Differences and characteristics of symptoms by tumor location, size, and degree of spinal cord compression: a retrospective study on 53 surgically treated, symptomatic spinal meningiomas

Satoshi Yamaguchi, MD,¹ Arnold H. Menezes, MD,¹ Kiyoharu Shimizu, MD,² Royce W. Woodroffe, MD,¹ Logan C. Helland, MD,¹ Patrick W. Hitchon, MD,¹ and Matthew A. Howard III, MD¹

¹Department of Neurosurgery, University of Iowa Hospitals and Clinics, Iowa City, Iowa; and ²Department of Neurosurgery, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima, Japan

OBJECTIVE The differences in symptoms of spinal meningiomas have rarely been discussed from the perspective of tumor characteristics. The main purpose of this paper was to define the differences, if any, in symptoms in patients with spinal meningiomas with respect to tumor size, location, and degree of spinal cord compression. The authors also sought the threshold of spinal cord compression that causes motor weakness.

METHODS The authors conducted a retrospective study of 53 cases of spinal meningiomas that were surgically treated from 2013 to 2018. Symptoms related to the tumor were classified as motor weakness, sensory disturbance, pain, and bowel/bladder dysfunction. Based on MR images, tumor location was classified by spinal level and by its attachment to the dura mater. Tumor dimensions were also measured. Occupation ratios of the tumors to the spinal canal and degree of spinal cord flattening were sought from the axial MR images that showed the highest degree of spinal cord compression.

RESULTS Motor weakness and sensory disturbance were significantly more common in thoracic spine meningiomas than in cervical spine meningiomas ($p < 0.001$ and $p = 0.013$, respectively), while pain was more common in meningiomas at the craniovertebral junction ($p < 0.001$). The attachment, height, width, depth, and volume of the tumor showed no significant difference irrespective of the presence or absence of each symptom. In cases of motor weakness and sensory disturbance, occupation ratios and spinal cord flattening ratios were significantly larger. However, these ratios were significantly smaller in the presence of pain. Multivariate logistic regression analysis revealed that occupation ratio independently contributed to motor weakness (OR 1.14, $p = 0.035$) and pain (OR 0.925, $p = 0.034$). Receiver operating characteristic curve analysis suggested that occupation ratio with a value of 63.678% is the threshold for the tumor to cause motor weakness.

CONCLUSIONS The study showed the difference in clinical presentation of spinal meningiomas by spinal level, occupation ratio, and spinal cord flattening ratio. An occupation ratio of approximately 64% could be utilized as the threshold value of tumor growth to cause motor weakness. Tumor growth in the cervical spine might cause pain symptoms before causing motor weakness. The relationship between the tumor and its symptomatology should be discussed with respect to tumor size relative to the surrounding spinal canal.

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KEYWORDS spinal meningioma; spinal level; tumor dimension; occupation ratio; oncology

SPINAL meningiomas are one of the most common intraspinal neoplasms and account for 24.4%–36% of primary spinal intradural tumors.^{4,5,21,29} Large epidemiological studies from the United States have revealed that the overall age-adjusted incidence of spinal menin-

giomas is 0.19–0.35 per 100,000 population,^{4,15,29} with the mean patient age ranging from 49 to 54 years.^{7,10,16} Female patients account for 75%–85% of all patients. The reason for female preponderance is speculated to be the dependence of tumor growth on sex hormones.^{5,7,9,10,15,16,25,29} As

ABBREVIATIONS BBD = bowel/bladder dysfunction; CVJ = craniovertebral junction; OPLL = ossification of the posterior longitudinal ligament.

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for spinal level, 55%–83% of spinal meningiomas affect the thoracic spine. Approximately 15% of the tumors are found in the cervical spine. The lumbar spine is the least affected site, with a frequency of only 2%.^{2,7,8,16,25} More than 95% of spinal meningiomas are classified as benign or WHO grade I, while less than 2% of meningiomas are classified as grade II or III.^{10,15,21,29} The slow-growing nature of the tumor contributes to a longer duration of symptoms before diagnosis and treatment. The mean duration of symptoms in the literature ranges from 6 to 23 months.^{10,16,18,23,25} Symptoms are generally due to compression of the spinal cord and/or nerve roots, simply described as sensory disturbance, motor weakness, bowel/bladder dysfunction (BBD), and pain.^{2,3,7,9,19,23} The differences and characteristics of the symptoms have rarely been studied from the perspective of spinal level and tumor size.^{3,22} The threshold of spinal cord compression that leads to the onset of neurological symptoms has never been sought before. In this paper, we retrospectively reviewed 53 cases of surgically treated spinal meningiomas to find an association of symptoms with the location and size of the tumor. The symptomatology of spinal meningiomas will be reviewed.

