



Opinion

Arterial Spin Labeling in Neurosurgical Practice: Emerging Applications and Translational Challenges



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Arterial spin labeling (ASL) has emerged as a noninvasive magnetic resonance imaging technique capable of quantifying cerebral blood flow (CBF) without exogenous contrast agents. Current evidence suggests that ASL-derived perfusion measures have the potential to inform neurosurgical decision-making across multiple domains, although their routine clinical use requires further prospective validation. ASL measures CBF by magnetically labeling arterial water protons as an endogenous diffusible tracer, eliminating the need for gadolinium-based contrast agents. Unlike dynamic susceptibility contrast (DSC) perfusion magnetic resonance imaging, which can be affected by blood-brain barrier leakage and susceptibility artifacts, ASL provides absolute CBF quantification and is less susceptible to these effects. However, the technique has inherent limitations, including a lower signal-to-noise ratio and sensitivity to arterial transit time, which must be considered in clinical interpretation.¹ While ASL's diagnostic utility in Alzheimer's disease and related dementias has been increasingly recognized, its translation into neurosurgical practice remains underexplored. Our recent study demonstrated that ASL-derived CBF was significantly associated with amyloid-beta levels, particularly A β 42, across the cognitive spectrum, even after adjusting for age, sex, APOE4 status, and polygenic hazard scores.² These findings reinforce the concept that perfusion deficits may serve as early markers of amyloid pathology.

In neuro-oncology, the distinction between true tumor progression and treatment-related effects such as pseudoprogression or radiation necrosis remains a persistent clinical challenge. A recent meta-analysis by Alsulami *et al.*³ demonstrated that ASL-derived relative CBF and maximum absolute CBF can discriminate progressive disease from therapy-induced changes, with pooled sensitivities of 0.85–0.93 and specificities of 0.83–0.84. These findings align with those of Lavrova *et al.*,⁴ who reported comparable diagnostic accuracy between ASL and DSC perfusion magnetic resonance imaging for brain tumor surveillance, with ASL

offering the advantage of being less affected by blood-brain barrier disruption and susceptibility artifacts. Furthermore, Fukumura *et al.*⁵ utilized ASL to objectively quantify tumor blood flow reduction following preoperative embolization of meningiomas, demonstrating significantly greater flow reduction with intratumoral embolization compared to feeder occlusion alone. Beyond treatment response assessment, recent evidence suggests that ASL may also contribute to glioma molecular profiling. Prysiazhniuk *et al.*⁶ demonstrated that ASL-derived normalized CBF achieved comparable performance to DSC-derived normalized cerebral blood volume in distinguishing IDH-mutant from IDH-wildtype gliomas, supporting ASL as a gadolinium-free alternative for molecular characterization of diffuse gliomas. Collectively, these studies support the diagnostic utility of ASL in neuro-oncology, though prospective validation of its impact on clinical decision-making is still needed. The diagnostic performance of ASL across these neurosurgical domains is summarized in Figure 1.^{3,4,6,7}

Beyond oncology, ASL has shown promise in the evaluation of cerebrospinal fluid (CSF) dynamics and vascular disorders. In idiopathic normal pressure hydrocephalus, Virhammar *et al.*⁸ utilized pseudo-continuous ASL to measure regional CBF before and after CSF removal, demonstrating that patients with increased CBF in lateral and frontal white matter after CSF tapping showed greater improvement in gait function compared to those with decreased CBF in these regions. Nevertheless, the predictive value of ASL for identifying shunt-responsive patients has not yet been established, and prospective studies are required before ASL can be recommended for patient selection in clinical practice. In chronic subdural hematoma, Li *et al.*⁷ introduced the “rainbow sign” on ASL imaging as a potential predictor of recurrence following middle meningeal artery embolization. Resolution of this hyperperfusion sign after embolization was associated with favorable outcomes, whereas its aggravation strongly predicted hematoma recurrence.⁷ These findings suggest that ASL may offer a noninvasive means of monitoring treatment response, but validation in larger, multicenter cohorts is necessary.

Beyond these diagnostic applications, technical refinements have expanded the feasibility of ASL in intraoperative settings. Sánchez-Albardíaz *et al.*⁹ optimized pseudo-continuous ASL parameters for the intraoperative environment, demonstrating that shortening the labeling pulse interval and increasing gradient strength significantly improve labeling efficiency and CBF quanti-

