Clinical Neurology and Neurosurgery xxx (xxxx) xxx

Contents lists available at ScienceDirect

Clinical Neurology and Neurosurgery

journal homepage: www.elsevier.com/locate/clineuro

MRI characteristics and resectability in spinal cord glioma

Scott C. Seaman [a], Girish Bathla [b], Brian J. Park [a], Royce W. Woodroffe [a], Mark Smith [c], Arnold H. Menezes [a], Jennifer Noeller [a], Satoshi Yamaguchi [a], Patrick W. Hitchon [a,*]

[a] Department of Neurosurgery, University of Iowa Carver College of Medicine, Iowa City, IA USA
[b] Department of Radiology, University of Iowa Carver College of Medicine, Iowa City, IA USA
[c] Department of Radiation Oncology, University of Iowa Carver College of Medicine, Iowa City, IA USA

ARTICLE INFO

Keywords:
MRI
Spinal cord astrocytoma
Spinal cord ependymoma

ABSTRACT

Objective: The histopathology of intramedullary spinal cord tumors (IMSCT) can be suspected from the MRI features and characteristics. Ultimately, the confirmation of diagnosis requires surgery. This retrospective study addresses MRI features including homogeneity of enhancement, margination, and associated syrinx in intramedullary astrocytomas (IMA) and ependymomas (IME) that assist in diagnosis and predict resectability of these tumors.

Methods: Single-center retrospective analysis of IMA and IME cases since 2005 extracted from the departmental registry/electronic medical records post IRB approval (IRB 201,710,760). We compared imaging findings (enhancement, margination, homogeneity, and associated syrinxes) between tumor types and examined patient outcomes.

Results: There were 18 IME and 21 IMA. On preoperative MRI, IME was favored to have homogenous enhancement (OR 1.8, $p = 0.0001$), well-marginated ($p < 0.0001$, OR 0.019 [95 % CI 0.002–0.184]), and associated syrinx ($p = 0.015$, OR 0.192 [95 % CI 0.049–0.760]). Total excision, subtotal excision, and biopsy were performed in 12, 5, and 1 patients in the IME cohort, respectively. In the IMA group, tumors were heterogeneous and poorly marginated in 20 of the 21 patients. Total excision, subtotal excision, and biopsy were undertaken in 2, 13, and 6 patients, respectively. The success of excision was predicted by MRI, with a significant difference in the extent of resection between IME and IMA ($X^2 = 14.123$, $p = 0.001$). In terms of outcome, ordinal regression analysis showed that well-margined tumors and those with homogeneous enhancement were associated with a better postoperative McCormick score. Extent of resection had statistically significant survival ($p = 0.026$) and recurrence-free survival ($p = 0.008$) benefits.

Conclusion: The imaging characteristics of IME and IMA have meaningful clinical significance. Homogeneity, margination, and associated syrinxes in IME can predict resectability and complexity of surgery.

1. Introduction

Intramedullary spinal cord tumors (IMSCT) are rare lesions and constitute only 4–10 % of all primary central nervous system tumors [1–4]. The majority of IMSCTs are comprised of gliomas (80–90 %), of which 60–70 % are ependymomas and 30–40 % are astrocytomas [1,5,6]. Intramedullary astrocytomas are more common in children under 18 years of age, whereas ependymomas are more common between the ages of 20 and 50 [2,7,8].

Taking into account the location of the tumor, enhancement characteristics, and associated syrinx formation, diagnosis of IMSCTs can often be accurately made from MRI imaging. Confirmation of diagnosis, however, demands surgery. To identify radiographic features of spinal cord tumors, we reviewed our records of intramedullary spinal cord tumors for the past 15 years, including radiology reports, pathology, treatment, and outcomes.

2. Materials and methods

We reviewed our caseload of intramedullary spinal cord tumors with accessible MRI images since 2005. All patients had standard axial and sagittal T1- and T2-weighted pre-contrast imaging as well as axial and sagittal post-contrast imaging in the region of interest using standard institutional imaging protocol. Surgery consisted of laminoplasty with

* Corresponding author at: Department of Neurosurgery, University of Iowa Hospitals and Clinics, 200 Hawkins Drive, Iowa City, IA 52242, USA.
E-mail address: patrick-hitchon@uiowa.edu (P.W. Hitchon).

https://doi.org/10.1016/j.clineuro.2020.106321
Received 8 September 2020; Received in revised form 14 October 2020; Accepted 16 October 2020
Available online 19 October 2020

tumor localization confirmed with intraoperative ultrasonography prior to dural opening. Tumor resection was undertaken under microscopic dissection with or without ultrasonic aspiration, at the discretion of the surgeon. Where the margins were clear, total excision was undertaken. If the margins were poorly delineated, subtotal resection was performed. In cases where the extent of the pathology and tumor was not clearly identifiable, a biopsy only was performed. Somatosensory evoked potentials (SSEP's) were monitored in 31 of our 35 cases, and motor evoked potentials (MEP's) in 17 cases. Earlier in our series, monitoring was adopted at the surgeon's discretion, considering urgency and logistical issues. In the past 5 years, however, both sensory and motor evoked potentials have been routinely used. The intraoperative neuromonitoring (IONM) data was continuously collected throughout the surgery by a technologist and interpreted by a Clinical neurophysiologist. For upper extremity SSEP, the left and right ulnar nerves were stimulated using bipolar needle electrodes. The stimulus intensity was 7−10 mA at the stimulus rate of 3.07 HZ. The recording electrodes were located at CP3, CP4, A1, A2, and Erb's Point. For lower extremity SSEP, the left and right tibial nerves were stimulated using bipolar needle electrodes. The stimulus intensity was 15−50 mA at the stimulus rate of 3.07 HZ. The recording electrodes were located at CP1, CP2, CPZ, FZ, A1, A2, and Popliteal Fossa. For upper extremity MEP, CMAPs were recorded from the bilateral abdcutor digiti minimi & brachioradialis. For lower extremity MEP, CMAPs were recorded from the bilateral abductor hallucis, tibialis anterior, extensor hallucis longus, & rectus femoris. MEP technical parameters included a stimulus intensity was 300−650 volts and 398−1366 mA. An 8 train was used with an interstimulus interval of 1 msec.