Methods

This study was approved by our institutional review board. We conducted a retrospective study on spinal meningiomas 1) to see if there was any difference in frequency of symptoms depending on the location and size of the tumor; 2) to see if there was any difference in tumor dimensions and the degree of the spinal cord compression between the presence and absence of certain symptoms; 3) to identify contributing factors for the symptoms; and 4) to determine the critical size of the tumor for presentation of neurological symptoms. From January 2013 to December 2018, we identified 63 surgical cases of spinal meningiomas at the Department of Neurosurgery, University of Iowa Hospitals and Clinics. Among 63 cases, 7 cases of asymptomatic meningiomas were excluded. Two cases of meningiomas in the lumbar spine and 1 case of an extradural meningioma were excluded because of an absence of mass effect on the spinal cord. Thus, 53 meningiomas in 53 patients were reviewed for statistical analysis. The electronic medical records and preoperative MR images were sought to obtain the following data, in addition to the following basic information of the patients:

- WHO grade: grade I, II, or III;
- Spinal level of tumor attachment: craniovertebral junction (CVJ; foramen magnum to C2), subaxial cervical spine (C3–7), and thoracic spine (T1–12);
- Clinical symptoms: motor weakness, sensory disturbance, pain, and BBD;
- Tumor dimensions: height, width, and depth (mm) (Fig. 1a and b);
- The attachment of the tumor in the spinal canal (Fig. 2);
- Estimated tumor volume:⁶ volume (mm³) = ($\pi \times \text{height} \times \text{width} \times \text{depth}$)/6;
- Cross-sectional area (mm²) of the spinal canal and that of the tumor measured on the axial T1-weighted contrast-enhanced MR image that showed the highest degree of spinal cord compression;

FIG. 1. Images demonstrating how the tumor dimensions were measured in this study. All measurements were made based on contrast-enhanced T1-weighted MR images. **a and b:** Height (H) was measured on sagittal images. Width (W) and depth (D) were measured on axial images. All measurements were recorded in millimeters. **c and d:** Cross-sectional area (mm²) of the spinal canal (c) and that of the tumor (d) were measured on axial images, which showed the highest degree of spinal cord compression. Occupation ratios (%) were then sought from these values.

- Occupation ratio of the tumor in the spinal canal: occupation ratio (%) = tumor area (mm²)/spinal canal area (mm²) × 100 (Fig. 1c and d);
- The degree of spinal cord flattening by tumor was sought by the following formula based on axial T2-weighted MR images:³ spinal cord flattening ratio (%) = 100 – (area of spinal cord at maximum compression/[area of cord above + area of cord below]/2) × 100.

Measurements were taken using a picture archiving communication system (version 12.1.6.1005, Carestream Vue PACS Carestream Health) by a single author (S.Y.). Patients were then classified according to the presence or absence of motor weakness, sensory disturbance, pain, and BBD. Patients with motor weakness were further classified as follows: 1) subjective motor weakness: patients complaining of difficulty walking and/or hand clumsiness but still preserving grade 5 muscle strength in all extremities; and 2) objective motor weakness: muscle strength ≤ grade 4 seen in at least 1 extremity. Sensory disturbance included numbness, tingling, and decreased sensation. Pain symptoms included radicular-type pain and local pain along the spinal axis. Occipitalgia was also classified in this category in cases of CVJ meningiomas.

