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A proposed imaging scoring system to differentiate dural-based metastasis from meningioma using MR and CT images

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Abstract

Background and purpose The differentiation between dural-based metastasis and meningioma, which is the most common benign extra axial tumor, is crucial, particularly when staging patients with known primary neoplasms. The purpose of this study was to assess CT and MR imaging features and to validate a proposed imaging scoring system to differentiate between the two pathologies.

Materials and methods A total of 84 patients with pathologically proven meningioma and 31 dural-based metastases were included in this retrospective study. The CT and MR imaging features, including the mean apparent diffusion coefficient (ADC), presence of edema, cystic changes, dural tail, leptomeningeal enhancement, calcifications, bone destruction and hyperostosis, were evaluated. The efficacy of the proposed imaging method for meningioma and its benign findings was evaluated.

Results There was a significant difference in most of the imaging features between patients with meningiomas and those with dural-based metastasis. The presence of vasogenic edema, leptomeningeal enhancement and bone destruction was significantly greater in patients with dural-based metastasis. Bone destruction and leptomeningeal enhancement showed the highest specificity for dural-based metastasis. There was also a significant difference between the two pathologies according to the proposed scoring system, with a P value < 0.001. Receiver Operator Characteristic (ROC) curve analysis was done to optimize the cutoff point which was identified as score 2 and above which has high 89.6% diagnostic accuracy for meningioma.

Conclusion The proposed imaging scoring system could be an effective tool for predicting the diagnosis of meningioma. This can be utilized to discriminate between meningioma and dural-based metastasis, particularly when staging patients with known primary neoplasms.

Keywords Meningioma, Dural metastasis, Scoring, Diagnosis

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Background

Meningiomas are the most common intracranial neoplasms, accounting for 39% of all intracranial tumors overall [1]. Meningiomas originate from the meninges surrounding the brain and typically have benign histology. Headache is the most common presentation in patients with meningioma and is seen in more than 48% of patients [2]. Asymptomatic incidental meningioma can also be commonly seen as an incidental finding in almost 0.52% of all MRI exams, as reported in one of the large meta-analysis studies [3].

On the other hand, metastasis is the most common malignant brain neoplasm. Dural-based metastasis is a subset of brain metastasis that usually originates from hematogenous spread or direct extension from adjacent osseous metastasis. Dural metastasis is not uncommon and can occur in up to 9% of patients with primary cancer at autopsy [4].

MRI (magnetic resonance imaging) of the brain is the modality of choice for evaluating patients with neurological symptoms and assessing for intracranial neoplasms if clinically suspected. Both meningiomas and dural-based metastases involve the meninges and can be difficult to distinguish on MRI. Dural-based metastasis is one of the known meningioma mimics in MR images of the brain [5]. The distinction between the two pathologies can be a clinical dilemma, especially in patients with known primary cancer. This distinction has clinical significance in regard to the staging of patients with primary cancer. This is also important in regard to the management of these two pathologies. Meningioma is a benign tumor that can be conservatively managed with follow-up, especially if it is asymptomatic and not associated with mass effects. Surgical resection is still the mainstay for meningioma management if clinically warranted [6]. On the other hand, dural-based metastases are malignant tumors that are managed differently and usually require a combination of surgical resection and chemoradiotherapy.

The imaging features can overlap with different degrees of specificity and accuracy. Currently, there is no MRI or CT diagnostic tool or scoring system to confidently distinguish between the two pathologies. The aim of this study was to assess MRI and CT imaging features and to validate a scoring system to discriminate between the two pathologies.

Table 1 Patients demographics and pathology findings

		n	
Age	Mean ± sd	51.9	11.6
Gender	Female	89	77%
	Male	26	23%
Diagnosis	Meningioma	84	73%
	Dural metastasis	31	27%
Meningioma Grade	1	68	81%
	2	16	19%
All cases	Meningioma Grade 1	68	59%
	Meningioma Grade 2	16	14%
	Dural metastasis	31	27%

Methods

Study setting

This retrospective, single-center study was approved by our local institutional review board. The study included patients who were treated for dural-based metastasis or meningioma in the oncology and neurosurgical departments. All imaging features were assessed in the radiology department utilizing dedicated diagnostic radiology monitors with the integrated Picture Archiving and Communication System (PACS).