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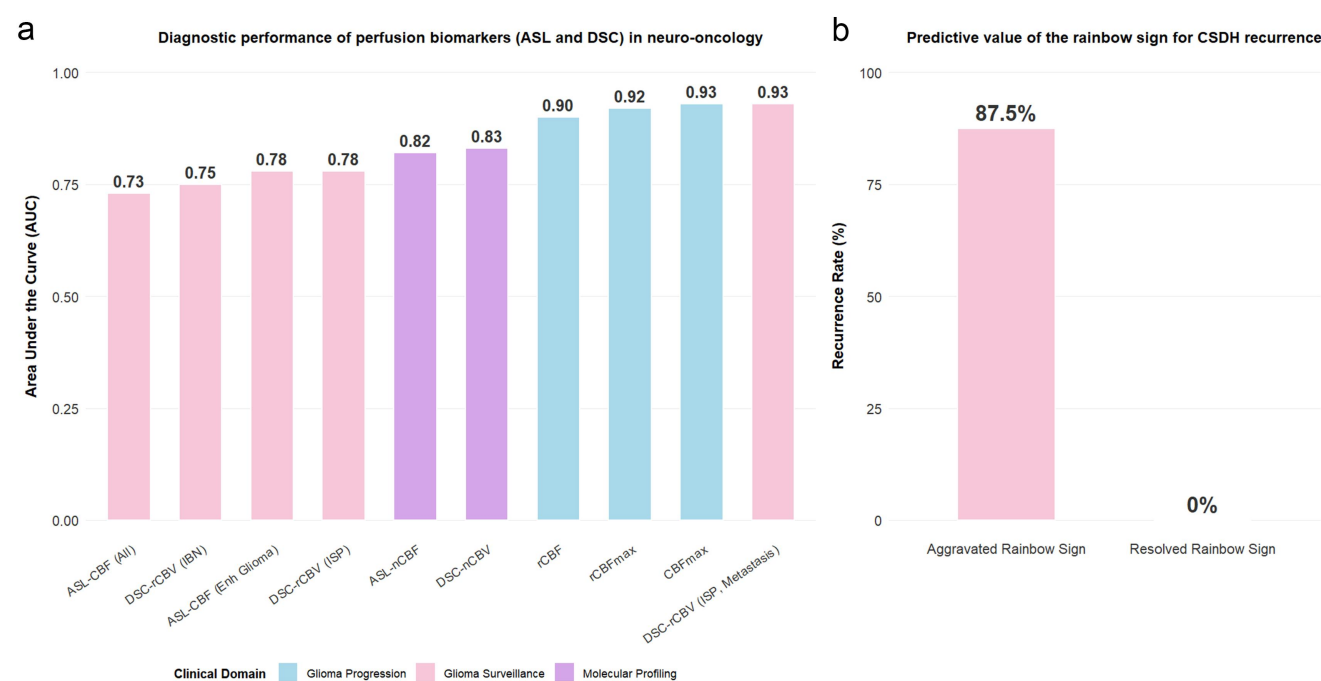


Fig. 1. Clinical utility of ASL in neurosurgical practice. (a) Diagnostic performance of perfusion biomarkers (ASL and DSC) in neuro-oncology. The bar chart summarizes AUC values reported in three independent studies: discrimination of glioma progression from treatment-related effects using rCBF, rCBFmax, and CBFmax³; differentiation of IDH-mutant from IDH-wildtype gliomas using ASL-nCBF and DSC-nCBV⁶; and brain tumor surveillance using ASL-CBF and DSC-rCBV.⁴ For the brain tumor surveillance study, DSC-rCBV AUC values for the overall cohort were 0.78 using ISP and 0.75 using IBN, whereas ASL-CBF AUC values were 0.73 for the overall cohort and 0.78 for the enhancing glioma subgroup. The DSC-rCBV AUC of 0.93 for metastasis corresponds to ISP-based post-processing. Because these values were derived from different study populations and clinical endpoints, they are presented descriptively and should not be interpreted as direct cross-study comparisons. (b) Predictive value of the “rainbow sign” on ASL imaging for chronic subdural hematoma recurrence following middle meningeal artery embolization.⁷ Resolution of the rainbow sign was associated with 0% recurrence (0/27 patients), whereas aggravation of the sign was associated with 87.5% recurrence (7/8 patients). The figure was created by the author using RStudio (version 2026.05.0, Build 218; Posit Software, PBC) based on data extracted from the cited publications. ASL, arterial spin labeling; AUC, area under the curve; CBF, cerebral blood flow; CSDH, chronic subdural hematoma; DSC, dynamic susceptibility contrast; IBN, IB Neuro; IDH, isocitrate dehydrogenase; ISP, IntelliSpace Portal; nCBF, normalized cerebral blood flow; nCBV, normalized cerebral blood volume; rCBF, relative cerebral blood flow; rCBV, relative cerebral blood volume.

fication in the presence of anesthesia-induced flow velocity reductions and magnetic field inhomogeneities. While this advancement improves image quality, evidence demonstrating that intraoperative ASL directly enhances real-time perfusion guidance, extent of resection, or clinical outcomes is currently lacking. The technique should therefore be viewed as a promising technical development requiring further clinical validation.

Despite these promising applications, several barriers to widespread clinical adoption remain. ASL continues to suffer from a lower signal-to-noise ratio compared to DSC perfusion, and its quantification is influenced by arterial transit time, labeling efficiency, and partial volume effects.¹ The lack of standardized acquisition protocols across centers further complicates comparative analyses. Consensus recommendations from the International Society for Magnetic Resonance in Medicine provide a framework for standardization, and ongoing technical refinements continue to improve the robustness and reproducibility of ASL.¹⁰ Still, the path from technical feasibility to routine clinical use will require coordinated efforts across institutions and disciplines.

In summary, current evidence indicates that ASL has diagnostic potential across several neurosurgical domains, including neuro-oncology, CSF disorders, and vascular pathology. Current evidence supports technical feasibility and diagnostic associations, but the impact of ASL on clinical decision-making and patient outcomes remains to be established through prospective, multicenter validation studies. ASL should therefore be viewed as a promising emerging tool whose integration into routine neurosurgical practice should depend on rigorous evidence demonstrating added value beyond existing imaging modalities. Future prospective, multicenter studies will be critical in determining whether ASL can translate its technical and diagnostic promise into meaningful improvements in neurosurgical decision-making and patient outcomes.

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Conflict of interest

The author declares no conflicts of interest.

Author contributions

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