

## Research Article

# THE DIAGNOSTIC ACCURACY OF ARTERIAL SPIN LABELING MR PERFUSION IMAGING IN INTRA-AXIAL SPACE OCCUPYING BRAIN LESIONS

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**Abstract:** **Introduction:** Differentiation of intra-axial brain lesions remains challenging due to overlapping MRI features. Arterial spin labeling (ASL) is a non-invasive perfusion technique that provides quantitative cerebral blood flow without contrast, aiding lesion characterization. **Aim:** To evaluate the diagnostic accuracy of arterial spin labeling MR perfusion imaging in intra-axial space-occupying brain lesions and to assess its role in differentiating neoplastic from non-neoplastic lesions and in glioma grading. **Methods:** This cross-sectional study included 60 patients with intra-axial brain lesions who underwent conventional MRI and ASL imaging. Quantitative perfusion parameters (mean CBFL, mean CBFPE, rCBFL, rCBFE) were analyzed, and statistical tests including t-test, ANOVA, and ROC analysis were used to assess diagnostic performance. **Results:** Neoplastic lesions (75%) showed significantly higher perfusion than non-neoplastic lesions ( $p < 0.001$ ). Glioblastomas had the highest perfusion, while infective lesions showed low values. High-grade gliomas demonstrated significantly higher perfusion than low-grade gliomas. rCBFL showed the best diagnostic performance (accuracy 96.7%, AUC 1.00), followed by mean CBFL (AUC 0.99). **Conclusion:** ASL MR perfusion is a reliable, non-invasive technique for characterizing intra-axial lesions, effectively differentiating lesion types and aiding glioma grading, with strong diagnostic performance supporting routine clinical use.

**Keywords:** Arterial spin labeling, ASL MRI, brain tumors, intra-axial lesions, cerebral blood flow, glioma grading, perfusion imaging, non-invasive imaging, neuroimaging, diagnostic accuracy

## INTRODUCTION

Intracranial intra-axial space-occupying lesions constitute a heterogeneous group of neurological disorders associated with substantial morbidity, mortality, and long-term disability. These lesions encompass a wide spectrum of pathological entities including primary brain tumors, metastatic deposits, infectious granulomas, inflammatory conditions, demyelinating lesions, and vascular abnormalities, all of which often demonstrate

overlapping radiological features on conventional imaging. Accurate differentiation among these entities is critical, as therapeutic strategies, prognostic outcomes, and survival rates vary significantly depending on the underlying pathology<sup>1,2</sup>. Early and precise diagnosis therefore plays a pivotal role in guiding clinical management, determining surgical candidacy, and optimizing patient outcomes.

Magnetic resonance imaging (MRI) remains the cornerstone for evaluation of intracranial lesions due to

its superior soft-tissue contrast, multiplanar capability, and absence of ionizing radiation<sup>3</sup>. Conventional MRI sequences, including T1-weighted, T2-weighted, FLAIR, diffusion-weighted imaging (DWI), and susceptibility-weighted imaging (SWI), Detailed anatomical and structural information regarding lesion morphology, edema, necrosis, hemorrhage, and mass effect<sup>4</sup>. However, despite high sensitivity, conventional MRI lacks specificity in differentiating neoplastic from non-neoplastic lesions and often fails to reliably distinguish tumor grades, particularly in cases with atypical imaging features<sup>5</sup>. Contrast-enhanced MRI improves lesion characterization by demonstrating blood-brain barrier disruption. Nevertheless, contrast enhancement is not pathognomonic for neoplasia and may also be observed in infections, inflammatory conditions, and subacute infarcts<sup>6</sup>. Conversely, certain aggressive tumors may exhibit minimal or absent enhancement, further contributing to diagnostic ambiguity<sup>7</sup>. These limitations highlight the need for advanced imaging techniques that provide functional and physiological insights beyond structural assessment.

Perfusion imaging has emerged as a valuable adjunct in neuroimaging by enabling evaluation of tumor vascularity, angiogenesis, and microcirculatory dynamics. Tumor angiogenesis is a hallmark of malignancy and correlates strongly with tumor grade and biological aggressiveness<sup>8</sup>. Perfusion parameters such as cerebral blood flow (CBF), cerebral blood volume (CBV), and mean transit time (MTT) provide important information regarding tumor behavior, aiding in grading, differentiation, and treatment response assessment<sup>9</sup>. Dynamic susceptibility contrast (DSC) and dynamic contrast-enhanced (DCE) MRI are widely used perfusion techniques; however, both require intravenous administration of gadolinium-based contrast agents<sup>10</sup>. These techniques are limited by contrast-related risks including nephrogenic systemic fibrosis, gadolinium deposition in brain tissue, and contraindications in patients with renal impairment or contrast allergy<sup>11</sup>. Additionally, repeated contrast administration poses concerns in patients requiring long-term follow-up, particularly in pediatric and vulnerable populations<sup>12</sup>.

