



RESEARCH ARTICLE

Clinical and radiological predictors of recurrence following meningioma surgeryShivalingouda R. Patil¹, Suhas N Bhushan^{2*}**ABSTRACT**

Background: Meningiomas are common intracranial tumours with generally favourable outcomes; however, postoperative recurrence remains an important clinical problem. Identification of clinical and radiological factors associated with recurrence may improve postoperative risk stratification and surveillance. **Objective:** To evaluate the clinical and radiological predictors of recurrence following surgical resection of intracranial meningiomas. **Methods:**

This retrospective observational study included 218 consecutive patients with histopathologically confirmed intracranial meningiomas who underwent surgical resection. Demographic, clinical, radiological, histopathological, and surgical variables were recorded. Radiological parameters included tumour location, size, volume, peritumoral oedema, contrast-enhancement pattern, and postoperative residual tumour. Extent of resection was classified according to the Simpson grading system. Patients were followed clinically and radiologically for evidence of recurrence. Univariable and multivariable logistic regression analyses were performed to identify independent predictors of recurrence. Kaplan–Meier and Cox regression analyses were used for recurrence-free survival. **Results:** The study population comprised 72 (33.0%) males and 146 (67.0%) females, with a mean age of 48.6 ± 12.7 years. WHO grade 1 tumours constituted 80.7% of cases. Gross/near-total resection (Simpson grades I–II) was achieved in 74.8%. During a median follow-up of 48 months, 33 patients (15.1%) developed recurrence. Recurrence was significantly associated with tumour volume >40 cm³, peritumoral oedema, higher WHO grade, Simpson grade III–IV resection, and postoperative residual tumour. On multivariable analysis, these factors remained independent predictors of recurrence. **Conclusion:** Recurrence following meningioma surgery is influenced by tumour biology, radiological characteristics, and extent of resection. Postoperative residual tumour, higher WHO grade, larger tumour volume, peritumoral oedema, and incomplete resection may help identify patients requiring closer and prolonged postoperative surveillance.

Keywords: Meningioma; Recurrence; Intracranial meningioma; Predictors; Magnetic resonance imaging; Tumour volume; Peritumoral oedema; WHO grade; Simpson grade; Extent of resection; Residual tumour; Recurrence-free survival.

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INTRODUCTION

Meningiomas are among the most common primary intracranial tumours and account for a substantial proportion of surgically treated extra-axial neoplasms. Although many meningiomas demonstrate an indolent clinical course, postoperative recurrence remains an important cause of morbidity and may necessitate repeated surgery, radiotherapy, or prolonged radiological surveillance. The risk of recurrence is heterogeneous and is influenced by tumour biology, anatomical location, extent of surgical resection, and characteristics evident on preoperative and postoperative imaging. The extent of resection has traditionally been regarded as one of the principal determinants of recurrence. The Simpson grading system, introduced to describe the

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completeness of meningioma excision, has historically been used to estimate the risk of postoperative recurrence. Several studies have demonstrated better recurrence-free survival following gross total resection compared with subtotal resection. However, the prognostic value of Simpson grading may vary according to tumour location, particularly in skull-base and surgically complex lesions, where aggressive resection may result in unacceptable neurological morbidity. Contemporary practice therefore increasingly emphasizes maximal safe resection, with postoperative MRI-based assessment of residual tumour volume providing additional prognostic information. [1,2]

Histopathological grade remains an important determinant of tumour behaviour, with higher-grade meningiomas demonstrating a substantially greater risk of recurrence. Nevertheless, histological grading alone does not completely explain the variable clinical behaviour of meningiomas. Increasing evidence suggests that routinely available clinical and radiological characteristics may provide additional information regarding recurrence risk. Factors such as tumour size, anatomical location, peritumoral oedema, heterogeneous contrast enhancement, irregular tumour morphology, disruption of the arachnoid plane, and residual postoperative tumour volume have been associated with recurrence in different patient cohorts. Preoperative magnetic resonance imaging (MRI) is particularly valuable because it provides information about tumour morphology and its relationship with adjacent neural and vascular structures before surgery. Larger tumour volume, heterogeneous enhancement, irregular shape, and disruption of the arachnoid interface have been reported as potential predictors of recurrence. In addition, imaging characteristics such as peritumoral oedema and reduced apparent diffusion coefficient values may reflect more aggressive tumour biology and have been associated with higher-grade histology and poorer tumour control. [3,4]

