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Minimally invasive surgery for intradural spinal meningioma: a new standard? A comparative study between minimally invasive and open approaches

Abstract :

Background: Some authors used minimally invasive surgery (MIS) in the treatment of spinal cord tumor, but these studies had a small sample sizes and mixed extra- and intra-medullary tumors, resulting in confounding biases. The objectives of the present study were to evaluate the effectiveness and safety of MIS for spinal meningioma resection in comparison with open surgery (OS).

Methods: Consecutive patients with spinal meningioma who received either MIS or OS were included. Data for extent of resection, functional outcome, postoperative morbidity and recurrence were collected.

Results: A total of 48 patients (with 51 spinal meningiomas) were included. Eighteen underwent MIS and 30 OS. Meningioma volume and location did not differ significantly between groups: tumors were predominantly thoracic (n=39, 76.5%) and voluminous (occupying more than 50% of the spinal canal: n=43, 84.3%). In the MIS group, patients were older (mean age: 66.5 *vs.* 56.4 years, p = 0.02) and more fragile (mean ASA score: 2.0 *vs.* 1.6, p = 0.06). In the MIS group, the surgical procedure was shorter (mean duration: 2.07 *vs.* 2.56 h, p = 0.04), blood loss lower (mean: 252 *vs.* 456 mL, p = 0.02), and hospital stay shorter (mean: 6.6 *vs.* 8.1 days). Surgery improved the modified McCormick scale (p < 0.0001) irrespective of the surgical technique. MIS led to no significant differences in extent of resection or postoperative morbidity. Mean follow-up was 46.6 months. At last follow-up, 91.7% (n = 44) of patients were free of progression; all cases of tumor progression (n = 4) occurred in the OS group.

Conclusions: MIS outperformed OS in the management of intradural spinal meningioma, irrespective of location and volume. MIS appears to be particularly suitable for elderly and fragile patients.

Abbreviations:

ASA: American Society of Anesthesiologists, CSF: cerebrospinal fluid, GTR: gross total resection, HR: hazard ratio, MIS: minimally invasive surgery, MRI: magnetic resonance imaging, SD: standard deviation, STR: sub-total resection, WHO: World Health Organization.

Introduction

Meningiomas represent one of the most frequent histological type of intradural extramedullary tumors in adults,[1] and microsurgical resection is the gold standard for symptomatic meningioma.[2–4] Although the primary objective of these surgeries is the gross-total resection (GTR) to release nervous system compression and avoid recurrence, the secondary objective is to ensure optimal neurological recovery with minimal permanent deficit.

Previous studies on spinal meningiomas reported surgical outcomes using the open approach.[2–9] With the improvement of neurosurgical techniques,[10] recent studies have proposed resection of spinal tumor, including intradural location, using a minimally invasive approach.[11–14] As already demonstrated for degenerative spinal pathologies, minimally invasive surgery (MIS) reduces soft tissue destruction, peri-operative blood loss, postoperative pain, and length of hospital stay.[15,16] Authors have reported the feasibility and use of MIS in the treatment of spinal cord tumors,[11–14,17–20] but these studies had a small sample size,[12–14,18,20] and/or mixed extra and intramedullary tumors in the same cohort.[12,14,17,19,20] However, from a surgical point of view, the management of extramedullary tumors is very different from intramedullary ones, with fewer complications and better outcomes.[21] Moreover, from a methodological point of view, this leads to major confounding bias, potentially explaining why published studies that compared MIS to open techniques failed to find significant differences between these for spinal meningiomas.[22,23]

In the present study, we aimed at determining the safety and effectiveness of MIS for spinal meningiomas resection, comparing the extent of resection, functional outcomes, postoperative morbidity, and recurrence with the open approach.

Methods

All procedures were carried out in accordance with the applicable guidelines, in compliance with the 1964 Helsinki declaration, and with the ethical standards of the institutional research committee (IRB: 00011687-2020/44). The present study included consecutive adult patients operated on, from January 2015 to December 2019 in our university hospital, for a de novo intradural extramedullary tumor strictly located in the spinal canal (cervical, thoracic, or lumbar) and with a histological diagnosis of meningioma according to the WHO criteria.[24] A retrospective chart review of prospective data was performed, and meningiomas with paravertebral extension were not included.

The preoperative neurological status were reported according to the McCormick scale.[25] Each patient had a preoperative spinal MRI, including gadolinium injection (**Figure 1a, b**). The tumor volumes were graded in accordance with the Bayoumi classification whereby the grade of the meningioma is proportional to its volume within the spinal canal; grade I: < 25% of the spinal canal, grade II: between 25% and 50% of the spinal canal, grade III: between 50% and 75% of the spinal canal, and grade IV: > 75% of the spinal canal.[26] Bayoumi classification also give information about the insertion of the meningioma on the dura by its appendix letter: "a" means that meningioma is ventral, "b" is dorsal, and "c" is lateral.