Statistical Analysis

Statistical analysis was performed using Easy R (Saita-

FIG. 2. The classification of the attachment of the tumor. The type of attachments was classified into ventral, dorsal, lateral, dorso-lateral, and ventrolateral, depending on the location of the tumor and the direction of the deviation of the spinal cord.

ma Medical Center, Jichi Medical University), a graphical user interface for R (The R Foundation for Statistical Computing).¹³ Fisher's exact test was applied to see if there was a nonrandom association between two categorical variables. To compare continuous variables among 2 and 3 groups, the Mann-Whitney U-test and Kruskal-Wallis test were used, respectively. When the Kruskal-Wallis test showed a significant difference, the Mann-Whitney U-test was used for pairwise comparison. The *p* values were then adjusted by Bonferroni correction. Univariate logistic regression analysis was applied to find contributing factors for the presentation of each symptom. Multivariate logistic regression analysis was performed to identify independent contributing factors to each symptom; *p* < 0.05 was considered significant.

Results

Patient Demographics

Demographic data of the 53 patients are listed in Table 1. Forty-eight patients (90.6%) were female. The mean patient age was 60 ± 16.48 years (range 9–93 years). All meningiomas but one were found in adults. WHO grade I accounted for 94.3% of all meningiomas (50 of 53). Only 3 meningiomas (5.7%) were WHO grade II. There were no WHO grade III meningiomas in our series. The thoracic spine was the most affected area, where 64.2% (34 of 53) of the tumors were found. The CVJ (24.5%) and subaxial cervical spine (C3–7, 11.3%) followed. As to clinical symptoms, 32 of 53 patients (60.4%) exhibited motor weakness and were further classified into groups with subjective weakness (26.4%) and objective weakness (34%). Sensory disturbance was seen in 49.1% of patients (26 of 53 patients). Either radicular pain (30.2%, 16 of 53

patients) or axial pain (34%, 18 of 53 patients) was seen in 64.2% of patients (34 of 53). Nine of 53 patients (17%) had BBD. With regard to attachment of the tumor in the spinal canal, lateral attachment was most frequent (32.1%), followed by ventrolateral (30.2%) and dorsolateral (26.4%) attachment. Pure ventral and dorsal attachment were relatively rare, with frequencies of 3.8% and 7.5%, respectively.

Frequency of Each Symptom Depending on Spinal Level of Meningioma and Tumor Attachment

The frequency of motor weakness, sensory disturbance, and pain was uneven among the 3 spinal level groups. More precisely, motor weakness and sensory disturbance were significantly more common in patients with thoracic spine meningiomas than in those with meningiomas at other spinal levels (*p* < 0.001 and *p* = 0.013, respectively). While pain was more commonly associated with CVJ meningiomas than with other spinal level meningiomas (*p* < 0.001), BBD was only seen in patients with thoracic spine meningiomas (*p* = 0.05). The frequency of each symptom by tumor attachment did not differ significantly (Table 2).

Is There Any Difference in Tumor Dimensions Between the Presence and Absence of Symptoms?

Height, width, depth, and volume of the tumors were not significantly different irrespective of the presence or absence of each symptom. Occupation ratios and spinal cord flattening ratios were significantly larger in the presence of motor weakness and sensory disturbance than in the absence of those symptoms, while those ratios in the presence of pain were significantly smaller than in the absence of pain (all *p* < 0.05; see detailed *p* values in Table 3).

TABLE 1. Overall patient demographics

	Value
No. of patients	53
Male	5 (9.4)
Female	48 (90.6)
Mean age $\pm$ SD, yrs	60 $\pm$ 16.48
WHO grade	
I	50 (94.3)
II	3 (5.7)
Atypical	2
Clear cell	1
Spinal level	
CVJ	13 (24.5)
C3–7	6 (11.3)
T1–12	34 (64.2)
Motor weakness	
No weakness	21 (39.6)
Any weakness	32 (60.4)
Subjective	14 (26.4)
Objective	18 (34.0)
Sensory disturbance	
None	27 (50.9)
Any	26 (49.1)
Pain	
No pain	26 (49.1)
Radicular pain	16 (30.2)
Axial pain	18 (34.0)
BBD	9 (17.0)
Attachment of the tumor	
Ventral	2 (3.8)
Ventrolateral	16 (30.2)
Lateral	17 (32.1)
Dorsal	4 (7.5)
Dorsolateral	14 (26.4)

Values represent the number of patients (%) unless stated otherwise.