Arterial spin labeling (ASL) has emerged as a promising non-invasive perfusion imaging technique that overcomes these limitations. ASL utilizes magnetically labeled arterial blood water as an endogenous tracer, allowing quantitative measurement of cerebral blood flow without the need for exogenous contrast agents<sup>13</sup>. By comparing labeled and control images, ASL generates perfusion maps that reflect tissue vascularity in absolute physiological units, facilitating objective comparison across patients and imaging sessions<sup>14</sup>. The non-invasive nature of ASL provides significant clinical advantages. It is particularly useful in patients with renal dysfunction, contrast allergies, pregnancy, or difficult venous access, and in those requiring repeated imaging for disease monitoring<sup>15</sup>. Furthermore, ASL enables multiple acquisitions within a single session, allowing dynamic assessment of hemodynamic changes and treatment response<sup>16</sup>.

Gliomas, the most common primary intra-axial brain tumors, exhibit a wide spectrum of biological behavior ranging from low-grade indolent lesions to highly aggressive glioblastomas<sup>17</sup>. Accurate preoperative grading of gliomas is essential because treatment strategies and prognosis differ significantly between tumor grades. Perfusion imaging has demonstrated a strong correlation with tumor grade, as high-grade gliomas typically show increased vascularity and elevated perfusion values compared to low-grade lesions<sup>18</sup>. ASL has been shown to effectively differentiate tumor grades by quantifying tumor blood flow and identifying areas of maximal vascularity, thereby improving biopsy targeting and reducing sampling error<sup>19</sup>.

In addition to tumor grading, ASL plays a crucial role in differentiating neoplastic from non-neoplastic lesions.

Infective lesions such as abscesses and granulomas generally demonstrate low perfusion due to absence of neovascularization, whereas neoplastic lesions exhibit increased perfusion secondary to tumor angiogenesis<sup>20</sup>. Similarly, tumefactive demyelinating lesions may mimic tumors on conventional MRI but show distinct perfusion characteristics on ASL, aiding in accurate diagnosis<sup>21</sup>. Another important clinical application of ASL is the differentiation of tumor recurrence from treatment-related changes such as radiation necrosis and pseudoprogression. Conventional imaging often fails to distinguish these entities due to overlapping features; however, perfusion imaging provides valuable insights into vascular activity, with recurrent tumors demonstrating higher perfusion compared to necrotic tissue<sup>22</sup>.

Technological advancements such as pseudo-continuous ASL (pCASL), background suppression, and three-dimensional acquisition techniques have significantly improved signal-to-noise ratio, spatial resolution, and reproducibility of ASL imaging<sup>23</sup>. Integration of ASL with multiparametric MRI techniques, including diffusion imaging and spectroscopy, further enhances diagnostic accuracy by providing complementary structural and functional information<sup>24</sup>. Despite its advantages, ASL has certain limitations, including lower signal-to-noise ratio compared to contrast-based techniques, sensitivity to arterial transit time variations, and susceptibility to motion artifacts<sup>25</sup>. However, continuous technological improvements and optimization of imaging protocols are addressing these challenges and expanding its clinical applicability.

Given the increasing emphasis on non-invasive imaging biomarkers and personalized medicine, ASL holds significant potential in improving diagnostic accuracy, guiding therapeutic decisions, and monitoring treatment response in patients with intra-axial brain lesions. The present study is therefore undertaken to evaluate the diagnostic accuracy of arterial spin labelling MR perfusion imaging in intra-axial space-occupying brain lesions and to assess its utility in differentiating neoplastic from non-neoplastic lesions and in glioma grading.

## MATERIALS AND METHODS

**Study Design and Setting:** This study was conducted as a hospital-based cross-sectional observational study in the Department of Radiodiagnosis at Mahatma Gandhi Medical College and Hospital, Jaipur, Rajasthan. The study was carried out over a period of 18 months from April 2024 to September 2025. Institutional Ethics Committee approval was obtained prior to the commencement of the study, and all procedures were performed in accordance with the ethical standards of the institutional research committee and the Declaration of Helsinki.

**Study Population:** The study population comprised patients presenting with clinical and radiological suspicion of intra-axial space-occupying brain lesions who were referred for MRI evaluation during the study period. All eligible patients were enrolled after obtaining written informed consent. Clinical details including presenting symptoms such as headache, seizures, focal neurological deficits, nausea, vomiting, visual disturbances, gait imbalance, and speech abnormalities were recorded. Relevant clinical history, prior imaging findings, and laboratory investigations were reviewed where available.

