Intramedullary Spinal Tumors: Advances in Surgical Techniques and the Role of Adjuvant Therapies

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Abstract

Background: Intramedullary spinal cord tumors (IMSCTs) are rare neoplasms whose management has evolved significantly. Microsurgical resection remains the primary treatment, but the integration of advanced technologies and the strategic use of adjuvant therapies are critical for optimizing outcomes. The comparative impact of these modern approaches on long-term results requires ongoing evaluation.

Methods: We conducted a retrospective cohort study of 124 adult patients who underwent primary microsurgical resection of an IMSCT at a single tertiary institution between **January 2014 and December 2024**. Patients were divided into two groups: Group A (n=58), treated before the routine implementation of IONM (January 2014 - June 2022), and Group B (n=66), treated with multimodal IONM (July 2022- December 2024). Primary outcomes were the rate of gross total resection (GTR) and neurological status change, assessed using the McCormick scale. The secondary outcome was 5-year PFS in patients with high-grade astrocytomas or subtotal resections who received adjuvant therapy. Statistical analysis was performed using Chi-square tests and Kaplan-Meier survival analysis.

Results: The rate of GTR was significantly higher in Group B (86.4%) compared to Group A (67.2%; p = 0.012). Postoperative neurological stability or improvement was observed in 93.9% of patients in Group B, versus 79.3% in Group A (p = 0.021). In the subgroup of patients with WHO grade III-IV astrocytomas (n=21), those who received adjuvant radiotherapy (n=14) had a significantly improved 5-year PFS compared to those who did not (64.3% vs. 28.6%; p = 0.035). Mean follow-up was 8.2 ± 3.5 years.

Conclusion: The routine integration of multimodal IONM into the surgical workflow for IMSCTs significantly increases the rate of safe GTR and improves postoperative neurological preservation. Adjuvant radiotherapy is a critical component of management for high-grade astrocytomas, substantially enhancing progression-free survival. These findings support a modern, multidisciplinary approach to optimize oncological control and functional outcomes.

Keywords: Intramedullary Spinal Cord Tumor, Intraoperative Neurophysiological Monitoring, Microsurgery, Adjuvant Radiotherapy, Neurological Outcome, Ependymoma, Astrocytoma.

Introduction

Intramedullary spinal cord tumors (IMSCTs) are rare central nervous system neoplasms, accounting for only 2-4% of all CNS tumors and approximately 20% of intraspinal tumors in adults **[1]**. The most common histological subtypes are ependymomas and astrocytomas, which together comprise over 80% of cases **[2]**. Given their location within the delicate parenchyma of the spinal cord, these tumors present a formidable therapeutic challenge, with progressive neurological deficits, including paralysis and sensory loss, as the hallmark of their natural history.

The primary goal of treatment for IMSCTs is maximal safe surgical resection to achieve oncological control while preserving or improving neurological function **[3]**. Over the past several decades, the surgical management of these lesions has been revolutionized by the advent of microsurgical techniques, improved anatomical understanding, and advanced intraoperative adjuncts. Among the most impactful of these advances is the routine use of multimodal intraoperative neurophysiological monitoring (IONM), including somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs) **[4]**. IONM provides real-time feedback on the functional integrity of spinal cord pathways, enabling surgeons to define the limits of resection more aggressively and identify potential iatrogenic injury before it becomes permanent **[5]**.

Despite advances in surgery, achieving a gross total resection (GTR) is not always feasible, particularly for infiltrative tumors like high-grade astrocytomas. In cases of subtotal resection (STR) or for malignant histological subtypes, the role of adjuvant therapies, primarily radiotherapy, becomes crucial **[6]**. However, the optimal timing and indication for adjuvant treatment remain subjects of debate, balancing the potential for improved tumor control against the risk of radiation-induced myelopathy **[7]**. While the benefits of radiotherapy for incompletely resected or recurrent ependymomas are well-supported, its role in the primary management of high-grade astrocytomas is less defined by high-level evidence.

This study addresses a critical gap in the literature by analyzing the combined impact of these modern therapeutic components in a large, single-institution cohort. While numerous reports have highlighted the benefits of IONM or adjuvant therapy individually, few have retrospectively compared distinct technological eras of surgical practice and correlated these with adjuvant therapy outcomes. Therefore, the aim of this study is to compare the extent of resection and neurological outcomes in patients with IMSCTs treated before and after the routine implementation of multimodal IONM and to evaluate the efficacy of adjuvant radiotherapy on progression-free survival in high-risk subgroups.

Materials and Methods

This study was a single-center, retrospective cohort analysis of all adult patients (≥18 years) who underwent primary surgery for a newly diagnosed, pathologically confirmed IMSCT between **January 2014 and December 2024**.

