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Original Article

Correlations Among Consistency, Computed Tomography Values, and Histopathological Subtypes of Spinal Meningioma

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The consistency of spinal meningiomas is important to consider when performing tumor removal surgery. This study evaluated the correlations between spinal meningioma consistency and both preoperative computed tomography (CT) values and histopathological subtypes. Fifteen consecutive patients who underwent surgical resection of spinal meningioma at our institution were identified, and preoperative CT values and the signal intensity of T2-weighted magnetic resonance images of the tumor were determined retrospectively. The consistency of the spinal meningioma was defined based on the ultrasonic surgical aspirator output during tumor debulking. Patients were assigned to 2 groups: a soft group (n = 4) and a hard group (n = 11). The T2 signal intensity was significantly higher in the soft group than in the hard group ($p = 0.001$). While the CT values were considerably higher in the hard group, the difference was not significant ($p = 0.19$). Regarding the histopathological subtypes, psammomatous meningioma exhibited significantly higher CT values than meningothelial meningioma ($p = 0.019$); however, there was a higher frequency of hard tumors in meningothelial meningioma cases than in psammomatous meningioma cases. Although neither robust correlations between tumor consistency and CT values nor a relationship between tumor consistency and histopathological subtype has been established, these results might help with the perioperative manegement of spinal tumors.

Key words: calcification, computed tomography, psammoma body, spinal meningioma

Spinal meningiomas are generally benign, slow-growing tumors that represent 25-46% of primary spinal cord tumors [1]. They occur most frequently in middle-aged women in the region of the thoracic spine. Treatment of spinal meningiomas predominantly involves surgical resection, and the outcomes are mostly favorable [2]. Histopathologically, psammomatous meningioma is the most common subtype, followed by meningothelial and transitional meningiomas [3]. Grossly calcified meningiomas are uncommon and account for only 1-5% of all spinal meningiomas, although ~50-90% of spinal meningiomas contain psammoma bodies [4,5]. Hard tumors such as calcified tumors are accompanied by an increased risk of neurological outcome due to the additional manipulations required to dissect the tumor [6]. Therefore, determining the consistency of the spinal meningioma is important in order to predict the difficulty of the surgery and plan the surgical strategy as is the case when treating intracranial meningioma. A variety of neuroimaging

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approaches have been used to predict the consistency of intracranial meningiomas. However, few studies have focused on the consistency of spinal meningiomas, particularly the consistency assessed using computed tomography (CT) values [7]. This study was performed to analyze the correlation between the consistency of spinal meningiomas and the preoperative CT values of the tumor, as well as the correlations between tumor consistency and histopathological subtype.

Material and Methods

Fifteen consecutive patients underwent surgical resection of spinal meningiomas at our institution between April 2005 and March 2014. All patients included in this study provided informed consent. CT and magnetic resonance imaging (MRI) with contrast medium were performed preoperatively in all cases. In this study, CT was performed on a multi-detector GE Lightspeed Ultra 16 (April 2005-March 2009) or GE LightSpeed VCT XT 64 (April 2009-March 2014) (General Electric Healthcare, Milwaukee, WI, USA). Our series consisted of 5 male and 10 female patients, ranging in age from 42 to 85 (mean, 62.6) years at the time of surgery. The locations of the tumors were cervical (6 patients) and thoracic (9 patients); there were no cases of lumbosacral lesions. All patients had intradural extramedullary tumors. The histopathological subtypes according to the World Health Organization classification were meningothelial (n = 8), psammomatous (5), fibrous (1), and metaplastic (1). Psammoma bodies were pathologically identified in 11 of the 15 cases — specifically, in 4 of the 8 meningothelial, 5 psammomatous, 1 fibrous, and 1 metaplastic meningioma. All 4 cases without histological psammoma bodies belonged to the meningothelial meningioma histopathological subtype (Table 1).

