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Early Neurological Deterioration and Longitudinal Recovery After Spinal Ependymoma Surgery: A Multidimensional Outcome Analysis

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Abbreviations: AIS: American Spinal Injury Association Impairment Scale; AMB: ambulatory status; EOR: extent of resection; GTR: gross-total resection; IONM: intraoperative neurophysiological monitoring; MEP: motor evoked potential; MMS: modified McCormick scale; mRS: modified Rankin scale; SSEP: somatosensory evoked potential; STR: subtotal resection; WHO: World Health Organization.

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ABSTRACT

Objective: To characterize longitudinal neurological and functional outcomes after spinal ependymoma surgery and explore factors associated with early postoperative deterioration.

Methods: A retrospective cohort study was conducted including adult patients who underwent surgical resection of a histologically confirmed spinal ependymoma between 2018 and 2024. Neurological and functional status was assessed using the American Spinal Injury Association Impairment Scale (AIS), Modified McCormick Scale (MMS), modified Rankin Scale (mRS), and ambulatory status at baseline, discharge, and 3, 6, and 12 months. The primary endpoint was deterioration in at least one measure at discharge relative to baseline. Longitudinal analyses evaluated postoperative trajectories, while multivariable logistic regression was used to explore factors associated with deterioration at discharge.

Results: Fifty-five patients were included. Composite deterioration at discharge occurred in 23 patients (41.8%). Outcomes varied across timepoints (Friedman test, all $p<0.001$), with early worsening followed by recovery predominantly within 6 months. At 12 months, 15 patients (27.3%) remained worse than baseline in at least one measure; all had deteriorated at discharge, whereas none without discharge deterioration developed new late worsening ($p<0.001$). In exploratory multivariable analysis, cervical (OR, 7.06; $p=0.017$) and thoracic location (OR, 5.27; $p=0.043$) were associated with composite deterioration compared with lumbosacral location. Greater tumor extension was associated with MMS and mRS deterioration.

Conclusion: Postoperative deterioration was common, although cohort-level outcomes generally improved during the first 6 months. Persistent 12-month deficits occurred exclusively among patients who had deteriorated at discharge. Multidimensional longitudinal assessment may support postoperative counseling and targeted follow-up.

Keywords: Ependymoma; Spinal Cord Neoplasms; Postoperative Complications; Neurologic Manifestations; Treatment Outcome; Follow-Up Studies.

MAIN TEXT

INTRODUCTION

Spinal ependymomas comprise anatomically distinct tumors arising within the spinal cord, conus medullaris, filum terminale, or cauda equina. Intramedullary ependymomas are the most common primary intramedullary spinal cord tumors in adults, whereas tumors of the filum and cauda equina, frequently of myxopapillary histology, have different anatomical and surgical characteristics [**1,2**]. Surgical resection is the mainstay of treatment and can provide durable tumor control; however, it may be followed by deterioration in motor, sensory, ambulatory, or functional status [**3,4**]. Characterizing the extent, duration, and recovery of these deficits is important for perioperative counseling, postoperative monitoring, and rehabilitation planning.

Evidence on functional outcomes after spinal ependymoma surgery remains heterogeneous. Some surgical series combine different intramedullary tumor histologies, despite substantial differences in biological behavior, resectability, and neurological risk [**2,5-8**]. Even in ependymoma-specific cohorts, postoperative function is commonly summarized using a single outcome measure, most often the Modified McCormick Scale, or assessed only at the last available follow-up. These approaches may obscure early postoperative deterioration, differences among neurological and functional domains, and the distinction between partial improvement and return to the individual preoperative baseline [**9-12**]. Consequently, the timing and completeness of postoperative recovery remain insufficiently characterized.

To address these limitations, postoperative trajectories were evaluated using four complementary measures: the American Spinal Injury Association Impairment Scale to grade neurological impairment, the Modified McCormick Scale to assess neurological disability, the modified Rankin Scale to evaluate global functional independence, and an ambulation measure to specifically characterize walking ability. The primary endpoint was deterioration in at least one outcome measure at discharge relative to the individual preoperative baseline. Longitudinal objectives were to determine the timing and completeness of recovery, identify persistent individual deterioration at 12 months, and compare trajectories across outcome domains. Associations between preoperative characteristics and deterioration at discharge were explored as secondary analyses.

METHODS

Study design and patient population

A retrospective cohort study was conducted using a prospectively maintained institutional database. All adults aged 18 years or older who were evaluated between January 2018 and December 2024 for a radiologically suspected spinal ependymoma were screened. Patients with incidentally detected asymptomatic lesions who were managed conservatively were not included in the surgical cohort. Among patients undergoing resection, eligibility required histopathological confirmation of spinal ependymoma and clinical and radiological data sufficient to evaluate the prespecified longitudinal outcomes. Patients were excluded from the final analysis in cases of subependymoma histology, postoperative follow-up shorter than 12 months, or incomplete data precluding longitudinal neurological and functional assessment. The patient-selection process is presented in a STROBE flow diagram (**Figure 1**).

The study was conducted in accordance with the Declaration of Helsinki and applicable national regulations. According to institutional policy of the University of Turin, formal ethics committee approval was not required because the study involved the retrospective analysis of fully anonymized data collected during routine clinical care. Written informed consent for surgical treatment was obtained from all patients as part of routine clinical practice.

Clinical, radiological, histopathological, and surgical variables

Clinical variables included age, sex, and symptom duration, defined as the interval between the onset of the first tumor-related symptom and surgical treatment. Preoperative neurological and functional status was assessed using the American Spinal Injury Association Impairment Scale (AIS), Modified McCormick Scale (MMS), modified Rankin Scale (mRS), and ambulatory status.

Preoperative MR imaging was reviewed for anatomical compartment, tumor location, craniocaudal extension, maximum lesion extent, intralesional hemorrhage, syringomyelia, spinal cord myelopathic signal changes, multifocal dissemination, and contrast-enhancement pattern. Tumors were classified as intramedullary when located within the spinal cord parenchyma, including the conus medullaris, and as extramedullary when arising from the filum terminale or located within the cauda equina. Predominant tumor region was categorized as cervical, thoracic, or lumbosacral according to the anatomical region containing the largest proportion of the lesion's craniocaudal extension. Craniocaudal extension was recorded as the number of involved vertebral levels and analyzed as a continuous variable. Maximum tumor diameter was recorded in millimeters.

