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5–year recurrent rate and factors related recurrent spinal meningioma

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Abstract

Introduction

Spinal meningiomas are usually benign spinal cord tumors, representing about 25% of all spinal tumors. Treatment options include watchful waiting and surgery, which typically removes the tumor completely with a low recurrence risk. However, undetected recurrences can cause neurological issues, necessitating regular MRI scans. Previous studies showed a 7-9% recurrence rate at 5 years post-surgery, increasing to 20-25% after 10 years3. This study aims to find 5-year recurrence rate and related factors for recurrence.

Methods

The authors conducted a single-center retrospective descriptive study in patients with spinal meningiomas treated in Siriraj hospital from July 2006 to November 2024. Finding 5-year and overall recurrence rate of 66 spinal meningiomas and related factors for recurrence.

Results

5-year and overall recurrence rates were 10.6% and 24.2%, respectively. The factors mostly affected recurrence were younger age at diagnosis (esp. <45 years) and history of neurofibromatosis type 2 (NF2). Other factors included gender, volume, location of tumor, dural tail sign, histopathological diagnosis and intra-operative finding did not showed statistically significance for tumor recurrence.

Conclusions

The study at Siriraj Hospital shows that surgical removal of spinal meningiomas is effective but has a significant risk of recurrence, especially in younger patients or those with NF2. Despite benign nature of disease, our findings emphasize the importance of careful surgery and long-term follow-up. High-risk groups may need early and more frequent investigation.

Keywords: Spinal meningioma, Recurrent meningioma, Recurrent rate, Recurrent factor, Spinal cord tumor

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Introduction

Spinal meningioma is type of spinal cord tumors which classified as slow-growing tumors, and most are non-invasive. The incidence rate of this type of tumor is low. In the United States, it is found in approximately 0.33 people per 100,000 individuals. [1]At Siriraj Hospital, there are 4-6 cases of this tumor per year. However, meningiomas are the most common type among spinal cord tumors, accounting for about 25% of all pinal cord tumors.2 Symptoms found in patients include weakness or numbness in specific areas corresponding to the location of the tumor in the spinal cord.

There are several treatment options for spinal meningiomas, including observation in cases where there are few neurological symptoms, as well as surgery. Regarding surgical treatment, almost all cases can be completely removed, and the recurrence rate is low. However, recurrence of the tumor can lead to neurological dysfunction. In some cases where recurrence occurs early, no symptoms may be detected, requiring periodic MRI scans for monitoring. At Siriraj hospital, there was not protocol for routine image follow-up. Some cases were suspected recurrence by clinical presentation before imaging.

Over the years, several studies worldwide have been conducted on the recurrence rates of spinal meningiomas. The recurrence rate after 5 years post-surgery is around 7-9%, and the recurrence rate after 10 years is about 20-25%.3 However, no studies on recurrence rates have been conducted in Thailand. Therefore, the researchers are interested in studying the recurrence rate of this tumor type, using it as a reference for recurrence rates in the country and determining the appropriate treatments and follow-up intervals.

For this study, “Recurrence” means recurring of the tumor on the same dural base after surgery of total resection (at least Simpson 2 grading) which found by MRI after clinical presentation.

Materials and methods

Study design

The authors conducted a single-center retrospective descriptive study in patients with spinal meningiomas treated in Siriraj hospital from July 2006 to November 2024. Regarding ethical issue, this study was approved by Siriraj Institutional Review Board (SIRB), Faculty of Medicine Siriraj Hospital, Mahidol University, Bangkok, Thailand; Certificate of Approval (COA) number Si 369/2024. The patient data in the study was kept confidential according to the Declaration of Helsinki.

Patient selection

This study included all patients with spinal meningiomas, treated by surgical procedures in Siriraj hospital with follow-up period for at least 5 years by magnetic resonance imaging (MRI). The tumor was diagnosed by histopathological examination. The patients who were not followed up for at least 5 years was excluded from the study.

All symptomatic recurrent patients were diagnosed by MRI and undergone surgery for treatment.

Data collection

The collected data were described as the follows

1. Demographic characteristics included gender, age, history of neurofibromatosis type 2 (NF2), and presenting symptoms.

2. Tumor characteristics included volume of tumor in milliliter (mL), site of tumor, extension of tumor, dural tail sign, pathological diagnosis and WHO grade of tumor.