At our institute, we used an ultrasonic surgical aspirator (SONOPET; Stryker, Kalamazoo, MI, USA) for debulking the tumor during the spinal meningioma surgery. The tumor consistency was determined based on the intraoperative findings, with the ultrasonic surgical aspirator output during tumor debulking used as an index. In all 15 cases, the meningiomas were classified as hard or soft based on the tumor consistency. Tumors in the soft group ($n = 4$) were defined as tumors that were easily removed using an ultrasonic surgical aspirator output ≤70%. Tumors in the hard group ($n = 11$) were defined as those that required an output >70% to remove the lesion. The preoperative CT values and the signal intensity on T2-weighted images (WIs) of the tumors were retrospectively measured in all patients by the same experienced neurosurgeon (TA, KI). The CT values of the tumors were measured in the region of interest (ROI) at the axial slice with the maximal tumor diameter. In cases with partial calcification, the CT values were measured at the highest-density ROI. The T2 signal intensity of the tumor relative to subcutane-

Table 1 Summary of clinical data in 15 patients with surgical resection of spinal meningiomas

Case	Age	Sex	Tumor location	CT values (HU)	T2 signal intensity ratio (Tumor/Subcutaneous fat)	Histopathological subtype	Presence of psammoma body	Consistency
1	42	F	C3	50	0.34	fibrous	Yes	hard
2	44	F	Th1-2	34	0.48	meningothelial	Yes	soft
3	68	M	Th1-2	66	0.28	meningothelial	Yes	hard
4	53	F	C7	69	0.34	meningothelial	No	hard
5	67	F	Th8-10	62	0.49	meningothelial	Yes	soft
6	72	M	Th1	87	0.32	meningothelial	No	hard
7	62	M	Th1	54	0.10	meningothelial	No	hard
8	64	M	C4-5	34	0.41	meningothelial	No	hard
9	51	F	Th2	86	0.43	psammomatous	Yes	soft
10	75	F	Th10	737	0.16	psammomatous	Yes	hard
11	66	M	C6	40	0.38	meningothelial	Yes	hard
12	33	M	C6-7	158	0.25	psammomatous	Yes	hard
13	85	F	Th8	393	0.13	metaplastic	Yes	hard
14	85	F	Th7	125	0.85	psammomatous	Yes	soft
15	72	F	C1-2	255	0.31	psammomatous	Yes	hard

C, cervical; Th, thoracic.

ous fat tissue using ROIs was also calculated as the signal intensity ratio. The correlations among tumor consistency, CT values, signal intensity of the T2-WI on MRI, and histopathological subtype were statistically analyzed. Statistical analyses were performed using Student's *t*-test, the Mann-Whitney *U* test, and Fisher's exact test. In all analyses, statistical significance was set at $p < 0.05$.

Results

The patient data for both groups are summarized in Table 2. There were no significant between-group differences in patient age, sex, or lesion location. The mean CT values were 76.7 (range, 34-125 Hounsfield units (HU)) and 176.7 HU (range, 34-737 HU) in the soft and hard groups, respectively. Although the mean CT value of the tumors was considerably higher in the hard group, the difference was not statistically significant ($p = 0.19$) (Fig. 1). The T2 signal intensity ratio of the tumor to the subcutaneous fat tissue was significantly higher in the soft group than in the hard group ($p = 0.001$).

The series consisted of the following histopathological subtypes: meningothelial (n = 8), psammomatous (5), fibrous (1), and metaplastic (1) meningiomas. The mean CT values were 55.7 HU (range, 34-87 HU) in meningothelial and 272.2 HU (range, 86-737 HU), in psammomatous meningiomas, respectively. Psammomatous meningiomas exhibited a higher CT value than meningothelial meningiomas, and the difference was statistically significant ($p = 0.019$), when cases of fibrous meningioma and metaplastic meningioma were excluded because there was only one case of each subtype (Fig. 2). There were no statistically significant correlations between the histopathological subtypes and the consistency, as determined by Fisher's exact test ($p = 0.885$), although the CT values and histopatholog-

