


Original Article

Corresponding Author

Tao Fan

 <https://orcid.org/0000-0001-8885-1480>

Spine Center, Sanbo Brain Hospital,
Capital Medical University, NO. 50
XiangshanYikesong Road, Haidian
District, Beijing, China
Email: fant@ccmu.edu.cn

*Dongao Zhang and Tao Fan contributed
equally to this study as co-first authors.

Received: July 30, 2022

Revised: November 30, 2022

Accepted: December 10, 2022



This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

Copyright © 2023 by the Korean Spinal
Neurosurgery Society

INTRODUCTION

Long-level intramedullary spinal cord tumors (LIMSCTs) are defined as tumors that involve at least 5 spinal vertebral segments.¹ Generally, most intramedullary tumors present clinically due to nerve compression rather than tumor invasion.² In rarer cases, intramedullary tumors can be long-segmental lo-

Clinical Characteristics and Treatment Outcomes of Long-Level Intramedullary Spinal Cord Tumors: A Consecutive Series of 43 Cases

Dongao Zhang^{1,*}, Tao Fan^{1,*}, Wayne Fan², Xingang Zhao¹, Cong Liang¹,
Yinqian Wang¹, Kun Wu¹

¹Spine Center, Sanbo Brain Hospital, Capital Medical University, Beijing, China

²Faculty of Science, University of British Columbia, Vancouver, BC, Canada

Objective: Long-level intramedullary spinal cord tumors (LIMSCTs) cause complex treatment issues. However, LIMSCTs have rarely been analyzed separately. The authors reported a large case series of LIMSCTs and analyzed the clinical characteristics and treatment outcomes.

Methods: The medical data of patients with LIMSCTs at our institution between January 2015 and December 2019 were retrospectively reviewed. Demographics, tumor size and location, pathology, extent of resection, and neurological functional status were collected.

Results: A total of 43 consecutive cases were included. Twenty-three cases (53.5%) of LIMSCTs were ependymal tumors. All patients with ependymal tumors achieved gross total resection (GTR). In ependymal tumor cases, 3 cases (13%) of ependymal tumors experienced postoperative neurological deterioration, and 66% of them showed an improvement at follow-up; 25.6% were low-grade astrocytic tumors. The rates of GTR, subtotal resection (STR) and partial resection (PR) were 63.6%, 27.3%, and 9.1%, respectively. Twenty-seven percent cases showed postoperative neurological worsening, and 33% of them had an improvement at follow-up; 20.9% were high-grade astrocytic tumors. The excision rates were 44.4% for GTR, 44.4% for STR, and 11% for PR, respectively. Fifty-five percent cases showed postoperative neurological worsening, and none of them had an improvement at follow-up.

Conclusion: In this series, all LIMSCTs were gliomas. Aggressive tumor resection did not increase the risk of long-term functional deterioration in ependymal tumors and low-grade astrocytic tumors, but in high-grade astrocytic tumors, patients had a higher risk of neurological deterioration and difficulty in recovery. In ependymal tumors and low-grade astrocytic tumors, patients can achieve long-time survival after performing aggressive tumor resection.

Keywords: Intramedullary tumors, Long level, Ependymoma, Astrocytoma, Outcome

calized. Long-level lesions gradually progress neurologically. Patients may suffer from weakness, sense disorders, and sphincter defects and eventually become significantly disabled, morbidly ill, and even die.

Given that patients with long-level intramedullary lesions suffer more neurological deterioration and postoperative complications, some surgeons may choose conservative manage-

ment.^{3,4} These conservative protocols cannot prevent disease progression.^{5,6} In addition, several studies have also noted that aggressive resection increases the overall survival of patients with intramedullary tumors, and the earlier the radical resection of intramedullary tumors is performed, the greater the chance of preserving the patient's neurological function.⁷ To date, the optimal management for LIMSCTs remains unclear.

In this study, we reported our experience with LIMSCTs, which has rarely been discussed separately in previous literature.^{8,9} Based on a series of 43 patients treated in our institution, we analyzed the tumor characteristics, extent of resection and clinical outcomes and attempted to provide answers on optimal treatment strategies for LIMSCTs.

MATERIALS AND METHODS

1. Study Patients

This study was a retrospective analysis of data from surgical cases who underwent microsurgical LIMSCT resection at Beijing Sanbo Brain Hospital between January 2015 and December 2019. The collective patient databases were analyzed to determine cases of intramedullary tumors in which the tumor involved at least 5 spinal vertebral levels or longer. Patients with terminal filum tumors or cauda equina tumors were excluded. Data were collected from our computerized database, follow-up appointments and telephone interviews.

A total of 43 cases were included in this analysis. Patient data, including age, sex, symptoms, tumor size and location, pathology, extent of resection, neurological functional status, and follow-up outcomes, were recorded. We used the modified McCormick Scale¹⁰ (MMS) to evaluate the neurological function of each patient at the first presentation, postoperation, and follow-up visits. The location of each LIMSCT was categorized as cervical, cervicothoracic (tumor that involved C7 and T1 level), thoracic, thoracolumbar (tumor that involved T12 and L1 level), and holocord involvement (tumor involved cervical, thoracic, and lumbar levels).