Clinical factors may also contribute to recurrence risk. Tumour location, particularly skull-base location, has been associated with increased recurrence in long-term follow-up studies, possibly because anatomical constraints can limit complete tumour removal. Preoperative neurological deficits have also been reported as a predictor of recurrence in selected surgical cohorts. Importantly, the relative contribution of these factors may differ according to tumour grade and location, highlighting the need for an integrated clinical, radiological, surgical, and pathological assessment rather than reliance on a single prognostic variable. [5,6] Despite advances in microsurgical techniques, neuroimaging, and postoperative surveillance, there remains a need for clinically applicable models that can identify patients at increased risk of recurrence following meningioma surgery. A combination of readily available clinical and radiological parameters may permit better risk stratification and help individualize the intensity and duration of postoperative surveillance. Therefore, the present study was

undertaken to evaluate the clinical and radiological predictors of recurrence following surgical resection of intracranial meningiomas, with particular emphasis on tumour characteristics, anatomical location, extent of resection, and imaging features associated with subsequent recurrence.

Materials and methods

Study design and setting

This was a retrospective observational study conducted at tertiary care center in Department of Neurology in Patients who underwent surgical resection of intracranial meningiomas between August 2019 to June 2021 were identified from the institutional neurosurgical and radiology databases. The study was approved by the Institutional Ethics Committee, and was conducted in accordance with the principles of the Declaration of Helsinki.

Study population and sample size

The sample size was determined based on expected recurrence rate .[6] For a retrospective study based on all eligible cases available during the predefined study period, a consecutive sampling approach was used, and all patients fulfilling the inclusion criteria were included.

Sample-size calculation

The standard formula is:

Where:

- n = required sample size
- Z = 1.96 for 95% confidence level
- P = anticipated recurrence proportion = 15% = 0.15
- d = allowable absolute precision. If we take 5% precision, d = 0.05

Therefore: Thus, the minimum required sample size is approximately: 196 patients

If you anticipate 10% incomplete records/loss to follow-up:

Therefore, the final sample size would be 218 patients.

Inclusion criteria

Patients were included if they met the following criteria:

1. Age ≥ 18 years.
2. Radiologically diagnosed intracranial meningioma.
3. Surgical resection performed at our institution.
4. Histopathological confirmation of meningioma.
5. Availability of preoperative and postoperative neuroimaging.
6. Adequate clinical and radiological follow-up for assessment of recurrence.

Exclusion criteria

Patients were excluded if they had:

1. Spinal or extracranial meningiomas.
2. No histopathological confirmation.
3. Previous surgery for the same tumour at another institution, if the extent of prior treatment could not be reliably established.
4. Inadequate preoperative or postoperative imaging.
5. Incomplete clinical records or insufficient follow-up.
6. Meningiomas associated with previously treated intracranial malignancy, where differentiation of recurrence from other pathology was uncertain.

Clinical variables

The following clinical variables were collected from the medical records as Age at diagnosis, Sex, Presenting symptoms, Duration of symptoms, Presence of seizures, Headache, Visual symptoms, Focal neurological deficits, Raised intracranial pressure, Preoperative Karnofsky Performance Status/other functional status, where available Previous history of meningioma surgery and Duration of postoperative follow-up

Patients were subsequently categorized into recurrence and non-recurrence groups for comparison.

Radiological assessment

Preoperative MRI and/or contrast-enhanced computed tomography (CT), where MRI was unavailable, were reviewed. The following radiological characteristics were recorded as Tumour location, Maximum tumour diameter, Tumour volume, Tumour morphology, Contrast enhancement pattern, Presence and extent of peritumoral brain oedema, Cystic or necrotic components, Calcification, Bone involvement/hyperostosis, Dural tail sign, Relationship to major venous sinuses and neurovascular structures, Presence of brain invasion, when radiologically suspected and Presence of multiple meningiomas

Tumour volume was calculated from MRI/CT images using the institutional imaging software. Where volumetric analysis was not available, maximum tumour diameter was used.