Study subjects

A total of 84 patients (73%) with pathologically proven meningioma and 31 (27%) with dural-based metastasis were included in this study. A total of 89 (77%) patients were female, and 26 (23%) patients were male, with an average age of 51.9 years (Table 1). The inclusion criteria included adults with pathologically proven diagnoses who had undergone preoperative MRI and CT of the brain according to our radiology system. Patients with primary brain neoplasms such as glioma were excluded. All patients underwent surgical resection or debulking, and the diagnosis was made by an experienced neuropathologist. Meningiomas were classified according to the WHO grading system as grade I-III. Of the 84 meningiomas, 68 (81%) were Grade I, and 16 (19%) were Grade II. No grade III meningiomas were found in our cohort.

MRI scanning setting

The patients were scanned on 3T Philips Achieva (Eindhoven, Netherlands), 1.5T Siemens Espree (Erlangen, Germany) or 3T GE Discovery (Milwaukee, Wisconsin) scanners. Enhanced routine MRI of the brain was performed for all patients. The routine protocol included Sag T1, axial FLAIR, axial T2, SWI, DWI/ADC and contrast-enhanced T1-weighted images. Dotarem (Guerbet, Aulnay-Sous-Bois, France) was used as the MRI contrast agent for all patients.

Data collection methods

The MRI and CT imaging features were assessed by a senior radiology resident and reviewed by a neuroradiologist with 7 years of experience in brain imaging. The neuroradiologist was blinded to the final pathological diagnosis. First, the CT images were evaluated for the presence of calcifications, bone destruction and hyperostosis. Axial FLAIR, T2, and apparent diffusion coefficient (ADC) maps and postgadolinium T1-weighted images were used to evaluate these dural-based lesions

on MR images. The MRI imaging features included vasogenic edema, cystic changes, CSF cleft signs, leptomeningeal enhancement and dural tail. The T2 appearance was also assessed and classified as isointense, hypointense, hyperintense or heterogeneous compared to the gray matter. The mean apparent diffusion coefficient was also obtained by placing the region of interest (ROI) on the solid component as much as possible to avoid heterogeneity and necrosis. The ROI was drawn along the homogenously enhancing component with care to avoid cystic changes, necrosis and areas of calcifications. One measurement was obtained from each case. Finally, these dural-based lesions were scored for benign findings, including the presence of a CSF cleft, dural tail, calcifications, hyperostosis, and the absence of bone destruction. The total imaging score was calculated by adding up the points, one point for each benign finding and a total score of 5.

Statistical methods

The data were entered into Microsoft Excel, and data analysis was carried out using SPSS v25.0. The descriptive statistics are presented as frequencies and percentages for the categorical variables, while the numerical variables are presented as the means ± standard deviations. The categorical variables were compared by diagnosis type using the chi-square test and Fisher's exact test. Screening analysis was used to compare the findings for dural based metastases, and the results are presented as percentages for the sensitivity, specificity, positive predictive value, and negative predictive value. The significance level was kept at 0.05 for all the statistical tests.

Table 2 Different locations of dural based lesions

		n	%
Location	Cerebral convexity	47	40.9
	Parasagittal	13	11.3
	Olfactory groove	13	11.3
	Sphenoid wing	12	10.4
	Sellar	10	8.7
	Cerebellar convexity	7	6.1
	Parafalcine	5	4.3
	Petroclival	3	2.6
	Tentorial	3	2.6
	Anterior clinoid	2	1.7
	Total	115	100

Table 3 The distribution of primary cancer in patients with dural based metastasis

		n	%
Primary cancer	Breast cancer	15	48%
	Rectal cancer	4	13%
	Lung cancer	3	10%
	Thyroid cancer	3	10%
	Prostate cancer	2	6%
	Marginal zone lymphoma	1	3%
	Mesenchymal chondrosarcoma	1	3%
	Osteosarcoma	1	3%
	Sebaceous cancer	1	3%