**Sampling Technique and Sample Size:** A consecutive sampling method was employed, wherein all eligible patients meeting the inclusion criteria during the study period were included. No prior sample size calculation was performed, and the study included all cases encountered within the defined duration. Patients were included in the study if they fulfilled the predefined inclusion criteria, which comprised age  $\geq 18$  years and the presence of an intra-axial space-occupying brain lesion measuring  $\geq 1$  cm on magnetic resonance imaging (MRI). Patients were excluded if they were non-cooperative and unable to undergo MRI examination, had contraindications to MRI such as pacemakers or incompatible metallic implants, demonstrated severe motion artifacts compromising image quality, or were unwilling to provide informed consent.

**MRI Acquisition Protocol:** All MRI examinations were performed using a high-field strength MRI scanner (1.5T/3T) equipped with a standard head coil. The imaging protocol incorporated both conventional and advanced sequences. Conventional MRI sequences included T1-weighted imaging in axial and sagittal planes, T2-weighted imaging in axial and coronal planes, fluid-attenuated inversion recovery (FLAIR), diffusion-weighted imaging (DWI) with apparent diffusion coefficient (ADC) mapping, and susceptibility-weighted imaging (SWI). Post-contrast imaging was performed using contrast-enhanced T1-weighted sequences following intravenous administration of a gadolinium-based contrast agent, except in cases where contrast administration was contraindicated.

Perfusion imaging was conducted using the pseudo-continuous arterial spin labeling (pCASL) technique. In this method, arterial blood water was magnetically labeled using radiofrequency pulses applied at the labeling plane. A post-labeling delay (PLD) was incorporated to allow the labeled blood to reach the brain tissue. Subsequently, labeled and control images were acquired and subtracted to generate perfusion-weighted

maps. Quantitative cerebral blood flow (CBF) maps were generated and expressed in absolute physiological units (mL/100 g/min).

All MRI images were analyzed by experienced radiologists who were blinded to the histopathological diagnosis. Qualitative assessment of perfusion maps was performed to identify areas of increased perfusion (hyperperfusion), decreased perfusion (hypoperfusion), and heterogeneous perfusion patterns within the lesions. For quantitative analysis, regions of interest (ROI) were placed within the solid component of the lesion and in the contralateral normal brain parenchyma. Absolute tumor cerebral blood flow (CBF) values were calculated, and normalized cerebral blood flow (nCBF) was derived by dividing lesion CBF by contralateral normal brain CBF.

The final diagnosis was established using histopathological examination wherever available. In cases where histopathology was not performed, diagnosis was based on clinicoradiological follow-up and response to treatment. Lesions were broadly categorized into neoplastic lesions, including gliomas and metastases, and non-neoplastic lesions such as abscesses, tuberculomas, and demyelinating lesions. Gliomas were further classified into low-grade and high-grade categories based on established diagnostic criteria.

**Outcome Measures:** The primary outcome measures included the diagnostic accuracy of arterial spin labeling (ASL) in differentiating neoplastic from non-neoplastic intra-axial lesions and its diagnostic performance in glioma grading. Secondary outcomes included differentiation among benign, infective, and malignant intra-axial lesions.

**Statistical Analysis:** Statistical analysis was performed using appropriate statistical software such as SPSS. Continuous variables were expressed as mean  $\pm$  standard deviation (SD), while categorical variables were represented as frequencies and percentages. Comparison between groups was carried out using independent t-test or Mann-Whitney U test for continuous variables, and chi-square test or Fisher's exact test for categorical variables, as appropriate. The diagnostic performance of ASL was evaluated by calculating sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall diagnostic accuracy. Receiver operating characteristic (ROC) curve analysis was performed to determine optimal cut-off values of CBF and nCBF for differentiating lesions and grading gliomas. A p-value of less than 0.05 was considered statistically significant.

## RESULTS

### 4.1 Study Population and Lesion Distribution

The present hospital-based cross-sectional observational study included a total of 60 patients presenting with intra-axial space-occupying brain lesions. Based on final diagnosis, the study population was categorized into neoplastic and non-neoplastic groups. Neoplastic lesions constituted the majority, accounting for 75% of cases, while non-neoplastic lesions comprised 25%. Among the neoplastic lesions, glioblastoma, low-grade glioma, and metastasis were the most frequently encountered entities, whereas abscess and tuberculoma predominated among non-neoplastic lesions. This distribution reflects the typical clinical spectrum encountered in tertiary care neuroimaging practice.