MIS or the classic open approach was used according to the neurosurgeon's habitual practice (the allocation of surgery – MIS vs open surgery – was done randomly during the first preoperative consultation, according to the senior neurosurgeon). Neurosurgeons who practiced MIS were all at the top of the MIS learning curve (more than 5 years of experience in intradural tumor resection using MIS). MIS was performed when the meningioma did not exceed 2 vertebral levels in height. For the MIS (**Supplementary material and**

Supplementary Figure 1), the skin incision was paramedian, an expandable tubular retractor (Quadrant retractor Medtronic Sofamor Danek, Memphis, TN, USA) or nonexpandable retractor (METRx system, Medtronic Sofamor Danek) was used according to the height of the meningioma (**Figure 2a, b, c**), and laminas were drilled (**Figure 2d**) over the entire length of the meningioma (**Figure 2e**).[27] The open approach considered all approach without the use of tubular retractor (bilateral exposure with laminectomy, bilateral exposure with laminotomy, unilateral laminectomy, and unilateral laminotomy). For both approaches, the dura mater was opened on the midline and then suspended. The peri-spinal cisterns were drained,[28] and the meningioma was removed under a surgical microscope. The amount of blood loss was recorded, the duration of the surgery and hospitalization were collected. The tumor resection was categorized as follows: 1) GTR, when resection was macroscopically complete and no tumor remnant was detectable on the postoperative MRI; 2) sub-total resection (STR), when a near-complete resection was achieved with remnant detectable on the postoperative MRI. The Simpson grading was also used to define the quality of the resection.[29]

Patient follow-up consisted of clinical examination and spinal MRI conducted at 3 months and 1 year postoperatively (**Figure 1c, d**). After this period, the follow-up was performed annually for at least 5 years, associated with a spinal cord MRI. After this period, the follow-up was performed every 2 years for 5 years. After 10 years follow-up, for patients with a gross-total resection, considering that it is very slowly growing tumor, the follow-up is then stopped. For the present study, the last clinical examination and spinal cord MRI were considered for analysis.

Statistical analysis

Categorical variables were expressed as number (n) and percentage. Quantitative variables were expressed as means ± standard deviation (SD). Categorical variables were compared

using the Chi squared test or Fisher's exact test (when the conditions of application of Chi squared test were not met), and continuous variables were compared using the Student t-test or Wilcoxon test (when the distribution was not normal) for continuous variables. The hypothesis of normal distribution of continuous variables was tested using the Shapiro and graphically confirmed with a histogram. The progression free survival (PFS) was defined by the interval between date of diagnosis and that of first progression (or recurrence) or last known status. Description of PFS was estimated by the Kaplan-Meier product limit method, and the effect of different parameters was assessed using the log-rank test. Statistical analyses were performed using the web-based statistical tool (https://biostatgv.sentiweb.fr), significance was set at $p<0.05$.

Results

Preoperative clinical and radiological findings

During the study period, 51 spinal meningiomas, in 48 patients required surgical management. Three patients harbored two meningiomas at different spine levels. The mean ±SD age of the population was 60.2±14.9 years at the time of surgery. There were 39 female patients (81.2%). Preoperatively, 5 patients (10.4%) were grade I according to the McCormick scale, 14 (29.2%) grade II, 16 (33.3%) grade III, 12 (25.0%) grade IV, and 1 was grade V (**Table 1**).

There were 11 (21.6%) meningiomas located at the cervical level (4 were between C0-C2, and 7 between C3-C7), 39 (75.0%) at the thoracic level (23 were between T1-T6, and 16 between T7-T12), and 1 (1.9%) was at the lumbar spine level. According to the volume classification proposed by Bayoumi et al.,[26] 3 (5.9%) meningioma was grade I, 5 (9.7%) was grade II, 13 (25.5%) were grade III, 30 (58.9%) were grade IV (Table 1). There was a

significant correlation between the volume of the meningioma and the severity of the neurological examination (Pearson test, ρ: 0.34, CI95% [0.0715; 0.5631] p=0.01). Edema was found in 37 patients, and syringomyelia in 2 patients. Edema and syringomyelia were not significantly associated with the severity of the neurological examination (p>0.5).

Surgical management: MIS versus open surgery

Eighteen (37.5%) patients underwent MIS, and 30 (62.5%) open surgery. MIS was performed for 17 (89.4%) thoracic, 1 (5.3%) cervical, and 1 (5.3%) lumbar meningiomas, while open surgery was performed for 22 (68.8%) thoracic and 10 (31.2%) cervical meningiomas. Concerning the latero-lateral meningioma extension, 17 (94.4%) patients who underwent MIS, and 25 (83.3%) patients who had open surgery, presented with a meningioma filling more than 50% of the spinal canal (≥ grade III according to the Bayoumi scale, p>0.5). Concerning the cranio-caudal meningioma extension, there was also no difference between groups (1.1±0.3 vertebral level in the MIS group *versus* 1.2±0.2 in the open group, p>0.5). Patients operated with MIS were older (66.5±14.1 years) than those operated with the open technique (56.4±14.3 years, p=0.02). There is a trend towards a higher ASA scale in patients who had a MIS (2 [1 – 3]) than in patients who had open surgery (2 [1 – 2], p=0.06). MIS was significantly shorter (2.07±0.66 hours) than open surgery (2.56±1.08 hours, p=0.04). Blood loss was significantly lower with a MIS (252.7±215.2 mL) than with an open approach (456.7±396.25 mL, p=0.02; **Table 2**). No significant difference regarding the extent of resection was reported according to the type of surgical approach. One patient had a STR (Simpson 4) in the MIS group, while 3 patients had a STR (Simpson 4) in the open surgery group (p>0.5). With the exception of meningiomas that were partially resected, all other meningiomas were classified Simpson 2 (GTR of the tumor with coagulation of dural attachments).

