Keyhole approaches to intradural pathologies

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OBJECTIVE Spinal tumors account for 2%–4% of all tumors of the central nervous system and can be intramedullary, intradural extramedullary, or extradural. In the past, wide approaches were used to obtain safe access to these tumors, as complete resection is the goal in treating most tumor entities. To reduce surgical complications due to large skin incisions and destabilizing laminectomies, minimally invasive approaches were established. In this study, the authors share their experience with mini-open approaches to intradural tumor pathologies.

METHODS The authors retrospectively reviewed cases involving patients with intramedullary and intradural extramedullary lesions treated between 2009 and 2016. They present their surgical mini-open approach to the spinal cord as well as unique characteristics, key steps, and postsurgical complications for specific tumor subgroups (meningioma, neuroma, and intramedullary tumors).

RESULTS A total of 245 intradural tumors were surgically treated during the study period. Of these lesions, 151 were intradural extramedullary meningiomas ($n = 79$) or neuromas ($n = 72$). Nine (12.5%) of the neuromas were dumbbell neuromas. Ninety-four tumors were intramedullary. The mean age of the patients was 51.4 years, and 53.9% were female. The mean duration of follow-up was 46.0 months.

All meningiomas and neuromas could be resected using a mini-open keyhole approach, but only 5.3% of the intramedullary lesions could be accessed using this technique. Of the 94 patients with intramedullary tumors, 76.6% required a laminotomy, 7.4% required a hemilaminectomy, and 10.6% required a 2-level laminectomy. Only 2 of the patients with intramedullary tumors needed stabilization for progressive cervical kyphosis during follow-up. None of the other patients developed spinal instability after undergoing surgery via the mini-open (keyhole/interlaminar) approach. There were significantly more surgery-associated complications in the large exposure group than in the patients treated with the mini-open approach (19.1% vs 9.6%, $p < 0.01$).

CONCLUSIONS Intradural extramedullary and in selected cases intramedullary pathologies may safely be resected using a mini-open interlaminar approach. Avoiding laminectomy, laminotomy, and even hemilaminectomy preserves spinal stability and significantly reduces comorbidities, while still allowing for complete resection of these tumors.

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KEY WORDS minimally invasive; spine; keyhole; intradural

SPINAL tumors are rare and diverse neoplasms accounting for about 2%–4% of all tumors of the central nervous system.⁵ Intradural lesions make up 40%–45% of these lesions, but only approximately 5% are intramedullary, with the remaining lesions being extramedullary.² Complete resection of these lesions is the gold-standard treatment, especially for tumors with less aggressive potential, such as meningiomas, neuromas, or ependymomas.⁵ Consequently, sufficient exposure for visibility and maneuvering space are essential to this type of surgery. To ensure that these requirements were met, extensive approaches were chosen in the past, with lami-

nectomies of 2 or more segments^{1,20,24} and large exposure of the tumor area. These approaches led to problems in terms of large wounds with high infection rates and possible bleeding sources^{4,17,18,23} and also predisposed patients to spinal instability^{4,25} and deformities,^{14,15} like the “swan neck” that was observed especially in young patients who underwent multilevel laminectomy.^{7,8} This led to an increase in reports of the use of additional spinal instrumentation to solve this problem.^{3,22,25,29}

However, with technology advancing, several studies have indicated that it may be possible to achieve an equivalent quality of resection with minimally invasive

ABBREVIATIONS CSF = cerebrospinal fluid.

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FIG. 1. Overview of surgical technique for intradural pathologies applied to a representative case of neuroma. The interlaminar window (A) is created by subperiosteal muscle retraction. The lamina is removed, exposing the dura mater (B), which is incised (C). Sutures are applied to the dura for retraction (D). Blunt dissection of the intradural tissues is performed for a primary overview (E) and the tumor is mobilized (F). After resection of the adhering nervous tissue, the tumor can be removed (G) while maintaining a minimal durotomy of approximately 1.5 cm (H). After closure with sutures, fibrin matrix is applied to ensure a watertight seal (I).

approaches,^{9,12,13,21,27} thereby reducing exposure-related comorbidities to a minimum.

Our objective was to share our experience with a large intradural tumor cohort and show the feasibility and safety of tumor resection using a mini-open approach through the interlaminar window or laminoplasty for intradural pathologies, including intramedullary lesions and lesions with broad paraspinal components (i.e., dumbbell-type neuroma). An overview of our surgical technique is shown in Fig. 1.