Histopathological diagnoses were recorded according to the 2021 World Health Organization (WHO) Classification of Tumors of the Central Nervous System and included spinal ependymoma, myxopapillary ependymoma, and spinal ependymoma with MYCN amplification, where applicable. WHO grade, MYCN amplification status, and Ki-67 proliferation index were also recorded. Diagnoses established before 2021 were retrospectively mapped to the 2021 diagnostic categories using the available histopathological reports and molecular information.

Surgical variables included operative time and extent of resection (EOR). EOR was determined on contrast-enhanced MR imaging performed 1 month after surgery and was categorized as gross-total resection (GTR), defined as the absence of radiologically detectable residual tumor, or subtotal resection (STR), defined as the presence of residual tumor, irrespective of the intraoperative assessment of resection completeness. GTR was pursued whenever safely achievable. When resection was intentionally limited, this was due to an indistinct dissection plane, adherence to neural structures, or persistent intraoperative neurophysiological deterioration despite corrective measures, when further resection was considered to carry an unacceptable risk of neurological injury.

All procedures were performed with multimodal intraoperative neurophysiological monitoring (IONM). Somatosensory evoked potentials (SSEPs) and motor evoked potentials (MEPs) were monitored in all patients; D-wave monitoring was used when anatomically applicable in patients with intramedullary tumors. For lesions involving the conus medullaris or cauda equina, direct nerve-root stimulation was additionally performed when the relevant neural structures were exposed. SSEP and MEP changes were categorized according to whether signals remained stable or showed a persistent reduction of less than 50% or greater than 50% from baseline despite corrective measures. Transient changes that recovered before the end of surgery were not classified as persistent monitoring alterations.

Postoperative complications were categorized as early when occurring during the index hospitalization and late when occurring after discharge. Adjuvant radiotherapy and radiological tumor recurrence or progression during follow-up were also recorded.

Postoperative neurological and functional status was assessed at discharge from the index hospitalization and at scheduled follow-up visits 3, 6, and 12 months after surgery. Clinical and radiological surveillance was subsequently continued annually. Contrast-enhanced MR imaging was performed 1 month after surgery to determine the EOR. At the same time, each case was reviewed by a multidisciplinary team comprising neurosurgeons, neuro-oncologists, and radiation oncologists to discuss postoperative management and the indication for adjuvant treatment. Radiological recurrence or progression was assessed during subsequent surveillance imaging.

Neurological and functional outcomes measures

Neurological and functional status was evaluated using four complementary measures: the American Spinal Injury Association Impairment Scale (AIS), Modified McCormick Scale (MMS), modified Rankin Scale (mRS), and ambulation status. Assessments were recorded at the preoperative baseline, discharge from the index hospitalization, and 3, 6, and 12 months after surgery.

The AIS grades neurological impairment from A, indicating complete impairment, to E, indicating normal motor and sensory function. For statistical analysis, AIS grades were converted to an ordinal numerical score ranging from 0 for grade A to 4 for grade E, with higher scores indicating better neurological status.

The MMS grades neurological disability from I to V, with higher grades indicating greater disability. The mRS evaluates global disability and functional independence on a scale from 0, indicating no symptoms, to 6, indicating death, with higher scores representing worse functional status.

Ambulatory status (AMB) was categorized using a four-level ordinal measure: independent ambulation without neurological gait impairment (3 points), independent but neurologically impaired ambulation (2 points), assisted or dependent ambulation (1 point), and inability to ambulate (0 points). Neurologically impaired ambulation was defined as independent walking affected by sensory ataxia, a spastic-paretic pattern, postural instability, or imbalance. Higher ambulation scores indicated better walking ability.

Outcome definitions and endpoints

For each outcome measure, deterioration was defined as worsening by at least one grade or point relative to the individual preoperative baseline. Accordingly, deterioration corresponded to a decrease of at least one grade or point in AIS grade or ambulatory-status score and to an increase of at least one point in MMS or mRS score. Deterioration was evaluated separately at discharge and at 3-, 6-, and 12-month follow-up.

The primary endpoint was composite neurological deterioration at discharge, defined as worsening relative to baseline in at least one of the four outcome measures. Scale-specific deterioration at discharge was evaluated as a secondary endpoint. Associations between baseline clinical and tumor characteristics and composite or scale-specific deterioration at discharge were considered exploratory.

Recovery at 12 months was evaluated among patients who had deteriorated at discharge. For each individual outcome measure, recovery was defined as return to the corresponding preoperative baseline value or improvement beyond baseline, whereas persistent deterioration was defined as a 12-month value that remained worse than baseline. At the composite level, recovery required the absence of deterioration from baseline across all four outcome measures at 12 months; persistent composite deterioration was defined as a 12-month status worse than baseline in at least one measure. New late deterioration was defined as deterioration at 12 months among patients who had not deteriorated at discharge.

Additional secondary endpoints included longitudinal changes in neurological and functional scores across the five assessment timepoints, the prevalence of scale-specific and composite deterioration during follow-up, and the association between deterioration at discharge and deterioration at 12 months.

Statistical Analysis

Continuous variables were reported as mean and standard deviation (SD) or median with interquartile range (IQR), according to their distribution. Categorical variables were reported as counts and percentages. Neurological and functional outcome data were complete for all 55 patients at baseline, discharge, and 3-, 6-, and 12-month follow-up.

Within-patient changes in AIS grade, MMS, mRS, and ambulatory-status score across the five assessment timepoints were evaluated using the Friedman test. Kendall's coefficient of concordance (W) was reported as an effect-size measure for the overall longitudinal change. Following a significant omnibus test, five prespecified pairwise comparisons were performed using two-sided Wilcoxon signed-rank tests: baseline versus discharge, discharge versus 3 months, 3 versus 6 months, 6 versus 12 months, and baseline versus 12 months. Multiplicity was controlled separately within each outcome measure using the Holm procedure. The magnitude and direction of each pairwise change were summarized using the matched-pairs rank-biserial correlation coefficient. Zero within-patient differences were excluded from the signed-rank statistic.

The association between deterioration at discharge and deterioration at 12 months was assessed using the two-sided Fisher exact test. Associations with deterioration at discharge were explored using conventional binary logistic regression, with results reported as odds ratios (ORs) and Wald 95% confidence intervals (CIs). Given the cohort size and number of outcome events, a limited set of clinically selected covariates was specified a priori to reduce model overfitting. A multivariable model was not fitted for AIS deterioration because only seven events were observed. All regression analyses were considered exploratory, particularly the scale-specific models, because of the limited number of events relative to the number of estimated parameters.