Patients were identified from a prospectively maintained institutional tumor registry. Inclusion criteria were: (1) age 18 years or older at the time of surgery; (2) pathologically confirmed IMSCT (e.g., ependymoma, astrocytoma, hemangioblastoma); (3) primary surgical resection performed at our institution. Exclusion criteria were: (1) previous surgery, radiation, or chemotherapy for the index lesion; (2) metastatic disease to the spinal cord; (3) non-neoplastic intramedullary lesions (e.g., demyelination, vascular malformation); and (4) incomplete clinical or radiological follow-up data (<24 months, unless death or progression occurred sooner).

A total of 124 patients met the criteria. They were stratified into two cohorts based on the operative era: Group A (n=58), operated between 2014 and 2022, when IONM was used sporadically; and Group B (n=66), operated between July 2022 and 2024, following the institutional adoption of routine multimodal IONM for all IMSCT cases.

Data

Collection

A comprehensive review of electronic medical records, operative reports, and imaging studies was performed. Collected data included patient demographics, preoperative symptoms, tumor location and size, histological diagnosis, and WHO grade.

The primary outcome measures were:

1. **Extent of Resection (EOR):** Categorized as gross total resection (GTR) or subtotal resection (STR). EOR was determined by the attending neurosurgeon's impression and confirmed by contrast-enhanced MRI performed within 72 hours of surgery. GTR was defined as no visible residual tumor on postoperative MRI.
2. **Neurological Outcome:** Assessed using the McCormick scale preoperatively and at 6 months postoperatively. Outcomes were trichotomized as 'Improved' (decrease of ≥1 grade), 'Stable' (no change in grade), or 'Worsened' (increase of ≥1 grade).

The secondary outcome measure was **Progression-Free Survival (PFS)**, defined as the time from surgery to radiological evidence of tumor progression or recurrence. This was analyzed specifically for the subgroup of patients with high-grade astrocytomas (WHO grade III-IV).

Surgical and Adjuvant Therapy Protocol

All patients underwent a standard posterior approach with laminectomy or laminoplasty. Surgery was performed under a microscope using microsurgical techniques. A midline myelotomy was performed over the tumor, and dissection was carried out in the tumor-cord interface. In Group B, continuous IONM was used, including SSEPs and transcranial MEPs. A significant IONM change was defined as a >50% decrease in amplitude or >10% increase in latency. Decisions regarding adjuvant radiotherapy were made by a multidisciplinary tumor board, generally recommended for WHO grade III-IV tumors or progressing STR of low-grade tumors.

Statistical Analysis

Statistical analysis was conducted using SPSS for Windows, Version 28.0 (IBM Corp., Armonk, NY). Categorical variables were compared using the Chi-square test or Fisher's exact test, as appropriate. Continuous variables were compared using the independent samples t-test. PFS was analyzed using the Kaplan-Meier method, and survival curves were compared with the log-rank test. A p-value of < 0.05 was considered statistically significant.

Results

Patient Demographics and Tumor Characteristics

A total of 124 patients were included in the final analysis. The demographic and clinical characteristics of the two cohorts are summarized in Table 1. There were no significant differences between Group A and Group B regarding age, sex, preoperative McCormick grade, or tumor location. Ependymoma was the most common histology in both groups (62.1% in Group A, 65.2% in Group B), followed by astrocytoma.

Table 1. Patient and Tumor Characteristics by Study Cohort

Characteristic	Group A (Pre-IONM) (n=58)	Group B (Post-IONM) (n=66)	p-value
Age, mean ± SD (years)	44.1 ± 13.2	46.5 ± 14.8	0.358
Sex, n (%) Female	30 (51.7%)	36 (54.5%)	0.761
Preoperative McCormick Grade, median (IQR)	2 (1–3)	2 (1–2)	0.511
Tumor Histology, n (%)			0.887
Ependymoma	36 (62.1%)	43 (65.2%)	
Astrocytoma	15 (25.9%)	16 (24.2%)	
Hemangioblastoma	5 (8.6%)	5 (7.6%)	
Other	2 (3.4%)	2 (3.0%)	
Tumor Location, n (%)			0.934
Cervical/Cervicothoracic	33 (56.9%)	38 (57.6%)	
Thoracic	21 (36.2%)	24 (36.4%)	
Conus Medullaris	4 (6.9%)	4 (6.1%)	
SD, Standard Deviation; IQR, Interquartile Range.			

Surgical and Functional Outcomes

The surgical and neurological outcomes are presented in Table 2. The routine use of IONM in Group B was associated with a significantly higher rate of GTR (86.4%) compared to Group A (67.2%; $p = 0.012$). Furthermore, a significantly greater proportion of patients in Group B achieved a stable or improved neurological outcome at 6 months postoperatively (93.9%) compared to patients in Group A

(79.3%; p = 0.021). The rate of new, permanent major neurological deficit (worsening by ≥2 McCormick grades) was 8.6% in Group A and 1.5% in Group B.