Methods

We retrospectively reviewed cases involving patients with intradural tumors treated at our institution from 2009 to 2016. We included patients with intramedullary tumors and intradural extramedullary tumors (i.e., meningiomas and neuromas). Patients were stratified by tumor location and surgical parameters as well as complications (cerebrospinal fluid [CSF] leak, hemorrhage, infection, deformity). Infection was deemed clinically significant if antibiotic

treatment was required or if it led to the need for surgical revision. Hemorrhage was identified as significant if it resulted in significant anemia or if the patient had to undergo a second surgery due to neurological deterioration because of a hematoma. Intraoperative tumor resection was graded as total or subtotal resection or biopsy to assess the feasibility of the approach.

Surgical Technique

We routinely position the patient in a prone position with the surgical target area tilted into neutral position in the horizontal plane and the arms either fixed to both sides in high cervical approaches or above the shoulders in all other areas. The target segment is then identified using lateral radiographs, and a skin incision of 3 cm in length is performed over the 2 spinous processes right above the lesion, usually slightly off midline, ipsilateral to the lesion. In treating dumbbell neuromas an additional lateral incision (at a 90° angle to the first incision) may be performed to reduce stress on the skin. When a 2-level approach

FIG. 2. Graphic illustration of the mini-open approach for the treatment of intradural lesions. **A:** The relationship between the Caspar retractor (light gray) and the spinal anatomy. The craniocaudal and lateral extent of the target region is indicated by dark red. The black broken line indicates the skin incision for the standard approach. The extension of the approach to treat dumbbell neuromas requires in some cases an additional lateral skin incision, which is indicated by the broken red line. **B:** Dural sutures (black) prevent collapsing of the opened dura mater into the visual field. Furthermore, due to the pressure onto the epidural veins, bleeding is reduced. The intradural lesion is illustrated (deep red) with the adjacent intradural nerves. **C:** Suturing the dura mater after resection. At least at this surgical step, further minimization of the approach would fail due to the space required for suturing. Copyright Klaus C. Mende. Published with permission.

(laminoplasty and in few cases laminectomy) is used to treat larger spinal cord tumors, a 6-cm midline skin incision is performed. After preparation of the dorsal muscle fascia and unilateral incision, the paraspinal muscles are dissected from the bone in a subperiosteal manner. A Caspar retractor of adequate size is then inserted, exposing the ipsilateral lamina of the target segment (Fig. 2). The segment is then again confirmed with lateral radiographs and the lamina thinned with a high-speed microdrill directly above the expected lesion location until only a fine bone bridge is left, which can be safely removed with a punch. In most cases, hemilaminectomy is unnecessary, and an interlaminar window with thinning of both laminae directly adjacent to the tumor is sufficient. In some cases, however, the tumor mass lies directly below the lamina, which then must be removed, performing at least a hemilaminectomy, for sufficient exposure.

After removal of the bone, the following steps are performed under a surgical microscope. The yellow ligaments and epidural fat are removed, and the dura is lined with wadding all around the expected entry zone. If epidural bleeding occurs, the surgeon may use hemostypics (like Gelita-SPON sponges [Gelita Medical]) to provide gentle tamponade around the dural cylinder to secure a “dry” durotomy. The durotomy is then performed in a longitudinal manner with a primary incision of 3 mm and extended in a blunt manner with a miniature hook instrument. For optimized visibility, we advise tacking the dural edges to the lateral and medial access walls so that unobstructed

tumor preparation is possible. After this it is essential to drain as much CSF as possible to gain maneuvering space to safely inspect and dissect the intradural pathology. If the preoperative surgical planning and interpretation of radiographs were correctly performed, the tumor should be right inside the field of vision and can be resected using the usual instruments of choice.

After tumor dissection, we favor a dural closure with stitches and the addition of TachoSil (Takeda). If in doubt about the watertight closure, we add 2 ml of fibrin glue. Residual bleeding within the peridural space can be treated by renewing the Gelita sponges (removing and replacing with fresh ones). The small laminar defect is left open and the muscle closed at the tip of the spinous process using the muscle fascia as an index structure. Wound suturing may be performed according to the preference of the operating surgeon.

Special Considerations for Approach and Resection Based on Tumor Location

Meningioma

Blunt dissection using a dissector of adequate size with a soft curvature has proven very effective, but bipolar forceps and suction may be necessary for complete tumor removal, especially of softer lesions. Routine coagulation of the dura mater is performed to achieve a Simpson Grade II resection, which has a lower recurrence rate than incomplete resection.

FIG. 3. Axial (A) and sagittal (B) contrast-enhanced T1-weighted MR images showing a dumbbell neuroma. The arrows represent the pressure vectors from intraabdominal or intrathoracic pressures “pushing” the tumor toward the neuroforamen.