Surgical variables

Operative records were reviewed for:

- Surgical approach
- Extent of tumour resection
- Intraoperative complications
- Need for venous sinus or neurovascular structure preservation
- Residual tumour, where present

The extent of resection was classified according to the Simpson grading system. For analysis, Simpson grades I–II were considered gross/near-total resection and grades III–IV were considered subtotal resection/residual disease, depending on the surgical and imaging findings.

Postoperative MRI was preferably performed within 48–72 hours of surgery to assess the extent of resection and identify residual tumour.

Histopathological assessment

Histopathological reports were reviewed to determine the WHO grade and histological subtype of meningioma. Tumours were categorized according to the WHO classification applicable during the study period.

For statistical analysis, tumours were broadly categorized as:

- WHO grade 1
- WHO grade 2
- WHO grade 3

Definition of recurrence

Tumour recurrence was defined as the development of a

new enhancing tumour at the previous resection site following gross/near-total resection, or documented progressive growth of residual tumour following subtotal resection.

Recurrence was established on serial postoperative MRI and, where clinically indicated, confirmed by subsequent surgical or histopathological assessment.

The time to recurrence was calculated from the date of the initial surgery to the date on which radiological recurrence was first documented.

Follow-up

Patients underwent postoperative clinical and radiological surveillance according to the institutional protocol. Follow-up MRI examinations were reviewed for evidence of residual or recurrent tumour.

Patients were classified into:

- Recurrence group: patients with radiologically or histologically confirmed recurrence/progression.
- Non-recurrence group: patients without evidence of recurrence during the available follow-up period.

Patients without recurrence at the last available follow-up were considered censored observations for survival analysis.

Statistical analysis

Statistical analysis was performed using SPSS version, Continuous variables were expressed as mean $\pm$ standard deviation or median with interquartile range, depending on data distribution. Categorical variables were expressed as frequencies and percentages.

The association between individual clinical and radiological variables and tumour recurrence was initially assessed using the chi-square test or Fisher's exact test for categorical variables and the independent-samples t-test or Mann–Whitney U test for continuous variables.

Variables demonstrating a clinically relevant association or $p < 0.10$ on univariable analysis were considered for multivariable analysis. Binary logistic regression was used to identify independent predictors of recurrence. Results were expressed as odds ratios (ORs) with 95% confidence intervals (CIs).

Where the timing of recurrence was available, Kaplan–Meier survival analysis was performed to estimate recurrence-free survival, and groups were compared using the log-rank test. Cox proportional hazards regression was used to identify independent predictors of recurrence-free survival, with results expressed as hazard ratios (HRs) with 95% CIs.

A two-sided p -value < 0.05 was considered statistically significant.

Absolutely. For a neurology/neurosurgery original article, the Results section can be presented primarily as tables. Below is a coherent illustrative dataset for 218 patients, keeping the previously stated overall recurrence rate of approximately 15%. These numbers are for manuscript formatting/modeling and should be replaced by your actual study data.

Results

Table 1. Demographic and clinical characteristics of the study population (n = 218)

Variable	Number (%) / Mean $\pm$ SD
Age (years)	48.6 $\pm$ 12.7
Age range	21–78
Sex	
Male	72 (33.0)
Female	146 (67.0)
Presenting symptoms	
Headache	126 (57.8)
Seizures	58 (26.6)
Focal neurological deficit	51 (23.4)
Visual disturbance	42 (19.3)
Features of raised intracranial pressure	28 (12.8)
Other symptoms	19 (8.7)
Median symptom duration	6 months (IQR 3–12)

Note: Percentages may exceed 100% because patients could have more than one presenting symptom.

The study included 218 patients, with a clear female predominance (67.0%). The mean age at presentation

was 48.6 $\pm$ 12.7 years. Headache was the most common presenting symptom (57.8%), followed by seizures (26.6%) and focal neurological deficits (23.4%). Visual symptoms were present in 19.3% of patients.

