used to quantitatively measure CBF (mL/100 g·min) by calculating the difference between labeled and unlabeled images, in which arterial blood is magnetically tagged using a radiofrequency pulse, enabling accurate assessment of cerebral perfusion and providing clinicians with quantitative information on regional blood flow status [16]. CBF represents the volume of blood passing through a unit mass of brain tissue per unit time, which is determined by the product of blood flow velocity and vascular cross-sectional area [17]. Clinically, CBF can be assessed using multiple imaging modalities, including Magnetic Resonance Angiography (MRA), Computed Tomography Angiography (CTA), and DSA. In healthy adults, the normal CBF value in brain tissue typically ranges from 50 to 55 mL/(100 g·min) [18]. Abnormalities in cerebral blood flow have been shown to be associated with several cerebrovascular disorders, such as atherosclerosis and cerebral infarction, where significant reductions in blood supply can result in ischemic injury and neuronal dysfunction [19, 20]. In ASL imaging, the PLD is a key parameter that defines the interval between the completion of arterial blood labeling and the acquisition of perfusion images [21]. Variations in PLD directly influence the accuracy of quantitative CBF estimation [22]. For healthy individuals, a PLD of approximately 1.5 s is commonly used to determine anterograde perfusion [23]. However, in AIS, arterial stenosis and the development of collateral circulation often alter hemodynamics, making it difficult for a single PLD to accurately evaluate ischemic areas or reflect true perfusion status. Thus, the use of multiple PLDs (*e.g.*, 1.5 s and 2.5 s) provides a more comprehensive assessment of dynamic cerebral perfusion, enabling visualization of both early and delayed blood flow phases [24, 25].

A PLD of 1.5 s primarily reflects the anterograde perfusion effect but may lead to overestimation of hypoperfused regions, whereas a PLD of 2.5 s provides a more accurate depiction of the final perfusion outcome, incorporating the contribution of collateral circulation. Therefore, subtracting the infarct core region observed on DWI from the hypoperfused area identified on the 2.5 s CBF map can delineate a more realistic IP [26]. The findings of this study further support these observations. When the PLD was 1500 ms, there were no significant differences in CBF values between the poor and good prognosis groups in the infarct core, IP, or contralateral mirror regions ($p > 0.05$). However, when the PLD was extended to 2500 ms, the CBF values in both the infarct core and IP regions were significantly lower in patients with poor prognosis than in those with good prognosis ($p < 0.05$), whereas no significant difference was found in the contralateral mirror region ($p > 0.05$). This suggests that a PLD of 2500 ms provides sufficient delay for labeled blood to traverse regions with severe ischemia and near-complete perfusion deficits. Compared with the shorter 1500 ms delay, the longer PLD allows the labeled blood to pass through a broader cerebrovascular network, thereby more accurately reflecting the actual perfusion state of brain tissue and highlighting the perfusion differences in the infarct core and IP regions associated with poor prognosis.

Currently, there is growing evidence supporting the value of 3D-ASL in identifying patients with ischemic stroke who are likely to experience poor clinical outcomes. Liu S *et al.* [27] used arterial transit artifacts observed on ASL images to predict favorable 90-day outcomes in AIS, demonstrating that such artifacts can effectively reflect collateral circulation and serve as indicators of prognosis. Wu L *et al.* [28] further confirmed that relative CBF derived from ASL plays a key role in evaluating the risk of hemorrhagic transformation during the subacute phase of ischemic stroke. Similarly, Nam KW *et al.* [29] reported that abnormal 3D-ASL perfusion, arterial transit artifacts, and high-intensity intra-arterial signals are useful in predicting early recurrent ischemic lesions in AIS. The perfusion status in 3D-ASL can be characterized quantitatively through CBF measurements, where regions with relative CBF $\geq$1.4 are considered hyperperfused [30]. Hyperperfusion on 3D-ASL has been associated with successful recanalization after thrombolysis and may represent an independent imaging marker of favorable 90-day prognosis in AIS [31]. In the present study, a CBF threshold of 33.870 mL/(100 g·min) in the IP region demonstrated good diagnostic performance for predicting poor prognosis in AIS patients, with an AUC of 0.757 (95% CI: 0.633–0.880), sensitivity of 90%, and specificity of 63.3%. When the CBF threshold in the infarct core region was 23.045 mL/(100 g·min), the diagnostic performance remained satisfactory, with an AUC of 0.800 (95% CI: 0.687–0.913), specificity of 86.7%, and sensitivity of 70%. These findings are consistent with those of Wang J *et al.* [32], who reported that CBF derived from ASL-MRI was valuable for evaluating poor prognosis, including crossed cerebellar diaschisis, in stroke patients. Similarly, Zhang M *et al.* [33] found that the low-perfusion volume ratio calculated from 3D-ASL CBF effectively predicted early neurological improvement in ischemic stroke, with an AUC of 0.794. Moreover, reduced cerebral perfusion has been significantly linked to cognitive decline in the elderly, and cerebrovascular insufficiency may accelerate memory deterioration and worsen clinical outcomes in susceptible individuals [34]. Both the IP and infarct core regions are characterized by severely compromised blood perfusion, leaving neurons in a highly vulnerable state and predisposing them to irreversible injury, which contributes to unfavorable prognosis. The combined evaluation of these two regions achieved the highest diagnostic efficiency, with an AUC of 0.882 (95% CI: 0.800–0.964) and both sensitivity and specificity of 80%. The CBF in the IP region exhibited high sensitivity (90%), making it suitable for screening high-risk patients who may benefit from enhanced monitoring or additional therapeutic strategies. In contrast, the CBF in the infarct core region demonstrated higher specificity (86.7%), which is useful for confirming poor outcomes and avoiding unnecessary aggressive interventions. The combined model (sensitivity = 80%, specificity = 80%) integrates the advantages of both parameters, providing a practical and balanced approach for clinical prediction and decision-making in AIS management.