Neuroma

Essential for resection of neuromas is the point of origin, which can easily be identified by following the nerve roots in view. After confirmation, one may try to dissect the tumor from the nerve root itself, but often a plane of dissection is missing and the removal is unsuccessful. Since the nerve function often has already been lost even before the operation, resection of the root itself is a viable therapeutic option for complete resection. Resection of dumbbell neuromas, which extend laterally beyond the neuroforamen, constitutes a special subcategory of neuroma resection. In these cases, it is advisable to first progress as described and then approach the extradural tumor mass. However, if the mass effect is too big, extradural tumor debulking may be performed for better visibility. When approaching the extradural tumor mass, the focus should be on the neuroforamen, which can be cautiously expanded. After resection of the intraforaminal tumor mass, we usually find that the tumor lying paraspinally is pressed in the direction of the approach by the intraabdominal or intrathoracic pressure so that resection is simplified (Fig. 3) and no secondary approach to the paraspinous tumor portion is necessary.

Intradural Tumors

For the treatment of intramedullary tumors, laminoplasty of 2 laminae was routinely performed. In these cases CSF drainage is indispensable, since swelling in the initial surgical period may pose a problem in tumor identification and dissection and may even lead to spinal infarction if herniation through the durotomy occurs. At our center, we routinely performed a midline myelotomy with pial sutures for tumor resection. Only in rare cases, where the tumor reached the surface of the spinal cord laterally, could we choose a direct mini-open approach through the interlaminar window (Fig. 4). Resection was performed either in a blunt manner with 2 dissectors or using a laser. If bipolar forceps and suction were necessary, they were used in a low-energy mode (5 W) to ensure precision and safety of the vulnerable cord.

Results

Between 2009 and 2016 we operated on a total of 245

intradural tumors. The most common lesions were intradural extramedullary tumors ($n = 151$), represented by meningiomas ($n = 79$) and neuromas ($n = 72$); the latter were either intradural or of combined intra- and extradural location (dumbbell form, $n = 9$, 12.5%). Intramedullary lesions ($n = 94$) were also routinely treated at our institution, but only 5 (5.3% of all intramedullary lesions) were accessed by an interlaminar approach.

The patients' mean age was 51.4 years (SD 18.4 years, range 5–86 years), and 132 (53.9%) of the patients were female. The duration of follow-up for patients in the different tumor groups ranged between 2 and 97 months (mean 46.0 months, SD 25.6 months) (Table 1). A total of 156 patients had interlaminar surgery, and 89 had open, larger-exposure operations (all for treatment of intramedullary lesions). There were significantly more complications in the large-exposure group when all complications were included (9.6% vs 19.1%, $p < 0.01$) as well as when new postoperative deficits were excluded (5.4% vs 17.2%, $p < 0.01$). The resection rate was high in patients with extramedullary tumors, with gross-total resection achieved in all but 1 case (99.3%) and subtotal resection achieved in the remaining case; 33% of patients with intramedullary lesions (31 of 94) received subtotal resection.

In the group of patients with meningiomas, the mean age was 62 years (SD 14.2 years, range 19–86 years), and 62 (78.5%) of the 79 patients were female. Tumors were located in the cervical region in 25 cases (31.6%), in the thoracic region in 50 cases (63.3%), and in the lumbar or sacral region in 4 cases (5.1%). Five tumors extended over more than 1 segment, and the remainder were confined to a single spinal motion segment. All patients were operated on via the keyhole approach described above. The mean length of hospital stay was 9.5 days (SD 5.3 days, range 4–40 days). The mean duration of follow-up was 40 months (SD 26.5 months, range 2–95 months). Ten (12.7%) of the patients in this group had surgery-related complications. Five patients (6.3%) presented with CSF leaks, of whom 4 could be treated conservatively with bed rest and 1 had to be treated with surgical revision. The remaining 5 patients (6.3%) showed new postoperative neurological deficits, including 1 case each of spinal ataxia, radicular hypoesthesia, deltoid palsy, pseudoradicular palsy of the

FIG. 4. **A:** T2-weighted sagittal MR image showing an intramedullary hemangioma with syringomyelia reaching up to the cervical medulla. The patient presented with intermittent dysesthesia of the arms. **B and C:** Axial (B) and sagittal (C) contrast-enhanced T1-weighted MR images showing the lesion at the conus. **D–G:** Intraoperative images. After durotomy and lateral retraction via the applied sutures (D), the plane of dissection is prepared in a blunt manner (E) and is represented by the circumferential gliosis (E, yellow plane). The tumor (F, red intramedullary mass) is shrunk by bipolar cauterization and removed in toto, and the dura mater is then closed (G).

left leg, and persisting neuropathic pain of the lower extremities. Resection was macroscopically complete in all cases (Simpson Grade II); however, 2 patients experienced tumor recurrence (2.5%).