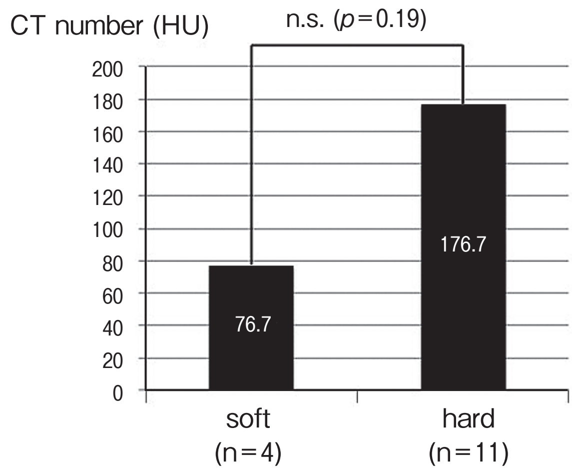
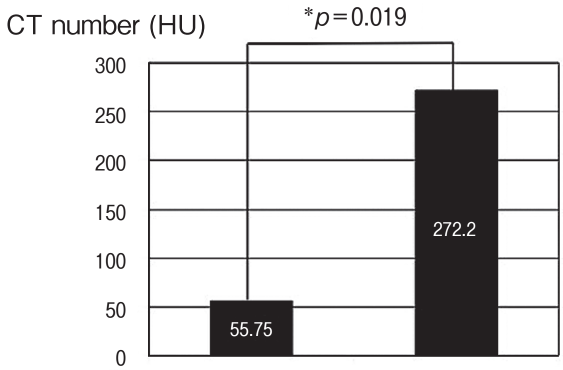


Fig. 1 Correlations between computed tomography value and tumor consistency.

Table 2 Demographic data of patients with spinal meningioma in both group

	Soft group	Hard group	*P* value
Number of patients	4	11	
Age in yrs, mean (range)	61.8 (44–85)	62.9 (33–85)	0.844
Sex, n (%)			0.103
Male	0 (0)	6 (54.5)	
Female	4 (100)	5 (45.5)	
Lesion location			0.103
cervical	0 (0)	6 (54.5)	
thoracic	4 (100)	5 (45.5)	
CT values (HU), mean (range)	76.8 (34–125)	176.6 (40–737)	0.19
T2 signal intensity ratio (Tumor/Subcutaneous fat), mean (range)	0.56 (0.43–0.85)	0.28 (0.16–0.41)	0.001*
Histopathological subtypes, n (%)			0.885
Meningothelial	2 (50.0)	6 (54.5)	
Psammomatous	2 (50.0)	3 (27.3)	
Fibrous	0 (0)	1 (9.1)	
Metaplastic	0 (0)	1 (9.1)	
Presence of psammoma body (%)	4 (100)	3 (27.3)	0.516



	meningothelial	psammomatous
hard	n=6 (75%)	n=3 (60%)
soft	n=2 (25%)	n=2 (40%)

Fig. 2 Correlations between histological subtypes and tumor consistency.

ical subtypes were correlated. Psammoma bodies were histopathologically identified in all 4 cases (100%) in the soft group and in 3 of 11 cases (27.3%) in the hard group. Nevertheless, the difference in the presence of psammoma bodies between the 2 groups was not significant ($p=0.516$).

There was one case of thoracic metaplastic meningioma in which the preoperative CT revealed a completely calcified tumor with a CT value of 393 HU. This metaplastic case was the most difficult to remove and was the hardest tumor in our series. It was removed in a piecemeal fashion using an ultrasonic surgical aspirator with a high-frequency output. There was no adhesion between the tumor and the spinal cord or nerve roots, and gross total tumor resection was successfully achieved (Fig. 3). Gross total resection was achieved in all tumors (Simpson Gr. 2), and no cases required reoperation for the resection of recurrent tumors in the >5-year follow-up period in either group.