Clinical outcome was assessed using the McCormick scale [3,9–11], with grade I being intact and grade V representing paraplegia. Statistical analysis was conducted with IBM SPSS Statistics for Windows, version 26 (IBM Corp., Armonk, NY, USA). Scalar variables were compared using two-way independent t-tests, and categorical variables were compared using Chi-Square tests with corresponding odds ratios; in cases where cells had a count <5, Fisher's exact test was used. For ordinal variables, ordinal regression analysis was performed to assess for between group effects, and odds ratios were then calculated. Mortality and recurrence Kaplan-Meier curves were calculated, and statistical comparisons made using log rank (Mantel-Cox) tests in cases of late divergence and Breslow (Generalized Wilcoxon) in cases of early divergence.

3. Results

3.1. Demographics

Of the intramedullary gliomas, 21 were astrocytomas (IMA) and 18 were ependymomas (IME). Fifteen males and 6 females with mean age ± SD of 29 ± 11 were identified with intramedullary astrocytomas (IMA). Nine males and 9 females with a mean age 42 ± 11 were diagnosed with intramedullary ependymoma (IME). Gender distribution between IMA and IME was not statistically significant (p = 0.10, Table 1). IMA patients tended to be younger than IME patients, although this did not reach significance in the current cohort (p = 0.077). In terms of location, 7 patients had IMA in the cervical cord, and the remaining 14 were in the thoracic cord. In the IME cohort, the distribution of tumor was 12 cervical and 6 thoracic. Distribution of tumor location between IMA and IME was significant, with IME more commonly located in the cervical cord (p = 0.0379, OR 4.0 [95 % CI 1.098−14.17]).

Table 1
Demographics.

Parameter	Astrocytoma	Ependymoma	Statistical Significance
Number	21	18	–
Gender (M/F)	15/6	9/9	0.170
Age	29 ± 21	42 ± 11	0.077
Distribution C/T	7/14	12/6	p = 0.0379, OR 4.0 (95 % CI 1.098−14.17)

M - male; F - Female; C - Cervical; T - Thoracic; OR - Odds Ratio; 95 % CI - 95 % Confidence Interval.

3.2. MRI features and resectability

Intramedullary astrocytomas showed enhancement in 17, compared to all 18 with IME cohort (Table 2). The size of enhancement was not statistically different between IMA and IME (54 ± 31 vs 41 ± 28 mm, respectively; p = 0.191) Enhancement was homogeneous in only 1 IMA and considered heterogenous in the rest. Homogeneous enhancement was significantly more frequent in IME and encountered in 8 patients of that cohort ($X^2 = 11.742$, p = 0.001, OR 1.8 [95 % CI 1.191–2.721], Fig. 1). The tumor was considered well-marginated in only 1 IMA, but well-marginated in 13 IME (Fisher's exact p < 0.0001, OR 0.019 [95 % CI 0.002−0.184]). An associated syrinx was more prevalent in IME (15) compared to IMA (9), ($X^2 = 5.867$ p = 0.015, OR 0.192 [95 % CI 0.049−0.760]). The overall size of the lesion, including edema and associated cyst/syrinx, was greater in IME (139 ± 85 mm) compared to IMA (111 ± 82 mm), but this difference was not significant (p = 0.294).

The success of excision was predicted by the MRI characteristics. Thus, total excision, subtotal excision, and biopsy were undertaken in 2, 13, and 6 patients, respectively, in the IMA group; tumors were heterogeneous and poorly marginated in 20 of the 21 patients (Table 3, Fig. 2). Conversely, total excision, subtotal excision, and biopsy were performed in 12, 5, and 1 patients in the IME cohort, respectively, of which 13 were well-marginated. The difference in extent of resection was significant ($X^2 = 14.123$, p = 0.001).

3.3. Histopathology and management

In the IMA cohort, the diagnosis was glioblastoma in 2, anaplastic grade III astrocytoma in 3, grade II astrocytoma in 7, and grade I pilocytic astrocytoma in 9. In the IME cohort, the histopathology was that of grade III ependymoma in 3, grade II ependymoma in 14, and grade I in 1. Thirteen patients in the IMA group with subtotal resection or biopsy were treated with radiation, generally 50 Gy over 30 sessions. In the IME cohort, 5 patients with subtotal resection and 3 patients who were totally resected (2 grade II and 1 grade III) were irradiated. This difference in radiation was not significant ($X^2 = 1.189$, p = 0.276). Follow-up intervals in the IMA and IME were not different: 5.8 ± 5.0 and 4.8 ± 3.7 years, respectively (p = 0.488).

3.4. Functional status at presentation and follow-up

At presentation, functional status as measured by McCormick scores was higher in the IME cohort (Table 4) than in the IMA. Ordinal

Table 2
MRI characteristics.

Parameter	Astrocytoma (21)	Ependymoma (18)	Statistical significance
Enhancement	17	18	p = 0.110
Size of enhancement mm (SD)	54 ± 31	41 ± 28	p = 0.191
Homogenous Enhancement	1/20	8/10	0.001, OR 1.8 [95 % CI 1.191−2.721
Margination	1	13	<0.0001, OR 0.019 [95 % 0.002−0.184]
Syrinx	9	15	0.015, OR 0.192 [95 % CI 0.049−0.760]
Overall size mm (SD)	111 ± 82	139 ± 85	p = 0.294

mm - millimeter; SD - Standard Deviation.