3. Intra-operative information included surgical grade, dural excision and arachnoid invasion.

4. Post-surgical information included post-surgical status, recurrence status at 5 years after surgery, overall recurrence status, timing of recurrence and follow-up.

Statistical analysis

The study on spinal meningiomas focuses on the following aspects:

1. **Recurrence rate at 5 years** - This will be reported using the recurrence rate and 95% confidence interval (95%CI) to indicate the reliability of the data.

2. **Factors Related to Tumor Recurrence** - Analyzed using Univariate Analysis to identify any significant associations.

3. **Qualitative Data Factors** - Includes gender, NF2 status, symptoms, MRI characteristics of the tumor, tumor location, histopathological findings reported by pathologists, surgical grade, arachnoid invasion and dural excision. These will be analyzed using Chi-square test or Fisher's Exact test, and Kaplan-Meier method (for time to recurrence), with results presented as percentages.

4. **Quantitative Data Factors** - Includes age and tumor volume, analyzed using independent t-test or Mann Whitney-U Test based on the appropriate data distribution. Results will be reported as means (with standard deviation) for normally distributed data or medians (range) for non-normally distributed data.

Results

Patient characteristics

This study included 66 cases with female predominance (51 patients, 77.3%). The average age of the patient cohort was 50.32 years, and 20 patients (30.3%) had a history of neurofibromatosis type 2 (NF2). Common presenting symptoms included weakness (81.8%), paresthesia (86.4%), and pain (25.8%).

Analysis of patient characteristics in relation to 5-year recurrence revealed that age was a significant factor. The mean age of patients experiencing 5-year recurrence was 35 years, significantly lower than the 52.14 years observed in the non-recurrence group ($p = 0.014$). From ROC graph of age, about 45 ($p = 0.01$) is cut off age which give best sensitivity (0.857) and specificity (about 0.7).

Gender did not demonstrate a significant association with recurrence.

History of NF2 had significant effect to 5-year recurrence with rate of 25% compared with 4.3% in non-NF2 group ($p = 0.023$). Time to recurrence in NF2 group were found to be earlier than in non-NF2 group for both 5-year recurrence and overall recurrence

Finally, the presenting symptoms, including weakness, paresthesia, and pain, did not differ significantly between the recurrence and non-recurrence groups.

Tumor characteristics

First diagnostic tumor volume was estimated using the formula (AP diameter x coronal diameter x craniocaudal length/ 2) and expressed in milliliters. The mean volume was 1.69 mL. While 5-year recurrence group exhibited higher mean tumor volume of 3.17 mL compared to 1.51 mL in the non-recurrence group, this difference did not reach statistical significance (p=0.212).

Tumor location was categorized by spinal level (cervical, thoracic, or lumbar) and by quadrant within the spinal canal (dorsal, dorsolateral, lateral, ventral, or ventrolateral). Thoracic tumors were

most prevalent (65.2%), followed by cervical (30.3%) and lumbar (4.5%) tumors. Spinal level did not correlate with recurrence (p = 0.423). In the recurrence group, tumors were predominantly located in the dorsolateral region (42.9%), whereas in the non-recurrence group, they were more commonly found in the ventrolateral region (39%). Extension of tumor still did not affect recurrence (*p*=0.384).

The majority of tumors were classified as WHO grade 1 meningiomas (98.5%), with only one case of WHO grade 2, atypical meningioma. Among the WHO grade 1 tumors, subtypes included psammomatous (34.8%), meningothelial (15.2%), transitional (3%), and angiomatous (1.5%), while a significant proportion remained unclassified (43.9%). Pathological diagnosis did not influence 5-year recurrence status (p = 0.099), but there were more ratio of psammomatous type in recurrence group (71.4%) compared to non-recurrence group (30.5%).

Intra–operative information

Surgical grade was categorized as total, subtotal, or partial, based on operative notes. Total resection was achieved in the majority of cases (86.4%), with no statistically significant difference observed between the recurrence and non-recurrence groups. Dural excision was performed in only a small number, 5 cases in non-recurrence group. No dural excision was performed in recurrence group, but procedure did not affect recurrence (*p* = 0.414). No arachnoid invasion was noted in recurrence group, but 9 in the non-recurrence group (15.3%), again showing no significant difference between the groups (*p* = 0.58).