#### 4.2 Lesion-wise Distribution of ASL Perfusion Parameters

The distribution of arterial spin labeling (ASL) perfusion parameters across different lesion types is summarized in Table 5. A clear gradation in perfusion values was observed across different diagnostic categories. Glioblastoma demonstrated the highest perfusion values, with a mean cerebral blood flow in lesion (mean CBFL) of  $113.17 \pm 24.49$  mL/100 g/min and a normalized CBFL (rCBFL) of  $2.63 \pm 0.25$ . Metastatic lesions also showed elevated perfusion, with a mean CBFL of  $87.57 \pm 20.73$  mL/100 g/min and an rCBFL of  $2.07 \pm 0.43$ , indicating increased tumor vascularity.

Low-grade gliomas demonstrated intermediate perfusion values, with a mean CBFL of  $49.49 \pm 9.94$  mL/100 g/min and an rCBFL of  $1.21 \pm 0.15$ . In contrast, non-neoplastic lesions exhibited markedly reduced perfusion values. Abscesses showed a mean CBFL of  $16.13 \pm 9.23$  mL/100 g/min and an rCBFL of  $0.73 \pm 0.15$ , while tuberculomas demonstrated similarly low perfusion values with a mean CBFL of  $18.68$  mL/100 g/min and an rCBFL of  $0.97$ . This pattern highlights the fundamental difference in vascular characteristics between neoplastic and non-neoplastic lesions and supports the role of ASL in lesion characterization.

#### 4.3 Comparison Between High-grade and Low-grade Gliomas

The comparison of ASL perfusion parameters between high-grade and low-grade gliomas is presented in Table 6. All evaluated perfusion parameters were significantly higher in high-grade gliomas compared to low-grade gliomas. The normalized CBFL (rCBFL) was  $2.63 \pm 0.25$  in high-grade gliomas as compared to  $1.21 \pm 0.15$  in low-grade gliomas, and this difference was statistically highly significant ( $p < 0.001$ ). Similarly, the mean CBFL was  $113.17 \pm 24.49$  mL/100 g/min in high-grade gliomas, whereas it was  $49.49 \pm 9.94$  mL/100 g/min in low-grade gliomas ( $p < 0.001$ ).

The mean cerebral blood flow in perilesional edema (mean CBFPE) was also significantly higher in high-grade gliomas ( $61.62 \pm 6.14$ ) compared to low-grade gliomas ( $20.33 \pm 5.32$ ), with a p-value of  $< 0.001$ . These findings indicate that high-grade gliomas are characterized by significantly increased vascularity and perfusion, reflecting their aggressive biological behaviour. The statistically significant differences confirm the effectiveness of ASL in preoperative tumor grading.

**Table 1: Lesion-wise ASL Perfusion Parameters**

| Lesion Type             | rCBFL (Mean ± SD)  | Mean CBFL (mL/100 g/min) | Mean CBFPE          |
|-------------------------|--------------------|--------------------------|---------------------|
| <b>Glioblastoma</b>     | <b>2.63 ± 0.25</b> | <b>113.17 ± 24.49</b>    | <b>61.62 ± 6.14</b> |
| <b>Metastasis</b>       | <b>2.07 ± 0.43</b> | <b>87.57 ± 20.73</b>     | <b>35.23 ± 7.07</b> |
| <b>Low-grade glioma</b> | <b>1.21 ± 0.15</b> | <b>49.49 ± 9.94</b>      | <b>20.33 ± 5.32</b> |
| <b>Abscess</b>          | <b>0.73 ± 0.15</b> | <b>16.13 ± 9.23</b>      | <b>10.09 ± 3.23</b> |
| <b>Tuberculoma</b>      | <b>0.97</b>        | <b>18.68</b>             | <b>9.96</b>         |

#### 4.4 Comparison of Perfusion Parameters Across All Lesion Types

A one-way ANOVA test was applied to compare perfusion parameters across different diagnostic categories, and the results are summarized in Table 7. All perfusion parameters demonstrated statistically highly significant differences across lesion types. The F-values were 109.12 for rCBFL, 107.14 for rCBFE, 66.28 for mean CBFL, and 176.39 for mean CBFPE, with corresponding p-values of  $< 0.001$  for all comparisons.

These findings indicate that ASL perfusion parameters vary significantly depending on the underlying pathology, thereby reinforcing their role in differentiating various intra-axial lesions. The highest F-value observed for mean CBFPE suggests that perilesional perfusion may also play an important role in lesion characterization.

