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Computers in Biology and Medicine
Volume 187, March 2025, 109763

# MRI morphological features combined with apparent diffusion coefficient can predict brain invasion in meningioma

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Received 30 December 2023, Revised 12 January 2025, Accepted 28 January 2025, Available online 4 February 2025, Version of Record 4 February 2025.

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## Highlights

- Preoperative prediction of brain invasion in meningiomas is critical for improving clinical decision-making and prognosis.
- A combined model integrating ADC values, MRI morphological features, and clinical factors was developed.

- The model demonstrated excellent performance, with an AUC of 0.924 and a sensitivity of 92.2%.
- ADCmin was identified as a key predictor, alongside tumor size and peritumoral edema.
- The proposed nomogram provides a non-invasive, reliable tool for clinicians to assess brain invasion in meningiomas.


## Abstract

### Objectives

Accurately predicting meningioma brain invasion preoperatively helps to select the appropriate surgical approach and predict prognosis, but there are few imaging features that are sufficient for discriminating it alone. We investigate the joint MR imaging features and apparent diffusion coefficient (ADC) to predict the risk of brain invasion of meningiomas preoperatively.

### Methods

In this retrospective study, 143 patients (invasion group:51, non-invasion group: 92) diagnosed with meningioma by histopathology were included. The maximum ($ADC_{max}$), minimum ($ADC_{min}$) and mean ($ADC_{mean}$) values of ADC and the mean ADC values of a comparative ROI in the normal appearing white matter ($ADC_{NAWM}$) were calculated. Differences between clinical features, MRI morphological features, and all ADC values were assessed by Pearson's chi-square test and Kruskal-Wallis rank-sum test. Stepwise logistic regression analysis was used to select the optimal features and construct a prediction model. Furthermore, A nomogram was used to predict the risk of brain invasion, and a decision curve was used to verify the clinical utility of the nomogram.

### Results

According to stepwise logistic regression analysis, we found that sex, maximum diameter, peritumoral edema and $ADC_{min}$ were closely related to brain invasion in meningioma. The model of the above four variables has the optimal discriminative ability to predict brain invasion, with an AUC of 0.924 (95% CI, 0.879–0.969) and a sensitivity of 92.2% (95% CI, 74.5%–98.0%).

### Conclusions

Combining clinical features, MRI morphological characteristics and $ADC_{min}$, the model exhibits excellent discriminatory ability and high sensitivity, which can be used for predicting the risk of brain invasion of meningiomas.

## Introduction

The pathological examination of brain invasion is an independent grading diagnostic criterion for tumor heterogeneity in the 2021 World Health Organization classification [1]. The invasion of the brain by a meningioma is defined as the presence of meningioma tissue adjacent to the brain, without a separating layer of connective tissue. Since it is independently associated with therapeutic decisions, histopathologic grading, poor prognosis, and recurrence [[2], [3], [4], [5], [6]], Therefore, preoperative prediction of brain invasion has significant clinical implications.

Currently, the pathological examination of organizations is the gold standard for the diagnosis of brain invasion in meningioma [7]. But there are significant challenges in the detection of brain invasion in meningiomas using neuropathology, due to the lack of unified scientific surgical sampling and neuropathological analysis methods. Additionally, the difficulty in obtaining appropriate brain tissue samples from patients with invasive meningiomas may hinder the ability of neuropathology to accurately detect brain invasion in clinical practice. Therefore, neuropathology may have difficulty in truly detecting brain invasion of meningiomas at the clinical practice level [8]. And previous research showed that 85% of the samples were" unable to assess" pathologically [9]. Compared to local pathological diagnosis, imaging studies have the advantage of evaluating tumors and their surrounding environment as a whole [10,11], and Adeli et al. [9], found that preoperative conventional MRI predicted brain invasion and found that increased heterogeneity, irregular tumor shape, and peritumoral edema could be used as predictors of brain invasion. Whereas, preoperative, imaging-guided detection of brain invasion is unspecific [4,12], and the results are still controversial [13]. Recently, several studies have focused on the predicting brain invasion of meningiomas using radiomic features, and found that radiomic model or combined model demonstrated good diagnostic efficiency [11,13]. However, limited by the need for a large sample of data and advanced computational technology support, radiomics analysis has not been routinely applied to clinical practice.