Contributing Factors for the Presentation of Each Symptom

Univariate logistic regression analysis was performed to find contributing factors for each symptom (Table 4). As a result, both motor weakness and sensory disturbance were significantly related to thoracic spine lesions ($p < 0.001$ and $p = 0.016$, respectively), occupation ratio ($p < 0.001$ and $p = 0.010$, respectively), and spinal cord flattening ratio ($p < 0.001$ and $p = 0.025$, respectively). As to pain, CVJ lesions ($p = 0.006$), occupancy ratio ($p < 0.001$), and spinal cord flattening ratio ($p = 0.001$) were significant contributing factors. To identify independent factors that contributed to each symptom, we conducted multivariate logistic regression. Occupation ratio was an independent contributing factor for the presentation of motor weakness (OR 1.14, 95% CI 1.01–1.29, $p = 0.035$) and pain (OR 0.925, 95% CI 0.861–0.994, $p = 0.034$).

Threshold Value of Occupation Ratio to Cause Motor Weakness

When the motor weakness group was further classified into subjective and objective weakness, the occupation ratio of the no-weakness group was significantly smaller than that of the subjective- and objective-weakness groups ($p < 0.001$), while no significant difference in occupation ratio was found between subjective and objective weakness (Fig. 3 left). Receiver operating characteristic curve analysis suggested that an occupation ratio with a value of 63.678% had the highest sensitivity and specificity for the presence of subjective motor weakness. We can therefore conclude that an occupation ratio of 63.678% is the threshold to cause motor weakness (Fig. 3 right).

Discussion

Symptoms of Spinal Meningiomas

In the present study, motor weakness and sensory disturbance were significantly more common in thoracic meningiomas, and pain was more common in CVJ meningiomas. The ranges of incidence for each symptom reported in the literature are as follows: motor weakness, 63.5%–92.5%; coordination/balance disorder, 6.7%–93%, sensory disturbance, 50%–100%; localized or radicular pain, 20%–83%; and BBD, 1.0%–50%.^{3,5,7,8,10,14,16,18,23,25} As listed above, the frequencies of each symptom are quite heterogeneous among the reports. For example, Gezen et al. reported localized or radicular pain as the most common symptom with a frequency of 83%, while in the retrospective analysis of 194 spinal meningiomas by Hua et al., pain was the second least common symptom, with a frequency of only 26%.^{7,10} Probably because of this heterogeneity, the researchers paid less attention to the symptomatology of spinal meningiomas. To our knowledge, there have been only a few reports regarding the relationship of the size of spinal meningioma to the presenting symptoms.^{1,3,22}

Degree of Spinal Cord Compression by Intradural Extramedullary Tumors and Its Relation to the Symptomatology

The present study showed that the occupation ratio is an independent contributing factor to the presentation of motor weakness and pain. Ahn et al. retrospectively analyzed 11 surgical cases of intradural extramedullary tumors comprising 8 schwannomas, 2 meningiomas, and 1 extramedullary grown ependymoma.¹ Their metrics of occupation ratio were not based on the cross-sectional areas of tumors and the spinal canal, like the present study. The occupation ratio was calculated based on the ratio of the diameter of the tumor and the spinal canal at the level of the most significant spinal cord compression. The mean percentage of the occupation ratio of the tumor in the spinal canal was 82.9%. This occupation ratio was highly associated with visual analog scale scores and Nurick grades.¹ Davies et al. retrospectively analyzed their series of 31 surgically treated spinal meningiomas to find the relationship between degree of spinal cord compression and patients' functional status. They evaluated the occupation ratio by the same metrics as in the present study. The average tumor occupation ratio from preoperative MR images

TABLE 2. Frequency of each symptom by spinal level

	Motor Weakness		Sensory Disturbance		Pain		BBD	
	Yes	No	Yes	No	Yes	No	Yes	No
Spinal level of tumor								
CVJ	3	10	2	11	12	1	0	13
C3–7	1	5	3	3	4	2	0	6
T1–12	28	6	21	13	11	23	9	25
p value*	<0.001		0.013		<0.001		0.05	
Attachment of tumor								
Ventral	1	1	0	2	2	0	0	2
Ventrolateral	8	8	7	9	9	7	3	13
Lateral	10	7	9	8	10	7	1	16
Dorsal	2	2	3	1	2	2	1	3
Dorsolateral	11	3	7	7	4	10	4	10
p value*	0.52		0.627		0.282		0.43	

Boldface type indicates statistical significance.