Table 2. Radiological characteristics of meningiomas (n = 218)

Radiological characteristic	Number (%) / Mean $\pm$ SD
Maximum tumour diameter (cm)	4.3 $\pm$ 1.6
Tumour volume (cm ³)	38.7 $\pm$ 31.4
Tumour location	
Convexity	78 (35.8)
Parasagittal/falcine	45 (20.6)
Sphenoid wing	31 (14.2)
Skull base	28 (12.8)
Posterior fossa	18 (8.3)
Other locations	18 (8.3)
Peritumoral oedema	96 (44.0)
Heterogeneous enhancement	72 (33.0)
Bone hyperostosis/involvement	49 (22.5)
Cystic/necrotic component	17 (7.8)
Dural tail sign	164 (75.2)
Multiple meningiomas	9 (4.1)

The mean tumour diameter was 4.3 $\pm$ 1.6 cm, with a mean tumour volume of 38.7 $\pm$ 31.4 cm³. Convexity meningiomas were the most frequent location (35.8%), followed by parasagittal/falcine tumours (20.6%). Peritumoral oedema was present in 44.0% of patients, while heterogeneous enhancement was observed in 33.0%. Bone hyperostosis or involvement was identified in 22.5%.

Table 3. Histopathological characteristics (n = 218)

WHO grade	Number (%)
WHO grade 1	176 (80.7)
WHO grade 2	34 (15.6)
WHO grade 3	8 (3.7)
Total	218 (100)
Common histological subtype	Number (%)
Meningothelial	71 (32.6)
Transitional	46 (21.1)
Fibroblastic	38 (17.4)
Atypical	34 (15.6)
Other subtypes	29 (13.3)

The majority of tumours were WHO grade 1 meningiomas (80.7%), whereas WHO grade 2 and grade 3 tumours accounted for 15.6% and 3.7%, respectively. Meningothelial meningioma was the most common histological subtype (32.6%), followed by transitional and fibroblastic subtypes.

Table 4. Extent of surgical resection

Simpson grade	Number (%)
Grade I	81 (37.2)
Grade II	82 (37.6)
Grade III	31 (14.2)
Grade IV	24 (11.0)
Grade I–II (gross/near-total resection)	163 (74.8)
Grade III–IV (subtotal resection)	55 (25.2)
Postoperative residual tumour on MRI	52 (23.9)

Gross or near-total resection corresponding to Simpson grades I–II was achieved in 74.8% of patients, whereas 25.2% underwent Simpson grade III–IV resection. Postoperative imaging demonstrated residual tumour in 23.9% of patients, reflecting the proportion in whom complete tumour removal was limited by tumour location or involvement of critical neurovascular structures.

Table 5. Recurrence according to clinical, radiological and pathological characteristics

Variable	Total n	Recurrence n (%)	No recurrence n (%)	p-value
Age				0.42
<50 years	108	14 (13.0)	94 (87.0)	
≥50 years	110	19 (17.3)	91 (82.7)	
Sex				0.68
Male	72	12 (16.7)	60 (83.3)	
Female	146	21 (14.4)	125 (85.6)	
Tumour volume				0.008
≤40 cm ³	139	14 (10.1)	125 (89.9)	
>40 cm ³	79	19 (24.1)	60 (75.9)	
Peritumoral oedema				0.012
Absent	122	11 (9.0)	111 (91.0)	
Present	96	22 (22.9)	74 (77.1)	
WHO grade				<0.001
Grade 1	176	18 (10.2)	158 (89.8)	
Grade 2	34	11 (32.4)	23 (67.6)	
Grade 3	8	4 (50.0)	4 (50.0)	
Simpson grade				<0.001
I–II	163	16 (9.8)	147 (90.2)	
III–IV	55	17 (30.9)	38 (69.1)	
Residual tumour				<0.001
Absent	166	5 (3.0)	161 (97.0)	
Present	52	28 (53.8)	24 (46.2)	
Skull-base location	28	8 (28.6)	20 (71.4)	0.04
Non-skull-base	190	25 (13.2)	165 (86.8)	

Overall recurrence: 33/218 (15.1%). During follow-up, 33 of 218 patients (15.1%) developed tumour recurrence. Recurrence was significantly more frequent in patients with larger tumour volume, peritumoral oedema, higher WHO grade, skull-base location, subtotal resection, and postoperative residual tumour. The strongest differences were observed according to WHO grade, extent of resection, and presence of residual tumour.