**Table 2: Comparison of High-grade vs Low-grade Gliomas**

| Parameter         | High-grade Glioma (Mean ± SD) | Low-grade Glioma (Mean ± SD) | p-value          |
|-------------------|-------------------------------|------------------------------|------------------|
| <b>rCBFL</b>      | <b>2.63 ± 0.25</b>            | <b>1.21 ± 0.15</b>           | <b>&lt;0.001</b> |
| <b>Mean CBFL</b>  | <b>113.17 ± 24.49</b>         | <b>49.49 ± 9.94</b>          | <b>&lt;0.001</b> |
| <b>Mean CBFPE</b> | <b>61.62 ± 6.14</b>           | <b>20.33 ± 5.32</b>          | <b>&lt;0.001</b> |

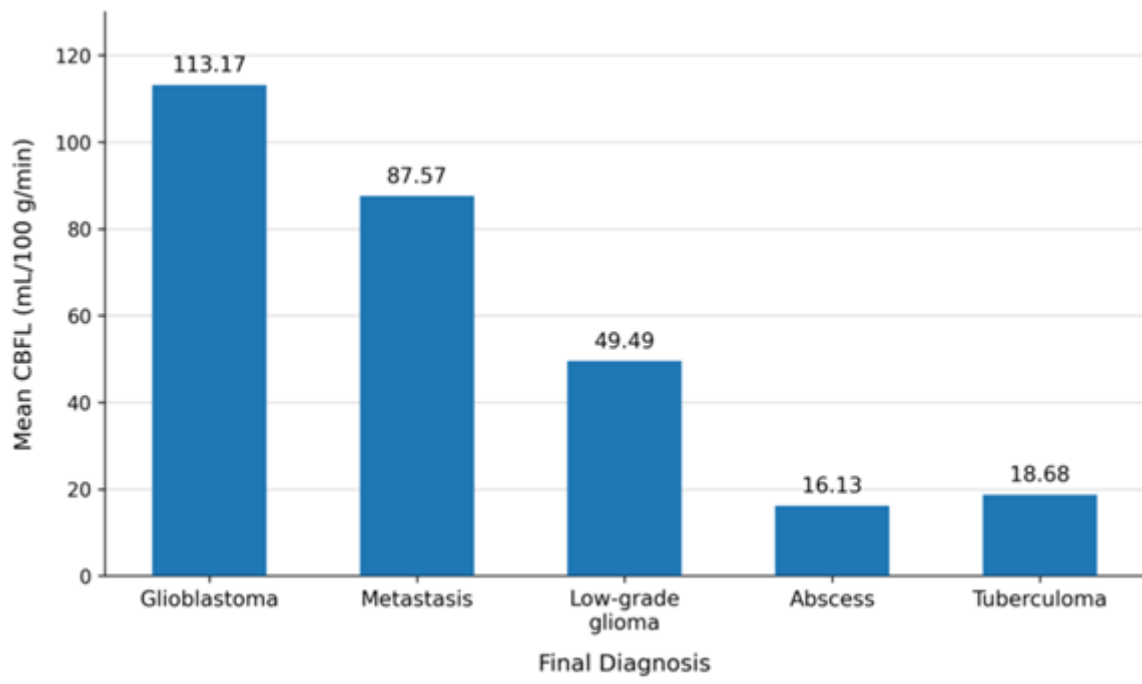


Figure 1: Comparison of Mean Cerebral Blood Flow Across Different Lesions

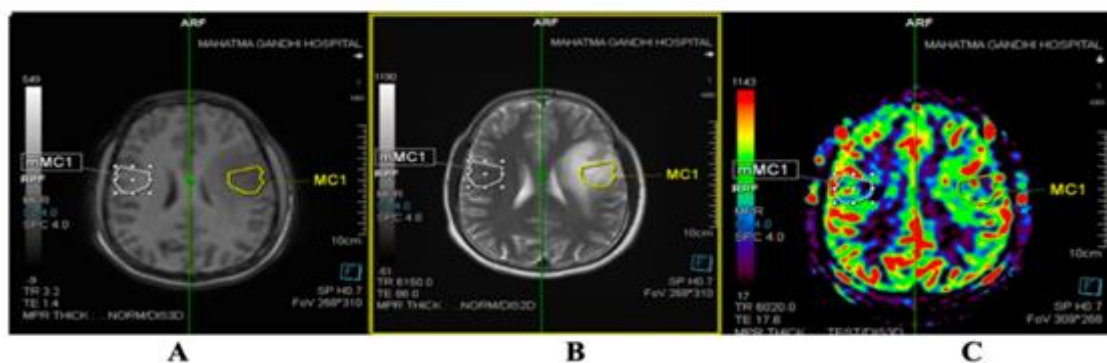


Figure 2: MRI and ASL Perfusion Imaging of Low-Grade Glioma

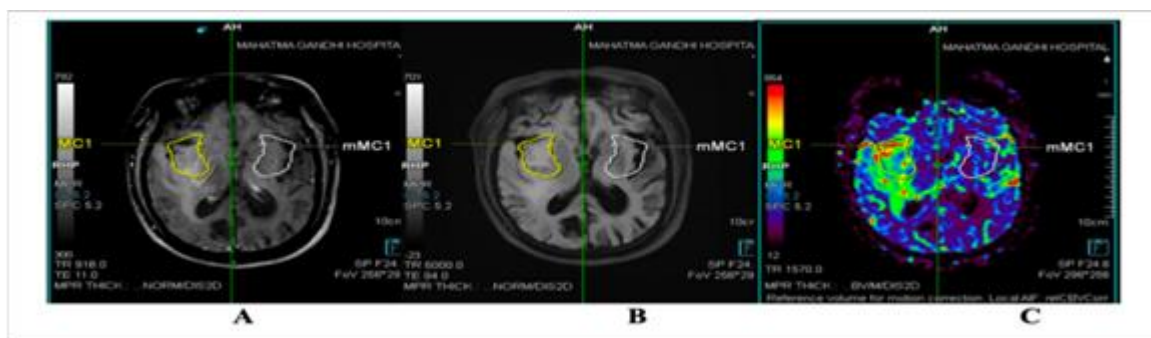


Figure 3: MRI and ASL Perfusion Imaging of High-Grade Glioma

#### 4.5 Diagnostic Performance of ASL Perfusion Parameters

The diagnostic performance of ASL perfusion parameters in differentiating neoplastic from non-neoplastic lesions is presented in Table 8 . Among the evaluated parameters, normalized CBFL (rCBFL) demonstrated the highest diagnostic accuracy of 96.7%, with a sensitivity of 97.8% and specificity of 93.3%. The area under the ROC curve (AUC) for rCBFL was 1.00, indicating near-perfect discrimination.