* Fisher's exact probability test.

was 72%. In contrast to the study by Ahn et al., no obvious relationship was found between occupation ratio and pre- or postoperative Nurick grade.³ In their retrospective analysis of 88 patients with spinal meningiomas, Schwake et al. found that tumor volume was not correlated to clinical symptoms such as sensory, motor deficit, radicular pain, or incontinence.²² No correlation was found between tumor volume and McCormick score. They found that tumor volume only correlated with the presence of low-back pain. The weak point of this study was that they did not take the size of the corresponding spinal canal into consideration. As shown in Table 3, there were no significant differences in the height, width, depth, and volume of the tumors irrespective of the presence or absence of each symptom, while occupation ratios showed significant differences in the presence of motor weakness, sensory disturbance, and pain. These results imply that the emergence of neurological symptoms depends more on the size of the tumor relative to the spinal canal rather than the actual size of the tumor. Finally, multivariate analysis in the present study disclosed that occupation ratio was the sole independent contributing factor for the presence of motor weakness and pain. We believe that the occupation ratio is useful to study the effect of intraspinal mass lesions on the spinal cord.

Degree of Spinal Cord Compression by Lesions Other Than Spinal Cord Tumors and Its Relation to Symptomatology

Quantification of the degree of spinal cord compression and its influence on clinical symptoms has also been studied in spinal diseases other than spinal cord tumors. Ossification of the posterior longitudinal ligament (OPLL) is a well-known cause of compressive myelopathy in the cervical spine. Matsunaga et al. prospectively studied patients with asymptomatic cervical OPLL with a mean follow-up duration of 19.6 years.¹⁷ They evaluated the degree of spinal cord compression on lateral cervical radiographs

by dividing anteroposterior thickness of the ossified ligament by anteroposterior diameter of the corresponding spinal canal. All patients with an occupation ratio greater than 60% developed cervical myelopathy at some point in the follow-up period. Kameyama et al. histologically analyzed spinal cords that were obtained from 9 autopsy cases of patients who had known cervical OPLL.¹² They found that irreversible pathological changes were associated with a triangular-shaped deformity of the spinal cord and were also associated with occupation ratios exceeding 40%. Tung et al. evaluated the thickness of spinal epidural abscesses to find a correlation between degree of spinal cord compression and postoperative symptoms.²⁸ The occupation ratio was measured based on the anteroposterior diameter of the spinal canal and abscess. Spinal epidural abscesses with an occupation ratio greater than 50% were associated with persistent weakness, back pain, and incomplete clinical recovery. As shown above, the threshold of spinal cord compression to present with neurological symptoms and its radiological parameters have been a matter of interest to many researchers.²⁴ These studies suggested that an occupation ratio of 40%–60%, measured from the anteroposterior diameter of the lesion and the spinal canal, seems to be a critical point of spinal cord compression to manifest as significant neurological symptoms. The present study suggests that an occupation ratio of 63.678% is the threshold to cause motor weakness. Unfortunately, we cannot simply compare the results of the present study with those of prior ones because of the difference in metrics for the occupation ratio. In the process of study planning, we thought that an occupation ratio based on anteroposterior diameter of the lesion and spinal canal was inappropriate for spinal meningiomas because spinal cord compression by the tumor is not always anteroposterior, like OPLL. The direction of spinal cord compression by spinal meningiomas varies depending on tumor attachment. Therefore, we decided to evaluate the occupation ratio based on the cross-sectional area of the tumor and the spinal canal. We hope that further studies

TABLE 3. Differences of tumor dimensions between presence and absence of symptoms