Post–surgical information

This study observed a 5-year recurrence rate of 10.6% (7 out of 66 cases) and an overall recurrence rate of 24.2% (16 out of 66 cases). The mean time to 5-year and overall recurrence was 3.86 and 6.81 years, respectively. Furthermore, no significant differences were found between the groups regarding post-surgical improvement or worsening of symptoms.

Discussion

Our study of 66 cases in Siriraj hospital showed a 10.6% 5-year recurrence rate, with overall recurrence rate of 24.2%. Mean 5-year recurrence time is 3.86 years and overall recurrence time of 6.81 years in a mean follow-up time of 7.85 years (range 5–16 years) which revealed importance of long-

Table 1 Overall patient demographic data

		N = 66
Age (yr), mean ± SD; range		50.32 ± 17.63; 11-82
Gender, n (%)	Male	15 (22.7)
	Female	51 (77.3)
NF2 history, n (%)		20 (30.3)
Presentation, n (%)	Weakness	54 (81.8)
	Paresthesia	57 (86.4)
	Pain	17 (25.8)

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Table 2 Tumor characteristic data

		N = 66
Volume (mL), mean		1.69
Gender, n (%)	Cervical	20 (30.3)
	Thoracic	43 (65.2)
	Lumbar	3 (4.5)
Extension level, n (%)	1	15 (22.7)
	2	43 (65.2)
	3	7 (10.6)
	4	1 (1.5)
Site of tumor, n (%)	Dorsal	7 (10.6)
	Dorsolateral	13 (10.7)
	Lateral	9 (13.6)
	Ventral	6 (9.1)
	Ventrolateral	24 (36.4)
Dural tail sign, n (%)		37 (56.1)
Histopathology, n (%)	Meningioma	29 (43.9)
	Psammomatous	23 (34.8)
	Meningothelial	10 (15.2)
	Transitional	2 (3)
	Angiomatous	1 (1.5)
	Atypical	1 (1.5)
WHO grading, n (%)	1	65 (98.5)
	2	1 (1.5)

Table 3 Intra-operative information

		N = 66
Surgical grading, n (%)	Total	57 (86.4)
	Subtotal	4 (6.1)
	Partial	2 (3.0)
Dural excision, n (%)	Yes	9 (13.6)
	No	54 (81.8)

Table 4 Post-operative information

		N = 66
Postsurgical status, n (%)	Improve	58 (87.9)
	Stable	4 (6.1)
	Worsening	2 (3.0)
Overall follow-up time (yr), mean ± SD; range		7.85 ± 2.80; 5-16
5-year recurrence, n (%)		7 (10.6)
Overall recurrence, n (%)		16 (24.2)
Time to 5-year recurrence (yr), mean ± SD; range		3.86 ± 1.07; 3-5
Time to overall recurrence (yr), mean ± SD; range		6.81 ± 3.53; 3-15

Table 5 5-year recurrence information

		Recurrence (n =7)	Non-recurrence (n =59)	p-value
Patient demographic data				
Age (yr), mean ± SD		35.0 ± 15.14	52.14 ± 17.12	0.014
Age (yr), range		12 – 82	11 – 46	
Age ≤ 45 yr		6 (85.7)	19 (32.2)	0.01
Age > 45 yr		1 (14.3)	40 (67.8)	
Gender, n (%)	Male	1 (14.2)	14 (23.7)	1.00
	Female	6 (85.8)	45 (76.3)	
NF2 history, n (%)	Yes	5 (71.4)	15 (25.4)	0.023
	No	2 (28.6)	44(74.6)	
Tumor characteristic data				
Volume (mL), mean ± SD		3.17 ± 3.12	1.51 ± 0.88	0.212
Volume (mL), range		0.72 - 7.72	0.06 - 3.26	
Level, n (%)	Cervical	2 (28.6)	18 (30.5)	0.423
	Thoracic	4 (57.1)	39 (66.1)	
	Lumbar	1 (14.3)	2 (3.4)	
Extension level, n (%)	1	2 (28.6)	13 (22.0)	0.384
	2	5 (71.4)	38 (64.4)	
	3	0 (0)	7 (11.9)	
	4	0 (0)	1 (1.7)	

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Table 5 5-year recurrence information (Cont.)