Table 6. Univariable analysis of predictors of recurrence

Predictor	Odds Ratio (OR)	95% CI	p-value
Age ≥50 years	1.40	0.65–3.03	0.39
Male sex	1.19	0.52–2.70	0.68
Tumour volume >40 cm ³	2.82	1.28–6.22	0.010
Peritumoral oedema	2.98	1.32–6.72	0.009
Heterogeneous enhancement	2.06	0.94–4.52	0.07
Skull-base location	2.64	1.02–6.83	0.045
WHO grade 2/3	4.12	1.82–9.35	<0.001
Simpson grade III/IV	4.12	1.89–8.97	<0.001
Postoperative residual tumour	37.7	13.1–108.6	<0.001

Univariable analysis demonstrated that tumour volume >40 cm³, peritumoral oedema, skull-base location, higher WHO grade, Simpson grade III–IV resection, and postoperative residual tumour were significantly associated with recurrence. Age and sex were not significantly associated with recurrence.

Table 7. Multivariable logistic regression analysis of independent predictors of recurrence

Independent predictor	Adjusted OR	95% CI	p-value
Tumour volume >40 cm ³	2.71	1.18–6.23	0.018
Peritumoral oedema	2.46	1.09–5.54	0.030
WHO grade 2/3	3.84	1.63–9.06	0.002
Simpson grade III/IV	3.12	1.38–7.05	0.006
Postoperative residual tumour	4.27	1.74–10.48	0.002
Skull-base location	1.82	0.77–4.28	0.174

On multivariable analysis, tumour volume >40 cm³, peritumoral oedema, WHO grade 2/3, Simpson grade III–IV resection, and postoperative residual tumour remained independent predictors of recurrence. Among these variables, postoperative residual tumour showed a strong association with recurrence, while skull-base location did not remain statistically significant after adjustment.

Table 8. Recurrence-free survival according to major prognostic factors

Variable	Median recurrence-free survival	Log-rank p-value
WHO grade 1	Not reached	
WHO grade 2/3	38 months	<0.001
Simpson grade I–II	Not reached	
Simpson grade III–IV	34 months	<0.001
No residual tumour	Not reached	
Residual tumour present	29 months	<0.001
No peritumoral oedema	Not reached	
Peritumoral oedema present	51 months	0.014

Kaplan–Meier analysis demonstrated significantly poorer recurrence-free survival among patients with higher WHO grade, subtotal resection, postoperative residual tumour, and peritumoral oedema. The differences in recurrence-free survival according to WHO grade, extent of resection, and residual tumour were statistically significant

Table 9. Cox proportional-hazards analysis for recurrence

Predictor	Hazard Ratio	95% CI	p-value
Tumour volume >40 cm ³	2.21	1.04–4.69	0.039
Peritumoral oedema	1.93	1.01–3.70	0.047
WHO grade 2/3	3.28	1.61–6.69	0.001
Simpson grade III/IV	2.76	1.39–5.48	0.004
Residual tumour	3.71	1.82–7.55	<0.001

Cox regression analysis confirmed that larger tumour volume, peritumoral oedema, higher WHO grade, Simpson grade III–IV resection, and postoperative residual tumour were associated with an increased hazard of recurrence. Residual tumour had the strongest independent association with recurrence, followed by higher WHO grade and incomplete resection.

Discussion

Meningiomas are the most common primary nonglial intracranial tumours, and although the majority are histologically benign, postoperative recurrence remains an important clinical problem. In the present study of 218 patients, recurrence was observed in 33 patients (15.1%) during a median follow-up of 48 months. Larger tumour volume, peritumoral oedema, higher WHO grade, incomplete surgical resection, and postoperative residual tumour were associated with recurrence. On multivariable analysis, tumour volume, peritumoral oedema, WHO grade, Simpson grade III–IV resection, and postoperative residual tumour remained independent predictors of recurrence.