Diffusion-weighted imaging (DWI) is a commonly used imaging method for tumor diagnosis [14]. It can non-invasively measure water diffusion within a tissue and provide information concerning regions of tissue microstructures and increased cellularity [15,16], which is related to the density of cells and the integrity of their membranes [17]. The outer space of small cells, high cell density, and high nucleus-cytoplasmic ratio determine the diffusion efficiency of water molecules [18]. The apparent diffusion coefficient (ADC) obtained by DWI represents the average diffusion level for each voxel. At present, ADC values have been routinely used for differential diagnosis and preoperative grading of meningiomas, including extrahemangiocytomas, solitary fibrous neoplasms, benign and atypical or malignant meningiomas, and microcystic meningioma from atypical meningioma [15,16,[19], [20], [21]]. However, there are few researches evaluating whether ADC is suitable for predicting brain invasion of brain meningiomas.

Thus, in this research, we constructed a predictive model fusing clinical characteristics, MRI morphological features and ADC values to explore the potential link between them and brain invasion. We hypothesize that predictive models can more accurately predict meningioma brain invasion. So, the purpose of our research is: (1) Selection of clinical features, MRI morphological features, and ADC values are related to the brain invasion of meningiomas. (2) A predictive model is established based on these characteristics and ADC values. (3) A nomogram is constructed to predict brain invasion in meningioma patients based on MRI and combined with clinical risk factors, MRI features, and ADC values.



## Section snippets

### Patient cohort

This was a retrospective study and has been approved by the Ethics Review Committee of the Lanzhou University Second Hospital with the ethical review approval number 2020A-109, and abandoned patient's informed consent. Included all meningioma patients who underwent surgery according to the inclusion and exclusion criteria. The inclusion criteria were as follows: (1) Patients are diagnosed with meningioma with clear histological grading; and (2) MR examinations were performed within 1 week prior …

### Patients

Finally, a total of 143 patients at the Lanzhou University Second Hospital were enrolled from January 2016 to January 2021. After surgeon's evaluation, 51 patients (31 female and 20 male, mean age 52.5±10.5 years) were included in the invasion group, and 92 patients (71 female and 21 male, mean age 51.4±10.6 years) were included in the non-invasion group. …

### MRI findings

The MRI morphological and clinical features of the patients are shown in Table 1.

Pearson's $\chi 2$ test and Kruskal-Wallis rank sum test showed …

### Discussion

Until now, this is a preliminary research based on clinical features to develop a nomogram to predict the risk of brain invasion of meningioma, MRI morphological features and ADC values. This fusion model demonstrated excellent discrimination (AUC 0.924) and high sensitivity (92.2%), and can identify and diagnose over 90% of cases of brain invasion of meningiomas. The performance of this nomogram was validated via calibration curves and a more accurate prediction of brain invasion was …

## Conclusion

Preoperative identification of brain invasion will effectively improve the accuracy of clinical decision-making and predict the grading and prognosis of meningiomas. Though stepwise logistic regression analysis, four features (sex, maximum diameter, peritumoral edema and $ADC_{min)}$ showed high correlation with brain invasion. The model combining the above four characteristics showed excellent performance and high sensitivity in predicting brain invasion, which is suitable for the diagnosis of …

## CRediT authorship contribution statement

**Xiaoyu Huang:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation. **Yuntai Cao:** Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Investigation, Conceptualization. **Guojin Zhang:** Writing – review & editing, Writing – original draft, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **FuQiang Tang:** Writing – original draft, Visualization, …

## Key points

- Apparent diffusion coefficient (ADC) measurements aided to improve the discrimination ability for predicting brain invasion in meningioma, which is a non-invasive, convenient method. …
- Maximum diameter and peritumoural edema were multivariable predictors of brain invasion in meningioma. …
- A model combination of Clinical features, MRI morphological features, and ADCmin defined brain invasion in meningioma with sensitivity of 92.2%. …

…

## Ethics statement

This study was approved by the Ethics Review Committee of the Lanzhou University Second Hospital (Approval No. 2020A-109). As a retrospective study, patient informed consent was waived by the ethics committee. All procedures followed ethical guidelines and were conducted in accordance with the Declaration of Helsinki. …

## Declaration of competing interest

The authors hereby declare that there are no conflicts of interest related to this study. All aspects of the research, including study design, data collection, analysis, and interpretation, were conducted independently and without any financial, professional, or personal relationships that could potentially influence the outcomes. We affirm that this work was undertaken solely for the advancement of scientific knowledge and clinical practice. ...

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FuQiang Tang, Dandan Sun, Jialiang Ren, Wenyi Li, Junlin Zhou, and Jing Zhang contributed to the study in the order listed.

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