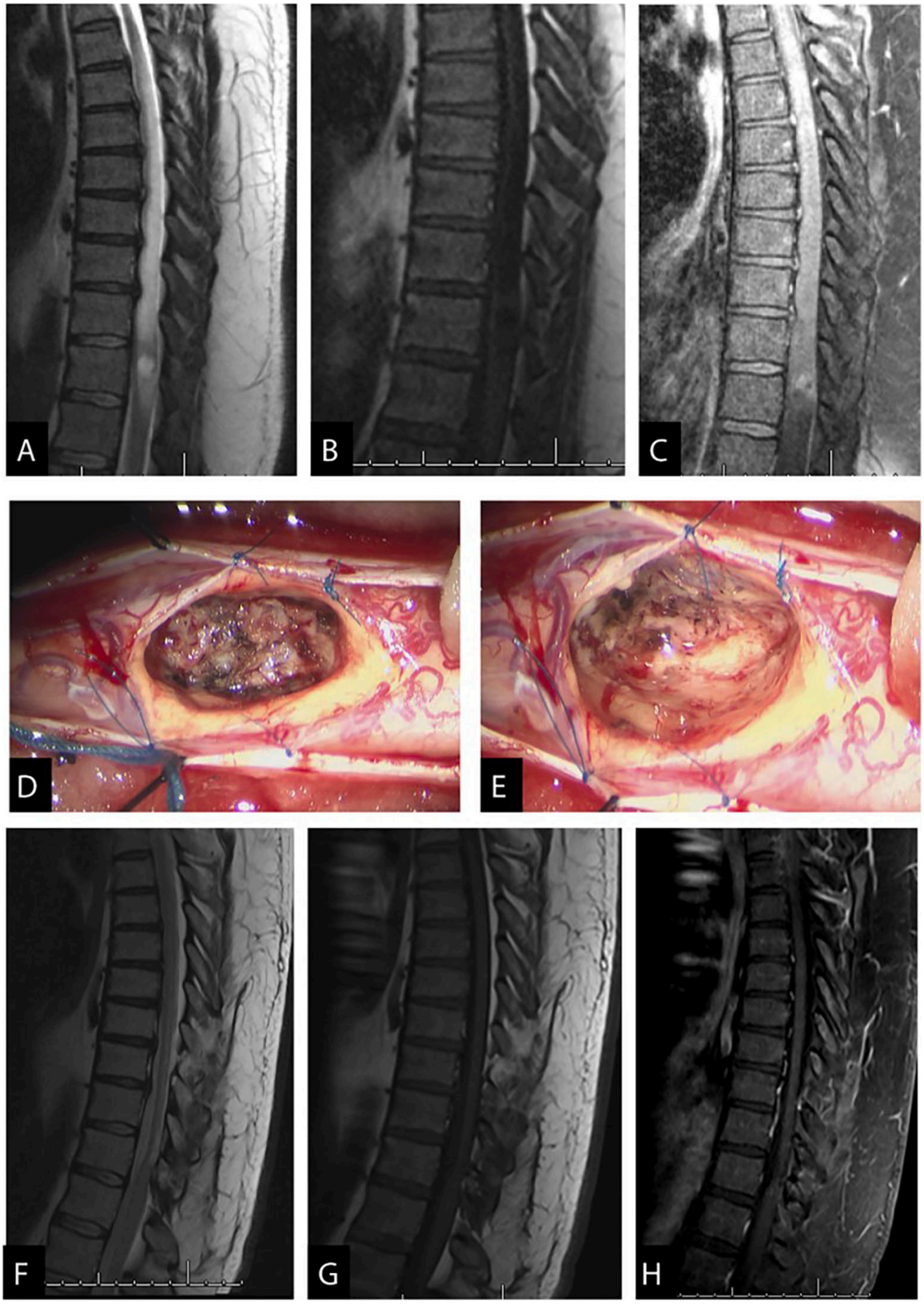

Fig. 1. Thoracic astrocytoma. A 37-year-old male presented with shaking in his legs, and stiffness in walking. He had a sensory level and clonus. MRI shows abnormal high T2 signal **(A)** and low signal on T1 **(B)** in the thoracic spinal cord. There is minimal heterogeneous enhancement compatible with astrocytoma **(C)**. Depicted is the intraoperative exposure with circumferential dissection **(D)** and excision of infiltrating grade II astrocytoma **(E)**. Three years postoperatively, the patient is employed as a schoolteacher and is ambulatory with a cane. He had 4/5 motor strength in the left leg with diminished sensory perception. There is a stable small residual hyperintensity on T2 signal **(F)**, none on T1 **(G)**, and no evidence of residual tumor enhancement **(H)**.

Table 3
Management and outcome.

Treatment & follow-up	Astrocytoma (21)	Ependymoma (18)	Statistical Significance
Surgery Total excision	2	12	0.001
Subtotal excision	13	5	
Biopsy	6	1	
Radiation	13	8	0.276
Chemotherapy	7	0	–
Alive/Dead	14	17	$p = 0.0322$
Follow-up (years)	5.8 ± 5.0	4.8 ± 3.7	$p = 0.488$

regression analysis showed odds ratios favoring IMA patients with less favorable McCormick scores of 3, 4, and 5 (Table 4 and Fig. 3A). At follow-up, a decline in performance was encountered in both IME and IMA groups; however, on ordinal regression analysis, the odds favored IME to have more patients with a favorable McCormick score of 1 (Table 4, Fig. 3B). When stratified by margination status as identified on the preoperative MRI, ordinal regression analysis showed a tumor identified as well-marginated was associated with a favorable post-operative McCormick score of 1 (Table 4, Fig. 3C). Similarly, when stratified by homogeneous or heterogeneous enhancement on the pre-operative MRI, ordinal regression analysis showed an association of homogeneous enhancement with a McCormick score of 1 (Table 4, Fig. 3D). Location (Table 1), and size of the lesions (Table 2) were examined and analyzed in relation to the post-operative McCormick score. Location did not have a significant bearing on the post-operative McCormick score (Pearson Chi-square $p = 0.226$). Neither the size of enhancement, nor the overall size of the lesion, had a significant bearing upon the post-operative McCormick score (Kuskal-Wallis test $p = 0.149$ and $p = 0.360$ respectively).

3.5. Recurrence and survival

There were no operative deaths. Regarding mortality following the index operation, the IMA group had 7/21 mortalities during follow-up time compared to 1/18 in the IME group, with cumulative survival in IMA of 67.7 % vs 94.4 % in IME. This was significant ($X^2 = 3.496$, $p = 0.0322$). When stratified by extent of resection, cumulative survivals for gross total resection (GTR0, subtotal resection (STR), and biopsy were 100 %, 48.4 %, and 57.1 %, respectively, which was significant ($X^2 = 7.335$, $p = 0.026$, Fig. 4A). Cumulative recurrence-free survival for GTR, STR, and biopsy (100 %, 85.6 %, and 60.0 %, respectively) was similarly significant ($X^2 = 9.554$, $p = 0.008$, Fig. 4B). When looking at survival as a function of radiation regardless of histological diagnosis, there was a significant difference, with worse survival in the radiated population (94.4 % no radiation vs 31.6 % radiation, $X^2 = 4.741$ $p = 0.029$). This finding is reflective of the factors relating to the decision to irradiate, as all patients who were irradiated and died had subtotal resection or biopsy.