All tests were two-sided. Statistical significance was defined as $p<0.05$ after adjustment for multiple comparisons, where applicable. Analyses were performed using IBM SPSS Statistics, version 28.0 (IBM Corp., Armonk, NY, USA), and R, version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Study cohort and baseline characteristics

Fifty-five patients met the eligibility criteria and were included in the analysis (**Figure 1**). The mean age at surgery was 48.9 ± 16.7 years, and 31 patients (56.4%) were female. The median interval between symptom onset and surgery was 6 months (IQR, 3-12), while the median last available follow-up was 50.0 months (IQR, 31.5-80.0). Neurological and functional assessments were complete for all patients at baseline, discharge, and 3-, 6-, and 12-month follow-up.

The predominant tumor region was lumbosacral in 27 patients (49.1%), cervical in 17 (30.9%), and thoracic in 11 (20.0%). Thirty-eight tumors (69.1%) were intramedullary and 17 (30.9%) were extramedullary; 39 lesions (70.9%) involved no more than two vertebral levels. Histopathological examination identified 38 conventional ependymomas (69.1%) and 17 myxopapillary ependymomas (30.9%). GTR was achieved in 42 patients (76.4%), whereas 13 (23.6%) had residual tumor and were classified as having undergone STR. Additional demographic, radiological, histopathological, surgical, and postoperative characteristics are summarized in **Table 1**.

Longitudinal neurological and functional outcomes

Neurological and functional score distributions changed significantly across the five assessment timepoints for AIS grade, MMS, mRS, and ambulatory status (Friedman test, all $p<0.001$). The magnitude of the overall longitudinal change was small across the four measures, with Kendall's W ranging from 0.10 for AIS grade to 0.18 for ambulatory status. Summary statistics and overall longitudinal comparisons are reported in **Table 2**, while the corresponding category distributions are illustrated in **Figure 2**.

Pairwise analyses showed an early postoperative decline followed by progressive recovery (**Table 3**). Between baseline and discharge, significant deterioration was observed for MMS (adjusted $p=0.002$), mRS (adjusted $p=0.004$), and ambulatory status (adjusted $p<0.001$), whereas the change in AIS grade did not remain significant after adjustment for multiple comparisons (adjusted $p=0.101$). Despite the limited change in median

values for some scales, the distributional and mean-score shifts consistently indicated greater disability at discharge.

Recovery was most evident during the early postoperative period. Between discharge and 3 months, significant improvement occurred in AIS grade (adjusted p=0.023), MMS (adjusted p=0.033), and ambulatory status (adjusted p=0.030), while the improvement in mRS did not reach statistical significance after adjustment (adjusted p=0.071). Further improvement between 3 and 6 months was detected for MMS (adjusted p=0.033) and mRS (adjusted p=0.046), but not for AIS grade or ambulatory status. No significant changes occurred between 6 and 12 months, indicating relative stabilization during the later follow-up period. At 12 months, none of the four outcome distributions differed significantly from baseline in the prespecified pairwise comparisons.

Early postoperative deterioration and associated factors

At discharge, 23 of 55 patients (41.8%) had deteriorated relative to baseline in at least one neurological or functional measure. Scale-specific deterioration occurred in 7 patients (12.7%) according to AIS grade, 17 (30.9%) according to MMS, 14 (25.5%) according to mRS, and 20 (36.4%) according to ambulatory status.

In the multivariable analysis of composite deterioration, cervical location (adjusted OR, 7.06; 95% CI, 1.42-34.96; p=0.017) and thoracic location (adjusted OR, 5.27; 95% CI, 1.05-26.36; p=0.043) were associated with higher odds of deterioration compared with lumbosacral location (**Table 4**). Tumor extension showed a nonsignificant trend toward higher odds of deterioration with each additional involved vertebral level (adjusted OR, 1.51; 95% CI, 0.95-2.41; p=0.081), whereas baseline MMS was not independently associated with the outcome.

Scale-specific models showed partly differing patterns of association (**Table 5**). MMS deterioration was associated with thoracic location (adjusted OR, 8.41; 95% CI, 1.51-46.88; p=0.015) and greater tumor extension (adjusted OR per additional vertebral level, 1.56; 95% CI, 1.04-2.34; p=0.032). Similarly, mRS deterioration was associated with thoracic location (adjusted OR, 12.67; 95% CI, 1.57-102.01; p=0.017) and tumor extension (adjusted OR per additional vertebral level, 2.00; 95% CI, 1.18-3.39; p=0.010). Ambulatory-status deterioration was associated with cervical location (adjusted OR, 6.43; 95% CI, 1.35-30.76; p=0.020), while the associations with thoracic location and tumor extension did not reach statistical significance. Baseline scale values were not independently associated with deterioration in any of the scale-specific models. Owing to the limited number of AIS deterioration events, no multivariable model was fitted for this outcome.

Recovery and persistent deterioration at 12 months

At 12 months, 15 of 55 patients (27.3%) remained deteriorated relative to baseline in at least one neurological or functional measure (**Table 6** and **Figure 3**). Among the 23 patients with composite deterioration at discharge, 8 (34.8%) had recovered to baseline or better across all four measures by 12 months, whereas 15 (65.2%) had persistent deterioration in at least one measure. All patients with composite deterioration at 12 months had already deteriorated at discharge; no new deterioration occurred among the 32 patients without early postoperative deterioration (15/23 vs. 0/32; p<0.001).

Scale-specific deterioration decreased from discharge to 12 months for AIS grade (7/55 [12.7%] to 3/55 [5.5%]), MMS (17/55 [30.9%] to 10/55 [18.2%]), mRS (14/55 [25.5%] to 8/55 [14.5%]), and ambulatory status (20/55 [36.4%] to 9/55 [16.4%]). Among patients who had deteriorated at discharge, recovery to baseline or better by 12 months occurred in 4 of 7 patients (57.1%) according to AIS grade, 7 of 17 (41.2%) according to MMS, 6 of 14 (42.9%) according to mRS, and 11 of 20 (55.0%) according to ambulatory status. For every scale, all cases of 12-month deterioration arose among patients with deterioration already present at discharge, and none occurred de novo among patients with stable or improved discharge status (all p≤0.001).