By quantifying CBF using 3D-ASL imaging, clinicians can more accurately evaluate the perfusion status of brain tissue and predict patient prognosis. The non-invasive and non-radiative nature of 3D-ASL provides a safe and effective means for assessing cerebral hemodynamics in stroke patients, offering an alternative to traditional perfusion imaging techniques. Although this study yielded promising results, several limitations should be acknowledged. First, it was a single-center retrospective study with a relatively small sample size (n = 60), which may restrict the generalizability of the findings. Second, the study did not incorporate clinical parameters, such as the 90-day modified Rankin Scale (mRS) score, infarct volume changes on follow-up imaging, or laboratory indicators (*e.g.*, blood glucose levels, inflammatory factors), which might have further enhanced prognostic accuracy. Third, due to its retrospective design, the inclusion of only patients with complete imaging data may have introduced potential selection bias.

Future studies could aim to: (1) validate these findings in larger, multicenter cohorts to improve external generalizability; (2) integrate 3D-ASL with other imaging modalitie, such as DSC-MRI or diffusion tensor imaging, as well as with serum biomarkers including inflammatory cytokines, to achieve more comprehensive prognostic evaluation; (3) explore the application of 3D-ASL in guiding individualized thrombolytic timing and dosage adjustments; and (4) investigate long-term outcomes, such as 3-month functional recovery, through serial 3D-ASL follow-up imaging to assess dynamic changes in cerebral perfusion.

5. Conclusions

Cerebral blood flow (CBF) values in the infarct core and ischemic penumbra (IP) measured by 3D-ASL imaging at a post-labeling delay (PLD) of 2500 ms are valuable indicators for predicting early poor prognosis after intravenous thrombolysis in acute ischemic stroke (AIS). Combined assessment of CBF in these regions improves diagnostic performance (AUC = 0.882, sensitivity = 80%, specificity = 80%), outperforming single-region analysis. These findings support 3D-ASL as a non-invasive tool for evaluating cerebral microcirculatory perfusion and guiding clinical decision-making in AIS management. However, the preliminary nature of this single-center retrospective study highlights the need for validation in larger prospective multicenter cohorts.

AVAILABILITY OF DATA AND MATERIALS

The authors declare that all data supporting the findings of this study are available within the paper and any raw data can be obtained from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

LH, LW—designed the study and carried them out; prepared the manuscript for publication and reviewed the draft of the manuscript. LH, LW, SLH, DBZ, WC, XQP—supervised the data collection; analyzed the data; interpreted the data. All authors have read and approved the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Ethical approval was obtained from the Ethics Committee of Shiyan Taihe Hospital (Approval No.: 2025KS115). Written informed consent was obtained from a legally authorized representative(s) for anonymized patient information to be published in this article.

ACKNOWLEDGMENT

Not applicable.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Kalchev E. The role of fetal-type posterior cerebral artery in mediating occipital and thalamic perfusion: an arterial spin labeling MRI study. Journal of Medical Imaging and Radiation Sciences. 2023; 54: 590–594.

[2] Zhou J, Li G, Meng Y, Hu F, Wang W, Chen X. Analysis of the posterior cerebral perfusion status and clinical prognostic value in chronic unilateral middle cerebral artery occlusion using SWAN combined with 3D-ASL. Medicine. 2023; 102: e35836.

[3] Spiro JD, James WF, Cho AA. Utility of susceptibility weighted imaging (SWI) and pseudo-continuous arterial spin labeling (pCASL) in diagnosis of falcine venous thrombosis in a child with transient ischemic attack. Emergency Radiology. 2021; 28: 683–686.