In the group of patients with neuromas, the mean age was 51 years (SD 17.0 years, range 17–79 years), and 30 (41.6%) of the 72 patients were female. Tumors were in the cervical region in 22 cases (30.6%), the thoracic region in 24 cases (33.3%), and the lumbar or sacral region in 26 cases (36.1%). Four tumors extended over more than 1 segment and the remaining neuromas were located within 1 spinal motion segment. Nine tumors (12.5%) were dumbbell neuromas with an extraforaminal tumor mass. All patients were operated on via the keyhole approach described above. The mean length of hospital stay was 8.7 days (SD 5.7 days, range 4–29 days). The mean duration of follow-up was 44.6 months (SD 22.0 months, range 10–97 months). Five (6.9%) of the patients in this group had surgery-related complications, including 1 CSF leak (1.4%) that could be treated conservatively with bed rest. The other 4 patients showed new postoperative neurological deficits (in 2 patients), persisting neuropathic pain in the lower extremities (in 1 patient) or persisting, mild unilateral L-5 palsy (in 1 patient). Two patients had to undergo revision surgery because of infection, and in 1 of these 2 patients, the infection progressed to spondylodiscitis and a fusion operation was required. Resection was macroscopically

complete in all cases but one, where a dumbbell neuroma was left with an extraforaminal tumor capsule in situ. No patient experienced tumor recurrence.

In the group of patients with intramedullary tumors, the mean age was 42 years (SD 17.6 years, range 5–78 years), and 40 (42.5%) of the patients were female. Tumors were located in the cervical region in 52 cases (55.3%), the thoracic region in 34 cases (36.2%), and at the conus in 8 cases (8.5%). Five patients (5.3%) were operated on via the keyhole approach described above; 72 (76.6%) were treated with laminotomy, 7 (7.4%) with hemilaminectomy, and 10 (10.6%) with full laminectomy. Overall, the mean length of hospital stay for patients with intramedullary tumors was 12.4 days (SD 6.7 days, range 3–38 days). After laminotomy the mean stay was 13.2 days, after laminectomy 12.1 days, after hemilaminectomy 9.0 days, and after the above-described keyhole approach 8.8 days. The mean duration of follow-up was 35.5 months (SD 16.6 months, range 8–61 months). Seventeen patients (18.1%) in this group presented with surgery-related complications, including 5 CSF leaks (6.3%). Of the 5 patients with CSF leaks, 4 were treated conservatively, 1 with bed rest alone and 3 with bed rest and a lumbar drain, and 1 patient had to undergo surgical revision. Four patients presented with symptomatic hematomas; the symptoms were all transient and completely resolved at discharge. One patient had a wound infection and required revision surgery after radiation therapy. Five

TABLE 1. Patient demographic and clinical characteristics, approaches, and complications

Characteristic	Extramedullary Lesions		Intramedullary Lesions
	Meningioma	Neuroma	
No. of patients	79 (32.2%)	72 (29.4%)*	94 (38.4%)
Age (yrs)			
Mean $\pm$ SD	62 $\pm$ 14.2	51 $\pm$ 17.0	42 $\pm$ 17.6
Range	19–86	17–79	5–78
Sex (M:F)	1:3.6	1:0.7	1:0.7
Stay (days)			
Mean $\pm$ SD	9.5 $\pm$ 5.3	8.7 $\pm$ 5.7	12.4 $\pm$ 6.7
Range	4–40	4–29	3–38
Follow-up (mos)			
Mean $\pm$ SD	40.0 $\pm$ 26.5	44.6 $\pm$ 22.0	35.5 $\pm$ 16.6
Range	2–95	10–97	8–61
Approach			
Keyhole surgery	79 (100%)	72 (100%)	5 (5.3%)
Laminotomy	—	—	72 (76.6%)
Hemilaminectomy	—	—	7 (7.4%)
Laminectomy	—	—	10 (10.6%)
Localization			
Cervical	25 (31.6%)	22 (30.6%)	52 (55.3%)
Thoracic	50 (63.3%)	24 (33.3%)	34 (36.2%)
Lumbar	4 (5.1%)	26 (36.1%)	8 (8.5%)
Complications			
CSF leak	5 (6.3%)	1 (1.4%)	5 (5.3%)
Infection	—	2 (2.8%)	1 (1.1%)
New deficit	5 (6.3%)	2 (2.8%)	2 (2.1%)
Kyphosis	—	—	5 (5.3%)
Hematoma	—	—	4 (4.2%)
Overall	10 (12.7%)	5 (6.9%)	17 (18.1%)
Gross-total resection	79 (100%)	71 (98.6%)	63 (67.0%)
Subtotal resection	0	1 (1.4%)†	20 (21.3%)
Biopsy	—	—	11 (11.7%)
Recurrence‡	2 (2.5%)	0	No reop

Values are number of patients (%) unless otherwise indicated.