This study protocol was approved by the University Institutional Review Board (SBNK-YJ-2020-006-03). Informed written consent was obtained from all participants.

2. Histological Evaluation and Pathological Findings

All histological specimens were reviewed by senior neuropathologists at our institution. Specimens were independently reviewed by one neuropathologist and then examined by another to confirm the diagnosis. We used the World Health Organiza-

tion (WHO) 2016 classification of central neural system tumors for diagnosis and classification.¹¹ For patients who underwent operation before 2016, tumor specimens were assessed according to the same classification system to maintain unified histological grading criteria.

3. Surgical Technique

Our operative technique has been described previously in detail.¹² Laminoplasty that spanned the length of the intramedullary lesion was performed in all patients. A C1 laminectomy was performed for tumor sections at the C1 level. In each case, the medial facet joint was exposed, and an effort was made to maintain the facet joint capsules. Bilateral laminectomies were performed using an ultrasonic bone scalpel. The spinous processes, interspinous ligaments, and ligamentum flavum of the planned laminoplasty section were kept intact. Using intraoperative neuro-monitor mapping, a midline dural and spinal cord incision was performed spanning the whole length of the tumor. The tumor was approached gently and resected piecemeal. After removing the tumor, the dura was closed via 5-0 absorbable sutures. Mini titanium plates were used to fix the laminae. Finally, the paraspinous muscles were sutured, and the skin incision was closed. In addition, 3 patients who suffered from LIMSCT complicated with scoliosis were treated by a 1-stage operation of tumor resection and scoliosis correction. Gross total resection (GTR) was attempted in all patients. GTR is defined as excision of $\geq 95\%$ of the tumor, as evidenced by a clean operative field at the end of the surgery or absence of residual enhancement signal on postoperative magnetic resonance imaging (MRI).^{5,12,13} The procedure was considered a subtotal resection (STR, 80%–95% resection) if a small tumor piece was deliberately left in place due to intraoperative conditions or a retained fragment was detected on postoperative MRI. Partial resection (PR) was defined as less than 80% tumor removal, which was rare in this case series. Intraoperative neurophysiological monitoring, including motor evoked potentials (MEPs) and somatosensory evoked potentials (SEP), was performed in all patients. The warning criteria were set for a 50% amplitude reduction of SEP or a 50% amplitude reduction of MEP. The permanent 75% amplitude reduction of MEP was used to stop the operation.¹⁴⁻¹⁶

4. Statistical Analysis

Statistical analyses were performed using GraphPad Prism ver. 8.0 (GraphPad Software Inc., La Jolla, CA, USA). Percentages were calculated for categorical data, and medians and in-

terquartile ranges (IQRs) were calculated for continuous data. The Mann-Whitney test was used to compare nonparametric data between the groups. For percentage analysis, the chi-square test was used. Kaplan-Meier analysis for overall survival was performed with log-rank tests. The differences were considered statistically significant if the p-value was < 0.05.

RESULTS

1. Demographic and Clinical Characteristics

A total of 43 consecutive cases underwent LIMSCT resection in the study period (Table 1). Twelve of them (27.9%) were pediatric patients (age ≤ 18 years), whereas 31 patients (72.1%) were adults. Nineteen patients (44.2%) were female, and 24 patients (55.8%) were male.

The most common presenting symptoms in this series were combined symptoms (65.1%) followed by sensory dysfunction (20.9%) and motor deficits (14.0%). In 19 cases (44.2%), the prodrome time persisted for ≤ 1 year from the initial symptomatology to surgical treatment. In 13 patients (30.2%), the prodrome time lasted 1 to 3 years. In 11 patients (25.6%), the prodrome time lasted > 3 years. The major sensory symptoms included pain, extremity numbness, and dysesthesia. Major motor deficits included extremity weakness, motor loss and muscle atrophy. The median preoperative MMS score in our series was 2 (IQR, 2–3).

2. Tumor Location, Resection, and Pathology

Based on preoperative imaging, patients most commonly presented with a lesion that involved the cervicothoracic spine. Thirteen tumors (30.2%) were located in the cervical spine, 21 tumors (44.8%) were located in the cervicothoracic spine, 4 tumors (9.3%) were located in the thoracic spine, 4 tumors (9.3%) were restricted to the thoracolumbar spine, and 1 tumor (2.3%) had a holocord tumor (Fig. 1A).