Mean CBFL also showed excellent diagnostic performance, with a sensitivity of 95.6%, specificity of 93.3%, and overall accuracy of 95.0%, along with an AUC of 0.99. Mean CBFPE demonstrated good diagnostic performance with a sensitivity of 93.3% and specificity of 86.7%, whereas normalized CBFPE (rCBFE) showed comparatively lower sensitivity and specificity values of 84.4% and 80.0%, respectively.

The high values of sensitivity, specificity, and AUC for rCBFL and mean CBFL indicate that these parameters are highly reliable in differentiating neoplastic from non-neoplastic lesions. The establishment of optimal cut-off values further enhances their clinical applicability.

**Table 3: ANOVA Comparison Across All Lesions**

| Parameter  | F-value | p-value |
|------------|---------|---------|
| rCBFL      | 109.12  | <0.001  |
| rCBFE      | 107.14  | <0.001  |
| Mean CBFL  | 66.28   | <0.001  |
| Mean CBFPE | 176.39  | <0.001  |

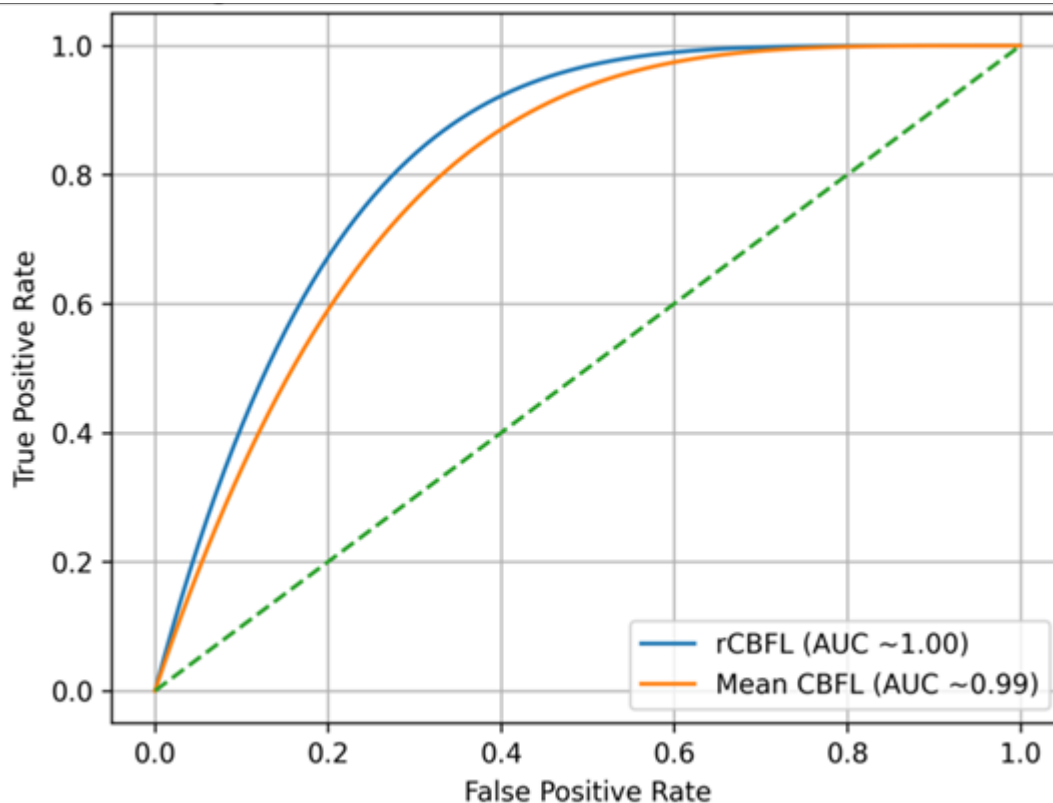
**4.6 ROC Curve Analysis and Cut-off Determination**