* Includes 9 patients (12.5%) with dumbbell neurinomas.

† Dumbbell neurinoma at C-2 root with paraspinous tumor capsule remaining in situ.

‡ Classified in this context as tumor regrowth requiring additional surgical treatment.

patients had postoperative kyphosis, which required operative correction in 2 cases; in both of these cases, the kyphosis was in the cervical or cervicothoracic region. Two patients had new neurological deficits after surgery which lasted until after discharge—dysesthesia of the lower extremities in 1 case and impairment in the coordination of 1 arm in the other.

Within the intramedullary tumor cohort the highest rate of overall complications was recorded for laminectomies (30%, 3 of 10 cases), followed by 28.6% (2 of 7) for hemilaminectomy and 16.7% (12 of 72) for laminotomy. None of the 5 patients treated via an interlaminar keyhole ap-

proach had any complications (Table 2). Gross-total resection was achieved in 63 (67.0%) of all intramedullary cases, in 20 cases resection remained incomplete (21.3%) and a biopsy was performed in 11 cases (11.7%). In the interlaminar window group we performed one biopsy of an oligoastrocytoma and complete resection was achieved in 1 intramedullary metastasis, 2 ependymomas, and 1 paraganglioma. There was no subtotal resection in this subgroup.

None of the 245 patients presented with symptomatic spinal instability manifested by cervical, thoracic, or lumbar pain. During follow-up, no signs of progressive osteochondrotic changes in the target or the adjacent levels were detected. At the 1-year follow-up evaluation, radiographs of the spine were obtained in 2 planes in addition to the routine MRI to discover potential deformities. In 5 patients, a slight kyphotic deformity after cervical or thoracic spinal cord tumor surgery was diagnosed during follow-up. The deformity remained stable in 3 of those patients, but 2 required surgical stabilization due to progressive cervical kyphosis or thoracic kyphosis and scoliosis after larger approaches to an intramedullary tumor. In both cases, the stabilization surgeries were performed using PEEK (polyetheretherketone)–carbon screws to avoid interfering with subsequent MRI screening of the tumor region. None of the other patients needed additional intersegmental instrumentation.

Discussion

Our cohort demonstrates that resection of intradural pathologies via an interlaminar approach is a feasible option allowing macroscopically complete resection rates of 100% in our meningioma cohort and 98.4% in our neuroma cohort. Also, if sufficient attention is given to tumor extent in the preoperative planning, the interlaminar approach may be suitable for small laterally and superficially located intramedullary lesions or biopsies. High rates of resection, equivalent to those for open approaches, may be achieved, and the reduction in approach-related comorbidities must also be taken into account. Patients who underwent our keyhole approach had a lower mean hospitalization time than the group of patients treated with mainly open surgery (laminectomy, laminotomy, or hemilaminectomy) for intramedullary tumors. Concerning the extent of resection, only 1 tumor that was planned for complete resection remained subtotally resected. This is in line with the current literature, where resection rates of 93.0%–100% are described for minimally invasive approaches^{21,26,28} and 70.5%–88.5% for open posterior approaches.^{1,21,29,30} These rates may be attributed to preoperative selection; if large tumors that are difficult to fully resect are not approached in a minimally invasive way from the start, lower rates of resection would be expected in the open approaches. However, the feasibility of minimally invasive approaches is supported by the high resection rates for such approaches throughout the literature. Two (2.5%) of our patients presented with recurrent meningioma during follow-up, and this rate compares favorably to the literature, where recurrence rates of approximately 9%^{1,16,22} are frequently recorded. Nakamura et al.¹⁶ found this frequency in their long-term evaluation of meningioma recurrence only for

TABLE 2. Complications and length of hospital stay stratified by approach

Variable	Keyhole Surgery (n = 5)	Laminotomy (n = 72)	Hemilaminectomy (n = 7)	Laminectomy (n = 10)
Complications	0	12 (16.7%)	2 (28.6%)	3 (30.0%)
CSF leak	—	4 (5.6%)	1 (14.3%)	—
Infection	—	1 (1.4%)	—	—
New deficit	—	1 (1.4%)	—	1 (10.0%)
Kyphosis	—	3 (4.2%)	—	2 (20.0%)
Hematoma	—	3 (4.2%)	1 (14.3%)	—
Hospital stay (days)				
Mean $\pm$ SD	8.8 $\pm$ 3.2	13.2 $\pm$ 7.4	9.0 $\pm$ 1.9	12.1 $\pm$ 3.4
Range	5.0–14.0	3.0–38.0	7.0–13.0	6.0–18.0

Values are number of patients (%) unless otherwise indicated.