DISCUSSION

This study characterized neurological and functional outcomes after spinal ependymoma surgery through a multidimensional longitudinal assessment incorporating AIS grade, MMS, mRS, and ambulatory status. Composite deterioration at discharge occurred in 41.8% of patients, although its frequency differed substantially across the individual measures. In the exploratory multivariable analysis, cervical and thoracic tumor locations were associated with higher odds of composite deterioration than lumbosacral location. Greater craniocaudal extension was associated with MMS and mRS deterioration but did not reach statistical significance in the composite model, while baseline functional status was not independently associated with early deterioration.

Longitudinal analyses showed a common pattern of early postoperative worsening followed by recovery, with the greatest changes occurring during the first 3-6 months and relative stabilization thereafter. Although the distributions of all four outcome measures at 12 months did not differ significantly from their respective preoperative distributions, patient-level analyses provided a complementary perspective: 15 patients (27.3%) remained worse than their individual baseline in at least one measure. All cases of persistent composite deterioration occurred among patients who had already deteriorated at discharge, whereas no new 12-month deterioration was observed among patients without early postoperative worsening. These findings emphasize the distinction between recovery at the cohort level and recovery of individual patients and support the use of repeated, multidimensional assessment to characterize postoperative trajectories.

Early postoperative deterioration and associated factors

Early postoperative neurological deterioration is well recognized after spinal ependymoma surgery, although reported frequencies vary according to the population studied, assessment scale, and timing of postoperative evaluation. Previous surgical series have reported early worsening in approximately 37%-67% of patients [**9,11,12**]. The 41.8% rate observed in the present cohort falls within this range but represents deterioration in any of four complementary measures and is therefore not directly interchangeable with rates derived from a single scale. Even when transient, early deficits may affect independence, psychological well-being, and quality of life, underscoring the importance of realistic preoperative counseling and structured postoperative assessment [**4**].

Tumor location showed the most consistent association with composite deterioration in the present analysis. Compared with lumbosacral lesions, cervical and thoracic tumors were associated with higher odds of worsening in at least one outcome measure. Scale-specific analyses suggested different patterns: thoracic location was associated with MMS and mRS deterioration, whereas cervical location was associated with deterioration in ambulatory status. Previous studies have also examined anatomical location as a determinant of outcome. Domazet et al. reported an association between spinal region and early postoperative function, with lumbar tumors showing the most favorable outcomes, while subsequent location-stratified analyses have further highlighted potential differences among cervical, thoracic, and lower spinal ependymomas. [**13,14**]. Similar associations between tumor location and postoperative morbidity have been described in broader series of intramedullary spinal cord tumors [**15**]. Nevertheless, the wide confidence intervals in the present models indicate substantial uncertainty regarding the magnitude of these associations, and the scale-specific findings should be interpreted as exploratory.

Several mechanisms could plausibly contribute to location-dependent vulnerability, including differences in the functional consequences of injury at different spinal levels and in the neural structures exposed during resection. However, such mechanisms cannot be established from the present data. Moreover, anatomical compartment and histological subtype were closely related in this cohort, with conventional ependymomas

occurring intramedullarily and myxopapillary tumors occurring extramedullarily. Consequently, the observed regional associations may partly reflect differences in surgical anatomy and tumor subtype rather than an isolated effect of spinal level.

Greater craniocaudal extension was associated with deterioration in MMS and mRS, with increasing odds for each additional involved vertebral level, whereas its association with the composite endpoint did not reach statistical significance. Prior evidence regarding tumor length is heterogeneous. An MRI-based study of intramedullary spinal ependymomas identified greater longitudinal tumor length as independently associated with worse 12-month neurological outcome [**16**]. Studies of other intramedullary histologies have similarly examined the influence of tumor localization and extension, although their findings cannot be directly extrapolated to ependymomas [**17**]. Long-level intramedullary tumors remain surgically challenging, but favorable recovery has been reported in patients with ependymal tumors despite their extensive involvement [**18**]. More recent ependymoma-specific work has continued to investigate longitudinal extension together with other MRI characteristics as potential indicators of neurological outcome [**19**]. In mixed intramedullary cohorts, lesions involving at least three vertebral segments were associated with more pronounced early postoperative deterioration, followed by substantial recovery [**20**]. Conversely, a comparison of multisegmental and monosegmental intramedullary ependymomas found worse preoperative function in multisegmental tumors but no significant difference in postoperative or long-term outcome [**21**]. Collectively, these findings suggest that longitudinal extension may influence perioperative neurological vulnerability, but its effect depends on the outcome definition, follow-up interval, and underlying tumor population.

Baseline scale values were not independently associated with deterioration at discharge in the present models. This differs from previous ependymoma and mixed intramedullary tumor series in which preoperative neurological status was associated with postoperative functional outcome or patient-reported quality of life [**22-24**]. The apparent discrepancy may reflect differences in endpoint and timing: the present analysis focused specifically on early change from each patient's own baseline, whereas most previous studies evaluated absolute function or quality of life at later follow-up. A patient with substantial preoperative disability may therefore remain stable after surgery, while a patient with initially preserved function may experience a clinically meaningful postoperative decline. This distinction supports evaluating postoperative change alongside absolute functional status.

Longitudinal recovery and multidimensional outcome assessment

Most previous studies of spinal ependymoma surgery have summarized neurological function using a single outcome measure, commonly the MMS, and have frequently reported outcomes only at the last available follow-up [**2-8**]. Although these approaches are useful for describing overall functional status, they provide limited information on the timing of postoperative deterioration and recovery or on differences among neurological and functional domains. Other series have included postoperative assessments at heterogeneous or incompletely standardized intervals, further complicating comparisons of recovery trajectories [**9-12**]. The present study addressed these limitations by applying four complementary measures at five predefined assessment timepoints.

The longitudinal findings showed that postoperative recovery was neither immediate nor uniform across measures. MMS, mRS, and ambulatory status worsened significantly between baseline and discharge, whereas the change in AIS grade did not remain significant after adjustment for multiple comparisons. Significant improvement was evident by 3 months for AIS grade, MMS, and ambulatory status, while additional improvement between 3 and 6 months was detected for MMS and mRS. No measure changed significantly between 6 and 12 months. This pattern suggests that the largest neurological and functional changes occur during the first 6 postoperative months, followed by relative stabilization. Previous ependymoma series have similarly described improvement beginning within the first postoperative months and continuing during the

first year, while multicenter data indicate that most patients with preserved preoperative mobility maintain independent ambulation after surgery [**25,26**].