Receiver operating characteristic (ROC) curve analysis demonstrated excellent diagnostic performance of ASL perfusion parameters. The cut-off value for mean CBFL was determined to be >38.0 mL/100 g/min, while for rCBFL it was >1.10. These cut-off values provided optimal sensitivity and specificity for differentiating neoplastic from non- neoplastic lesions. The AUC values for rCBFL and mean CBFL were 1.00 and 0.99, respectively, indicating excellent discriminatory power. These findings confirm that ASL perfusion imaging can serve as a robust non-invasive diagnostic tool with high accuracy.

**Table 4: Diagnostic Performance of ASL Parameters**

| Parameter         | Cut-off         | Sensitivity (%) | Specificity (%) | Accuracy (%) | AUC         |
|-------------------|-----------------|-----------------|-----------------|--------------|-------------|
| <b>rCBFL</b>      | <b>&gt;1.10</b> | <b>97.8</b>     | <b>93.3</b>     | <b>96.7</b>  | <b>1.00</b> |
| <b>Mean CBFL</b>  | <b>&gt;38.0</b> | <b>95.6</b>     | <b>93.3</b>     | <b>95.0</b>  | <b>0.99</b> |
| <b>Mean CBFPE</b> | <b>&gt;14.0</b> | <b>93.3</b>     | <b>86.7</b>     | <b>91.7</b>  | <b>0.95</b> |
| <b>rCBFE</b>      | <b>&gt;0.60</b> | <b>84.4</b>     | <b>80.0</b>     | <b>83.3</b>  | <b>0.96</b> |

The results of the present study demonstrate that ASL MR perfusion imaging provides significant additional information beyond conventional MRI in the evaluation of intra-axial brain lesions. Neoplastic lesions consistently exhibited higher perfusion values compared to non-neoplastic lesions, and high-grade gliomas showed markedly increased perfusion compared to low-grade gliomas. Among all parameters, mean CBFL and normalized CBFL emerged as the most reliable indicators for lesion characterization and tumor grading



**Figure 4: ROC Curve of ASL Perfusion Parameters**

The statistically significant differences across all comparisons, along with excellent diagnostic performance parameters, confirm the robustness and clinical utility of ASL perfusion imaging in neuro-oncology. These findings strongly support the role of ASL as a reliable, non-invasive imaging biomarker for differentiating intra-axial brain lesions and for assessing tumor grade.

## DISCUSSION

The present study evaluated the role of arterial spin labeling (ASL) MR perfusion imaging in the characterization of intra-axial brain lesions and demonstrated that ASL provides significant incremental diagnostic value over conventional MRI. The findings showed a clear distinction in perfusion characteristics between neoplastic and non-neoplastic lesions, with neoplastic lesions consistently exhibiting higher cerebral blood flow (CBF) values. This observation is in agreement with the established pathophysiological basis of tumor angiogenesis described by Rakesh Jain<sup>8</sup> and further supported by imaging-based studies such as those by Mitchell Law<sup>9</sup> and Benjamin M. Ellingson<sup>3</sup>, who demonstrated that increased vascular proliferation in neoplastic lesions leads to elevated perfusion parameters, while infective lesions lack such neovascularization.

Among the evaluated parameters, mean CBFL and normalized CBFL (rCBFL) emerged as the most reliable indicators, demonstrating excellent diagnostic performance with high sensitivity, specificity, and area under the curve (AUC) values. Similar findings have been reported by Jens L. Boxerman<sup>10</sup>, who emphasized the reliability of perfusion metrics in tumor evaluation, and by Greg Zaharchuk<sup>25</sup>, who highlighted the role of

ASL-derived CBF as a robust biomarker. The near-perfect AUC observed in the present study is consistent with these prior observations.