Table 4 Analysis of ADC value

	n	Mean	sd	*p*-value
Meningioma Grade 1	68	898.93	352.80	0.87
Meningioma Grade 2	16	853.63	265.59	
Dural metastasis	31	904.61	316.35	
Total	115	894.16	330.22	

Results

A total of 115 patients were included in this study. All patients underwent surgical resection, and the final diagnosis was verified by an expert neuro-pathologist. The locations of these lesions are summarized in (Table 2). A total of 84 (73%) patients with pathologically proven meningioma and 31 (27%) with dural-based metastasis were included. The distribution of primary neoplasms is summarized in (Table 3). Of the 84 meningiomas, 68 (81%) were Grade I, and 16 (19%) were Grade II. No grade III meningiomas were found in our cohort. Assessment of the apparent diffusion coefficient (ADC) revealed no significant difference between patients with meningiomas and patients with dural base metastasis, with a P value of 0.87 (Table 4). There was a significant difference between meningioma and dural base metastasis in regard to most of the MRI and CT imaging features, as detailed in (Table 5). The presence of vasogenic edema, leptomeningeal enhancement and bone destruction was significantly greater in patients with dural-based metastasis. Cystic changes were significantly more common in patients with Grade II meningioma. Dural tail, CSF cleft, calcification and hyperostosis were significantly more common in patients with meningioma than in those with dural-based metastasis. Among these imaging features, the presence of vasogenic edema has the highest sensitivity for predicting the diagnosis of dural based metastasis. Analysis of bone destruction and leptomeningeal enhancement showed the highest specificity for dural-based metastasis, as detailed in (Table 6) (Fig. 1). All patients were scored for benign imaging features, including the presence of a CSF cleft, dural tail, calcifications, hyperostosis, and the absence of bone destruction. Fisher's exact test revealed a significant difference between meningioma patients and patients with dural-based metastasis according to the aforementioned scoring system, with a P value < 0.001. Interestingly, patients with lesions with scores 3 and above had a greater than 90% probability of having meningioma (Fig. 2). Lesions with the highest score of 5/5 had a 100% probability of being meningioma rather than dural-based metastasis

Table 5 Analysis of the different MRI and CT imaging features

		Diagnosis & grade						p-value[a]
		Meningioma grade 1 (*n* = 68)		Meningioma grade 2 (*n* = 16)		Dural metastasis (*n* = 31)		
		n	%	n	%	n	%	
Edema	Yes	43	63%	14	88%	30	97%	**0.001**
	No	25	37%	2	13%	1	3%	
Cystic changes	Yes	11	16%	11	69%	8	26%	**< 0.001**
	No	57	84%	5	31%	23	74%	
CSF cleft	Yes	58	85%	14	88%	12	39%	**< 0.001**
	No	10	15%	2	13%	19	61%	
T2 appearance	Iso	30	44%	3	19%	4	13%	**0.013[b]**
	Hypo	6	9%	0	0%	6	19%	
	Hyperintense	9	13%	4	25%	7	23%	
	Heterogenous	23	34%	9	56%	14	45%	
Leptomeningeal enhancment	Yes	0	0%	1	6%	12	39%	**< 0.001[b]**
	No	68	100%	15	94%	19	61%	
Dural tail	Yes	57	84%	13	81%	6	19%	**< 0.001**
	No	11	16%	3	19%	25	81%	
Calcification	Yes	26	38%	8	50%	3	10%	**0.005**
	No	42	62%	8	50%	28	90%	
Bone destruction	Yes	5	7%	2	13%	15	48%	**< 0.001**
	No	63	93%	14	88%	16	52%	
Hyperosteosis	Yes	28	41%	11	69%	0	0%	**< 0.001**
	No	40	59%	5	31%	31	100%	

a p-values determined using Chi-Square test

b Fisher Exact test used instead of Chi-Square test

Table 6 The analysis of CT and MRI findings when it comes to predicting dural based metastasis

	Sensitivity	Specificity	PPV	NPV
Edema	97%	32%	34%	96%
Cystic changes	26%	74%	27%	73%
CSF cleft	39%	14%	14%	39%
Leptomeningeal enhancement	39%	99%	92%	81%
Dural tail	19%	17%	8%	36%
Calcification	10%	60%	8%	64%
Bone destruction	48%	92%	68%	83%
Hyperostosis	0%	54%	0%	59%

(Table 7). Receiver Operator Characteristic (ROC) curve analysis was done to optimize the cutoff point which was identified as score 2 and above (Fig. 3). Dural lesions with score 2 and above have 90.9% and 95.2% PPV and sensitivity respectively for meningioma. Lesions with score less than 2 have NPV of 85.2% and 74.2% specificity (Table 8).