In total, 23 cases (53.5%) were ependymal tumors, and 20 cases (46.5%) were astrocytic tumors. The detailed distribution of histopathological diagnosis was subependymoma in 2 cases (4.6%), ependymoma in 21 cases (48.8%), pilocytic astrocytoma (PA) in 3 cases (7%), diffuse astrocytoma in 8 cases (18.6%), anaplastic astrocytoma in 2 cases (4.6%), glioblastoma in 3 cases (7%), and diffuse midline glioma in 4 cases (9.3%) (Fig. 1B, C). Overall, GTR was achieved in 34 cases (79.1%), and STR was achieved in 7 cases (16.3%). Only 2 patients (4.6%) underwent PR. All patients with ependymoma achieved GTR. The rates of GTR, STR, and PR of low-grade astrocytomas (WHO grade I

Table 1. Summary of characteristic of patients with LIMSCTs

Characteristic	Value
Age	
Pediatric (≤ 18 yr)	12 (27.9)
Adult (> 18 yr)	31 (72.1)
Sex	
Male	24 (55.8)
Female	19 (44.2)
Clinical symptom	
Sensory	9 (20.9)
Motor	6 (14.0)
Combined	28 (65.1)
Symptom duration in years	
≤ 1	19 (44.2)
1–3	13 (30.2)
> 3	11 (25.6)
Classification of tumor (extent of resection)	
Ependymal tumor WHO I and II (GTR 100%)	23 (53.5)
Astrocytic tumor WHO I and II (GTR 63.6%, STR 27.3%, PR 9.1%)	11 (25.6)
Astrocytic tumor WHO III and IV (GTR 44.4%, STR 44.4%, PR 11.1%)	9 (20.9)
Extent of tumor involvement (spinal levels)	
5	16 (37.2)
6–8	23 (53.5)
11–13	3 (7.0)
Holocord	1 (2.3)
Preoperative MMS score	2 (2–3)
Length of stay in days	20 (17–25)
Postoperative adjuvant therapy	
Chemotherapy	3 (7.0)
Radiotherapy	4 (9.3)
Combined	4 (9.3)
Postoperative MMS score	3 (2–3)
Follow-up length in months	34 (25–60)

Values are presented as number (%) or median (interquartile range). LIMSCT, long-level intramedullary spinal cord tumor; WHO, World Health Organization; GTR, gross total resection; STR, subtotal resection; PR, partial resection; MMS, modified McCormick Scale.

and II) were 63.6%, 27.3%, and 9.1%, respectively. The excision rates for high-grade astrocytomas (WHO grade III and IV) were 44.4% for GTR, 44.4% for STR, and 11% for PR. High-grade tumors had a significantly lower possibility of achieving complete tumor resection than low-grade tumors ($p = 0.004$).

3. Surgical-Related Outcomes and Neurological Function

No patient died because of operative-related procedures. The median length of hospitalization was 20 days (IQR, 17–25 days). As reported in previous studies,¹² the modified MMS was used to best express the change in operation-induced neurological function. Overall, most patients (27 cases, 62.8%) had only a minor neurological deficit (MMS II) at presentation. In contrast, 8 cases (18.6%) had MMS III, and 5 cases (11.6%) had MMS IV. The median preoperative MMS score was 2 (IQR, 2–3), and the postoperative MMS score was 3 (IQR, 2–3).

Overall, no significant difference was noted between the pre- and postoperative MMS scores ($p=0.1067$). In ependymal tumor cases, 3 cases experienced postoperative neurological deterioration, and 2 of them showed an improvement at the last follow-up. Of the low-grade astrocytic tumor cases, 3 cases showed postoperative worsening in their neurological status, and one of them had an improved grade at the last follow-up. Of the high-grade astrocytic tumor cases, 5 cases experienced postoperative functional worsening. Unfortunately, functional improvement was not observed in those patients. No further