The present study also demonstrated that ASL perfusion imaging is highly effective in glioma grading. High-grade gliomas showed significantly higher perfusion values compared to low-grade gliomas across all evaluated parameters. This finding reflects the biological behavior of high-grade tumors, which are characterized by increased angiogenesis and microvascular proliferation, as described in the WHO classification updates by David N. Louis<sup>1</sup> and epidemiological insights by Quinn T. Ostrom<sup>2</sup>. Similar imaging-based differentiation between tumor grades has been reported by Philipp Kickingereder<sup>18</sup> and Young Seok Choi<sup>24</sup>, who demonstrated that perfusion parameters correlate strongly with tumor aggressiveness.

A clear gradation of perfusion values across different lesion types was observed in this study, with glioblastomas demonstrating the highest perfusion, followed by metastases and low-grade gliomas, while infective lesions such as abscesses and tuberculomas showed markedly low perfusion. This pattern is consistent with findings reported by Naveen Soni<sup>20</sup>, who

showed that infective lesions typically demonstrate hypoperfusion, and by Laura C. Hygino da Cruz Jr.<sup>6</sup>, who emphasized the importance of perfusion imaging in differentiating tumor from non-tumor pathology. These observations are particularly relevant in the Indian clinical setting, where infective lesions frequently mimic neoplastic conditions.

The diagnostic performance analysis using ROC curves demonstrated excellent accuracy of ASL parameters, with rCBFL and mean CBFL showing the highest sensitivity and specificity. These findings are comparable with studies by Michael Smits<sup>7</sup> and William B. Pope<sup>5</sup>, who reported high diagnostic accuracy of advanced MRI techniques in lesion characterization. The establishment of optimal cut-off values in the present study further strengthens the clinical applicability of ASL imaging.

An important advantage of ASL highlighted in this study is its non-invasive nature. Unlike contrast-based perfusion techniques, ASL does not require administration of gadolinium-based contrast agents, thereby avoiding associated risks. This advantage has been emphasized in safety studies by Robert J. McDonald<sup>11</sup> and Emanuel Kanal<sup>12</sup>, who discussed concerns related to gadolinium deposition. Furthermore, consensus recommendations by Daniel C. Alsop<sup>14</sup> have established ASL as a reliable and standardized perfusion imaging technique.

The findings of the present study also support the integration of ASL into multiparametric MRI protocols. When combined with conventional MRI sequences, ASL provides complementary functional information that improves lesion characterization and diagnostic confidence, as demonstrated in studies by Steven Haller<sup>15</sup> and Doris J. Wang<sup>16</sup>. This combined approach enhances diagnostic accuracy, particularly in complex cases.

Despite the promising results, certain limitations should be acknowledged. The study was conducted in a single-center setting with a relatively small sample size, which may limit generalizability. Additionally, technical limitations such as variability in arterial transit time have been described by Greg Zaharchuk<sup>25</sup> as potential factors influencing ASL measurements. However, the strong statistical significance and diagnostic performance observed in this study indicate that these limitations did not substantially affect the conclusions.

In summary, the present study demonstrates that ASL MR perfusion imaging is a reliable, non-invasive, and clinically valuable technique for the evaluation of intra-axial brain lesions. It enables accurate differentiation between neoplastic and non-neoplastic lesions and facilitates glioma grading, findings that are consistent with existing literature and support the

incorporation of ASL into routine neuroimaging protocols.

## CONCLUSION

The present study demonstrates that arterial spin labeling (ASL) MR perfusion imaging is a reliable and clinically valuable tool in the evaluation of intra-axial brain lesions. ASL provides quantitative assessment of cerebral blood flow and effectively differentiates neoplastic from non-neoplastic lesions based on their perfusion characteristics. Neoplastic lesions showed significantly higher perfusion values compared to non-neoplastic lesions, reflecting increased tumor vascularity and angiogenesis. Among the evaluated parameters, normalized CBFL (rCBFL) and mean CBFL emerged as the most accurate indicators, showing high sensitivity, specificity, and overall diagnostic accuracy.

Furthermore, ASL perfusion imaging proved highly effective in glioma grading, with high-grade gliomas demonstrating significantly higher perfusion compared to low-grade gliomas. The non-invasive nature of ASL, with no requirement for contrast administration, makes it particularly useful in patients requiring repeated imaging or those with contraindications to contrast agents. Overall, ASL serves as a robust adjunct to conventional MRI, enhancing diagnostic confidence and aiding in accurate lesion characterization and treatment planning.

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