Two patients with IMA of the thoracic cord underwent reoperation for recurrence following subtotal resection and biopsy respectively. The first, a 47-year-old man with glioblastoma at T8−11, had received radiation. Owing to paraplegia and recurrence, he underwent cordectomy 8 months following the index operation. He survived 12 years after cordectomy, and ultimately died from brain metastases [12]. The second, a 15-year-old male with grade II astrocytoma, underwent resection 4 months after biopsy. He survives 15 years after his index operation with a McCormick score of 2. Two patients with IME underwent reoperation for recurrence. A 45-year-old man with cervical grade II ependymoma underwent resection 5 months following biopsy and radiation. He survives 12 years after his index operation with a McCormick score of 2. The second, a 54-year-old man with cervical grade III ependymoma, underwent reoperation for recurrence 4 years after subtotal resection. He survives 10 years after his index operation with a McCormick score of 2.

3.6. Postoperative complications

Two patients with IMA suffered postoperative respiratory distress. The first was a 33-year-old man who underwent subtotal resection for a C1−6 pilocytic astrocytoma that was complicated by respiratory distress and the need for tracheostomy. He suffered hypoxic brain injury but eventually recovered to his baseline McCormick score of 3. The second was a 54-year-old man with a McCormick score of 2, who had biopsy for a T1−2 infiltrating astrocytoma. He had to be reintubated post-operatively and required a tracheostomy 4 days later. He recovered to a McCormick score of 4. A 45-year-old man with a C6−7 IME developed wound dehiscence after biopsy, necessitating debridement a week later. His McCormick score of 2 remained unchanged at follow-up.

3.7. Electrophysiological monitoring

SSEP'e were monitored and reproducible in 31 cases, (15 IMA, and 16 IME), MEP's were available in 16 cases, (8 each in IMA and IME). In 6 IMA cases, SSEP's were deemed unreliable, and attenuated in 4 (one IMA, and 3 IME). To calculate sensitivity and specificity of neuromonitoring, the presence or absence of responses was adopted rather than delay of responses, or a decrease in amplitude (Park, World). Thus true negative SSEP responses were encountered in 8 cases (4 IMA and 4 IME). There were 4 true positive SSEP's, 2 each in IMA and IME. There were no false positive SEEP recordings. False positive SSEP's were seen in 9 case (2 IMA and 7 IME). There were 12 true negative MEP responses (7 in IMA, and 5 in IME cases). There were 3 true positive MEP's (one IMA and 2 IME cases). As with SSP's, there were no false negative MEP's. One IME had a false positive MEP response. The above findings yielded SSEP and MEP sensitivities of 100 %. The specificity of the other hand was superior in MEP's compared to SSEP's (92 % vs 47 %)

4. Discussion

Ependymoma is the most common intramedullary tumor in adults, accounting for 60–70 % of all intramedullary glial tumors [5]. It is uncommon in the pediatric population, except for patients with neurofibromatosis type 2 [13,14]. Astrocytomas account for 30–40 % of intramedullary glial tumors in adults and about 82 % of intramedullary tumors in pediatric patients [5]. Intramedullary spinal ependymomas are most commonly located in the cervical spine, followed by the thoracic and then lumbar areas [13]. There is a predilection for IMA to be in the thoracic levels in adults and in the cervical/cervicothoracic cord in the pediatric population [15]. Holocord involvement may occasionally be seen in children [14].

4.1. Imaging and diagnosis

Our MRI characteristics of IMA and IME (Table 2) agree with the previously reported literature. Ependymomas are iso- to hypointense on T1-weighted imaging (T1WI) and hyperintense on T2-weighted imaging (T2WI) (Fig. 2). The majority of ependymomas are centrally located in the cervical spine, and a majority (77 %) have well-defined margins [16]. The mean length of lesion is about 3.4–3.7 vertebrae [16,17]. A majority show some degree of contrast enhancement which is often homogeneous (75 %), but may be heterogeneous, rim, or nodular [18]. In 20–45 % of cases, a hypointense rim due to hemorrhage may be present on T2WI (cap sign) [17–19]. Tumoral cysts and syringohydromyelia are also common (10–50 %) [18]. There is a predilection for thoracic levels in adults (Fig. 2) and cervical/cervicothoracic cord in children [14,15]. On MRI, IMA typically have poorly defined margins given the infiltrative nature of the tumor. IMA tend to be iso- to hypointense on T1WI and hyperintense on T2WI [6,15] (Fig. 1). The average length of lesion spans 4 vertebrae