The histopathological analysis found meningioma grade 1 according to the WHO classification[24] in all cases.

Postoperative morbidity

Postoperative morbidities are reported in Table 2. There no significant difference in complications between groups: there were no patients with infectious meningitis in the MIS group, while there was 1 (3.3%) in the open surgery group (p>0.5); 1 (5.5%) patient had CSF leakage in the MIS group, while there were none in the open surgery group (p>0.5); and 2 (11.1%) patients had an immediate neurological worsening in the MIS group, while there were 4 (13.3%) in the open surgery group (p>0.5). During the postoperative course, no patients experienced venous thromboembolic complication.

Functional outcomes

The mean (±SD) follow-up was 46.6 (±14.2) months. At last follow-up, 34 patients (70.8%) were grade I according to the McCormick scale, 12 (25.0%) were grade II, 1 (2.1%) was grade IV, and 1 (2.1%) were grade IV. Irrespective of the surgical technic, surgery significantly improved the results of neurological examination with spinal cord meningioma: there were significantly more patients with McCormick grade I in the postoperative course (n=34, 70.8%) than in preoperative (n=5, 10.4% p<0.0001). Postoperatively, patients significantly improved their McCormick scale by a median of +1 [1 – 3] grade (p<0.0001): 5 (10.4%) patients improved their McCormick scale by 3 grades, 18 (37.5%) by 2 grades, 16 (33.3%) by 1 grade, and 9 (18.8%) did not improve (but 5 of these were already grade I according to the McCormick scale). The neurological recovery did not differ between MIS and open surgery (p>0.5). In the present study, there was no significant association between

neurological recovery and preoperative McCormick scale (p>0.5), or the volume of the meningioma according to the Bayoumi scale (p>0.5).

There was a trend towards shorter hospital stay in the MIS group (mean ±SD: 6.6±4.0 days) than in the open surgery group (8.1±5.6 days; p=0.3).

Progression-free survival

At last follow-up, 44 (91.7%) patients were free of progression; 4 (8.3%) patients experienced a recurrence. The mean (SD) time to recurrence was 63.6 (±20.4) months, and they all underwent open surgery. One patient (25.0%) had a GTR, and 3 (75.0%) a STR. There were significantly more patients with progression when the resection was incomplete than when a GTR was performed (75.0% versus 2.3%, HR = 83.06, 95%CI [3.9; 6397.8], p<0.0001, **Figure 3**). However, no significant association was reported between the recurrence and the location of the meningioma (p=0.2), or the volume of the meningioma (p>0.5). Of the 4 patients with a recurrence, 3 underwent a new surgical procedure (1 resulted in a GTR, and 2 in a new STR, due to a foraminal tumor remnant), and 1 had a strict follow-up (due to the small volume of tumor remnant).

Discussion

In the present study, we found that MIS allows GTR of large meningioma without spinal cord impairment or postoperative deficit. MIS enables significantly lower blood loss and reduces surgery time, and hospital stay. MIS appears to be suitable for elderly and fragile patients. Postoperative morbidities were not significantly different between MIS and open surgery, making MIS a safe and effective procedure.

The present study demonstrates the effectiveness of MIS for spinal meningioma resection. Notably, more than three-quarters of patients who received MIS presented initially with a meningioma filling more than 75% of the spinal canal, and, although MIS provides a limited corridor, GTR was attained in all-but-one patient. GTR is a recognized as a prognostic factor to avoid recurrence, as reported for a variety of spinal tumors,[2,30] but spinal meningioma recurrence is known to be uncommon (using the open approach).[8,31] To qualify the quality of meningioma resection, the Simpson scale is usually used.[29] However, this classification was initially created for cranial meningiomas;[29] in spinal meningiomas, the Simpson 1 resection (complete resection including dura and bone) is often unattainable. Due to the vast majority of lateral and anterior insertion of spinal meningiomas on the dura mater, resection Simpson 2 (GTR of the tumor with coagulation of dural attachment) is usually performed. In the present study, patients with Simpson 2 resection did not experience any recurrence. Although some authors have reported grade> Simpson 1 as a prognostic factor for recurrence,[32,33] our results are more nuanced and confirmed the importance of the tumor GTR.[34,35]