		Recurrence (n =7)	Non-recurrence (n =59)	p-value
Site of tumor, n (%)	Dorsal	0 (0)	7 (11.9)	0.246
	Dorsolateral	3 (42.9)	10 (16.9)	
	Lateral	1 (14.3)	8 (13.6)	
	Ventral	0 (0)	6 (10.2)	
	Ventrolateral	1 (14.3)	23 (39.0)	
Dural tail sign, n (%)		4 (57.1)	33 (55.9)	1.00
WHO grading, n (%)	1	7 (100)	58 (98.3)	0.729
	2	0 (0)	1 (1.7)	
Histopathology, n (%)	Meningioma	1 (14.3)	28 (47.5)	0.099
	Psammomatous	5 (71.4)	18 (30.5)	
	Meningothelial	0 (0)	10 (16.9)	
	Transitional	1 (14.3)	1 (1.7)	
	Angiomatous	0 (0)	1 (1.7)	
	Atypical	0 (0)	1 (1.7)	
Intra-operative information				
Dural excision, n (%)	Yes	0 (0)	5 (8.5)	0.414
	No	7 (100)	52 (88.1)	
Plain of tumor, n (%)	Good	7 (100)	47 (79.7)	0.58
	Poor	0(0)	9(15.3)	
Consistency, n (%)	Hard	1 (14.2)	5 (8.5)	
	Firm	0 (0)	13 (22.0)	
	Soft	3 (42.9)	20 (33.9)	
Overall follow-up time (yr), mean ± SD		9.56 ± 3.65	7.30 ± 2.25	0.004

Table 6 Correlation of NF2 and recurrence

	NF2	Non-NF2	p-value
Age (yr), mean ± SD	33.05 ± 15.12	57.83 ± 12.75	<0.001
Time to 5-year recurrence (yr), mean ± SD	3.4 ± 0.89	5.0 ± 0	0.016
Time to overall recurrence (yr), mean ± SD	5.57 ± 3.78	7.78 ± 3.19	0.22