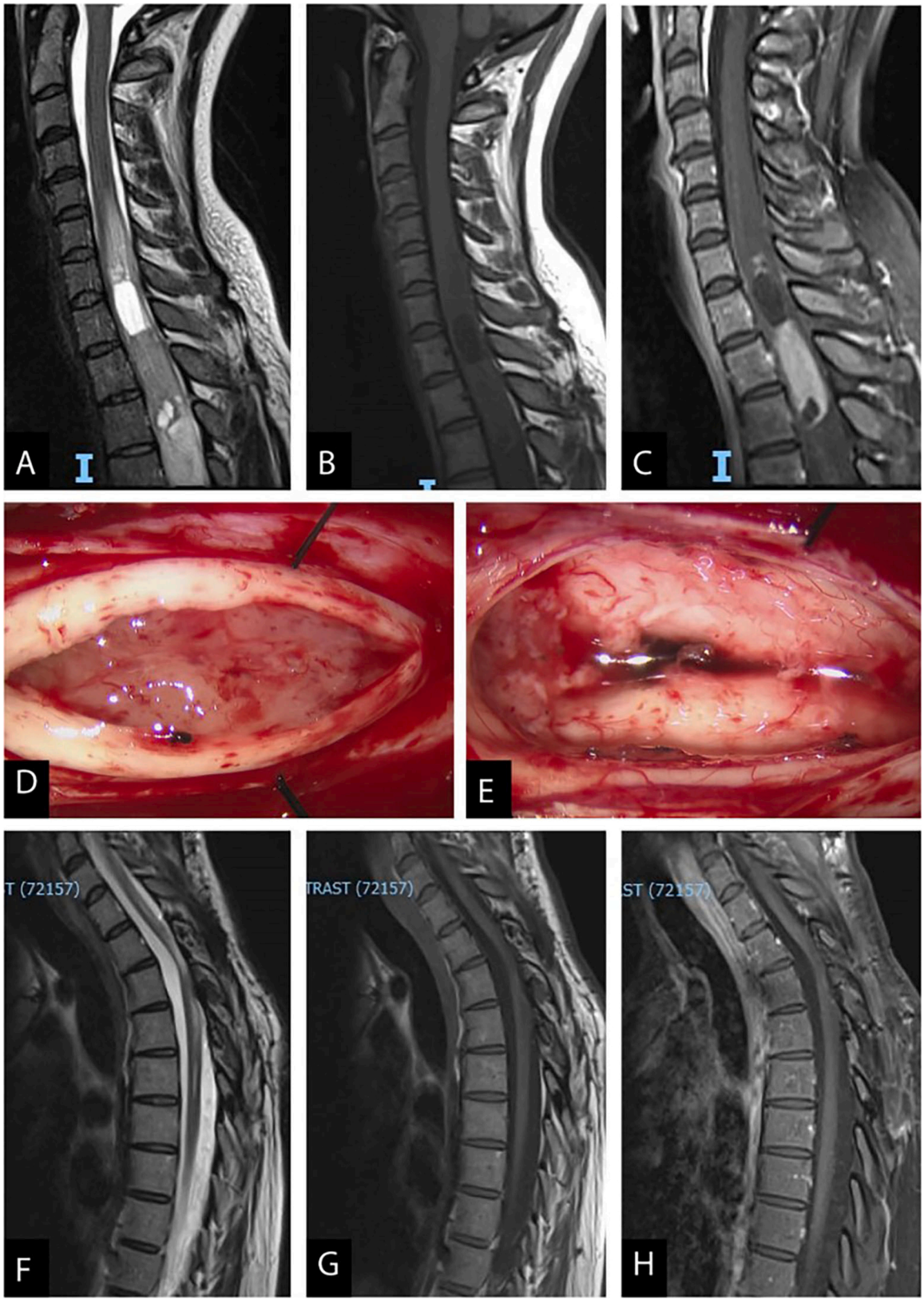

Fig. 2. Cervical ependymoma. A 36-year-old lady presented with mid back pain and numbness along the left side to her chest. Magnetic resonance T2-weighted **(A),** T1-weighted **(B),** and enhanced cervical MRI **(C)** images reveal a well-marginated enhancing mass with polar cysts and extensive rostral and caudal edema. Intraoperative myelotomy **(D)** revealed a well-demarcated soft mass distinct from the surrounding spinal cord. Following total excision, the tumor bed **(E)** was free of visible tumor. SSEPs were attenuated but still present at the end of surgery. Six years following resection, she returned for follow-up still employed and, other than subtle diminution in pinprick sensation in the right leg, was without gross deficit. MRI T2-weighted **(F)**, T1-weighted **(G)**, and enhanced **(H)** images show an attenuated, posteriorly displaced spinal cord without evidence of residual or recurrent tumor.

Table 4
Odds Ratios from Ordinal Regression Analyses for McCormick Grade.

McCormick Scale	Pre-op Status by Tumor Histology (IMA > 1, IME < 1)	Post-op Status by Tumor Histology (IMA > 1, IME < 1)	Post-op Status by Margination Status (<1 well marginated)	Post-op Status by Enhancement Homogeneity Status (<1 homogenous enhancement)
1	0.83 [0.07−10.37], p = 0.883	**0.038 [0.002−0.677], p = 0.026**	**0.019 [0.001−0.27], p = 0.004**	**0.048 [0.002−0.941, p = 0.045**
2	14.94 [0.98−226.83], p = 0.051	0.926 [0.075−11.508], p = 0.952	0.448 [0.053−3.78], p = 0.460	1.238 [0.087−17.652], p = 0.875
3	**OR 32.97 [1.80−603.8], p = 0.018**	1.271 [0.132−22.457], p = 0.679	0.811 [0.03−7.09], p = 0.849	2.338 [0.156−35.046], p = 0.539
4−5	**68.17 [2.69−1728.64], p = 0.010**	4.198 [0.277−63.549], p = 0.301	1.921 [0.190−19.42, p = 0.580	5.742 [0.332−99.440], p = 0.230

Values reported as Odds Ratio [95 % Confidence Interval], p-value. Odds ratio >1 favored IMA, poor margination, and heterogeneous enhancement, and odds ratios < 1 favored IME, well marginated, and homogeneous enhancement, respectively.