[4] Mizowaki T, Hosoda K, Inoue S, Kuroda R, Kurihara E. Pseudo-continuous arterial spin labeling with short post-labeling delay time sensitively reflects the hemodynamics of symptomatic patients with permanent large vessel occlusion before and after revascularization. The Neuroradiology Journal. 2022; 35: 706–712.

[5] Ito Y, Sugiyama T, Terasaka S, Matsuzawa H, Harada K, Nakayama N, *et al*. Differences between acute embolic and atherosclerotic middle cerebral artery occlusion in multiphase arterial spin-labeling imaging. Neurologia Medico-Chirurgica. 2024; 64: 197–204.

[6] Lindner T, Bolar DS, Achten E, Barkhof F, Bastos-Leite AJ, Detre JA, *et al*.; on behalf of the ISMRM Perfusion Study Group. Current state and guidance on arterial spin labeling perfusion MRI in clinical neuroimaging. Magnetic Resonance in Medicine. 2023; 89: 2024–2047.

[7] Hurford R, Sekhar A, Hughes TAT, Muir KW. Diagnosis and management of acute ischaemic stroke. Practical Neurology. 2020; 20: 304–316.

[8] Khan MSA, Ahmad S, Ghafoor B, Shah MH, Mumtaz H, Ahmad W, *et al*. Inpatient assessment of the neurological outcome of acute stroke patients based on the National Institute of Health Stroke Scale (NIHSS). Annals of Medicine and Surgery. 2022; 82: 104770.

[9] Lee J, Park DW, Kim YS, Kim HY, Lee YJ. Arterial spin labeling signal ratio between the lesion and contralateral sides for evaluation of acute middle cerebral artery infarct. Medicine. 2022; 101: e28569.

[10] Oura D, Kawabori M, Niiya Y, Iwasaki M, Satoh S, Yokohama T, *et al*. The validity of the acute stroke assessment using rapid pseudo-continuous arterial spin labeling (ASAP-ASL) method for acute thrombectomy. Journal of Neurosurgical Sciences. 2021; 65: 480–485.

[11] Daftari Besheli L, Ahmed A, Hamam O, Luna L, Sun LR, Urrutia V, *et al*. Arterial Spin Labeling technique and clinical applications of the