The results of the present study demonstrate that MIS is a safe procedure. Although these large tumors crushing the spinal cord were gross-total resected using MIS, we did not report a greater rate of neurological impairment than with an open approach. In the total population all-but-four patients (all four had open surgery) experienced an improvement of their neurological status after surgery, suggesting that even patients suffering from severe preoperative neurological deficits could recover normal motor function and ability to walk after surgery – as reported previously.[36] There were, however, certain differences: for example the patients who received MIS were older and had a greater ASA score, they also had a lower blood loss and surgical time. This is of interest, as, in a study that reported on the

open approach, the factors leading to neurological deterioration revealed that in particular elderly patients were affected.[31] Other studies focused on elderly patients concluded that spinal meningioma surgery should always be attempted in elderly patients with a low or moderate anesthesiological risk, since no mortality or significant morbidity occurred.[37,38] Nevertheless, scientific community recognizes that elderly subjects are fragile patients, for whom postoperative complications can be more morbid.[39] Therefore, MIS could be an interesting choice for the fragile and elderly.

We also demonstrated that postoperative morbidities in patients who underwent MIS were not more frequent than in those patients who had the open approach. This further supports the safe character of this type of procedure, that has been adopted for intradural surgeries to reduce immediate postoperative morbidity (CSF leakage, infections, symptomatic epidural hematoma etc.).[22,23,40] Some authors explain this by principle of tubular surgery:[11,40] the tubular surgical corridor allows the scar tissue to close after tube removal, avoiding dead space in which CSF or blood could accumulate.[40] Also, the limited skin incision prevents introduction of skin flora that might impair wound healing or even produce a wound infection, either of which might perpetuate a CSF leak.[11] MIS procedures offer the advantage of decreased damage to adjacent soft tissue, resulting in decreased postoperative pain and discomfort. This advantage is shown by multiple studies, including that by Fan et al.,[41] in which multifidus atrophy in magnetic resonance images was relatively reduced in MIS compared with open procedures. Moreover, several studies[42,43] performed a biomechanical comparison between open surgery and MIS and demonstrated that the open surgery produced greater changes in flexion, extension, and axial rotation when compared with the minimally invasive technique. However, it is also of note that there is a learning curve for MIS. MIS can be initially challenging for neurosurgeons (without MIS experience) due to the potential limited angular visualization during the surgical procedure, and the

narrow surgical corridor. Nevertheless, a recent study had demonstrated that a 50% learning

curve is achieved by approximately 12 cases and 90% by 25-40 cases.[44] Surgical aptitude,

manual dexterity of the trainee, and structured training are important factors in reducing the

learning curve, and therefore to ensure the safety of spinal meningioma resection with MIS.

Another point to consider is that the safety of the procedure allows greater efficiency.

For instance, the lower blood loss and a shorter surgical time, MIS results in simpler

postoperative monitoring, and, therefore, in a reduction of the hospital stay.[22,23,40] This is

illustrated in a recent U.S. study: the total cost of care for patients with intradural

extramedullary tumors was reduced by 25% by performing MIS.[40] Even though MIS

required dedicated instruments and surgical microscope, its cost-efficiency make it suitable

for many care-givers in the long-term.[40]

The present study has several strengths. For instance, only adult patients with spinal

meningiomas were included avoiding bias related to age and other histological intramedullary

tumors, as proposed in several studies.[12,14,17,19,20,23,45] To the best of our knowledge,

the present study represented the largest dedicated comparison between open approach and

MIS for spinal meningiomas. Although meningioma characteristics (size, volume, etc.) were

not different between MIS and open surgery, the present study is however limited by its

nonrandomized design. Moreover, the retrospective design of the study can lead to a bias in

estimating recurrence. Nevertheless, meningioma being a slowly growing tumor and often

completely resected, with a low rate of recurrence, the ranking bias is probably not

underestimated, even if the follow-up time is different between patients.

Conclusion

In the present study, MIS was found to be a safe and effective procedure for the resection of voluminous spinal meningiomas, irrespective of their spinal location. The results highlight the advantages of MIS for spinal meningiomas, and could contribute through future clinical trials to elevate MIS to the gold standard for intradural extramedullary tumors.

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Table 1: Patient characteristics

Table 2: Comparison of population, surgical outcomes and perioperative morbidities between open and minimally invasive approaches.

Figure 1: a and b: Preoperative MRI showing a spinal cord meningioma Bayoumi grade IV, respectively on sagittal T2-weighted image and axial T1 with gadolinium enhancement. c and d: Postoperative MRI after gross-total resection of spinal cord meningioma using minimally invasive approach, respectively on sagittal and axial T2-weighted images.

Figure 2: a, b and c: MIS installation with tubular retractor and expendable tubular retractor. d: Drilling of laminas over the entire length of the meningioma. e: Dura mater is exposed bilaterally.