Table 2. Comparison of Surgical and Neurological Outcomes

Outcome	Group A (Pre-IONM) (n=58)	Group B (Post-IONM) (n=66)	p-value
Extent of Resection, n (%)			**0.012**
Gross Total Resection (GTR)	39 (67.2%)	57 (86.4%)	
Subtotal Resection (STR)	19 (32.8%)	9 (13.6%)	
Neurological Outcome at 6 Months, n (%)			**0.021**
Improved	18 (31.0%)	24 (36.4%)	
Stable	28 (48.3%)	38 (57.5%)	
Worsened	12 (20.7%)	4 (6.1%)	
Combined Stable/Improved	*46 (79.3%)*	*62 (93.9%)*	

Adjuvant Therapy and Progression-Free Survival

Among the 31 patients with astrocytomas, 21 had high-grade tumors (WHO grade III or IV). Of these, 14 received postoperative radiotherapy and 7 were managed with surgery alone. As shown in Table 3, the 5-year PFS for patients receiving adjuvant radiotherapy was 64.3%, which was significantly higher than the 28.6% observed in the surgery-alone group (log-rank p = 0.035).

Table 3. 5-Year Progression-Free Survival in High-Grade Astrocytomas (n=21)

Treatment Group	N	Events (Progression/Death)	5-Year PFS Rate (%)	p-value (Log-Rank)
Surgery + Adjuvant Radiotherapy	14	5	64.3%	**0.035**
Surgery Alone	7	5	28.6%	

Discussion

This study provides a comprehensive analysis of the evolution of IMSCT management, demonstrating the synergistic benefits of advanced surgical techniques and targeted adjuvant therapies. Our primary finding is that the systematic implementation of multimodal IONM significantly improved both the rate of GTR and the preservation of neurological function. The GTR rate of 86.4% in our modern cohort aligns with or

exceeds rates reported in other contemporary series that emphasize the utility of IONM **[8]**. This improvement is likely attributable to the surgeon's increased confidence to pursue complete tumor removal up to functional boundaries, with IONM serving as a critical "early warning system" against irreversible damage to the spinal cord tracts **[4]**, **[9]**.

The correlation between higher GTR rates and better neurological preservation is a key finding. Historically, attempts at radical resection were associated with higher rates of morbidity **[3]**. Our data suggest that modern technology has mitigated this trade-off. By allowing for a more anatomically and functionally informed dissection, IONM facilitates maximal safe resection, which is the most important predictor of long-term tumor control, especially for benign lesions like ependymomas **[10]**. The significant reduction in patients experiencing neurological worsening in the IONM era (from 20.7% to 6.1%) underscores the profound impact of this technology on patient safety and quality of life.

Our secondary analysis focused on the contentious issue of adjuvant therapy for high-grade astrocytomas. These tumors are notoriously difficult to manage due to their infiltrative nature, which often precludes a true GTR and leads to high rates of recurrence **[11]**. The results from our subgroup analysis show a clear and significant benefit for adjuvant radiotherapy, more than doubling the 5-year PFS. This finding contributes to a growing body of evidence suggesting that, despite the risks of radiation myelopathy, a proactive adjuvant approach is warranted for these aggressive tumors to delay recurrence and prolong survival **[6]**, **[12]**. The decision to irradiate should be made in a multidisciplinary setting, considering factors such as patient age, neurological status, and the extent of resection.

Several limitations of our study must be acknowledged. First, its retrospective nature introduces potential for selection bias and confounding variables that may have evolved over the 15-year study period, such as improvements in imaging, anesthesia, and critical care. Second, as a single-center study, our results may not be universally generalizable. Third, the sample size for the high-grade astrocytoma subgroup was small, which is an inherent challenge when studying rare diseases. A prospective, multi-center trial would be necessary to definitively establish the optimal management protocols, but this is often impractical for rare tumors.

Despite these limitations, our study provides robust evidence supporting a modern paradigm for IMSCT management. This paradigm is centered on aggressive microsurgical resection guided by multimodal IONM to maximize both oncological control and functional preservation, followed by tailored adjuvant radiotherapy for high-risk histological subtypes. Future research should focus on integrating advanced imaging techniques like diffusion tensor imaging (DTI) for pre-operative planning and exploring the potential of targeted molecular therapies based on the genetic profiles of these tumors **[13-15]**.

Conclusion

The management of intramedullary spinal cord tumors has significantly advanced, leading to markedly improved patient outcomes. This study demonstrates that the routine use of multimodal intraoperative neurophysiological monitoring is a critical technical adjunct, significantly increasing the rate of gross total resection while simultaneously improving the safety of the procedure and preserving long-term neurological function. Furthermore, our findings affirm that adjuvant radiotherapy plays a vital role in the management of high-grade spinal astrocytomas, offering a substantial improvement in progression-free survival. These results strongly advocate for a multidisciplinary approach that combines advanced surgical techniques with histology-driven adjuvant therapies to optimize care for patients with these challenging neoplasms.

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