	Height (mm)			Width (mm)			Depth (mm)			Vol (mm ³)			Occupation Ratio (%)			Spinal Cord Flattening Ratio (%)		
	Median	IQR		Median	IQR		Median	IQR		Median	IQR		Median	IQR		Median	IQR	
Motor weakness																		
No	18.6	17.7–23.1		12.7	10.6–14.6		11.2	8.9–12.9		1393.6	828.5–2089.6		52.4	38.4–62.3		18.2	10.8–28.8	
Yes	20.7	17.7–23.2		14.1	12.2–15.2		11.9	11.2–14.0		1754.2	1336.4–2619.5		80.5	76.9–85.1		58.3	47.7–66.1	
p value*	0.689			0.187			0.068			0.183			<0.001			<0.001		
Sensory disturbance																		
No	18.4	17.1–22.6		12.5	10.8–14.6		11.8	9.5–13.2		1623.6	939.1–2169.0		62.5	51.8–78.4		30.4	16.8–55.2	
Yes	20.7	18.1–23.2		14.2	12.6–15.3		11.8	10.8–14.1		1690.1	1347.0–2700.4		80	70.1–85.3		55.8	42.5–60.9	
p value*	0.298			0.142			0.618			0.363			0.001			0.025		
Pain																		
No	19.8	17.8–23.0		14.1	12.8–15.2		11.9	11.1–13.9		1891.5	1355.2–2512.1		81.3	75.8–85.6		57.3	44.6–65.3	
Yes	19	17.7–23.2		12.3	10.2–14.9		11.3	9.0–13.3		1567.1	801.1–2169.0		62.2	48.0–73.5		28.1	13.6–50.8	
p value*	0.689			0.097			0.226			0.193			<0.001			<0.001		
BBD																		
No	19.8	17.3–23.8		13.9	11.7–15.1		11.8	10.2–13.8		1559.5	1089.8–2769.2		71.3	52.3–81.9		45.8	25.1–59.1	
Yes	19	18.7–21.2		14.1	12.5–15.2		11.6	11.2–12.4		1793	1485.4–2113.6		80.4	69.4–80.7		57.8	33.6–68.0	
p value*	0.972			0.562			0.896			0.789			0.105			0.308		

Boldface type indicates statistical significance.
* Mann-Whitney U-test.

TABLE 4. Univariate and multivariate logistic regression analyses for each symptom

	Possible Contributing Factor	OR	Lower 95% CL	Upper 95% CL	p Value
Univariate logistic regression analysis					
Motor weakness	Age	1.02	0.982	1.05	0.357
	Male sex	2.86	0.297	27.5	0.364
	Thoracic spine lesion	17.5	4.26	71.8	<0.001
	Occupation ratio	1.2	1.09	1.33	<0.001
	Spinal cord flattening ratio	1.13	1.06	1.19	<0.001
Sensory disturbance	Age	0.994	0.961	1.03	0.708
	Male sex	1.63	0.25	10.6	0.61
	Thoracic spine lesion	4.52	1.32	15.5	0.016
	Occupation ratio	1.05	1.01	1.09	0.010
	Spinal cord flattening ratio	1.03	1.00	1.06	0.025
Pain	Age	0.991	0.959	1.02	0.606
	Male sex	0.613	0.093	4.01	0.61
	CVJ lesion	20	2.36	170	0.006
	Occupation ratio	0.903	0.851	0.958	<0.001
	Spinal cord flattening ratio	0.947	0.916	0.978	0.001
Multivariate logistic regression analysis					
Motor weakness	Thoracic spine lesion	0.835	0.0587	11.9	0.894
	Occupation ratio	1.14	1.01	1.29	0.035
	Spinal cord flattening ratio	1.06	0.993	1.14	0.078
Sensory disturbance	Thoracic spine lesion	1.74	0.327	9.11	0.521
	Occupation ratio	1.04	0.979	1.10	0.203
	Spinal cord flattening ratio	1.00	0.960	1.04	0.956
Pain	CVJ lesion	7.52	0.746	75.8	0.087
	Occupation ratio	0.925	0.861	0.994	0.034
	Spinal cord flattening ratio	0.997	0.952	1.050	0.912

CL = confidence limit.