Simpson Grade II resections, which is interesting, because in our cohort, no resection of the dural attachment was performed; in rare cases we coagulated the dura at the base but we do not do this routinely.

The aim of our study was to demonstrate a safe and efficient resection technique for intradural pathologies, especially in the light of recent publications focusing on large multilevel laminectomy approaches.^{1,24} Extensive approaches have been shown to be closely correlated with postoperative morbidity and deformity,^{14,25} especially with postoperative instability. The secondary goal of intramedullary tumor surgery, aside from tumor resection, was correctly defined by Samartzis et al.²⁴ in 2010 to be the preservation of stability in the course of tumor resection if possible. The preservation of stability is particularly important in patients with intradural extramedullary tumors. Due to the often benign nature of these tumors, the likelihood of surgical success should not overshadow awareness of the risk of related comorbidities when surgical treatment options are considered for these patients. Some authors recently advocated the use of immediate spinal fusion in intradural tumor surgery to prevent postoperative instability.^{3,22,25,27} The indication of fusion surgery was thereby based mainly on the extent of resection of the bone and ligaments. A special focus was set on extensive facetectomy, which harbored the risk of postoperative instability.³ Other indicators for simultaneous fusion were also discussed, such as young patient age.³ This is especially important because younger patients typically have a longer remaining life expectancy, and further surgical intervention for tumor recurrence might be more difficult after spinal fusion. Also, the region of interest in follow-up MRI will be severely and negatively affected by metallic implant artifacts. This is especially critical in the cohort of neurofibromatosis patients who are likely to develop progressive tumors in other areas of the neuraxis and for whom adequate treatment planning depends on a high-quality follow-up MRI. Due to the location and extent of some intradural pathologies, however, especially those with extraforaminal masses, facetectomy may be unavoidable. Nevertheless, the intrapleural and intraabdominal pressure from the ventral side often sufficiently mobilizes the extraforaminal tumor mass and brings it close to the neuroforamen, and complete resection may be possible through a minimally invasive approach as published by Krätzig et al.¹¹ In pa-

tients still requiring bony resection, thorough consideration should be given to the choice of implants used (e.g., carbon screws if possible), and instrumentation should be kept to a minimum. Subtotal resection of the extraforaminal tumor mass may also be an option with subsequent surgery using a lateral approach. In all other cases a minimally invasive approach²⁸ should be attempted, with a plan to switch to hemilaminectomy as the larger approach or even complete laminectomy if resection would otherwise remain insufficient. A number of smaller approaches have been introduced to reduce the above-described complications of laminectomy. Endoscopic procedures were evaluated by Parihar et al.¹⁹ in a small patient sample with very good success and low complication rates. However, this technique is described as technically demanding. A switch to an open procedure is not easy. In addition, the technique involves resection of the medial facet joint, which may in rare cases also cause further degeneration of the spinal segment and procure instability.²⁶ Watertight dural closure is also a challenging task in endoscopic surgery and may only be achieved using fibrin glue in most of the cases. The application of sutures is extremely challenging in an endoscopic procedure compared with an interlaminar approach where microscopic suturing may be performed as a standard procedure to ensure water tightness (Fig. 2B). Interlaminar approaches have the advantage of avoiding extensive resection of the facet joint. We made a special effort to preserve the joint capsule during surgery, only reducing the laminae for tumor exposure, which has been shown by Zhu et al.²⁸ to facilitate rapid recovery and preserve spinal stability. Compared with an endoscopic approach, intraoperative visibility and maneuvering options are increased and dural closure may be safely achieved with suturing and fibrin adhesives and confirmed under the microscope. Of course, one has to always bear in mind the increased dead space, favoring postoperative hematoma or CSF collections, and this may be significantly reduced in endoscopic approaches with an approach channel of less than 1 cm. In our cohort, interlaminar approaches were associated with a significantly lower overall rate of surgery-related complications (9.6% vs 19.1%, $p < 0.01$) compared with extended open surgery (with laminectomy, laminotomy, or hemilaminectomy), indicating superiority of our keyhole approach for selected patients. Our results are comparable to results in the current literature where

surgery-related complications occurred in 4.1%–8.0% of the minimal invasive approaches^{21,27} and 13.7%–37.0% of open treatments,^{6,21,22,27} always depending on the technique used and the pathologies involved in the cohort.