Figure 3: Progression-free survival (PFS) in patients with spinal cord meningioma determined using the Kaplan-Meier method. PFS according to the quality of the resection (gross-total resection (GTR, n = 44) *versus* incomplete resection, n = 4).
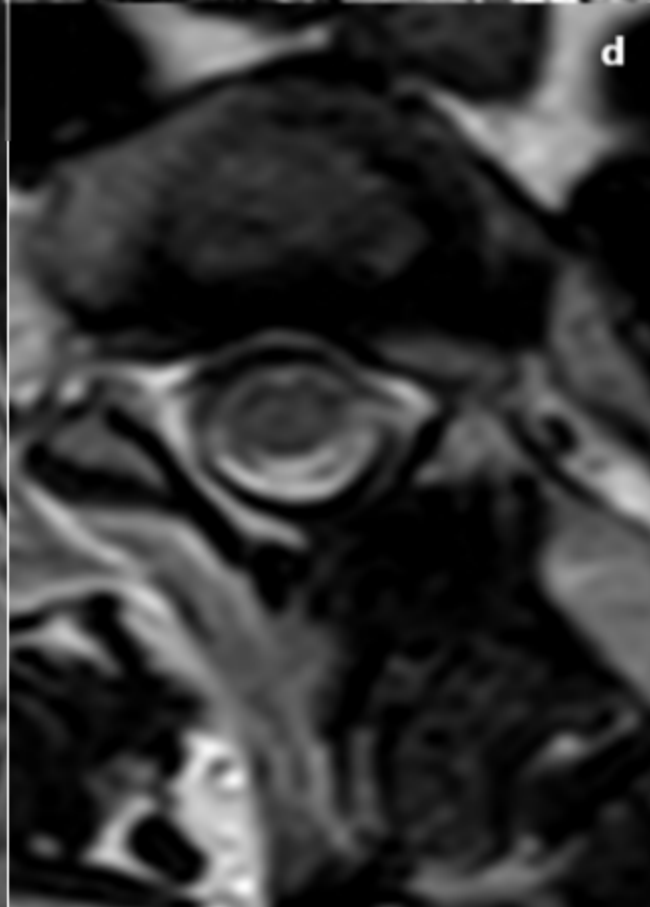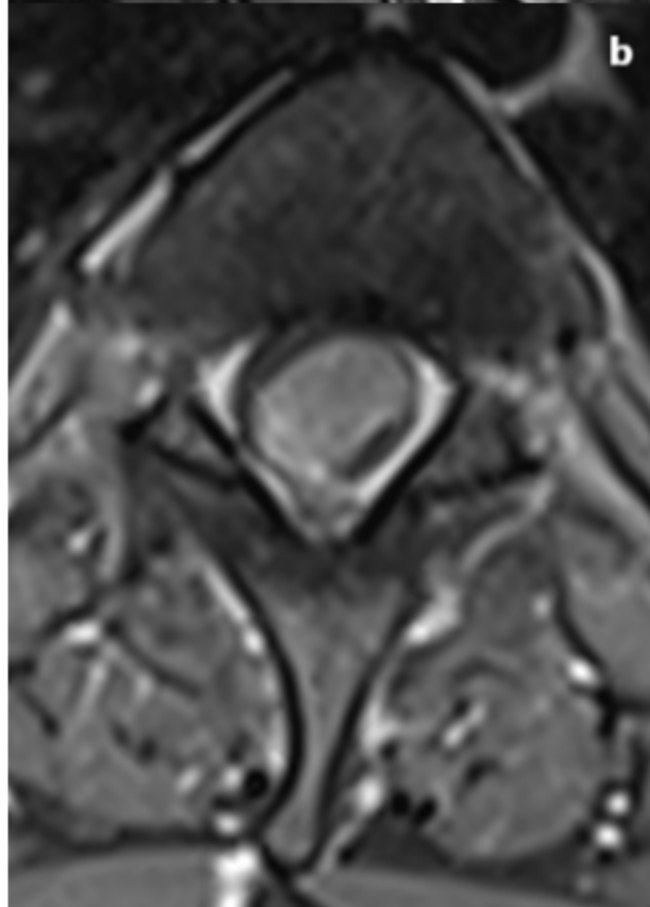