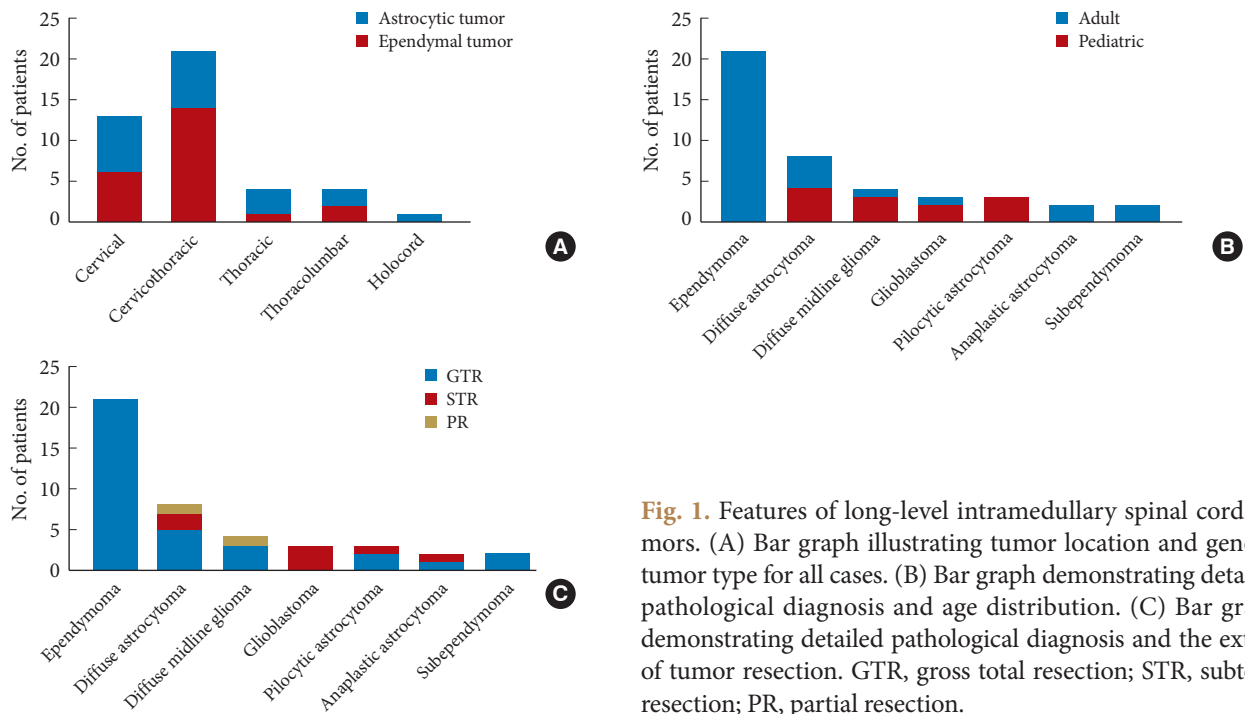


Fig. 1. Features of long-level intramedullary spinal cord tumors. (A) Bar graph illustrating tumor location and general tumor type for all cases. (B) Bar graph demonstrating detailed pathological diagnosis and age distribution. (C) Bar graph demonstrating detailed pathological diagnosis and the extent of tumor resection. GTR, gross total resection; STR, subtotal resection; PR, partial resection.

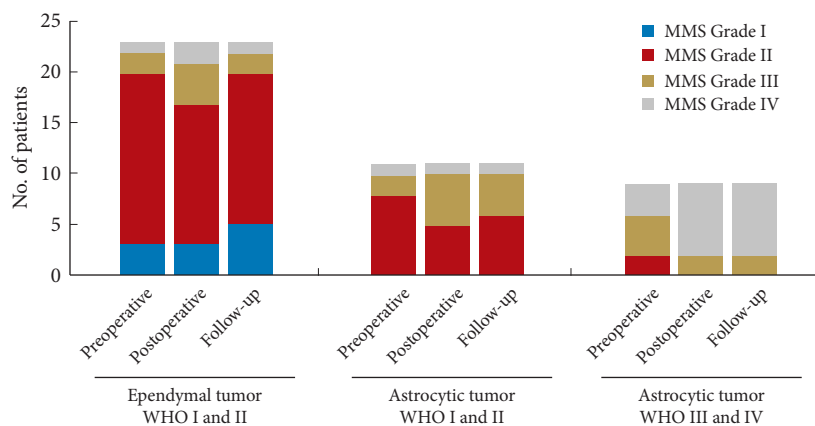


Fig. 2. The neurological status at the perioperative, postoperative, and last follow-up periods based on MMS is illustrated separately as ependymal tumor WHO grades I and II, astrocytic tumor WHO grades I and II, and astrocytic tumor WHO grades III and IV. MMS, McCormick Scale; WHO, World Health Organization; GTR, gross total resection.

neurological functional decrease in MMS was found in the follow-up duration (Fig. 2). Three patients encountered postoperative pneumonia. These complications were successfully treated by subsequent management.

All 43 patients had clinical follow-up, and the median follow-up duration was 34 months (IQR, 25–60 months). In the whole group, 39 patients (90.7%) remained alive at the time of this study. Four patients died of disease progression and respiratory failure, including 2 WHO grade IV astrocytic tumors (a 6-year-old girl died 20 months after surgery, and a 13-year-old boy died 24 months after surgery), one WHO grade III astrocytic tumor (a 34-year-old woman died 6 months after surgery) and one WHO grade II astrocytic tumor (a 2-year-old girl died 30 months after surgery). One patient with diffuse midline glioma was alive despite recurrence after adjuvant therapy at the 21-month follow-up. The remaining patients were progression-

free during the follow-up period. Survival was statistically correlated with tumor pathological grade ($p=0.004$). The following variables did not affect mortality independently: age, tumor location, tumor span, and extent of tumor resection. Four patients (9.3%) with astrocytic tumors who underwent incomplete tumor resection received adjuvant radiation therapy (3 cases of WHO grade II and 1 case of WHO grade III). Three patients (7.0%) with WHO grade IV astrocytic tumors who underwent complete tumor resection underwent adjuvant chemotherapy. Four patients (9.3%) with WHO grade IV astrocytic tumors with incomplete resection received combined therapy. The major determinant of overall survival was the WHO grade of the tumor in LIMSCTs (Fig. 3). An illustrative case of LIMSCT is presented in Fig. 4.

DISCUSSION

Generally, intramedullary tumors comprise approximately 20%–30% of all primary spinal cord tumors.^{17,18} Some rare cases present with neurological defects due to a long-level extent of tumor involvement, which complicates the management strategies. However, the clinical characteristics and surgical outcomes for LIMSCTs have rarely been studied before. In this study, we presented a series of 43 consecutive patients who had LIMSCT and underwent tumor resection at our institution. To our knowledge, this represents the largest series of patients with LIMSCT involvement who underwent tumor resection.