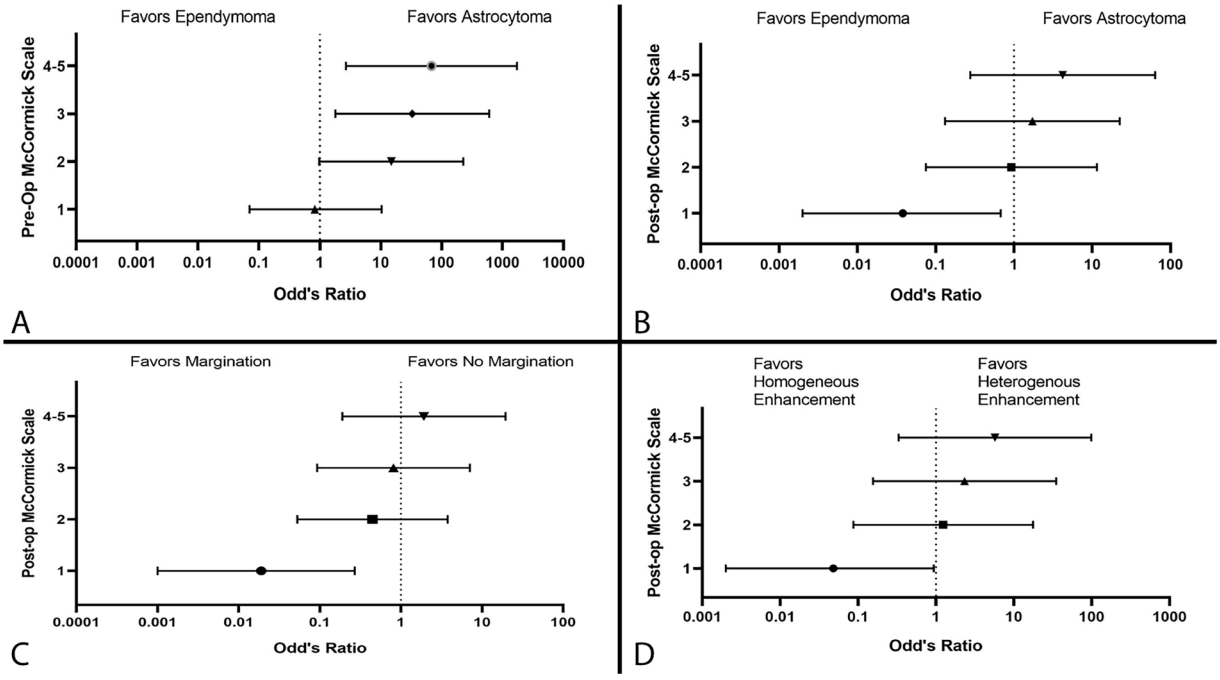

Fig. 3. Preoperative **(A)** and postoperative **(B)** McCormick scores and corresponding odds ratios by tumor histology with age and gender as covariates. On presentation, a poor functional status was associated with astrocytoma, while at follow-up a good functional status was more likely to occur with ependymoma. Preoperative MRI identification of tumor margination **(C)** and homogeneous enhancement **(D)** with postoperative McCormick scores showing well-marginated tumors that were homogeneously enhancing had a better postoperative functional status.

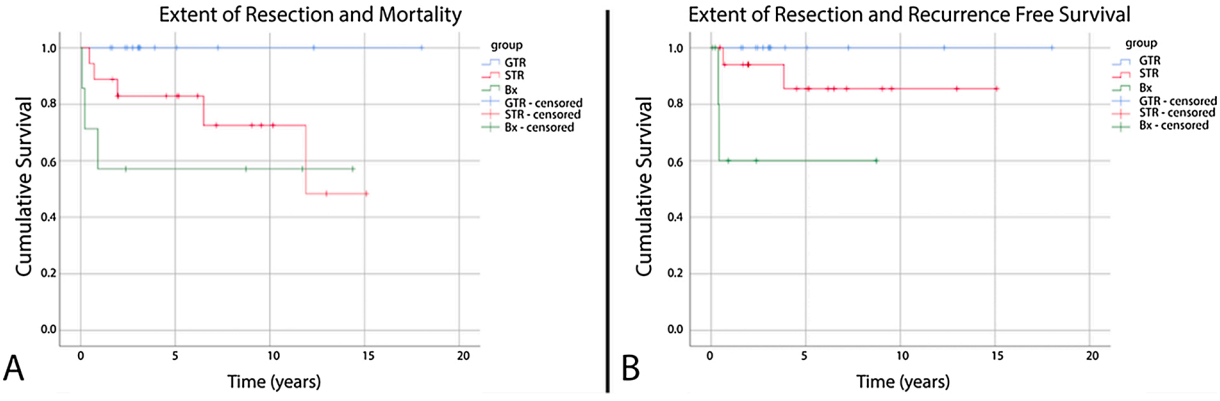

Fig. 4. Extent of resection conferred both survival (**A**, p = 0.026) and recurrence-free survival (**B**, p = 0.008) benefits. GTR: gross total resection; STR: subtotal resection; Bx: biopsy; yrs: years.

[20]. Cysts, both polar and tumoral, are less common compared to IME [17]. The majority of lesions enhance, although enhancement is often focal or patchy [14,17].

Our case review is comparable to the above, with 10 pediatric patients age <15 all diagnosed with IMA. The majority of IMA were in the thoracic cord, with ependymomas located predominantly in the cervical

cord (Table 1). The enhancement of ependymomas and astrocytomas was comparable (18 vs 17, NS, Table 2). The length of the enhancement in IMA (54 ± 31 mm) was greater than that of IME but was not significant (41 ± 28 mm, p = 0.191). Ependymomas showed more homogeneous enhancement (8/18) than IMA (1/21, p = 0.001, OR 1.8 [95 % CI 1.191–2.721]). Margination was encountered more frequently with IME (13/18) compared to IMA (1/21, p < 0.0001, OR 0.019 [95 % CI 0.002−0.184]). A significant difference did exist in the coexistence of a syrinx between the 2 tumor types, which were more commonly seen with IME (13 vs 7, p = 0.015, OR 0.192 [95 % CI 0.049−0.760], Table 2).

4.2. Imaging and resectability

In accordance with the literature [21–26], our review shows that the extent of resection correlates with cumulative survival, as well as recurrence-free survival (Table 3, Figs. 4A and B). The findings on MRI, homogeneity and margination, are reflected in the success of total excision of ependymomas [4] compared to astrocytoma, and consequently the success of surgical tumor resection [2,8,27–29] (Table 3). On the other hand, as revealed on MRI, the absence of margination in IMA resulted in far fewer being successfully excised [1], with the majority undergoing subtotal resection and biopsy [30]. Raco et al. [29] reported on 154 intramedullary gliomas. Of the 68 IME, 81 % were excised, compared to 31 % of the 86 IMA. In the review of 278 intramedullary tumors by Klekamp [28], there were 99 IME and 76 IMA. Gross total resection was achieved in 86 % of IME, compared to 20 % of IMA. Hongo et al. [27] reviewed 49 intramedullary tumors, 32 IME and 17 IMA. Total excision was achieved in 69 % and 12 % of these tumors, respectively. Our review confirms the above reports, showing that more IME were successfully excised (12/18) compared to IMA, where the majority were debulked or biopsied (19/21) and only 2 were excised (Table 3). Consequently, the postoperative outcome in astrocytomas is generally not as favorable as ependymomas. At follow-up, 7 patients in the IMA cohort were dead (33 %), compared to only 1 (6%) of the IME (p = 0.0322). This longer survival of IME patients is in agreement with the literature. In the review by Hongo et al. [27], progression-free survival was significantly longer with IME compared to IMA (p < 0.001). In the 32 cases of IME, 1 patient with a grade III anaplastic ependymoma (3%) was reported dead. In the 17 cases of IMA, 8 patients (47 %) had died.

Based on our findings and the cited literature, the goal of surgery is always maximal resection of neoplasms with preservation of neurologic function. The MRI characteristics described above are helpful in anticipating the ease or difficulty of resection, although exceptions exist. As Table 3 shows, excision was only possible in 12 of the 18 IME's, and was possible in 2 of the IMA tumors. Though margination and homogeneity of the tumor is helpful, resection should not be undertaken with impunity but meticulously and atraumatically to preserve healthy tissue. This does require patience, experience, and good judgement.