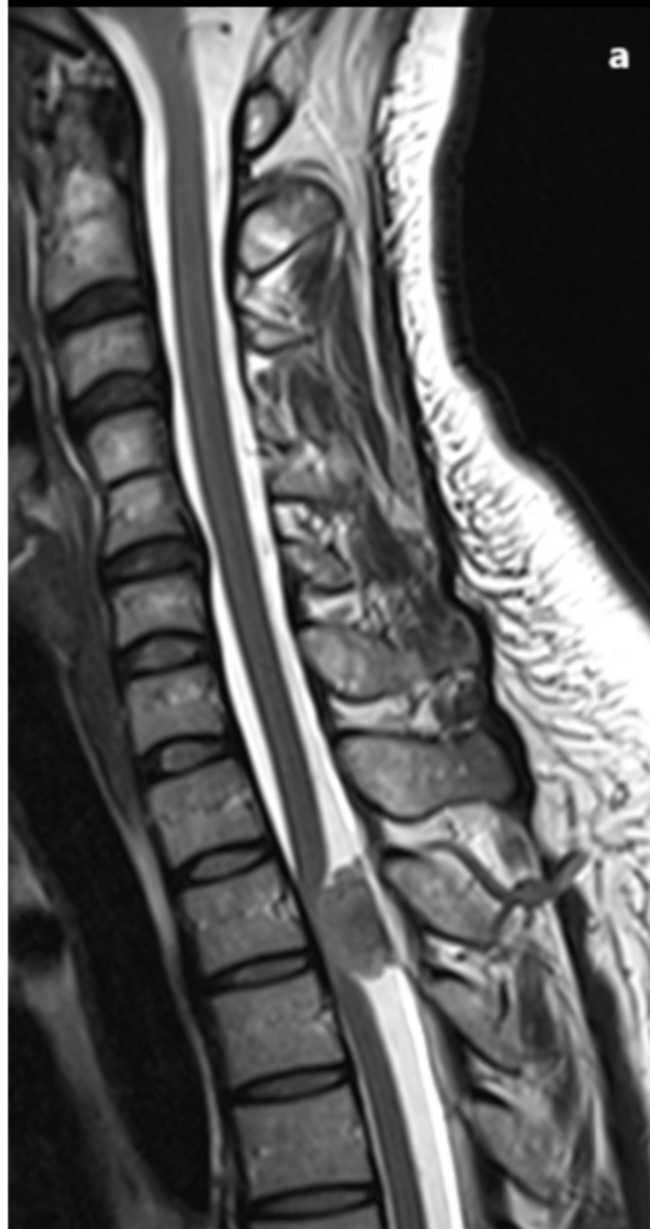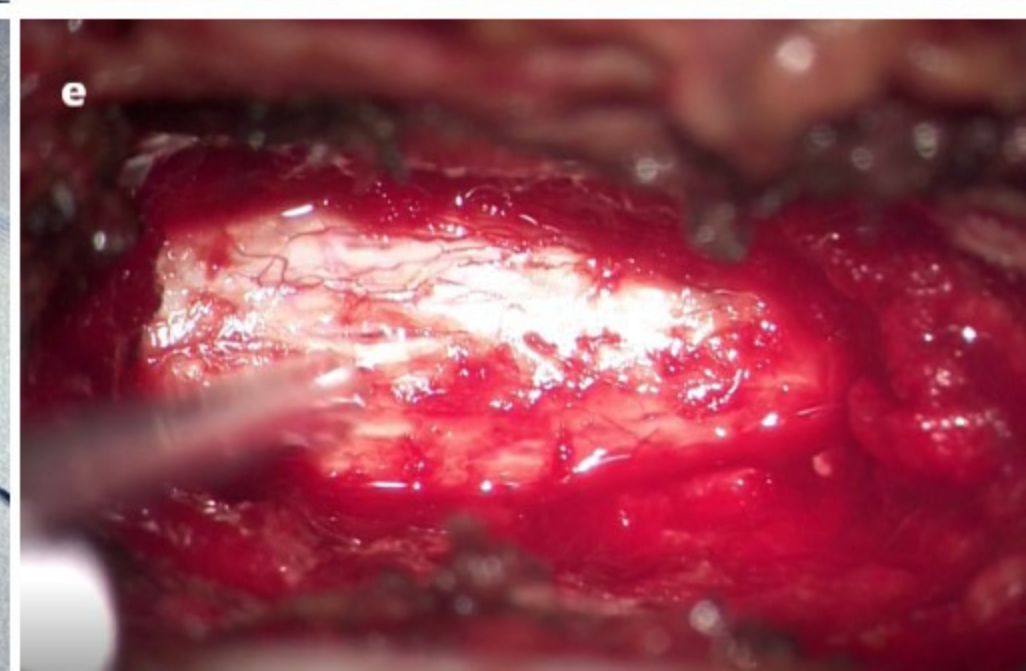
Preoperative	Postoperative
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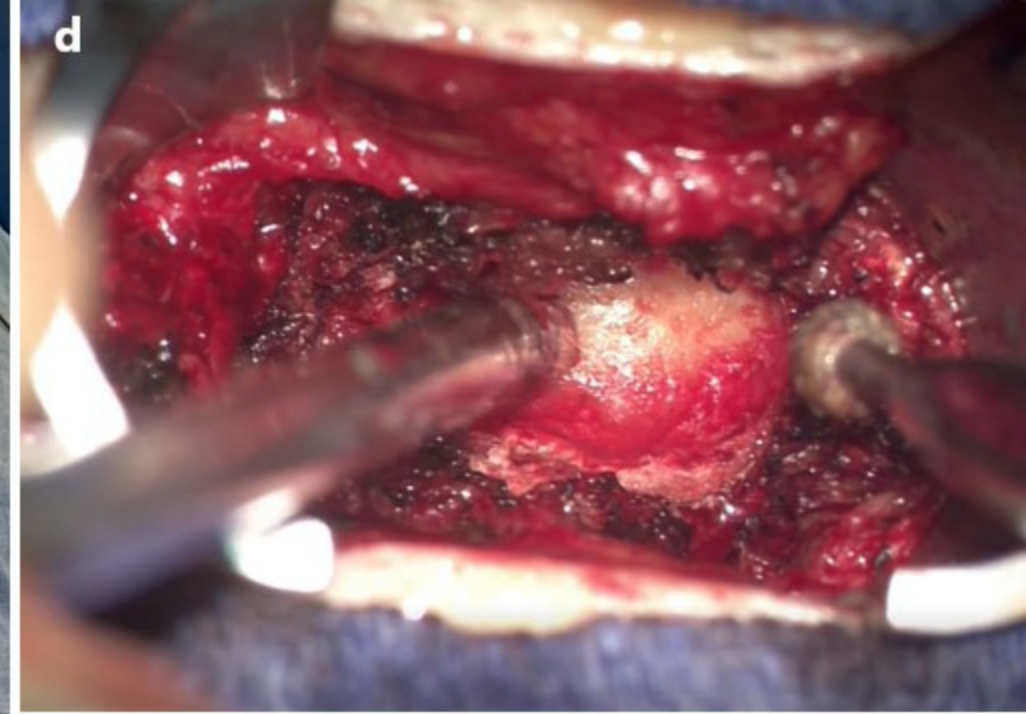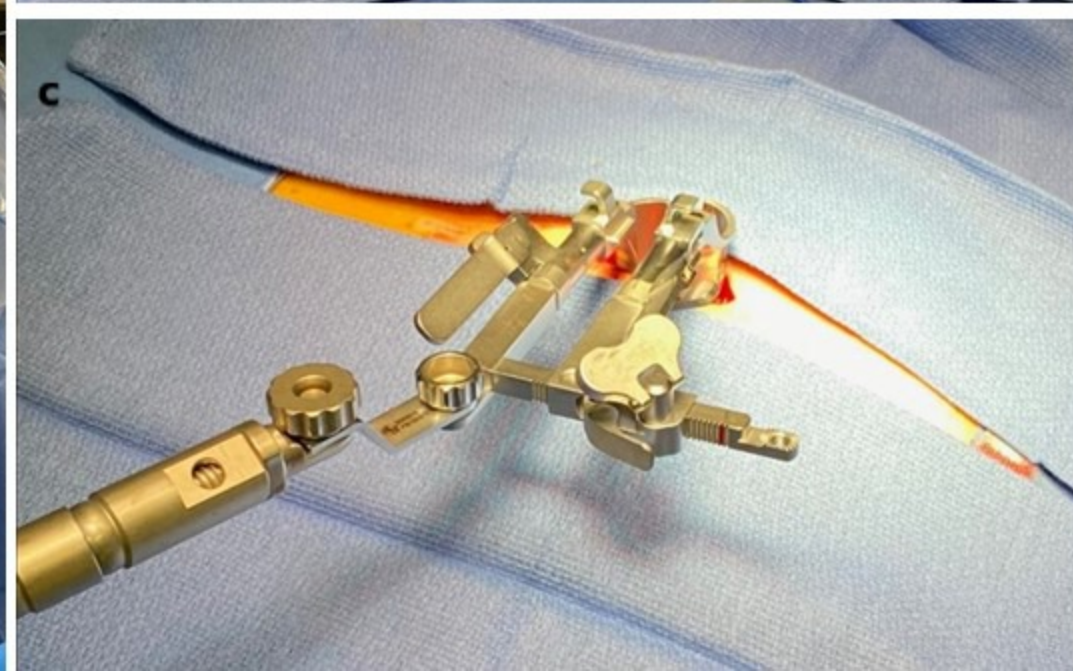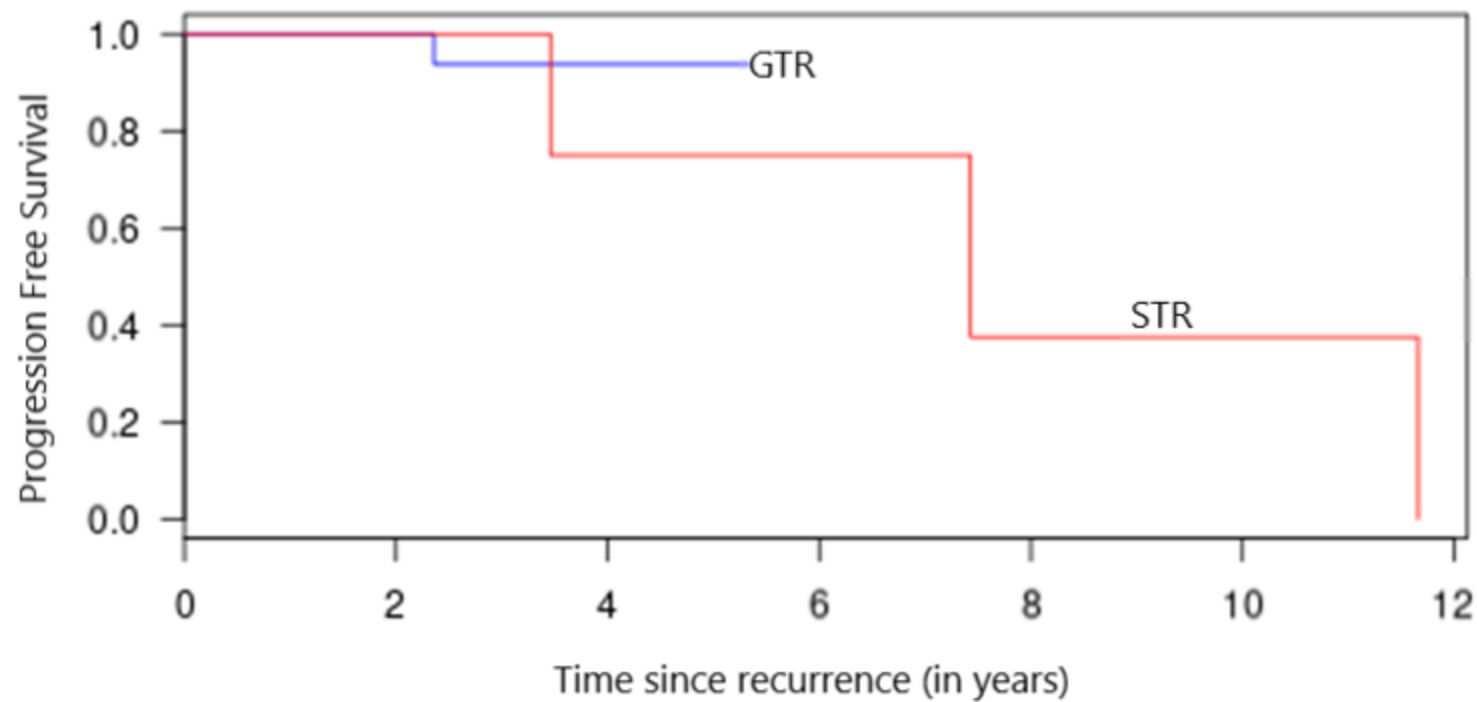
Table 1: Patient characteristics