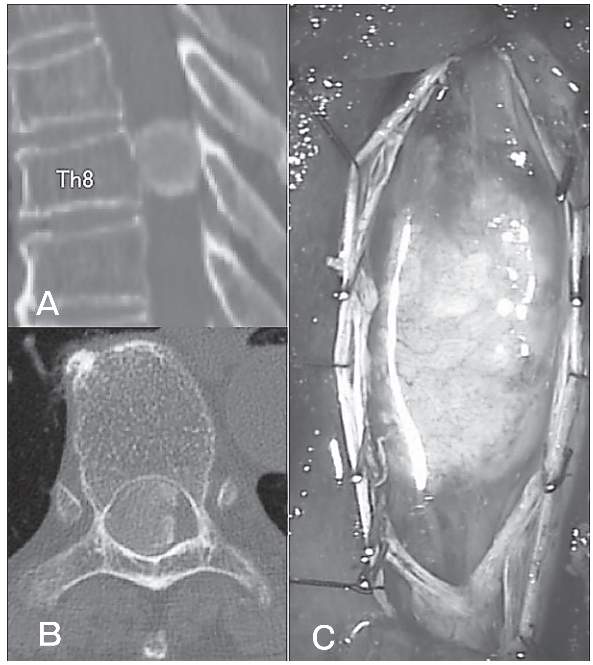


Fig. 3 **A**, Sagittal computed tomography image showing a high-density mass (393 HU) at the Th8 vertebral body level; **B**, Axial image; **C**, Intraoperative picture of completely ossified metaplastic meningioma.

Discussion

Spinal meningioma consistency and CT values. Several factors contribute to the difficulty of meningioma removal and the risk of postoperative complications, including tumor size, the degree of adhesion to the surrounding structures, tumor vascularization, and tumor consistency [8]. Meningiomas with a firm consistency are more difficult to excise. Therefore, preoperative determination of the consistency of a meningioma would be advantageous when planning the surgical strategy. Several studies have been conducted to predict the consistency of intracranial meningiomas based on preoperative neuroimaging; the imaging modalities used have included conventional MRI, diffusion MRI, MR elastography, MR spectroscopy, and CT scan [7,8]. Actually, the present study found a significant correlation between signal intensity on T2-WI and spinal meningioma consistency. However, few studies have focused on the consistency of spinal meningiomas [7].

The consistency of a spinal meningioma is one of the most important factors that can influence surgical planning and the degree of difficulty in resecting the tumor, as is the case with intracranial meningiomas. Gross total tumor resection is generally considered difficult to accomplish in cases with calcified meningiomas because of the hardness of the tumor. Grossly calcified meningiomas are uncommon and account for only 1-5% of all spinal meningiomas. Sandalcioglu *et al.* reported that evidence of calcification makes surgical removal difficult and increases the risk of neurological damage as a result of the additional manipulations required to dissect the tumor [9]. Zhu *et al.* reported that calcified spinal meningiomas are more likely to adhere to nerves and surrounding tissue, particularly the dura mater [10]. In calcified meningiomas, MRI reveals that the intensity of calcification within the tumor varies, and the obvious high-signal areas of calcification can be detected more easily on CT. If preoperative CT can detect whether a tumor is soft or hard, it would be useful to perform CT when devising the surgical strategy. Therefore, we focused on CT values as a predictive factor for tumor consistency. To our knowledge, this is the first case series to compare the correlations between the consistency of spinal meningiomas and CT values as well as histopathological subtype.