As described in Results above, our SSEP and MEP monitoring yielded no false negative results. On the other hand, false positive results occurred in 9 SSEP recordings, but in only one MEP response, yielding specificity of 47 % and 92 % respectively. The greater reliability of MEP monitoring during surgery is echoed by the literature [31]. The literature supports the use of IOPM in cases of spinal cord tumors, particularly IMSCT [31–33]. The dorsal approach through the posterior columns is reflected in the loss of SSEP's, yet with preservation of the MEP's, in patients without significant neurological change (false positive). Thus monitoring should alert the surgeon of "potential nerve damage", but ceasing continued tumor resection may affect "the long term outcome of the patient" [34]. In the report by Rijs et al. [34], SSEP's were not useful in predicting post-operative motor or sensory deficits, nor were they useful in modifying the intraoperative surgical strategy. There is consensus that the role of intraoperative neuromonitoring in IMSCT will only be resolved with multicenter prospective studies [32–34].

4.3. Adjunctive treatment

Most literature is supportive of the role of radiation in higher grade and subtotally resected lower grade gliomas [21,23,30,35,36]. Yet some reviews have been more reserved in their recommendations regarding radiation and chemotherapy [24,26]. Most of these have been retrospective single center series [21,23], multicenter series or registries [24,26,36], or reviews of the literature [3035]. Radiation was utilized in our cases of subtotal resection and higher-grade tumors. Thirteen patients in the IMA group with subtotal resection or biopsy were treated with radiation, generally 50 Gy over 30 sessions. In the IME cohort, 5 patients with subtotal resection and 3 patients who were totally resected (2 grade II and 1 grade III) were irradiated. In our series, those patients who received radiation did have worse mortality reflective of their more extensive unresectable disease, demonstrating the importance of appropriate patient selection in accordance with national guidelines [37].

5. Conclusion

Based on our single institution review, certain imaging characteristics of ependymomas and astrocytomas demonstrate usefulness, both in terms of preoperative diagnosis and resectability. Homogeneity, margination, and coexistence of syrinx favor total excision with better neurological performance and long-term outcomes. Despite MRI characteristics, patience and atraumatic dissection is paramount in dealing with spinal cord tumors.

CRediT authorship contribution statement

Scott C. Seaman: Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing - review & editing. **Girish Bathla:** Methodology, Writing - original draft, Writing - review & editing. **Brian J. Park:** Data curation, Writing - review & editing. **Royce W. Woodroffe:** Data curation, Writing - review & editing. **Mark Smith:** Data curation, Writing - review & editing. **Arnold H. Menezes:** Data curation, Writing - review & editing. **Jennifer Noeller:** Data curation, Writing - review & editing. **Satoshi Yamaguchi:** Data curation, Writing - review & editing. **Patrick W. Hitchon:** Conceptualization, Data curation, Project administration, Supervision, Writing - review & editing.

Acknowledgments

The authors are indebted to Ms. Faith Vaughn for her review, preparation, and editing of this manuscript.

References

[1] A. Boström, N.C. Kanther, A. Grote, J. Boström, Management and outcome in adult intramedullary spinal cord tumours: a 20-year single institution experience, BMC Res. Notes 7 (2014) 908.
[2] H.H. Engelhard, J.L. Villano, K.R. Porter, A.K. Stewart, M. Barua, F.G. Barker, H. B. Newton, Clinical presentation, histology, and treatment in 430 patients with primary tumors of the spinal cord, spinal meninges, or cauda equina, J. Neurosurg. Spine 13 (1) (2010) 67–77.
[3] G. Manzano, B.A. Green, S. Vanni, A.D. Levi, Contemporary management of adult intramedullary spinal tumors-pathology and neurological outcomes related to surgical resection, Spinal Cord 46 (8) (2008) 540–546.
[4] K.J. Minehan, P.D. Brown, B.W. Scheithauer, W.E. Krauss, M.P. Wright, Prognosis and treatment of spinal cord astrocytoma, Int. J. Radiat. Oncol. Biol. Phys. 73 (3) (2009) 727–733.
[5] S. Grimm, M.C. Chamberlain, Adult primary spinal cord tumors, Expert Rev. Neurother. 9 (10) (2009) 1487–1495.
[6] M. Horger, R. Ritz, R. Beschorner, M. Fenchel, T. Nägele, S. Danz, U. Ernemann, Spinal pilocytic astrocytoma: MR imaging findings at first presentation and following surgery, Eur. J. Radiol. 79 (3) (2011) 389–399.
[7] S. Mohajeri Moghaddam, A.A. Bhatt, Location, length, and enhancement: systematic approach to differentiating intramedullary spinal cord lesions, Insights Imaging 9 (4) (2018) 511–526.