The general characteristics of long-segment intramedullary neoplasms are somewhat different from those of general intramedullary neoplasms. According to other papers, intramedullary tumors are more common in adults and less common in

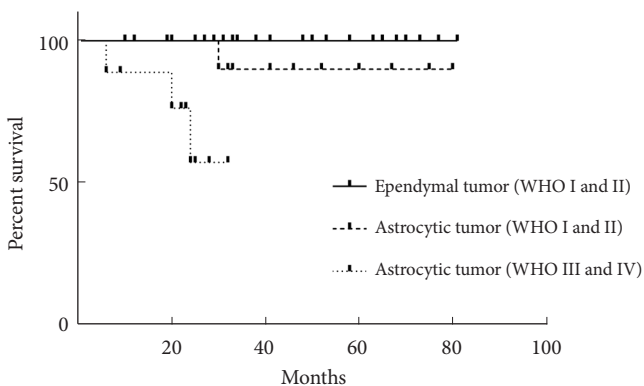


Fig. 3. Kaplan-Meier analysis for overall survival with regard to ependymal tumor WHO grades I and II, astrocytic tumor WHO grades I and II, and astrocytic tumor WHO grades III and IV. WHO, World Health Organization.



Fig. 4. (A) A 48-year-old female patient. Preoperative imaging indicated a long-level intramedullary tumor. (B) Gross total resection was achieved, and the pathology result was ependymoma WHO grade II. (C) Thirty-month follow-up imaging showed no tumor recurrence. WHO, World Health Organization

children. Only approximately 10%–13% of intramedullary tumors occur in children.^{7,12} However, in this series, approximately 30% of patients with long-segment intramedullary tumors were children, which was significantly greater than that generally noted for intramedullary tumors. The possible explanation for this finding is that the pathological properties of intramedullary tumors in children are often poor, and the degree of malignancy is high. Malignant tumors are more likely to grow rapidly and infiltrate the spinal cord. In addition, children often have higher neurological adaptability, and early numbness and weakness do not receive sufficient attention. Therefore, the proportion of children with long-segment intramedullary tumors is higher than that noted for general intramedullary tumors.

In our series, most LIMSTs involved the cervicothoracic and cervical levels. All the long-segment intramedullary tumors were gliomas, and no other types were observed. Ependymal tumors and astrocytic tumors occurred in 53.5% and 46.5% of all patients, respectively. All patients with ependymal tumors were adults, whereas pediatric patients exhibited a higher proportion of astrocytic tumors. This finding is compatible with previous studies.^{19,20} Ependymomas are the most frequent tumors, representing half of the patients in this series. Many studies have demonstrated the characteristics of ependymomas.^{21,22} Typically, intramedullary ependymomas are solitary tumors located centrally in the spinal cord. Ependymomas rarely show infiltrative growth. The relatively well-defined interface between the lesion and the surrounding spinal cord tissue facilitates the aggressive resection of ependymomas. In this study, we achieved GTR in all patients with long-level ependymomas. No recurrence was observed at the last follow-up of each patient. Interestingly, 2 patients were diagnosed with subependymoma in this study. Subependymomas are indolent, benign tumors that have been described as having a distinct pathological pattern.²³ Jain et al.²⁴ concluded that surgical treatment can provide long-term tumor control. In the current case of subependymoma, the patient received GTR and achieved long-term progression-free status at the 50-month follow-up duration. Compared with ependymal tumors, preserving the functional status in patients with astrocytic intramedullary tumors is comparatively difficult. Astrocytomas are infiltrating tumors. Therefore, aggressive resection cannot be achieved in most cases.^{25–27} In this series, we were able to achieve GTR in 63.6% of patients with long-level low-grade astrocytic tumors and in 44.4% of patients with high-grade astrocytic tumors. Considering the long-level extent of tumor involvement, the clinical outcome is still encouraging. The medical prognosis is relatively

poor in astrocytic tumors, especially those with high histological grade. Overall survival was mainly affected by the WHO grade of the tumor in LIMSTs.

Despite their rarity, intramedullary tumors can lead to severe neurological function defects prior to medical treatment.^{28,29} In addition, patients may have no specific complaints or even remain asymptomatic for a long period, which increases the difficulty of early diagnosis.²⁷ In our current series, most patients experienced combined symptoms of both sensory and motor defects. Neuropathic pain, numbness and muscle weakness were the most frequent complaints in our patients. There is a high index of suspicion for intramedullary tumors when patients experience intractable pain. Although there was a trend that patients with LIMSTs had a longer prodrome duration compared to other studies, neurological function grade was not statistically associated with the length of prodrome time. Most patients showed a relatively mild neurological defect (MMS grade II) when they presented to our institution. However, 5 patients experienced severe dysfunction (MMS grade IV) due to rapid deterioration. Previous studies have indicated that early removal of an intramedullary tumor increases the possibility of preserving neurological function.^{5,30} In our experience, all patients with ependymoma achieved GTR. The rates of GTR, STR, and PR of low-grade astrocytomas were 63.6%, 27.3%, and 9.1%, respectively. The above excision rates for high-grade astrocytomas were 44.4% for GTR, 44.4% for STR, and 11% for PR. In this case series, intraoperative neurophysiological monitoring, including MEPs and SEPs, was performed in all patients. The warning criteria were set for a 50% amplitude reduction of SEP or a 50% amplitude reduction of MEP. The permanent 75% amplitude reduction of MEP was used to stop the operation.^{14–16} When there were significant changes in MEP, the operation was suspended temporarily. Warm saline solution was used to irrigate the surgical field, and the blood pressure was increased to at least 60 mmHg. Several literatures have studied and reviewed different monitoring techniques.¹⁴ It is showed that intraoperative neuromonitoring facilitates more aggressive tumor resection given its high sensitivity and specificity and the D-wave signal also exhibits potentials for the prediction of the neurological status.^{14,31,32} However, the optimal criteria for monitoring techniques remains controversial and a small tumor piece may be deliberately left in place due to intraoperative conditions. After aggressive tumor resection, disease recurrence is rare. In the ependymal tumor group (WHO grade I and II), 13% of patients experienced postoperative neurological deterioration, and 66.6% of them showed an improvement at the last