Boldface type indicates statistical significance.

will standardize the method of quantification of spinal cord compression and will help elucidate the pathophysiology of compressive myelopathy.²⁷

Relationship Between Occupation Ratio and Pain

As shown in Table 4, the odds ratio of the occupation ratio for pain symptoms was 0.925. An odds ratio of < 1 means that the larger the occupation ratio, the less likely the tumor will cause pain. This is somewhat contradictory given the general idea of tumors becoming symptomatic with growth. This contradiction can probably be explained by the following results. Table 2 shows that pain symptoms were more common in patients with CVJ meningiomas than with thoracic spine meningiomas. When we focused on patients who presented exclusively with pain ($n = 18$), we found that 13 of 18 meningiomas (72%) arose in the cervical spine. This implies that meningiomas in the cervical spine are likely to present with pain. As to tumor size and the degree of the spinal cord compression, occupation ratios and spinal cord flattening ratios for meningiomas in the CVJ and subaxial cervical spine (C3–7) were significantly smaller than those ratios for meningiomas

in the thoracic spine ($p < 0.001$; Fig. 4). When we put all these results together, it might be concluded that relatively small spinal meningiomas in the cervical spine are likely to manifest as pain symptoms rather than motor weakness. Assuming that the neck and arms are more sensitive than the thoracic area to radicular-type pain, meningiomas arising in the cervical spine might take the patient to the hospital before the tumor grows large enough to cause motor weakness.

Study Limitations

There are some limitations in this study. First, this study did not take mobility of the spine into consideration. The development of compressive myelopathy mainly derives from two physical factors: static and dynamic compression. Under the existence of some space-occupying lesions in the spinal canal, the degree of compression and the magnitude of strain force on the spinal cord are known to change by physiological motion of the neck, especially in the middle cervical spine.^{11,20,26} The thoracic spine, which is surrounded by the rib cage, is more rigid than the cervical spine. The difference in symptoms between cervical

FIG. 3. Left: Occupation ratios in the no-weakness group were significantly smaller than those of groups with subjective and objective weakness ($p < 0.01$). Kruskal-Wallis test for primary comparison and Mann-Whitney U-test for pairwise comparison. **Right:** Receiver operating characteristic curve analysis indicating that an occupation ratio of 63.678% had the highest sensitivity and specificity for the presence of motor weakness.

FIG. 4. Left: Occupation ratios of meningiomas in the CVJ and subaxial spine (C3–7) were significantly smaller than those of meningiomas in the thoracic spine (T1–12) ($p < 0.001$). **Right:** Spinal cord flattening ratios in the CVJ and C3–7 were significantly smaller than those of meningiomas in the thoracic spine ($p < 0.001$). Kruskal-Wallis test for primary comparison and Mann-Whitney U-test for pairwise comparison.

and thoracic meningiomas might be partially explained by the difference in mobility of the affected spine. Second, we cannot exclude the possibility that hand clumsiness and walking difficulty, which were classified as subjective motor weakness in the study, might derive from disorders of proprioception and coordination. It is possible that our classification of pain might not have been completely accurate. Spinal meningiomas might have caused other types of pain, such as funicular pain. Considering the patients' mean age of 60 ± 16.48 years, mechanical pain deriving from cervical spondylosis in the background might have affected the intensity of the pain. However, further evaluation of symptoms in the electronic medical records was not possible because of the retrospective nature of this study. Lastly, the impact of this study on the management of spinal meningiomas might be small. However, we believe that this study will contribute to the elucidation of the pathophysiology of spinal meningiomas and compressive myelopathy.

Conclusions

The present study shows differences in the clinical presentation of spinal meningiomas by spinal level and occupation ratio. Motor weakness and sensory disturbance were more commonly seen in thoracic spine meningiomas. Pain was more common in meningiomas at the CVJ. Tumor growth in the cervical spine might cause pain symptoms before causing motor weakness. An occupation ratio of about 64% could be utilized as the threshold value of tumor growth to cause motor weakness. The relationship between the tumor and its symptomatology should be discussed not only with regard to actual size but also with regard to size of the tumor relative to the surrounding spinal canal.

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Disclosures

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

Author Contributions

Conception and design: Yamaguchi. Acquisition of data: Yamaguchi. Analysis and interpretation of data: Yamaguchi. Drafting the article: Yamaguchi. Critically revising the article: Menezes, Shimizu. Reviewed submitted version of manuscript: Woodroffe, Helland, Hitchon, Howard. Statistical analysis: Yamaguchi, Shimizu. Study supervision: Hitchon, Howard.

Correspondence

Satoshi Yamaguchi: University of Iowa Hospitals and Clinics, Iowa City, IA. satoshi-yamaguchi@uiowa.edu.