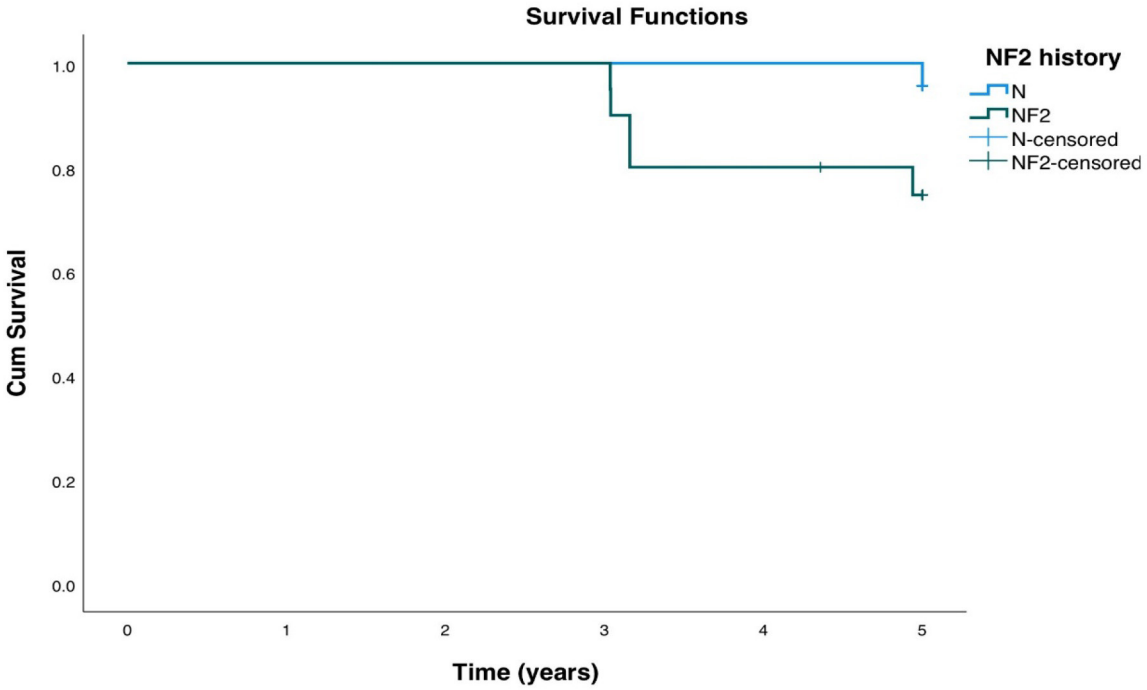

Figure 1 NF2 and recurrence-free graph

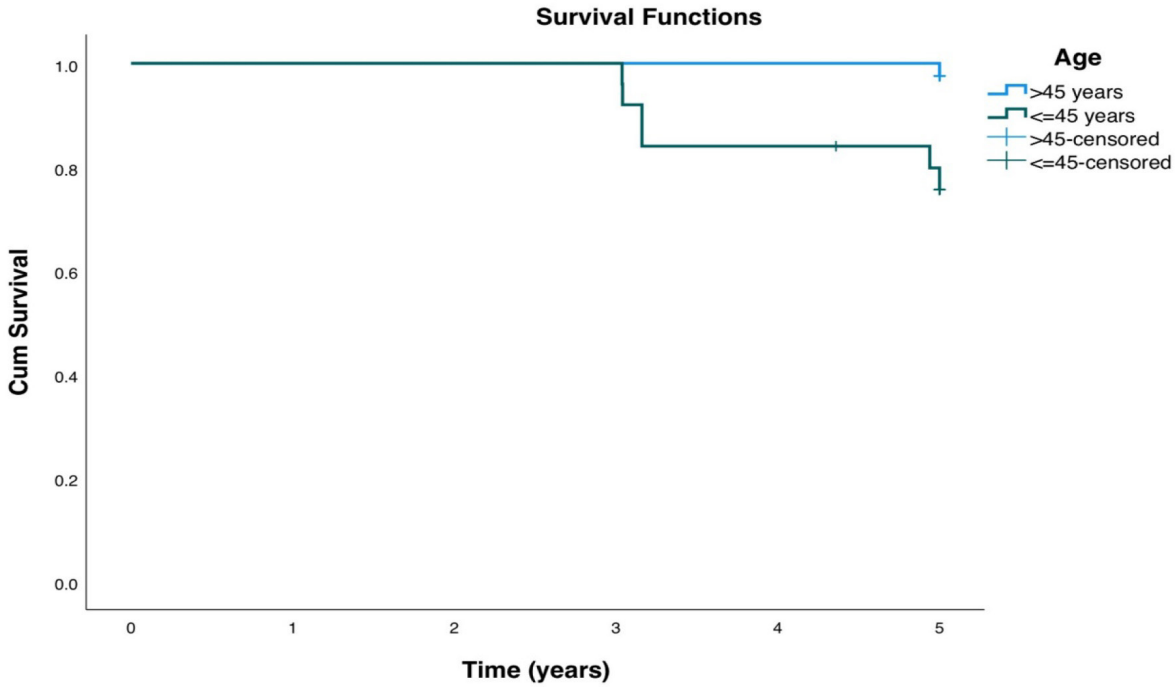

Figure 2 Age of 45 years and recurrence-free graph

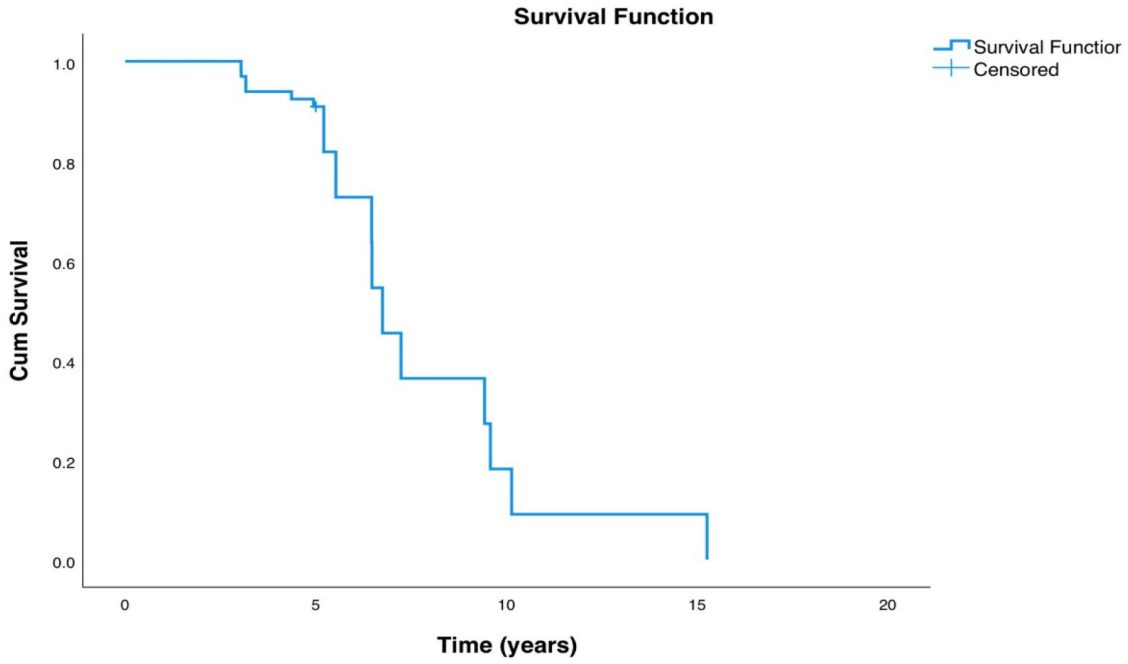

Figure 3 Overall recurrence-free graph

term observation. Recurrences were significantly associated with younger age (≤45 years, p=0.01) and presence of neurofibromatosis type 2 (NF2, p=0.023), but not with sex, surgical grade, tumor location, dural tail sign, tumor extension, or histopathologic subtype. Most tumors were WHO grade I, with the exception of one atypical WHO grade II case, which did not recur. The grade I tumors primarily included psammomatous (34.8%) and meningothelial (15.2%) subtypes, with all recurrences occurring in this grade.

Recurrence Rates and the Importance of Long–Term Follow–Up

Our study reveals that while the 5-year recurrence rate for spinal meningiomas is about 10%, the rate increases to 24.2% with longer follow-up, highlighting the tumors' indolent yet persistent risk. Historically, recurrence rates reported for spinal meningiomas have varied widely, from around 1% to about 20%[2,4-7], depending on the different factors. A recent systematic review by Kwee et al. reported recurrence rates ranging from 0% to 25% and suggested that studies with shorter follow-up likely underestimate the true recurrence risk.[3] Our data supports this; our 5-year recurrence rate was 10.6%, but extended surveillance revealed a rate more than double. Notably, one patient experienced recurrence 15 years postoperatively, underscoring the potential for late recurrence. Mirimanoff et al. also observed a decrease in recurrence-free survival from 93% at 5 years to 68% at 15 years post-gross-total resection.[7] Our data, which mostly included Simpson grade I–II resections, suggests that long-term follow-up is essential to monitor the recurrence.