An important distinction emerged between cohort-level and patient-level recovery. None of the four outcome distributions differed significantly between baseline and 12 months, which could suggest recovery toward the preoperative status when the cohort is considered as a whole. Nevertheless, 15 patients remained worse than their own baseline in at least one measure at 12 months. Group-level comparisons may therefore conceal persistent deficits in a clinically relevant subgroup, particularly when most patients are concentrated in the more favorable categories of an ordinal scale. Combining longitudinal distributional analyses with individual baseline-referenced deterioration provides a more informative representation of postoperative outcome than either approach alone.

The four measures also identified different frequencies of deterioration. AIS grade detected the fewest early deterioration events, whereas ambulatory status detected the most. This finding should not be interpreted as evidence that one scale is intrinsically superior, because each measure captures a different aspect of clinical status and has a different distributional range. AIS grades describe the severity and completeness of neurological impairment but may be relatively insensitive to smaller changes among patients clustered in grades D and E. MMS and mRS provide broader measures of neurological disability and functional independence, respectively, while ambulatory status specifically captures changes in walking ability that may arise from interacting motor, sensory, proprioceptive, and balance impairments. The partially divergent findings across these measures support their complementary use and help explain why deterioration in at least one measure was more frequent than deterioration detected by any individual scale.

Clinical implications

These findings may inform perioperative counseling and postoperative follow-up. Patients should be advised that neurological or functional worsening at discharge is relatively common, but that improvement frequently occurs during the subsequent months. Recovery was most active during the first 3-6 months, supporting close clinical surveillance and rehabilitation during this period. Nevertheless, recovery was incomplete in a clinically relevant subgroup, and the absence of a cohort-level difference between baseline and 12 months should not be interpreted as universal return to the individual preoperative condition.

Early postoperative deterioration may also help identify patients who warrant closer follow-up. In this cohort, every patient with persistent composite deterioration at 12 months had already deteriorated at discharge, whereas no new late deterioration occurred among patients without early worsening. This finding should not be interpreted as a validated prognostic rule, but it suggests that discharge assessment provides clinically relevant information about subsequent recovery. Similarly, the associations of cervical or thoracic location and greater tumor extension with selected outcomes may support individualized risk discussions, but their limited precision precludes prediction at the individual-patient level or modification of surgical indications on their basis alone.

Finally, the differences observed among AIS grade, MMS, mRS, and ambulatory status indicate that postoperative outcome cannot be fully represented by a single ordinal scale. Combining a global neurological measure with assessments of disability, independence, and ambulation may improve the detection and characterization of clinically relevant postoperative changes.

Limitations

This study has several limitations. Its retrospective, single-center design and relatively small cohort may introduce selection bias and limit the generalizability of the findings. The limited number of outcome events, particularly in the scale-specific analyses, resulted in wide confidence intervals and increased the risk of model

instability or overfitting. Accordingly, the multivariable findings should be considered exploratory and require confirmation in larger multicenter cohorts. In addition, conventional and myxopapillary ependymomas differed in anatomical compartment and predominant location within this cohort, preventing reliable separation of the effects of tumor region, compartment, and histological subtype. The predictive analyses were intentionally restricted to a limited set of preoperative variables, and residual confounding by unmeasured clinical or intraoperative factors cannot be excluded. Finally, the ordinal outcome measures may be affected by floor or ceiling effects, and deterioration defined by a one-point change may not have equivalent clinical relevance across scales or baseline categories. Patient-reported outcomes and detailed domain-specific assessments were not available.

CONCLUSIONS

Early neurological and functional deterioration was common after spinal ependymoma surgery but was generally followed by improvement, predominantly during the first 6 postoperative months. Nevertheless, more than one-quarter of patients remained worse than their individual preoperative baseline in at least one outcome measure at 12 months, despite the absence of significant cohort-level differences from baseline. Persistent deterioration occurred exclusively among patients who had already worsened at discharge, supporting close follow-up of this subgroup. Tumor location and craniocaudal extension showed outcome-specific associations with early deterioration, although these exploratory findings require external validation. Repeated assessment using complementary neurological and functional measures provides a more complete characterization of postoperative recovery than reliance on a single scale or follow-up timepoint.

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FIGURES

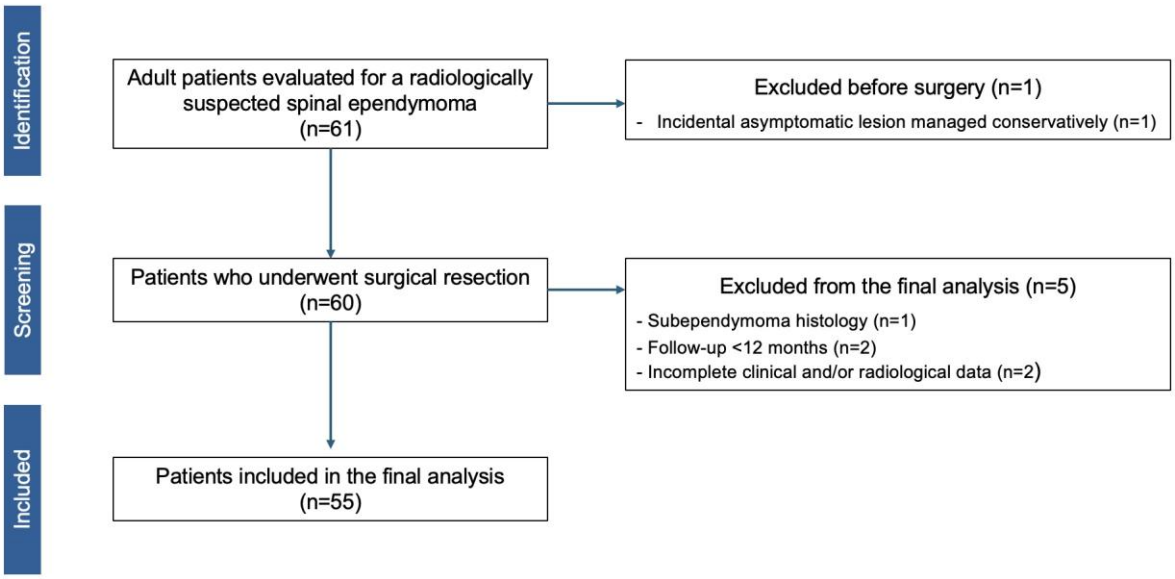


Figure 1. STROBE flow diagram of patient selection. Sixty-one adult patients with a suspected spinal ependymoma were assessed for eligibility. One asymptomatic patient managed conservatively was excluded. Among the 60 patients who underwent surgery, 5 were excluded because of a histopathological diagnosis of subependymoma (n=1), follow-up shorter than 12 months (n=2), or incomplete neurological outcome data (n=2). The final study cohort comprised 55 patients.