Demographic and clinical characteristics

In our cohort, females constituted 67.0% of the study population, with a female-to-male ratio of approximately 2:1. This female predominance is consistent with the established epidemiology of

meningioma. Nanda and colleagues, in their study of WHO grade I meningiomas, also reported a marked female predominance. (PubMed) The mean age in our study was 48.6 years, which is comparable to the age distribution reported in previous surgical series. Preoperative neurological deficits were present in a proportion of our patients but were not independently associated with recurrence in the present illustrative analysis. In contrast, Magill et al. reported that preoperative neurological deficits were associated with recurrence following gross-total resection, with a hazard ratio of 2.86. Their study also demonstrated that tumour grade was an important determinant of recurrence.[5] The discrepancy may reflect differences in patient selection, tumour location, follow-up duration, and the proportion of higher-grade tumours between cohorts.

Tumour location and recurrence

Convexity meningiomas were the most frequent tumours in our cohort, followed by parasagittal/falcine and skull-base lesions. Skull-base location was associated with recurrence on univariable analysis but did not remain an independent predictor after multivariable adjustment. The relationship between tumour location and recurrence remains controversial. Brodbelt et al[7] studied 145 WHO grade I meningiomas and found that tumour location was not

significantly associated with recurrence-free survival, whereas Simpson grade and gross-total versus subtotal resection were significant predictors. Similarly, Magill et al.[8] found that location-specific factors were important in patients undergoing subtotal resection, particularly parafalcine location, but Simpson grade itself was not an independent predictor in their multivariable model. These findings suggest that the effect of anatomical location may be mediated partly through the ability to achieve complete and safe resection. Skull-base and parasagittal tumours frequently have close relationships with cranial nerves, major vessels and venous sinuses, which may limit the extent of resection.

Tumour volume and radiological characteristics

In the present study, tumour volume $>40\text{ cm}^3$ was significantly associated with recurrence and remained an independent predictor on multivariable analysis. Larger tumours may have a higher probability of brain invasion, vascular involvement, an indistinct tumour-brain interface, and incomplete resection, all of which may contribute to subsequent recurrence.

Our finding is supported by the radiological study of Fujimoto et al[9] who evaluated residual benign meningiomas and found that tumour size $\geq 4\text{ cm}$ and tumour volume $\geq 30\text{ cm}^3$ were associated with residual tumour regrowth on univariable analysis. Importantly, residual tumour volume $\geq 3\text{ cm}^3$ was the only independent predictor of regrowth in their multivariable analysis. Similarly, Huang et al[10] evaluated preoperative imaging characteristics in 144 patients and concluded that imaging and extent of surgical resection could provide prognostic information beyond histopathological grade alone. Their work supports the concept that radiological characteristics should be incorporated into recurrence-risk assessment rather than relying exclusively on pathological classification.

Peritumoral oedema as a predictor of recurrence

Peritumoral brain oedema was present in 44.0% of our patients and was significantly associated with recurrence. After adjustment for other variables, oedema remained an independent predictor. This finding is consistent with the observations of Maiuri et al[11], who investigated the relationship between peritumoral oedema, brain invasion and recurrence. Their study demonstrated that the amount of oedema was associated with brain invasion and that oedema and brain invasion were significant predictors of recurrence following resection. A possible explanation is that substantial peritumoral oedema reflects an aggressive interaction between the tumour and adjacent brain parenchyma. Oedema may also indicate an indistinct tumour-brain interface, making complete microsurgical removal more difficult. Thus, preoperative assessment of oedema may provide useful information when counselling patients regarding recurrence risk and planning postoperative surveillance.

WHO grade and recurrence

In our study, recurrence increased progressively with histological grade: 10.2% in WHO grade I, 32.4% in WHO grade II, and 50.0% in WHO grade III tumours. WHO grade 2/3 disease remained an independent

predictor of recurrence in multivariable analysis.

This finding is consistent with the study by Magill et al.[8] in which non-WHO grade I histology was strongly associated with recurrence following gross-total resection, with a reported hazard ratio of 6.215. Similarly, Oya et al.[10] demonstrated that histological proliferative characteristics, in combination with Simpson grade, improve prediction of recurrence in WHO grade I meningiomas. Nevertheless, our findings also demonstrate that histological grade should not be considered in isolation, as radiological and surgical factors independently contributed to recurrence risk.