Discussion

Meningioma is the most common extra-axial-dural-based intracranial tumor. It is considered a benign tumor with grades ranging from I-III according to the WHO classification. The increased use of imaging has led to an increased number of incidental asymptomatic meningiomas, representing up to 20% of newly diagnosed cases [7]. On the other hand, dural-based metastasis can be observed in 4% of cancer patients [8]. Both meningiomas and dural-based metastases share some imaging features, making the distinction difficult and more of a clinical diagnostic dilemma. This is particularly crucial when performing MRI brain staging for patients with primary cancer. Several papers in the literature have discussed the differences in imaging features between meningiomas and dural-based metastases. However, there is still no particular diagnostic tool or scoring system to accurately predict the diagnosis to solve this clinical diagnostic problem.

There is still controversy about the ADC value and its relationship with tumor cellularity and histological nature [9]. The ADC can predict the grade of meningioma according to the literature. A higher ADC is significantly associated with a higher meningioma grade [10]. In our study, there was no significant difference in the apparent diffusion coefficient (ADC) between meningioma patients and patients with dural-based metastasis. These findings further support that meningioma can have similar ADC values to those of dural-based metastasis, as revealed in multiple research papers [11, 12]. The lack of significant difference could be also attributed to the heterogeneity of the meningioma cases as we included both grade I and II in comparison to dural based metastasis. Technical factors such as placement of the ROI,

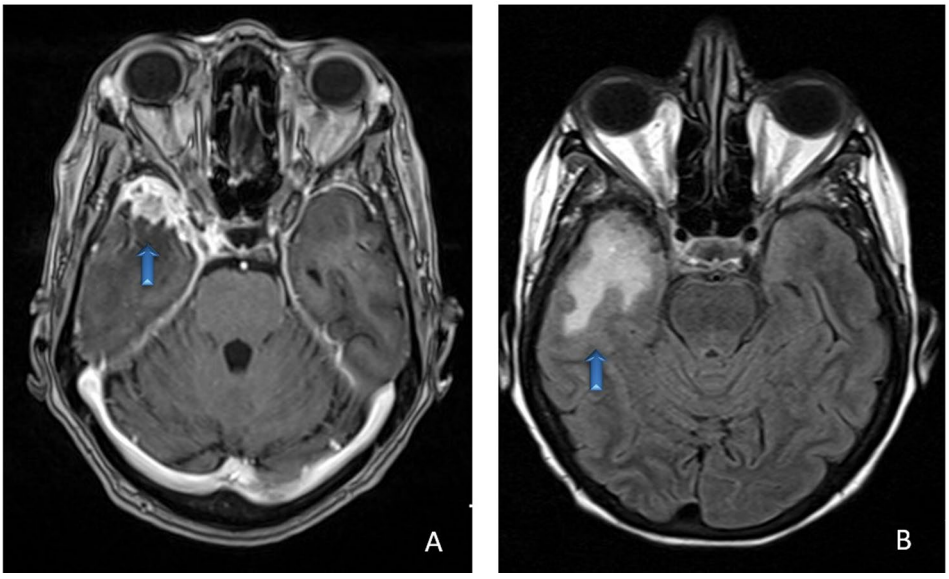

Fig. 1 **a**. Contrast enhanced T1WI shows an extra axial enhancing mass at the right sphenoid wing with dural tail and subtle leptomeningeal enhancement. **b**. Axial FLAIR image shows adjacent right temporal vasogenic edema. No other lesions found. Findings were favored to represent a meningioma initially. Final workup and pathology revealed breast cancer dural based metastasis

homogeneity of the tumor and ROI size could also be additional factors.