	Total population, Patients: n = 48 Meningiomas: n = 51
Age: mean ± SD, years	60.24 ± 14.9
Sex: Female, n (%)	39 (81.3)
Pre-operative McCormick scale: n (%)	
I	5 (10.4)
II	14 (29.2)
III	16 (33.3)
IV	12 (25.0)
V	1 (2.1)
Pre-operative ASA scale: median [Q1 – Q3]	2 [1 – 3]
Tumor location: n (%)	
Cervical canal	11 (21.6)
Thoracic canal	39 (75.0)
Lumbar canal	1 (1.9)
Tumor size according to the Bayoumi et al. scale: n (%)	
Grade I (< 25% spinal canal)	3 (5.9)
Grade II (25 – 50% spinal canal)	5 (9.7)
Grade III (50 – 75% spinal canal)	13 (25.5)
Grade IV (> 75% spinal canal)	30 (58.9)
Quality of resection: n (%)	
GTR	47 (92.1)
STR	4 (7.9)
Histology: n (%)	
WHO grade I	51 (100)
Post-operative McCormick scale: n (%)	
I	34 (70.8)
II	12 (25.0)
IV	1 (2.1)
V	1 (2.1)
Recurrence: n (%)	4 (8.3)
Follow-up: mean ± SD, months	46.6 ±14.2