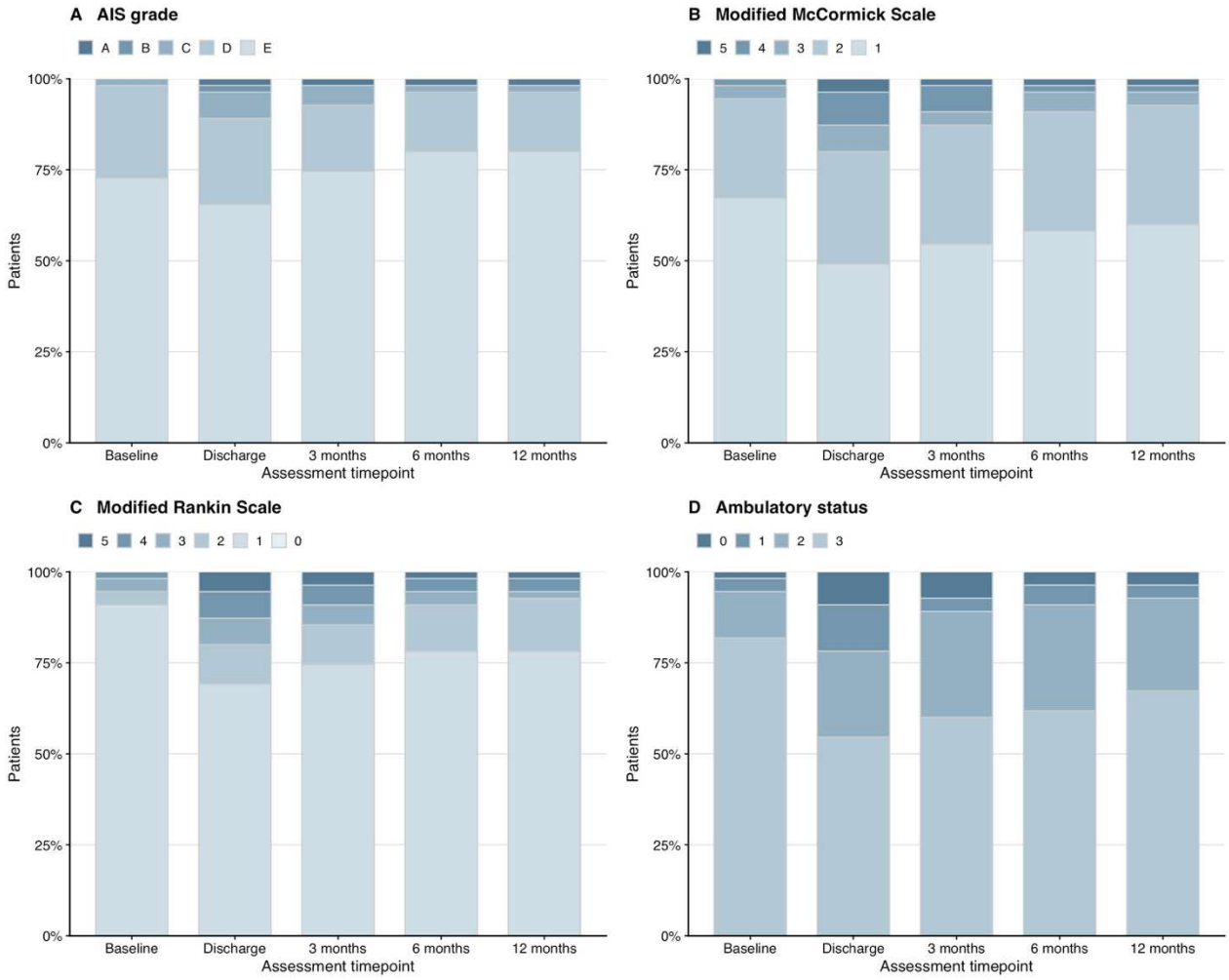


Figure 2. Longitudinal distribution of neurological and functional outcomes. Stacked bars show the percentage distribution of the 55 patients at baseline, hospital discharge, and 3-, 6-, and 12-month assessments according to (A) American Spinal Injury Association Impairment Scale (AIS) grade, (B) Modified McCormick Scale (MMS), (C) modified Rankin Scale (mRS), and (D) ambulatory status. Within each panel, darker shades indicate greater neurological or functional impairment, whereas progressively lighter shades indicate better status. Higher AIS grades and ambulatory-status scores indicate better function, whereas higher MMS and mRS scores indicate greater disability.