follow-up. In the low-grade astrocytic tumor group (WHO grade I and II), 27.3% of patients showed postoperative worsening in their neurological status, and one-third of them had improved their grades at the last follow-up. In the high-grade astrocytic tumor group (WHO grade III and IV), 55.6% of patients experienced postoperative functional worsening. Sadly, functional improvement was not observed in those patients. Our results indicated that low-level ependymal tumors and low-grade astrocytic tumors achieve a relatively better functional grade after tumor resection, whereas long-level high-grade astrocytic tumors are associated with a poor postoperative neurological status. The functional outcome was not affected by the extent of tumor resection in low-grade ependymal tumors and astrocytic tumors. During the follow-up period, no further functional aggravation was witnessed. In addition, high WHO grade tumors were significantly related to high mortality, which should not be neglected. For the treatment of high-grade gliomas, some institutions prefer conservative treatment strategies, such as biopsy with adjuvant therapy.³³ For a sensitive patient population, adjuvant therapies and immunotherapy may represent alternative options.^{34,35} However, the role of adjuvant therapies for high-grade intramedullary tumors still needs to be discussed.^{36,37} Tumor resection remains the mainstay of spinal cord tumors.^{7,38} In this study of LIMSCTs, we found that long-level tumor extent did not affect the benefits of surgical management. In contrast, the limitation of conservative treatment strategies is that the process cannot prevent tumor progression and finally cause intractable deterioration in patients with intramedullary tumors.^{6,39-41} Therefore, we strongly advocate that GTR, or even STR, should be attempted in patients with LIMSCTs, especially in ependymal tumors and low-grade astrocytic tumors, and a beneficial outcome can be expected.

In our case series, no postoperative progressive spinal scoliosis or kyphosis was observed. Three cases of long-segment intramedullary low-grade astrocytomas complicated with severe preoperative scoliosis were treated via a 1-stage operation. Laminectomy was performed for the entire tumor area, and complete resection of the tumor was performed; transpedicular screws were used to correct scoliosis. Patients achieved long-term tumor-free survival, and neurological function was basically preserved at the last follow-up. No serious short- or long-term complications resulted from the primary procedure. The correction of scoliosis prevents the development of spinal deformities and facilitates a return to normal life. Specifically, we encountered a unique case of primary holocord PA. PA is a subtype of glioma with a well-circumscribed, slow-growing,

and cystic nature.⁴² Primary holocord PAs are extremely rare.⁴³ We performed spinal internal fixation and posterior spinal fusion as well as laminoplasty. Even after performing spinal fixation, laminoplasty is still recommended. The reinsertion of the lamina plays an important role in reconstructing posterior spinal alignment, avoiding epidural scarring, preventing cerebrospinal fluid leakage, and facilitating reoperation if tumor recurrence occurs.^{44,45}

There were several limitations in this study. In addition to the nature of a retrospective study, all of the patients in this study underwent surgery in a single institution, which limited the generalizability. Additionally, the limited population of patients with LIMSCTs also leads to bias. Moreover, the true disease progression rate may be underestimated based on a mean follow-up duration of 37 months. To counter these limitations, further prospective randomized studies with large populations of patients with LIMSCTs are needed.

CONCLUSION

In the current case series, all LIMSCTs were gliomas, among which ependymoma was the main proportion type, and no other tumors were observed. LIMSCTs are most common in adults, whereas the proportion of children is increasing compared to general intramedullary tumors. All ependymal tumors achieved GTR, whereas astrocytic tumors exhibited a lower rate of complete tumor resection, especially in high-grade tumors. Aggressive tumor resection did not increase the risk of long-term neurological functional deterioration in low-grade ependymal tumors and astrocytic tumors. However, in high-grade astrocytic tumors, patients had a higher risk of neurological deterioration and difficulty in recovery. With attempting GTR, patients can expect a low disease progression rate in low-grade ependymal tumors and astrocytic tumors, and complete tumor removal remains the primary goal of treatment. We believe this protocol provides a good review of clinical characteristics and treatment outcomes for patients with LIMSCTs.

NOTES

Conflict of Interest: The authors have nothing to disclose.