Zhu et al.²⁸ discussed decreased hospitalization for patients with interlaminar approaches, reporting a mean length of stay of 13 days to which our finding of 9 days compares favorably. Laminectomies, in comparison, were frequently reported with hospital stays of 7–27 days.^{21,29,30} This difference may be explained by the larger wound and increased back pain and immobilization in laminectomies. However, the role of the health care system and its standards is not to be underestimated. At our institution, patients with intradural tumors were routinely transferred to a special neurological rehabilitation facility. Patient stay may be overestimated due to postoperative waiting times for a transfer to these institutions.

Complete resection rates were as high as 99.3% in extramedullary tumors treated with our keyhole approach (achieved in 150 of 151 cases). This rate was equal to or even higher than what has been reported for open surgery.²⁷ An interesting alternative to this approach is the mini-open transspinous procedure as described by Raygor et al.,²¹ reducing the retraction of the paraspinal muscle and removing the spinous process for better exposure of the index segment. This approach offers a wide view of bilateral and midline structures and may facilitate rigorous tumor removal in a variety of locations, but the muscle is still removed from the spinous process, and the interspinous ligaments bearing an important responsibility for spinal stability⁴⁰ are removed. In our opinion, this approach may be an interesting alternative to laminectomy for the resection of tumors that cannot be adequately reached by interlaminar approaches, but it does not preserve spinal stability to the same extent, and in the interest of stability preservation and comorbidity reduction, we advocate the use of less-invasive approaches.

Conclusions

In this study we demonstrate that intradural extramedullary and in select cases even intramedullary pathologies may safely be resected using an interlaminar approach, sparing the vital facets, bone, and ligaments, and thereby preserving spinal stability and reducing comorbidities. Significantly lower rates of complications occurred for mini-open interlaminar approaches compared with laminectomy, laminotomy, or hemilaminectomy within our mixed cohort, and high rates of complete tumor resection were still achieved. Spinal fusion was only necessary in the “extended-approach” group and should not be considered as a standard procedure in spinal intradural tumor surgery.

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References

- Ahn DK, Park HS, Choi DJ, Kim KS, Kim TW, Park SY: The surgical treatment for spinal intradural extramedullary tumors. *Clin Orthop Surg* **1**:165–172, 2009
- Arnautovic K, Arnautovic A: Extramedullary intradural spinal tumors: a review of modern diagnostic and treatment options and a report of a series. *Bosn J Basic Med Sci* **9** (Suppl 1):40–45, 2009
- Avila MJ, Walter CM, Skoch J, Abbasifard S, Patel AS, Satarov K, et al: Fusion after intradural spine tumor resection in adults: A review of evidence and practices. *Clin Neurol Neurosurg* **138**:169–173, 2015
- Bokhari I, Rehman L, Farooq G, Qureshi A: Postoperative functional outcome of intradural extramedullary spinal tumors through posterior approach. *J Coll Physicians Surg Pak* **26**:117–120, 2016
- Chamberlain MC, Tredway TL: Adult primary intradural spinal cord tumors: a review. *Curr Neurol Neurosci Rep* **11**:320–328, 2011
- Engelhard HH, Villano JL, Porter KR, Stewart AK, Barua M, Barker FG, et al: Clinical presentation, histology, and treatment in 430 patients with primary tumors of the spinal cord, spinal meninges, or cauda equina. *J Neurosurg Spine* **13**:67–77, 2010
- Fassett DR, Clark R, Brockmeyer DL, Schmidt MH: Cervical spine deformity associated with resection of spinal cord tumors. *Neurosurg Focus* **20**(2):E2, 2006
- Furtado SV, Murthy GK, Hegde AS: Cervical spine instability following resection of benign intradural extramedullary tumours in children. *Pediatr Neurosurg* **47**:38–44, 2011
- González-Martínez EL, García-Cosamalón PJ, Fernández-Fernández JJ, Ibáñez-Plágaro FJ, Alvarez B: [Minimally invasive approach of extramedullary intradural spinal tumours. Review of 30 cases.] *Neurocirugia (Astur)* **23**:175–181, 2012 (Span)
- Kode S, Kallemeyn NA, Smucker JD, Fredericks DC, Grossland NM: The effect of multi-level laminoplasty and laminectomy on the biomechanics of the cervical spine: a finite element study. *Iowa Orthop J* **34**:150–157, 2014
- Krätzig T, Dreimann M, Klingenhöfer M, Floeth FW, Krajewski K, Eicker SO: Treatment of large thoracic and lumbar paraspinal schwannoma. *Acta Neurochir (Wien)* **157**:531–538, 2015
- Lu DC, Chou D, Mummaneni PV: A comparison of mini-open and open approaches for resection of thoracolumbar intradural spinal tumors. *J Neurosurg Spine* **14**:758–764, 2011
- Mannon RJ, Nowitzke AM, Efendy J, Wood MJ: Safety and efficacy of intradural extramedullary spinal tumor removal using a minimally invasive approach. *Neurosurgery* **68** (1 Suppl Operative):208–216, 2011
- McGirt MJ, Garcés-Ambrossi GL, Parker SL, Sciubba DM, Bydon A, Wolinsky JP, et al: Short-term progressive spinal deformity following laminoplasty versus laminectomy for resection of intradural spinal tumors: analysis of 238 patients. *Neurosurgery* **66**:1005–1012, 2010
- Montano N, Trevisi G, Cioni B, Lucantoni C, Della Pepa GM, Meglio M, et al: The role of laminoplasty in preventing spinal deformity in adult patients submitted to resection of an intradural spinal tumor. Case series and literature review. *Clin Neurol Neurosurg* **125**:69–74, 2014
- Nakamura M, Tsuji O, Fujiyoshi K, Hosogane N, Watanabe K, Tsuji T, et al: Long-term surgical outcomes of spinal meningiomas. *Spine (Phila Pa 1976)* **37**:E617–E623, 2012
- Nanda A, Kukreja S, Ambekar S, Bollam P, Sin AH: Surgical strategies in the management of spinal nerve sheath tumors. *World Neurosurg* **83**:886–899, 2015
- Omeis IA, Dhir M, Sciubba DM, Gottfried ON, McGirt MJ, Attenello FJ, et al: Postoperative surgical site infections in patients undergoing spinal tumor surgery: incidence and risk factors. *Spine (Phila Pa 1976)* **36**:1410–1419, 2011
- Parihar VS, Yadav N, Yadav YR, Rathe S, Bajaj J, Kher Y: Endoscopic management of spinal intradural extramedullary