intracranial compartment in stroke and stroke mimics—a case-based review. The Neuroradiology Journal. 2022; 35: 437–453.
[12] Buch K, Hakimelahi R, Locascio JJ, Bolar DS, Gonzalez RG, Schaefer PW. Clinical utility of arterial spin labeling perfusion images in the emergency department for the work-up of stroke-like symptoms. Neuroradiology. 2022; 64: 925–934.
[13] Zerweck L, Pohmann R, Klose U, Martirosian P, Haas P, Ernemann U, *et al*. Evaluation of the contribution of individual arteries to the cerebral blood supply in patients with Moyamoya angiopathy: comparison of vessel-encoded arterial spin labeling and digital subtraction angiography. Neuroradiology. 2024; 66: 1131–1140.
[14] Lyu J, Duan Q, Xiao S, Meng Z, Wu X, Chen W, *et al*.; MR-STARS Investigators. Arterial spin labeling-based MRI estimation of penumbral tissue in acute ischemic stroke. Journal of Magnetic Resonance Imaging. 2023; 57: 1241–1247.
[15] Gopinath G, Aslam M, Anusha P. Role of magnetic resonance perfusion imaging in acute stroke: arterial spin labeling versus dynamic susceptibility contrast-enhanced perfusion. Cureus. 2022; 14: e23625.
[16] Lang SS, Tucker AM, Schreiber C, Storm PB, Liu H, Li Y, *et al*. Arterial spin labeling as an ancillary assessment to postoperative conventional angiogram in pediatric moyamoya disease. Journal of Neurosurgery: Pediatrics. 2021; 29: 40–47.
[17] Chen W, Song X, Chen S, Chen Z, Fu M, Wei C, *et al*. Blood flow and perfusion lateralization in border zone infarct using 4D flow and arterial spin labeling. Neuroradiology. 2022; 64: 2145–2152.
[18] Kidoguchi M, Akazawa A, Komori O, Isozaki M, Higashino Y, Kawajiri S, *et al*. Prediction of occurrence of cerebral infarction after successful mechanical thrombectomy for ischemic stroke in the anterior circulation by arterial spin labeling. Clinical Neuroradiology. 2023; 33: 965–971.
[19] Fan H, Su P, Lin DDM, Goldberg EB, Walker A, Leigh R, *et al*. Simultaneous hemodynamic and structural imaging of ischemic stroke with magnetic resonance fingerprinting arterial spin labeling. Stroke. 2022; 53: 2016–2025.
[20] Maier O, Spann SM, Pinter D, Gattringer T, Hinteregger N, Thallinger GG, *et al*. Non-linear fitting with joint spatial regularization in arterial spin labeling. Medical Image Analysis. 2021; 71: 102067.
[21] Di Napoli A, Cheng SF, Gregson J, Atkinson D, Markus JE, Richards T, *et al*. Arterial spin labeling MRI in carotid stenosis: arterial transit artifacts may predict symptoms. Radiology. 2020; 297: 652–660.
[22] Lee TJ, Roh HG, Kim HJ, Jeon YS, Ki HJ, Park JJ, *et al*. Prognostic value of collateral perfusion estimation by arterial spin labeling for acute anterior circulation ischemic stroke. Neuroradiology. 2023; 65: 1695–1705.
[23] Zhang M, Shi Q, Yue Y, Zhang M, Zhao L, Yan C. Evaluation of T2-FLAIR combined with ASL on the collateral circulation of acute ischemic stroke. Neurological Sciences. 2022; 43: 4891–4900.
[24] Luijten SPR, Bos D, van Doormaal PJ, Goyal M, Dijkhuizen RM, Dippel DWJ, *et al*. Cerebral blood flow quantification with multi-delay arterial spin labeling in ischemic stroke and the association with early neurological outcome. NeuroImage: Clinical. 2023; 37: 103340.
[25] Xu X, Tan Z, Fan M, Ma M, Fang W, Liang J, *et al*. Comparative study of multi-delay pseudo-continuous arterial spin labeling perfusion MRI and CT perfusion in ischemic stroke disease. Frontiers in Neuroinformatics. 2021; 15: 719719.
[26] Yan C, Yu F, Zhang Y, Zhang M, Li J, Wang Z, *et al*. Multidelay arterial spin labeling versus computed tomography perfusion in penumbra volume of acute ischemic stroke. Stroke. 2023; 54: 1037–1045.
[27] Liu S, Fan D, Zang F, Gu N, Yin Y, Ge X, *et al*. Collateral circulation detected by arterial spin labeling predicts outcome in acute ischemic stroke. Acta Neurologica Scandinavica. 2022; 146: 635–642.
[28] Wu L, Liu Y, Zhu L, Li T, Wang L, Zhang Y, *et al*. MRI arterial spin labeling in evaluating hemorrhagic transformation following endovascular recanalization of subacute ischemic stroke. Frontiers in Neuroscience. 2023; 17: 1105816.
[29] Nam KW, Kim CK, Yoon BW, Hwang I, Sohn CH. Multiphase arterial spin labeling imaging to predict early recurrent ischemic lesion in acute ischemic stroke. Scientific Reports. 2022; 12: 1456.
[30] Huang J, Hao P, Chen Z, Deng K, Liu B, Xu Y. Quantitative assessment of hyperperfusion using arterial spin labeling to predict hemorrhagic transformation in acute ischemic stroke patients with mechanical endovascular therapy. European Radiology. 2024; 34: 579–587.
[31] Lu SS, Cao YZ, Su CQ, Xu XQ, Zhao LB, Jia ZY, *et al*. Hyperperfusion on arterial spin labeling MRI predicts the 90-day functional outcome after mechanical thrombectomy in ischemic stroke. Journal of Magnetic Resonance Imaging. 2021; 53: 1815–1822.
[32] Wang J, Pan LJ, Zhou B, Zu JY, Zhao YX, Li Y, *et al*. Crossed cerebellar diaschisis after stroke detected noninvasively by arterial spin-labeling MR imaging. BMC Neuroscience. 2020; 21: 46.
[33] Zhang M, Zhu W, Ma Y, Huang K, Huang S, Chen Q, *et al*. Early neurological deterioration and hypoperfusion volume ratio on arterial spin labeling in patients with acute ischemic stroke. Journal of Stroke and Cerebrovascular Diseases. 2021; 30: 105885.
[34] Gyanwali B, Mutsaerts HJ, Tan CS, Kaweilh OR, Petr J, Chen C, *et al*. Association of arterial spin labeling parameters with cognitive decline, vascular events, and mortality in a memory-clinic sample. The American Journal of Geriatric Psychiatry. 2022; 30: 1298–1309.

How to cite this article: Li He, Liu Wang, Shengli Hu, Daobing Zeng, Wen Chen, Xiaoqin Peng. 3D-ASL imaging of cerebral blood flow in predicting early poor prognosis of intravenous thrombolysis in acute ischemic stroke. Signa Vitae. 2025; 21(12): 99-106. doi: 10.22514/sv.2025.193.