In our study, the presence of CSF cleft, dural tail and hyperostosis was significantly greater in patients with meningiomas. These findings usually indicate a long-standing process with reactive changes in the setting of meningioma resulting in dural tail and bony hyperostosis. Hyperostosis was also significantly greater in Grade II meningiomas, possibly because of certain bone stimulation factors [13]. A dural tail is considered a typical feature of meningioma, but other lesions can result in this appearance, such as granulomatous lesions [14]. In our study, the dural tail showed only a limited negative predictive value (36%) for dural metastasis. It is true that dural tail is highly suggestive of meningioma, but it is not pathognomonic. Dural tail has been also described with dural metastasis in the literature. As pathophysiology, dural tail can be seen as result of regional vascular stasis, lymphocytic or histiocytic infiltration as such it is not unique for meningioma.

Tumor calcification is a common finding in benign meningiomas in up to 30% of cases [15]. The presence of calcifications was significantly greater in patients with meningiomas in our cohort, similar to what was found in the literature [16]. Only 3 dural-based metastatic lesions showed calcification.

The pathogenesis of peritumoral edema is complex and multifactorial, depending on the tumor location, size, and mass effect. It can also be related to certain interleukin and endothelial growth factors [17]. The presence of these factors can also result in peritumoral vasogenic edema regardless of tumor grade [18]. Vasogenic edema can also be observed in patients with dural-based metastasis due to different factors. In this study, the presence of vasogenic edema showed a high sensitivity of up to 97% for detecting dural metastasis but a limited specificity of 32%. It was also present in 68% of patients in the meningioma group.

Bone destruction usually reflects an aggressive lesion. Our cohort showed high specificity for dural metastasis, reaching 92%. These findings were comparable to what was reported in the literature [19]. However, it was also present in 8% of the patients with meningiomas. Leptomeningeal enhancement also usually reflects an invasive aggressive lesion. It also showed a high specificity of 99% and a positive predictive value of 92%. Leptomeningeal enhancement was found only in one patient in the meningioma group.

In summary, most of these features were significantly different between meningioma and dural-based metastasis, but none of them were sufficient to make a clear distinction. The aim of this study was to use these imaging features in combination by proposing a scoring system. The use of all these features and scoring systems may have greater accuracy in predicting the final pathological diagnosis. In this study, there was a significant difference between dural-based metastasis and meningioma according to a score < 0.001. Lesions with at least 3 positive benign findings have a high probability (90%) of meningioma. Lesions with a score of 4/5 had a 96% probability of meningioma. Lesions with 5 benign findings scoring 5/5 were 100% more likely to be meningiomas than dural-based metastases. The cutoff point was also