Risk Factors for Recurrence

Age: In our study, younger patient age (≤45 years) was a significant predictor of recurrence, with these patients showing a higher recurrence likelihood (p=0.01). This aligns with global findings,

such as those by Cohen-Gadol et al., who reported that patients under 50 had a 22% recurrence rate, markedly higher than the 5% seen in older patients.[8] Notably, our younger patients often had neurofibromatosis type 2 (NF2), factors that contribute to the increased recurrence risk. These observations suggest that younger age may serve as an indicator of genetic or anatomical predispositions that enhance recurrence risks. Clinically, this indicates that even "benign" spinal meningiomas in younger patients require careful and prolonged monitoring, particularly with underlying conditions like NF2.

NF2 Status: In our series, 30.3% of patients had NF2, significantly higher than the approximately 3% prevalence noted in general spinal meningioma studies.[9] This high proportion likely reflects a referral bias due to Siriraj Hospital's status as a tertiary care center. NF2 status was a significant predictor of recurrence (p = 0.023) in our study. NF2 is associated with a higher incidence of spinal meningiomas, which constitute about 14% of all spinal tumors in NF2 patients, and these tumors often exhibit a more aggressive behavior compared to sporadic cases.10 This aggressiveness is attributed to genetic alterations, including the loss of the merlin protein, which contributes to increased tumor growth and lesion multiplicity. Given these dynamics, NF2 patients require intensive and ongoing surveillance. Despite complete resections, they remain at elevated risk for the development of new tumors or recurrence at the original site, underscoring the need for vigilant follow-up in this population.