We divided the 15 spinal meningioma cases into a soft group (4 cases) and a hard group (11 cases) based on the objective index of ultrasonic surgical aspirator output. It is valuable to have an objective method in contrast to the conventional neurosurgeon's subjective assessment of "hard" vs "soft." In our study, although the CT values were considerably higher in the hard group, there was no statistically significant correlation between the consistency of the tumors and the CT values. Calcified meningiomas are generally considered difficult to surgically remove because of their hardness and the increased risk of spinal cord injury during tumor dissection. However, our results indicated that not all spinal meningiomas with high CT values suggesting intratumoral calcification are hard tumors, and the lesions could be removed using an ultrasonic aspirator. Preoperative radiological calcification and high CT values may, therefore, not be useful in guiding the decision making regarding the surgical strategy.

Psammoma bodies in spinal meningioma. Psammoma bodies are frequently found in spinal meningiomas, even if the histopathological subtype is not a psammomatous meningioma. Approximately 50-90% of spinal meningiomas have psammoma bodies, compared with only 10% of intracranial meningiomas [5]. Camp *et al.* reported that the presence of psammoma bodies can increase the hardness of the meningioma [11]. In our series, psammoma bodies were found in 11 cases (4 meningothelial meningiomas, 5 psammomatous meningiomas, 1 fibrous meningioma, and 1 metaplastic meningioma) on pathological analysis. Psammoma bodies, so-called because of their resemblance to grains of sand, are concentric lamellate calcified structures and are thought to reflect the process of dystrophic calcification [12]. However, the mechanism of psammoma body formation is poorly understood. Triggiani *et al.* reported that these calcospherites are 50-70 μm in size, round in shape, and have a glassy appearance [13]. The small size of psammoma bodies may give spinal meningiomas a relatively soft texture, based on our data. However, our study also showed no correlation between the presence of psammoma bodies and tumor consistency.

A rare occurrence of a spinal meningioma as a "metaplastic meningioma". Metaplastic meningiomas constitute an uncommon subset of low-grade meningiomas that contain significant components of fat, bone, cartilage, or myxoid tissue. A review of the literature on spinal metaplastic meningioma using PubMed based on a search with the keywords "metaplastic meningioma" and "spinal" yielded only 2 reported cases [14, 15]. These reports on metaplastic meningiomas stated that "the tumor was very hard" and that an "ultrasonic aspirator is not useful to remove this severely ossified tumor." The 2 terms, calcification and ossification, are sometimes misused because they cannot be distinguished using CT. However, Chang *et al.* provided a clear description of the difference between these 2 terms [15]. As they described, calcified meningioma is more of a radiographic description than a histopathological diagnosis. An ossified meningioma is a tumor with a bony texture that is difficult to resect intraoperatively. Although the etiology of ossified meningiomas remains unknown, Mannoji *et al.* suggested that some types of mesenchymal stem cells, which may be derived from the neural crest, differentiate into osteoblasts and form bone [14]. Therefore, our case of metaplastic meningioma was classified as calcified meningioma, and not ossified meningioma. This challenging case was successfully resected.

Limitations. This was a single-center, retrospective, observational study in a limited number of consecutive patients with spinal meningioma. Although this study did not generate positive data showing correlations among consistency, CT values, and the histopathological subtypes of spinal meningiomas, the results might be valuable due to the inclusion of consecutive patients, and the definition of tumor consistency using an objective index of ultrasonic surgical aspirator output. Further studies in larger cohorts are needed to confirm the true predictors of the tumor consistency of spinal meningiomas.

In conclusions, the consistency of the tumor is an important predictive factor that contributes to the level of difficulty of surgery for resecting spinal meningiomas. Our study hypothesized that CT values would be an indicator of spinal meningioma consistency. However, this study could not prove a statistically significant correlation between consistency and the CT value of the spinal meningioma, although the CT values were considerably higher in the hard group. There was also no significant correlation between tumor consistency and histopathological subtype. In contrast, psammomatous meningiomas had significantly higher CT values than meningothelial meningiomas. Moreover, spinal meningiomas with histological psammoma bodies do not necessarily have a hard texture. With further study, these results might be helpful in the perioperative management of spinal tumors.

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