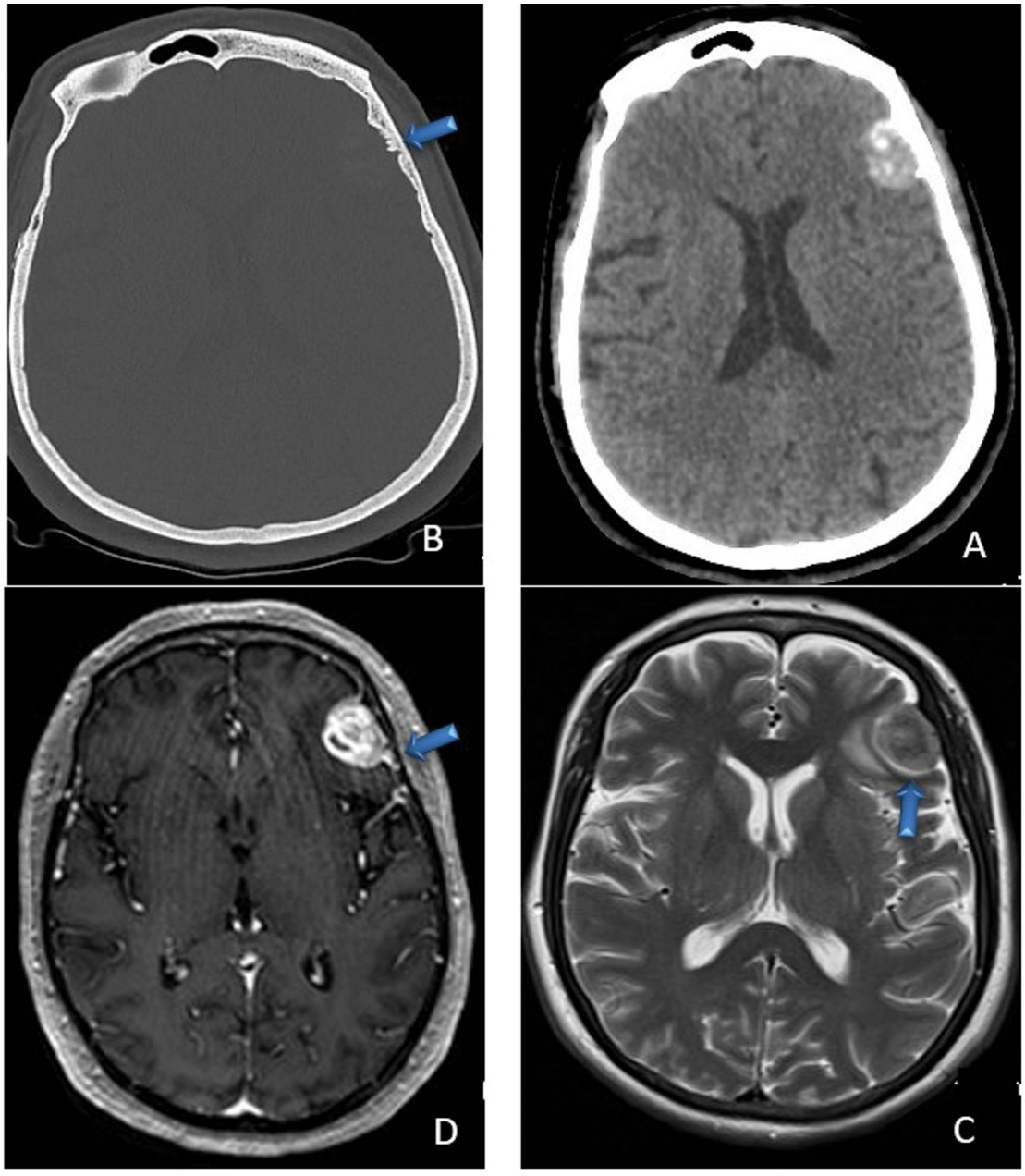

Fig. 2 **a**. Axial non enhanced CT brain shows left frontal extra axial calcified mass. **b**. Axial CT brain bone window shows underlying hyperostosis. **c**. MRI brain axial T2 image shows a CSF cleft along the lesion with mild surrounding edema. **d**. Contrast enhanced MRI brain T1WI shows enhancing extra axial mass with dural tail. Final pathology revealed grade I meningioma

optimized and identified as score 2 and above with high diagnostic accuracy.

Limitations

The small sample size of patients with dural-based metastasis could be a source of bias and might limits the generalizability of our findings. Although it is not uncommon for patients to have dural-based metastasis, we aimed to include only lesions with definitively confirmed cases by histopathology to minimize any bias. The lack of grade III meningioma might be a source of bias, as we did not have any cases of grade III meningioma in our cohort, but this is rarely encountered in clinical practice. This may also impact the validity of the proposed scoring system as grade III meningiomas are usually aggressive and could have overlapping features with dural based metastasis. In this study, we included only pathologically confirmed patients who underwent surgical resection or debulking, which are generally large lesions with mass effects necessitating surgical intervention. Smaller asymptomatic

Table 7 The probability of the dural based lesion based on the proposed scoring system. All dural-based lesions were scored for 5 benign findings, including the presence of a CSF cleft, dural tail, calcifications, hyperostosis, and the absence of bone destruction. The total imaging score was obtained by adding up the points, one point for each benign finding