Extent of Resection (Simpson Grade): Complete microsurgical resection is fundamental in treating meningiomas. In intracranial cases, achieving a Simpson grade I or II resection correlates with the lowest recurrence rates. In spinal meningiomas, the grading system is similarly applied but adapted: Simpson grade I involves excising the dural attachment, often necessitating a dural patch repair, while grade II involves coagulating the dural insertion without excision.

In our study, 86.4% of the spinal meningiomas were totally resected (Simpson I or II), with only 7 patients (10.6%) undergoing subtotal (Simpson III) or partial (Simpson IV) resections. We found no statistically significant difference in recurrence rates between Simpson grade I and others. While none of the 5 patients with a Simpson grade I resection experienced recurrence, the sample size might be too small to draw definitive conclusions. The majority, about 80%, underwent Simpson grade II resection, and experienced a modest recurrence rate.

Our findings align with recent studies, such as one by Kobayashi et al., which also reported no significant differences in recurrence between Simpson I and II resections over a mean follow-up of 7 years.[11] This suggests that aggressive dural resection (Simpson I) might not always be necessary, particularly if it poses additional risks like spinal cord manipulation or cerebrospinal fluid leakage.4 For spinal meningiomas, especially those located ventrally, attempting a Simpson I resection may increase these risks. The generally low recurrence rates observed with Simpson II in our study support a less aggressive approach when appropriate.

Tumor Location (Axial and Longitudinal): In our, the majority of spinal meningiomas were located in the thoracic region (65.2%), followed by the cervical (30.3%) and a few in the lumbar region (4.5%), reflecting the common preference for the thoracic spine.[12] The tumors were found in various axial positions, including dorsal, dorsolateral, lateral, ventral, and ventrolateral attachments.[13] Our analysis

showed that neither the spinal level nor the axial position significantly influenced ecurrence rates, suggesting that tumor location does not inherently determine recurrence risk, provided that gross-total resection is achieved.

However, the location does affect the ease of resection. Tumors located ventrally or ventrolaterally are often more challenging to remove completely due to the difficult surgical access to the dural attachment on the anterior side of the spinal cord. For example, Nakamura's study highlighted that all recurrences occurred in ventral tumors that only underwent a Simpson II resection, where the dura was coagulated but not excised.[14] In our series, despite these challenges, our ventral tumors did not show a significant difference in recurrence rates compared to dorsal tumors, likely because the ventral dura was adequately coagulated and the cases were followed long-term.

For large ventral tumors, we sometimes used posterolateral approaches to improve access, following techniques described in recent surgical literature.15 Additionally, the extent of the tumor vertically (number of spinal levels affected) did not correlate with recurrence; tumors spanning multiple levels were either removed en bloc or in piecemeal but completely, with outcomes similar to those of single-level tumors. This comprehensive approach helped us achieve satisfactory resection rates across various tumor locations and sizes.

Sex: Spinal meningiomas are more common in females, with our study showing 77% female patients. Despite this, studies like Kobayashi et al. report higher recurrence rates in males, suggesting more aggressive tumor biology or links to conditions like NF2 in this less commonly affected group.[11] Our data did not show significant sex differences in recurrence.

Dural Tail Sign: In our study, 56.1% of patients showed a dural tail on preoperative MRI, an indicator of significant dural involvement by the tumor. However, the presence of a dural tail did not statistically predict recurrence, likely because we consistently addressed the dural attachment zone through resection or coagulation in all cases. While a residual dural tail could potentially lead to recurrence if not completely coagulated, our thorough approach in treating these areas, regardless of resection type, may explain the lack of significant findings. This contrasts with other studies, such as the multicenter study that found a dural tail sign associated with higher recurrence risks[11], possibly due to less aggressive management in some centers. Our effective surgical techniques, including extensive cauterization of any dural tail, likely mitigated this risk, underscoring the importance of proper dural management in surgery.