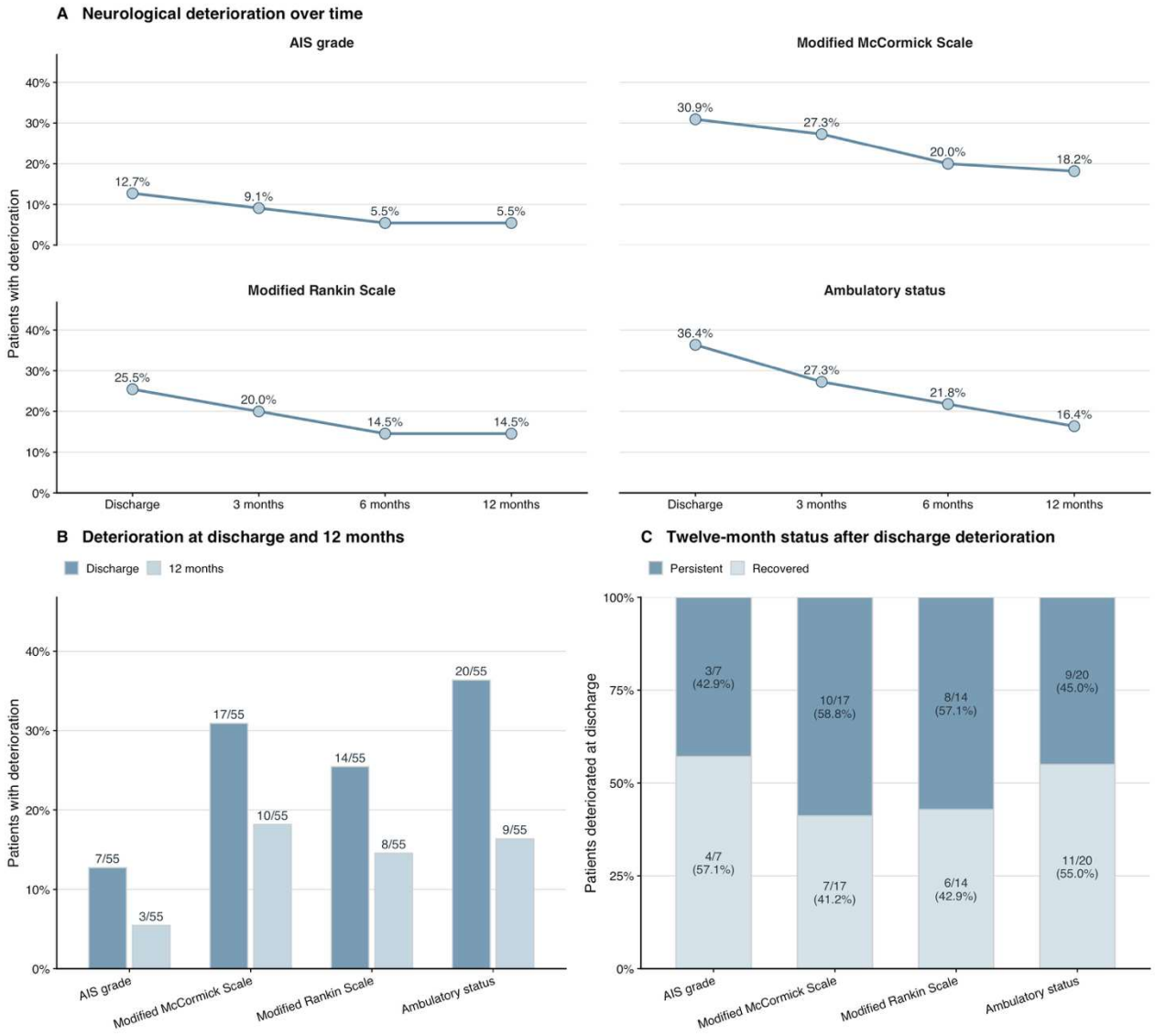


Figure 3. Evolution and persistence of postoperative neurological and functional deterioration. (**A**) Proportions of patients with deterioration relative to their individual preoperative baseline in American Spinal Injury Association Impairment Scale (AIS) grade, Modified McCormick Scale (MMS), modified Rankin Scale (mRS), and ambulatory status at hospital discharge and at 3, 6, and 12 months. (**B**) Scale-specific proportions of patients with deterioration at discharge and at 12 months. Labels show the number of patients with deterioration over the entire cohort (n=55). (**C**) Scale-specific 12-month status among patients who had deteriorated at discharge. Recovery was defined as return to the corresponding preoperative baseline value or improvement beyond baseline; persistent deterioration was defined as a 12-month value remaining worse than baseline. Labels show the number of patients over the scale-specific number who had deteriorated at discharge, with the corresponding percentage. Deterioration was defined as a decrease of at least one grade or point in AIS grade or ambulatory status and an increase of at least one point in MMS or mRS.

TABLES

Demographic and clinical characteristics	
Patients, n	55
Age, years, mean ± SD	48.9 ± 16.7
Sex, n (%) Male Female	 24 (43.6%) 31 (56.4%)
Symptom onset to surgery, months, median (IQR)	6 (3-12)
Last available follow-up, months, median (IQR)	50.0 (31.5-80.0)
Radiological characteristics	
Predominant tumor region, n (%) Cervical Thoracic Lumbosacral	 17 (30.9%) 11 (20.0%) 27 (49.1%)
Tumor compartment, n (%) Intramedullary Extramedullary	 38 (69.1%) 17 (30.9%)
Tumor extension, n (%) ≤2 vertebral levels >2 vertebral levels	 39 (70.9%) 16 (29.1%)
Maximum lesion extent, mm, mean ± SD	23.3 ±13.3
Enhancement pattern, n (%) Homogeneous Inhomogeneous	 25 (45.5%) 30 (54.5%)
Radiological characteristics, n (%) MRI evidence of myelopathy, n (%) Intralesional hemorrhage, n (%) Syringomyelia, n (%) Dissemination, n (%)	 6 (10.9%) 9 (16.4%) 7 (12.7%) 3 (5.5%)
Histopathological and staging characteristics	
Histopathological classification, n (%) Ependymoma, WHO grade 2 Ependymoma, WHO grade 3, non-MYCN-amplified Ependymoma, WHO grade 3, MYCN-amplified Myxopapillary ependymoma, WHO grade 2	 35 (63.6%) 2 (3.6%) 1 (1.8%) 17 (30.9%)
Ki-67 index, % median (IQR)	2 (1-4)
CSF cytology at 1 month, n (%) Negative Positive	 53 (96.4%) 2 (3.6%)
Surgical and postoperative characteristics	
Operative time, minutes median (IQR)	194.5 (135.0-240.0)
Posterior approach, n (%) Laminectomy Laminoplasty Hemilaminectomy	 38 (69.1%) 13 (23.6%) 4 (7.3%)
Primary spinal stabilization, n (%)	1 (1.8%)
EOR on 1-month MRI, n (%) GTR STR	 42 (76.4%) 13 (23.6%)
Postoperative complication, n (%) Early postoperative complication	 1 (1.8%)

Late postoperative complication	1 (1.8%)
Postoperative radiotherapy, n (%) Photons Protons	15 (27.3%) 11 (73.3%) 4 (26.7%)
Radiotherapy indication, n (%) Residual tumor Local recurrence Progression of known satellite lesions	n=15 11 (73.3%) 3 (20.0%) 1 (6.7%)
Chemotherapy, n (%)	2 (3.6%)

Table 1. Demographic, radiological, histopathological, surgical, and postoperative characteristics of the cohort. Abbreviations: CSF, cerebrospinal fluid; GTR, gross-total resection; IQR, interquartile range; MRI, magnetic resonance imaging; STR, subtotal resection.