		Diagnosis			*p*-value
		Total	**Meningioma**	**Dural metastasis**	
Scoring	0	7	0	7	**< 0.001**[a]
		100%	0%	100%	
	1	20	4	16	
		100%	20%	80%	
	2	15	11	4	
		100%	73%	27%	
	3	29	26	3	
		100%	90%	10%	
	4	28	27	1	
		100%	96%	4%	
	5	16	16	0	
		100%	100%	0%	
	Total	115	84	31	
		100%	73%	27%	

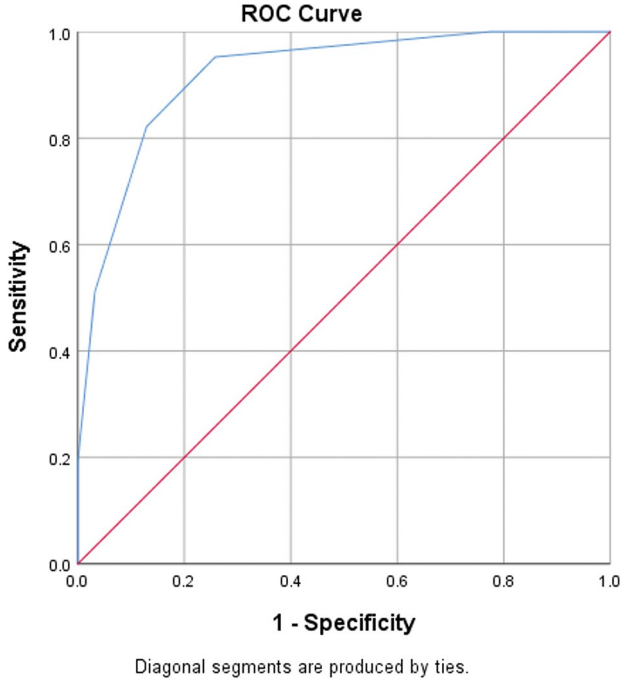

Fig. 3 ROC curve analysis and the optimal cutoff point

lesions may not behave similarly according to the proposed scoring system. However, further studies might be needed to generalize these results to smaller lesions. Finally, the proposed scoring system was tested in this cohort but it does need external validation and probably more cases to generalize these results.

Table 8 A the sensitivity and specificity of the scoring system using score 2 + as cutoff point. B the diagnostic test accuracy of the scoring system using score 2 + as cutoff point

	Meningioma		
Screening Score	**Yes**	**No**	**Total**
A			
Score 2+	80	8	**88**
Sensitivity (%)	95.2%		
Score < 2	4	23	**27**
Specificity (%)		74.2%	
Total	**84**	**31**	**115**
B			
Parameter	**Estimate**	**Lower - Upper 95% CIs**	
Sensitivity	95.2%	(88.4, 98.1)	
Specificity	74.2%	(56.8, 86.3)	
Positive Predictive Value	90.9%	(83.1, 95.3)	
Negative Predictive Value	85.2%	(67.5, 94.1)	
Diagnostic Accuracy	89.6%	(82.6, 93.93)	

Conclusion

Differentiating between meningioma and dural metastasis is crucial when staging oncology patients. The proposed imaging scoring system is likely an effective tool for predicting the diagnosis of meningioma. This can be utilized to discriminate between meningioma and dural-based metastasis, particularly when staging patients with known primary neoplasms. The implementation of such a scoring system will hopefully improve the diagnostic accuracy of discriminating between the two pathologies by imaging.

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Author contributions

AA contributed to conception, design, data analysis and interpretation, and drafting the manuscript. MA and KA contributed to data collection. All authors critically revised the manuscript and approved the final manuscript.

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Data availability

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

Declarations

Ethical approval

This study was approved by the National Committee of Bioethics in King Abdullah International Medical Research Center KAIMRC, Saudi Arabia (IRB/2782/22 Study number NRC22R/596/12) and was strictly performed in accordance with relevant guidelines and regulations. The participants informed consent was waived and deemed unnecessary in this retrospective study as approved by the National Committee of Bioethics in KAIMRC.

Consent for publication
Not applicable.

Disclosure
All authors have nothing to disclose.

Competing interests
The authors declare no competing interests.

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