[8] M.K. Tobin, J.R. Geraghty, H.H. Engelhard, A.A. Linninger, A.I. Mehta, Intramedullary spinal cord tumors: a review of current and future treatment strategies, Neurosurg. Focus 39 (2) (2015) E14.
[9] R. Ahmed, A.H. Menezes, J.C. Torner, Role of resection and adjuvant therapy in long-term disease outcomes for low-grade pediatric intramedullary spinal cord tumors, J. Neurosurg. Pediatr. 18 (5) (2016) 594–601.
[10] P.C. McCormick, R. Torres, K.D. Post, B.M. Stein, Intramedullary ependymoma of the spinal cord, J. Neurosurg. 72 (4) (1990) 523–532.
[11] P.C. McCormick, B.M. Stein, Intramedullary tumors in adults, Neurosurg. Clin. N. Am. 1 (3) (1990) 609–630.
[12] S. Viljoen, P.W. Hitchon, R. Ahmed, P.A. Kirby, Cordectomy for intramedullary spinal cord glioblastoma with a 12-year survival, Surg. Neurol. Int. 5 (2014) 101.
[13] Z. Merhemic, T. Stosic-Opincal, M.M. Thurnher, Neuroimaging of spinal tumors, Magn. Reson. Imaging Clin. N. Am. 24 (3) (2016) 563–579.
[14] A. Rossi, C. Gandolfo, G. Morana, P. Tortori-Donati, Tumors of the spine in children, Neuroimaging Clin. N. Am. 17 (1) (2007) 17–35.
[15] L.N. Ledbetter, J.D. Leever, Imaging of intraspinal tumors, Radiol. Clin. North Am. 57 (2) (2019) 341–357.
[16] B. Sun, C. Wang, J. Wang, A. Liu, MRI features of intramedullary spinal cord ependymomas, J. Neuroimaging 13 (4) (2003) 346–351.
[17] D.H. Kim, J.H. Kim, S.H. Choi, C.H. Sohn, T.J. Yun, C.H. Kim, K.H. Chang, Differentiation between intramedullary spinal ependymoma and astrocytoma: comparative MRI analysis, Clin. Radiol. 69 (1) (2014) 29–35.
[18] K. Kobayashi, K. Ando, F. Kato, K. Sato, M. Kamiya, M. Tsushima, M. Machino, K. Ota, M. Morozumi, S. Tanaka, S. Kanbara, S. Ito, N. Ishiguro, S. Imagama, Variety of preoperative MRI changes in spinal cord ependymoma of WHO grade II: a case series, Eur. Spine J. 28 (2) (2019) 426–433.
[19] K.K. Koeller, R.S. Rosenblum, A.L. Morrison, Neoplasms of the spinal cord and filum terminale: radiologic-pathologic correlation, Radiographics 20 (6) (2000) 1721–1749.
[20] R. Babu, I.O. Karikari, T.R. Owens, C.A. Bagley, Spinal cord astrocytomas: a modern 20-year experience at a single institution, Spine (Phila Pa 1976) 39 (7) (2014) 533–540.
[21] R. Ahmed, A.H. Menezes, O.O. Awe, J.C. Torner, Long-term disease and neurological outcomes in patients with pediatric intramedullary spinal cord tumors, J. Neurosurg. Pediatr. 13 (6) (2014) 600–612.
[22] T.D. Azad, A.V. Pendharkar, J. Pan, Y. Huang, A. Li, R. Esparza, S. Mehta, I. D. Connolly, A. Veeravagu, C.J. Campen, S.H. Cheshier, M.S.B. Edwards, P. G. Fisher, G.A. Grant, Surgical outcomes of pediatric spinal cord astrocytomas: systematic review and meta-analysis, J. Neurosurg. Pediatr. 22 (4) (2018) 404–410.
[23] G.I. Jallo, D. Freed, F. Epstein, Intramedullary spinal cord tumors in children, Childs Nerv. Syst. 19 (9) (2003) 641–649.
[24] S.I. Khalid, R. Kelly, O. Adogwa, A. Carlton, J. Woodward, S. Ahmed, R. Khanna, C. Bagley, J. Cheng, S. Shah, A.I. Mehta, Pediatric spinal ependymomas: an epidemiologic study, World Neurosurg. 115 (2018) e119–e128.
[25] M.J. McGirt, I.M. Goldstein, K.L. Chaichana, M.E. Tobias, K.F. Kothbauer, G. I. Jallo, Extent of surgical resection of malignant astrocytomas of the spinal cord: outcome analysis of 35 patients, Neurosurgery 63 (1) (2008) 55–60, discussion 60-61.
[26] M. Wostrack, F. Ringel, S.O. Eicker, M. Jägersberg, K. Schaller, J. Kerschbaumer, C. Thomé, E. Shiban, M. Stoffel, B. Friedrich, V. Kehl, P. Vajkoczy, B. Meyer, J. Onken, Spinal ependymoma in adults: a multicenter investigation of surgical outcome and progression-free survival, J. Neurosurg. Spine 28 (6) (2018) 654–662.
[27] H. Hongo, K. Takai, T. Komori, M. Taniguchi, Intramedullary spinal cord ependymoma and astrocytoma: intraoperative frozen-section diagnosis, extent of resection, and outcomes, J. Neurosurg. Spine 30 (1) (2018) 133–139.
[28] J. Klekamp, Treatment of intramedullary tumors: analysis of surgical morbidity and long-term results, J. Neurosurg. Spine 19 (1) (2013) 12–26.
[29] A. Raco, V. Esposito, J. Lenzi, M. Piccirilli, R. Delfini, G. Cantore, Long-term follow-up of intramedullary spinal cord tumors: a series of 202 cases, Neurosurgery 56 (5) (2005) 972–981, discussion 972-981.
[30] J.S. Harrop, A. Ganju, M. Groff, M. Bilsky, Primary intramedullary tumors of the spinal cord, Spine (Phila Pa 1976) 34 (22 Suppl) (2009) S69–77.
[31] J.H. Park, S.H. Lee, E.S. Kim, W. Eoh, Analysis of multimodal intraoperative monitoring during intramedullary spinal ependymoma surgery, World Neurosurg. 120 (2018) e169–e180.
[32] N. André-Obadia, F. Mauguière, [Electrophysiological testing in spinal cord tumors], Neurochirurgie 63 (5) (2017) 356–365.
[33] T. Verla, J.S. Fridley, A.B. Khan, R.R. Mayer, I. Omeis, Neuromonitoring for intramedullary spinal cord tumor surgery, World Neurosurg. 95 (2016) 108–116.
[34] K. Rijs, M. Klimek, M. Scheltens-de Boer, K. Biesheuvel, B.S. Harhangi, Intraoperative neuromonitoring in patients with intramedullary spinal cord tumor: a systematic review, meta-analysis, and case series, World Neurosurg. 125 (498-510) (2019) e2.
[35] S.R. Isaacson, Radiation therapy and the management of intramedullary spinal cord tumors, J. Neurooncol. 47 (3) (2000) 231–238.
[36] J. Liu, M. Zheng, W. Yang, S.L. Lo, J. Huang, Impact of surgery and radiation therapy on spinal high-grade gliomas: a population-based study, J. Neurooncol. 139 (3) (2018) 609–616.
[37] L.B. Nabors, J. Portnow, M. Ammirati, J. Baehring, H. Brem, P. Brown, N. Butowski, M.C. Chamberlain, R.A. Fenstermaker, A. Friedman, M.R. Gilbert, J. Hattangadi-Gluth, M. Holdhoff, L. Junck, T. Kaley, R. Lawson, J.S. Loeffler, M. P. Lovely, P.L. Moots, M.M. Mrugala, H.B. Newton, I. Parney, J.J. Raizer, L. Recht, N. Shonka, D.C. Shrieve, A.K. Sills, L.J. Swinnen, D. Tran, N. Tran, F.D. Vrionis, S. Weiss, P.Y. Wen, N. McMillian, A.M. Engh, Central nervous system cancers, version 1.2015, J. Compr. Canc. Netw. 13 (10) (2015) 1191–1202.