Outcome	Baseline	Discharge	3 months	6 months	12 months	p value	Friedman χ^2 (Kendall's W)
AIS	4 (3–4); 3.71 ± 0.50	4 (3–4); 3.49 ± 0.86	4 (3.5–4); 3.64 ± 0.75	4 (4–4); 3.73 ± 0.68	4 (4–4); 3.73 ± 0.68	<0.001	22.14 (0.10)
MMS	1 (1–2); 1.40 ± 0.66	2 (1–2); 1.87 ± 1.12	1 (1–2); 1.69 ± 0.98	1 (1–2); 1.56 ± 0.83	1 (1–2); 1.53 ± 0.81	<0.001	34.42 (0.16)
mRS	1 (1–1); 1.16 ± 0.57	1 (1–2); 1.69 ± 1.22	1 (1–1.5); 1.53 ± 1.07	1 (1–1); 1.38 ± 0.87	1 (1–1); 1.36 ± 0.85	<0.001	35.19 (0.16)
AMB	3 (3–3); 2.75 ± 0.62	3 (2–3); 2.24 ± 1.00	3 (2–3); 2.42 ± 0.88	3 (2–3); 2.49 ± 0.77	3 (2–3); 2.56 ± 0.74	<0.001	39.58 (0.18)

Table 2. Longitudinal neurological and functional outcomes across the five assessment timepoints. Values are presented as median (interquartile range) and mean ± standard deviation. Friedman tests evaluated overall within-patient changes across the five timepoints; all analyses included 55 patients with complete data. Kendall's W quantifies the magnitude of the overall longitudinal change. Higher AIS and ambulatory-status scores indicate better function, whereas higher MMS and mRS scores indicate greater disability.

Comparison	AIS grade	MMS	mRS	Ambulatory status
Baseline vs. discharge	-0.86; p=0.101	**0.93; p=0.002**	**1.00; p=0.004**	**-0.94; p<0.001**
Discharge vs. 3 months	**1.00; p=0.023**	**-1.00; p=0.033**	-1.00; p=0.071	**0.83; p=0.030**
3 vs. 6 months	1.00; p=0.101	**-1.00; p=0.033**	**-1.00; p=0.046**	0.67; p=0.137
6 vs. 12 months	0.00; p=1.000	-1.00; p=0.315	-1.00; p=0.317	1.00; p=0.137
Baseline vs. 12 months	0.27; p=0.811	0.29; p=0.315	0.59; p=0.140	-0.62; p=0.137

Table 3. Longitudinal pairwise comparisons of neurological and functional outcomes. Values are matched-pairs rank-biserial correlation coefficients followed by Holm-adjusted p values. Pairwise comparisons were performed using two-sided Wilcoxon signed-rank tests after a significant Friedman omnibus test. Holm adjustment was applied separately within each scale across the five prespecified comparisons. Positive coefficient values indicate an increase in the numerical score at the later timepoint, whereas negative values indicate a decrease. Accordingly, positive values represent clinical improvement for AIS and ambulatory status but clinical worsening for MMS and mRS.

	Predictor	Comparison or unit	Adjusted OR (95% CI)	p value
Composite neurological deterioration at discharge	Baseline MMS	Per 1-point increase	0.85 (0.33 – 2.19)	0.739
	Tumor extension	Per 1-level increase	1.51 (0.95 – 2.41)	0.081
	Tumor region - Cervical	vs. Lumbosacral	7.06 (1.42 – 34.96)	**0.017**
	Tumor region - Thoracic	vs. Lumbosacral	5.27 (1.05 – 26.36)	**0.043**

Table 4. Multivariable logistic regression for composite neurological deterioration at discharge. Composite neurological deterioration was defined as worsening at discharge relative to baseline in at least one of the following measures: AIS grade, MMS, mRS, or ambulatory status.

	Predictor	Comparison or unit	Adjusted OR (95% CI)	p value
MMS deterioration (17/55 events)	Baseline MMS	Per 1-point increase	0.54 (0.17-1.70)	0.294
	Tumor extension	Per 1-level increase	1.56 (1.04-2.34)	**0.032**
	Tumor region - Cervical	vs. Lumbosacral	2.45 (0.45-13.35)	0.299
	Tumor region - Thoracic	vs. Lumbosacral	8.41 (1.51-46.88)	**0.015**
mRS deterioration (14/55 events)	Baseline mRS	Per 1-point increase	0.91 (0.28-2.95)	0.880
	Tumor extension	Per 1-level increase	2.00 (1.18-3.39)	**0.010**
	Tumor region - Cervical	vs. Lumbosacral	3.88 (0.53-28.61)	0.183
	Tumor region - Thoracic	vs. Lumbosacral	12.67 (1.57-102.01)	**0.017**
Ambulatory status deterioration (20/55 events)	Baseline AMB	Per 1-point increase	1.38 (0.51-3.78)	0.527
	Tumor extension	Per 1-level increase	1.58 (0.99-2.53)	0.056
	Tumor region - Cervical	vs. Lumbosacral	6.43 (1.35-30.76)	**0.020**
	Tumor region - Thoracic	vs. Lumbosacral	4.98 (0.94-26.23)	0.058

Table 5. Multivariable logistic regression for scale-specific neurological deterioration at discharge. Scale-specific deterioration was defined as worsening at discharge relative to baseline on the corresponding scale. Each outcome was analyzed in a separate conventional multivariable logistic regression model including the baseline value of that scale, predominant tumor region, and tumor extension. Lumbosacral region served as the reference category. A multivariable model was not fitted for AIS deterioration because only 7 events were observed.

Outcome	Neurological deterioration		Recovery among patients deteriorated at discharge		New deterioration among patients without discharge deterioration	
	At discharge	At 12 months	By 12 months	Persistent deterioration at 12 months	At 12 months	p value
Composite outcome	23/55 (41.8%)	15/55 (27.3%)	8/23 (34.8%)	15/23 (65.2%)	0/32 (0.0%)	**<0.001**
AIS	7/55 (12.7%)	3/55 (5.5%)	4/7 (57.1%)	3/7 (42.9%)	0/48 (0.0%)	**0.001**
MMS	17/55 (30.9%)	10/55 (18.2%)	7/17 (41.2%)	10/17 (58.8%)	0/38 (0.0%)	**<0.001**
mRS	14/55 (25.5%)	8/55 (14.5%)	6/14 (42.9%)	8/14 (57.1%)	0/41 (0.0%)	**<0.001**
AMB	20/55 (36.4%)	9/55 (16.4%)	11/20 (55.0%)	9/20 (45.0%)	0/35 (0.0%)	**<0.001**

Table 6. Association between neurological deterioration at discharge and 12-month outcomes. Deterioration was defined relative to the baseline value of the corresponding scale. Composite deterioration was defined as worsening in at least one of AIS grade, MMS, mRS, or ambulatory status. Recovery by 12 months required return to the baseline value or improvement beyond baseline. Persistent deterioration indicates a 12-month value remaining worse than baseline. The association between deterioration at discharge and deterioration at 12 months was assessed using the two-sided Fisher exact test.