Funding/Support: This article was supported by Beijing Municipal Science and Technology Commission. NO. Z19110000 6619040; The Capital Health Research and Development of Special. NO. 2020-2-8011.

Acknowledgments: With the accomplishment of this study,

the authors would like to devotedly express their great admirations to professor Chung-Cheng Wang, who passed 11 years ago. Dr. Wang was the first Chinese neurosurgeon who surgically resects intramedullary spinal cord tumors with microsurgical technique in China in 20th century. Dr Wang contributed greatly to the establishment and development of neurosurgery in China. He was academician of the Chinese Academy of Engineering. He won the Bethune Prize in 2000 - the highest award for medicine in China. He won the National Highest Science and Technology Awards of China in 2008.

Author Contribution: Conceptualization: T Fan; Data curation: DZ, XZ, CL, YW, KW; Formal analysis: DZ, XZ, CL, YW, KW; Funding acquisition: TF; Methodology: DZ, WF; Project administration: TF; Visualization: DZ, WF; Writing - original draft: DZ; Writing - review & editing: TF, WF.

ORCID

Dongao Zhang: 0000-0002-0808-6203
 Tao Fan: 0000-0001-8885-1480
 Wayne Fan: 0000-0002-1276-7706
 Xingang Zhao: 0009-0005-8802-959X
 Cong Liang: 0009-0004-3906-8237
 Yinqian Wang: 0000-0001-5004-9417
 Kun Wu: 0009-0003-6663-0101

REFERENCES

1. Oral S, Tumturk A, Kucuk A, et al. Cervical hemilaminoplasty with miniplates in long segment intradural extramedullary ependymoma: case report and technical note. *Turk Neurosurg* 2018;28:158-63.
2. Jallo GI, Freed D, Epstein F. Intramedullary spinal cord tumors in children. *Childs Nerv Syst* 2003;19:641-9.
3. Huddart R, Traish D, Ashley S, et al. Management of spinal astrocytoma with conservative surgery and radiotherapy. *Br J Neurosurg* 1993;7:473-81.
4. Sandalcioglu IE, Gasser T, Wiedemayer H, et al. Favourable outcome after biopsy and decompression of a holocord intramedullary spinal cord astrocytoma in a newborn. *Eur J Paediatr Neurol* 2002;6:179-82.
5. Shrivastava RK, Epstein FJ, Perin NI, et al. Intramedullary spinal cord tumors in patients older than 50 years of age: management and outcome analysis. *J Neurosurg Spine* 2005; 2:249-55.
6. Constantini S, Miller DC, Allen JC, et al. Radical excision of intramedullary spinal cord tumors: surgical morbidity and long-term follow-up evaluation in 164 children and young adults. *J Neurosurg* 2000;93(2 Suppl):183-93.
7. Alizada O, Kemerdere R, Ulu MO, et al. Surgical management of spinal intramedullary tumors: ten-year experience in a single institution. *J Clin Neurosci* 2020;73:201-8.
8. Endo T, Inoue T, Mizuno M, et al. Current trends in the surgical management of intramedullary tumors: a multicenter study of 1,033 patients by the Neurospinal Society of Japan. *Neurospine* 2022;19:441-52.
9. Jecko V, Roblot P, Mongardi L, et al. Intramedullary spinal cord lesions: a single-center experience. *Neurospine* 2022; 19:108-17.
10. McCormick PC, Stein BM. Intramedullary tumors in adults. *Neurosurg Clin N Am* 1990;1:609-30.
11. Louis DN, Perry A, Reifenberger G, et al. The 2016 World Health Organization Classification of Tumors of the Central Nervous System: a summary. *Acta Neuropathol* 2016;131: 803-20.
12. Shi W, Wang S, Zhang H, et al. Risk factor analysis of progressive spinal deformity after resection of intramedullary spinal cord tumors in patients who underwent laminoplasty: a report of 105 consecutive cases. *J Neurosurg Spine* 2019 Feb 8:1-9. doi: 10.3171/2018.10.SPINE18110. [Epub].
13. Bakhshi SK, Waqas M, Shakaib B, et al. Management and outcomes of intramedullary spinal cord tumors: A single center experience from a developing country. *Surg Neurol Int* 2016;7(Suppl 23):S617-22.
14. Rijs K, Klimek M, Scheltens-de Boer M, et al. Intraoperative neuromonitoring in patients with intramedullary spinal cord tumor: a systematic review, meta-analysis, and case series. *World Neurosurg* 2019;125:498-510.e2.
15. Choi I, Hyun SJ, Kang JK, et al. Combined muscle motor and somatosensory evoked potentials for intramedullary spinal cord tumour surgery. *Yonsei Med J* 2014;55:1063-71.
16. Scibilia A, Terranova C, Rizzo V, et al. Intraoperative neurophysiological mapping and monitoring in spinal tumor surgery: sirens or indispensable tools? *Neurosurg Focus* 2016; 41:E18.
17. Bowers DC, Weprin BE. Intramedullary spinal cord tumors. *Curr Treat Options Neurol* 2003;5:207-12.
18. Steinbok P, Cochrane DD, Poskitt K. Intramedullary spinal cord tumors in children. *Neurosurg Clin N Am* 1992;3:931-45.
19. Samartzis D, Gillis CC, Shih P, et al. Intramedullary spinal cord tumors: part i-epidemiology, pathophysiology, and diagnosis. *Global Spine J* 2015;5:425-35.