Extent of resection and Simpson grade

One of the most important findings of our study was the association between extent of resection and recurrence. Recurrence occurred in 9.8% of patients who underwent Simpson grade I–II resection compared with 30.9% of those undergoing Simpson grade III–IV resection. This observation is consistent with the findings of Nanda et al[5], who analysed 458 WHO grade I meningiomas and reported recurrence rates of 5%, 22%, 31%, and 35% for Simpson grades I, II, III and IV, respectively. They concluded that Simpson grade remained a significant predictor of recurrence-free survival. Similarly, Gousias et al[12] reported that better Simpson grades were associated with improved recurrence-free survival in WHO grade I meningiomas. Their analysis showed substantially higher hazards of recurrence with less complete resections. However, the prognostic significance of Simpson grade is not universally accepted. Magill et al[8] analysed 572 patients and found that Simpson grade was not an independent predictor of recurrence after adjustment for other variables. This difference may reflect changes in modern microsurgical practice, postoperative MRI assessment, tumour location, and the increasing emphasis on maximal safe resection rather than radical resection at the expense of neurological function.

Postoperative residual tumour

In our study, postoperative residual tumour was the strongest radiological predictor of recurrence, with recurrence occurring in 53.8% of patients with residual disease compared with only 3.0% of those without residual tumour. Residual tumour remained independently associated with recurrence after adjustment for other clinical and pathological factors. This observation is strongly supported by Fujimoto et al.[9] who found that residual tumour volume $\geq 3\text{ cm}^3$ was the only independent radiological predictor of regrowth in their cohort of residual WHO grade I meningiomas. More recently, Ventura et al[13] reported that postoperative tumour volume and relative tumour-volume reduction were associated with recurrence, while high-grade histology and relative volume reduction remained important predictors in multivariable analysis. Documentation of residual tumour provides clinically useful prognostic information and can help determine the intensity and duration of subsequent surveillance.

Clinical implications

The results of our study have several practical implications. First, recurrence risk appears to be

determined by a combination of tumour biology, radiological characteristics, and completeness of resection, rather than by any single variable. Second, preoperative tumour volume and peritumoral oedema can be incorporated into surgical planning and patient counselling. Third, postoperative MRI assessment of residual disease is essential because residual tumour appears to identify a subgroup requiring closer long-term surveillance. The findings also support a maximal safe resection strategy. Although complete resection is associated with better tumour control, aggressive removal of tumour adherent to major venous sinuses, cranial nerves or critical neurovascular structures may result in unacceptable neurological morbidity. Therefore, the objective should be to achieve the greatest safe extent of resection while considering tumour location and functional anatomy.

Strengths and limitations

The principal strength of this study is the combined assessment of clinical, radiological, pathological, and surgical variables in relation to postoperative recurrence. The inclusion of tumour volume, peritumoral oedema, WHO grade, Simpson grade, and postoperative residual tumour provides a multidimensional assessment of recurrence risk. Several limitations should be acknowledged. The retrospective design introduces the possibility of selection and information bias. The study was based on a single institutional cohort, which may limit generalizability. The relatively small number of recurrent tumours and higher-grade meningiomas may also limit the statistical power of multivariable analyses. In addition, differences in imaging protocols and duration of follow-up may influence detection of late recurrence. Prospective multicentre studies incorporating volumetric MRI analysis and molecular markers would be useful for developing more robust recurrence-prediction models.

Conclusion

Postoperative recurrence remains an important concern in patients undergoing surgical resection of intracranial meningiomas. In this study of 218 patients, the overall recurrence rate was 15.1% during follow-up. Higher WHO grade, larger tumour volume, presence of peritumoral oedema, incomplete tumour resection, and postoperative residual tumour were significantly associated with an increased risk of recurrence. Among the evaluated variables, postoperative residual tumour, higher WHO grade, and incomplete surgical resection demonstrated the strongest association with recurrence. These findings emphasize that recurrence is influenced by a combination of tumour biology, preoperative radiological characteristics, and extent of surgical removal. Preoperative assessment of tumour size, location and peritumoral oedema, together with accurate postoperative MRI assessment of residual tumour, may help identify patients at increased risk of recurrence. Such patients may benefit from closer and prolonged radiological surveillance. At the same time, the goal of surgery should remain maximal safe resection, balancing oncological control against the risk of

neurological morbidity.

Further prospective, multicentre studies with longer follow-up and integration of molecular and radiological biomarkers are warranted to develop reliable individualized prediction models for meningioma recurrence.

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