- tumors. **J Neurol Surg A Cent Eur Neurosurg** 78:219–226, 2017
20. Ravindra VM, Schmidt MH: Management of spinal meningiomas. **Neurosurg Clin N Am** 27:195–205, 2016
 21. Raygor KP, Than KD, Chou D, Mummaneni PV: Comparison of minimally invasive transspinous and open approaches for thoracolumbar intradural-extramedullary spinal tumors. **Neurosurg Focus** 39(2):E12, 2015
 22. Safaee M, Oh T, Barbaro NM, Chou D, Mummaneni PV, Weinstein PR, et al: Results of spinal fusion after spinal nerve sheath tumor resection. **World Neurosurg** 90:6–13, 2016
 23. Safaee MM, Lyon R, Barbaro NM, Chou D, Mummaneni PV, Weinstein PR, et al: Neurological outcomes and surgical complications in 221 spinal nerve sheath tumors. **J Neurosurg Spine** 26:103–111, 2017
 24. Samartzis D, Gillis CC, Shih P, O'Toole JE, Fessler RG: Intramedullary spinal cord tumors: part II—management options and outcomes. **Global Spine J** 6:176–185, 2016
 25. Sciubba DM, Chaichana KL, Woodworth GF, McGirt MJ, Gokaslan ZL, Jallo GI: Factors associated with cervical instability requiring fusion after cervical laminectomy for intradural tumor resection. **J Neurosurg Spine** 8:413–419, 2008
 26. Turel MK, D'Souza WP, Rajshekhar V: Hemilaminectomy approach for intradural extramedullary spinal tumors: an analysis of 164 patients. **Neurosurg Focus** 39(2):E9, 2015
 27. Wong AP, Lall RR, Dahdaleh NS, Lawton CD, Smith ZA, Wong RH, et al: Comparison of open and minimally invasive surgery for intradural-extramedullary spine tumors. **Neurosurg Focus** 39(2):E11, 2015
 28. Zhu YJ, Ying GY, Chen AQ, Wang LL, Yu DF, Zhu LL, et al: Minimally invasive removal of lumbar intradural extramedullary lesions using the interlaminar approach. **Neurosurg Focus** 39(2):E10, 2015
 29. Zong S, Zeng G, Du L, Fang Y, Gao T, Zhao J: Treatment results in the different surgery of intradural extramedullary tumor of 122 cases. **PLoS One** 9:e111495, 2014
 30. Zong S, Zeng G, Xiong C, Wei B: Treatment results in the differential surgery of intradural extramedullary schwannoma of 110 cases. **PLoS One** 8:e63867, 2013

Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Mende, Westphal, Eicker. Acquisition of data: Mende, Krätzig, Westphal. Analysis and interpretation of data: Mende. Drafting the article: Mende, Krätzig, Mohme, Eicker. Critically revising the article: Mende, Krätzig, Mohme, Eicker. Reviewed submitted version of manuscript: Mende, Krätzig, Mohme, Eicker. Approved the final version of the manuscript on behalf of all authors: Mende. Statistical analysis: Mende. Study supervision: Westphal.

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