20. O'Sullivan C, Jenkin RD, Doherty MA, et al. Spinal cord tumors in children: long-term results of combined surgical and radiation treatment. *J Neurosurg* 1994;81:507-12.
21. Chang UK, Choe WJ, Chung SK, et al. Surgical outcome and prognostic factors of spinal intramedullary ependymomas in adults. *J Neurooncol* 2002;57:133-9.
22. Reni M, Gatta G, Mazza E, et al. Ependymoma. *Crit Rev Oncol Hematol* 2007;63:81-9.
23. Casey AT, Marsh H, Wilkins P. Subependymoma of the thoracic cord: potential pitfalls in diagnosis. *Br J Neurosurg* 1993;7:319-22.
24. Jain A, Amin AG, Jain P, et al. Subependymoma: clinical features and surgical outcomes. *Neurol Res* 2012;34:677-84.
25. Kim MS, Chung CK, Choe G, et al. Intramedullary spinal cord astrocytoma in adults: postoperative outcome. *J Neurooncol* 2001;52:85-94.
26. Karikari IO, Nimjee SM, Hodges TR, et al. Impact of tumor histology on resectability and neurological outcome in primary intramedullary spinal cord tumors: a single-center experience with 102 patients. *Neurosurgery* 2015;76 Suppl 1:S4-13; discussion S13.
27. Raco A, Esposito V, Lenzi J, et al. Long-term follow-up of intramedullary spinal cord tumors: a series of 202 cases. *Neurosurgery* 2005;56:972-81; discussion 972-81.
28. Schwartz TH, McCormick PC. Intramedullary ependymomas: clinical presentation, surgical treatment strategies and prognosis. *J Neurooncol* 2000;47:211-8.
29. Houten JK, Cooper PR. Spinal cord astrocytomas: presentation, management and outcome. *J Neurooncol* 2000;47:219-24.
30. Goh KY, Velasquez L, Epstein FJ. Pediatric intramedullary spinal cord tumors: is surgery alone enough? *Pediatr Neurosurg* 1997;27:34-9.
31. Sala F, Bricolo A, Faccioli F, et al. Surgery for intramedullary spinal cord tumors: the role of intraoperative (neurophysiological) monitoring. *Eur Spine J* 2007;16 Suppl 2(Suppl 2): S130-9.
32. Sala F, Palandri G, Basso E, et al. Motor evoked potential monitoring improves outcome after surgery for intramedullary spinal cord tumors: a historical control study. *Neurosurgery* 2006;58:1129-43; discussion 1129-43.
33. Bostrom A, Kanther NC, Grote A, et al. Management and outcome in adult intramedullary spinal cord tumours: a 20-year single institution experience. *BMC Res Notes* 2014;7: 908.
34. Nagashima Y, Nishimura Y, Eguchi K, et al. Recent molecular and genetic findings in intramedullary spinal cord tumors. *Neurospine* 2022;19:262-71.
35. Grady C, Melnick K, Porche K, et al. Glioma immunotherapy: advances and challenges for spinal cord gliomas. *Neurospine* 2022;19:13-29.
36. Guss ZD, Moningi S, Jallo GI, et al. Management of pediatric spinal cord astrocytomas: outcomes with adjuvant radiation. *Int J Radiat Oncol Biol Phys* 2013;85:1307-11.
37. Nadkarni TD, Rekate HL. Pediatric intramedullary spinal cord tumors. Critical review of the literature. *Childs Nerv Syst* 1999;15:17-28.
38. Wu L, Wang L, Yang J, et al. Clinical features, treatments, and prognosis of intramedullary spinal cord metastases from lung cancer: a case series and systematic review. *Neurospine* 2022;19:65-76.
39. Kane PJ, el-Mahdy W, Singh A, et al. Spinal intradural tumours: part II--intramedullary. *Br J Neurosurg* 1999;13:558-63.
40. Malis LI. Intramedullary spinal cord tumors. *Clin Neurosurg* 1978;25:512-39.
41. Stein BM. Intramedullary spinal cord tumors. *Clin Neurosurg* 1983;30:717-41.
42. Collins VP, Jones DT, Giannini C. Pilocytic astrocytoma: pathology, molecular mechanisms and markers. *Acta Neuropathol* 2015;129:775-88.
43. Ebner FH, Schittenhelm J, Roser F, et al. Management of holocord pilocytic astrocytomas in children and adolescents: an update. *Pediatr Neurosurg* 2012;48:133-40.
44. Pietila TA, Stendel R, Schilling A, et al. Surgical treatment of spinal hemangioblastomas. *Acta Neurochir (Wien)* 2000; 142:879-86.
45. Kokubun S, Kashimoto O, Tanaka Y. Histological verification of bone bonding and ingrowth into porous hydroxyapatite spinous process spacer for cervical laminoplasty. *Tohoku J Exp Med* 1994;173:337-44.