ASA: American Society of Anesthesiologists, GTR: gross total resection, SD: standard deviation, STR: sub-total resection, WHO: World health organization.

Table 2: Comparison of population, surgical outcomes, and perioperative morbidities between open and minimally invasive approaches.

	MIS n = 18	Open surgery n = 30	p-value
Follow-up: mean ± SD, years	3.2 ± 0.9	4.0 ± 1.5	0.1
Age: mean ± SD, years	66.5 ± 14.1	56.4 ± 14.3	0.02
ASA scale: median [Q1 – Q3]	2 [1 - 3]	2 [1 - 2]	0.06
Localization, n (%) Cervical canal Thoracic canal Lumbar canal	1 (5.55) 16 (88.9) 1 (5.55)	10 (31.2) 22 (68.8)	0.1
Volume of meningioma (Bayoumi scale), n (%) Grade I Grade II Grade III Grade IV	0 1 (5.5) 3 (16.7) 14 (77.8)	1 (3.3) 4 (13.3) 9 (30.0) 16 (53.4)	0.3
Quality of resection, n (%) GTR STR	17 (94.6) 1 (5.5)	27 (90.0) 3 (10.0)	> 0.5
Blood loss: mean ± SD, mL	252.7 ± 215.2	456.7 ± 396.25	0.02
Time of surgery: mean ± SD, hours	2.07 ± 0.66	2.56 ± 1.08	0.04
Hospitalization time: mean ± SD, days	6.6 ± 4.0	8.1 ± 5.6	0.3
Morbidities			
CSF Leakage, n (%)	1 (5.5)	0	> 0.5
Meningitidis, n (%)	0	1 (3.3)	> 0.5
Neurological worsening, n (%)	2 (11.1)	4 (13.3)	> 0.5
Postoperative compressive hematoma, n (%)	0	0	> 0.5

ASA: American Society of Anesthesiologists, CI: confidence interval, GTR: gross total resection, MIS: minimally invasive surgery, SD: standard deviation, STR: sub-total resection.