Histopathology and Subtype Considerations: In our study, nearly all tumors were WHO grade I meningiomas, with only one atypical WHO II case (1.5%) that did not recur. High-grade spinal meningiomas are rare, and even high-risk tumors can remain controlled under certain conditions. Histologically, psammomatous meningioma was the most common subtype (34.8%), followed by meningothelial (15.2%). Although histologic subtype did not significantly correlate with recurrence (p = 0.099), higher incidence of the psammomatous type in the recurrence group (71.4% compared to 30.5%) may indicate tumor calcification. This calcification tends to give the tumors a firmer consistency and often results in them being broadly attached to the dura, which can complicate surgical resection.

Our findings emphasize the clinical relevance of histologic subtypes and WHO grade in spinal meningioma management. Subtype identification can influence surgical strategies and follow-up, especially in cases with unusual pathology. Overall, while WHO grade is a primary prognostic factor, understanding the nuances of each subtype within the context of other risk factors, like NF2 status, is crucial for tailored treatment and surveillance.

Clinical Implications

Maximal Safe Resection is Crucial: We reaffirm that gross-total resection (Simpson grade I or II) should be the surgical goal whenever feasible, as it offers the best chance for long-term tumor control. However, attempting Simpson grade I (dural resection) in every case is not always necessary if it would incur undue risk.

Long-Term Surveillance is Essential: Our data strongly indicates the necessity for long-term follow-up in spinal meningioma patients, with recurrences as late as 10–15 years post-surgery not being uncommon. This aligns with recommendations from some studies that advise lifelong surveillance after resection.[11] Practically, this entails periodic MRI screenings for patients—initially more frequently within the first five years post-surgery, then possibly annually or biennially, even if they remain asymptomatic. Given the relatively slow progression of these tumors, as evidenced by the mean overall recurrence time of about 6–7 years in our study, early detection of recurrence allows for timely re-operation with minimal risk and before any significant neurological decline. The fact that our observed 5-year recurrence rate (10.6%) more than doubles with extended follow-up highlights the insufficiency of short-term monitoring. Therefore, we recommend continued surveillance for at least 10–15 years, or ideally for life, especially in younger patients or those with NF2 whose recurrence occurred earlier than the other group (3.4 yr vs 5.0 yr, p = 0.016).

Risk Factor–Tailored Management: Identifying patients at higher risk of recurrence is crucial for optimizing management strategies. In our cohort, younger patients, or those with NF2, are considered high-risk. These individuals may benefit from more aggressive initial surgical approaches, such as a Simpson I resection when feasible, given their longer potential duration for recurrence. Furthermore, such high-risk patients require closer and more consistent follow-up. Specifically, we recommend that these high-risk patients be clearly informed about their elevated recurrence risk to ensure they remain vigilant and engaged in long-term surveillance. For instance, in our practice, young patients with NF2 are scheduled for annual MRI scans indefinitely to monitor for any changes. Conversely, an elderly patient with a small, low-risk dorsal meningioma that has been completely resected might not require as frequent follow-up after an initial disease-free period. However, given that recurrences can occur even late in life, as seen with a patient at age 82 in our series, we still advise long-term imaging for most cases to ensure comprehensive care and early detection of any potential recurrence.

Conclusion

This study of spinal meningiomas at Siriraj hospital confirms that surgical treatment not only yields excellent outcomes in terms of symptom relief and initial tumor control, but also highlights the non-negligible risk of late recurrence. Younger age ≤45 years and NF2 are associated with higher recurrence risk, calling for meticulous resection

and prolonged observation in these patients. Histopathologic trends were noted (with psammomatous tumors being common in our cohort), though subtype alone did not significantly dictate recurrence. Even WHO grade I spinal meningiomas can recur a decade or more after resection, meaning that patients and clinicians must remain vigilant. Our series emphasized on long-term and frequent follow-up in spinal meningioma patients, especially in high risk group. Future research may focus on molecular predictors of recurrence and optimal management strategies for high-risk patients (e.g. NF2-associated meningiomas). Until then, adherence to established surgical principles (complete resection when safe) and sustained long-term postoperative surveillance are the best tools for ensuring the lasting success of our interventions.

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