Morphometric Analysis of Subaxial Cervical Spine with Myelopathy: A Comparison with the Normal Population

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Abstract:

Introduction: The specific morphology and differences between patients with cervical spondylotic myelopathy (CSM) and those with normal spines remain unclear. This study aimed to evaluate and determine the features of cervical spine morphology on reconstructive CT.

Methods: We investigated that axial reconstructive CT scans of the cervical spine at C3 to C7 were obtained from 309 individuals (97 CSM patients and 212 controls). Those of the optimal pedicle diameter were selected, and the following parameters were measured: (a) sagittal diameter of the spinal canal (b) transverse diameter of the spinal canal, (c) pedicle width, (d) lateral mass thickness, (e) transverse diameter of the foramen, (f) sagittal diameter of the vertebral body, and (g) transverse diameter of the vertebral body. The following ratios were calculated using these values: the sagittal-transverse ratio and the canal-body ratio.

Results: Most parameters differed significantly between the sexes in both groups. The parameters without the mean sagittal diameter of the spinal canal were significantly larger in men than in women. However, the mean sagittal diameter of the spinal canal did not differ significantly between the sexes in CSM patients. The sagittal-transverse ratio and canal-body ratio were significantly smaller in the CSM patients at all levels. According to relative operating characteristic curves of the sagittal diameter of the spinal canal, sagittal-transverse ratio, and canal-body ratio, the sensitivity from C3 to C7 in both sexes was > 60% at the threshold. In men, the specificity from C3 to C7 was also >60% at the threshold.

Conclusions: The morphometry of the sagittal diameter of the spinal canal, sagittal-transverse ratio, and canal-body ratio on axial reconstructive CT images appears useful for distinguishing cervical spinal canal stenosis involving myelopathy.

Keywords:

cervical spinal canal, cervical spondylotic myelopathy, cervical spinal canal stenosis, cervical spine morphology

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Introduction

There have been many reports on the measurement of cervical spinal canal dimensions on radiography and computed tomography (CT) scans[1-16]. Developmental spinal canal stenosis (DCS) has been identified to be an important predisposing factor for cervical spondylotic myelopathy (CSM)[1,2,4]. However, no accurate criteria for DCS have been established[8,9,12]. Furthermore, whether there is any specific bony morphology in the cervical spine that can predict cervical myelopathy in patients with DCS remains unknown.

Posterior spinal instrumentation is used to treat various cervical spinal disorders and associated spinal instability. It requires a highly skilled operator and detailed information on bony parameters in the cervical spine. Several radiological studies have determined standard values for bony parameters in the cervical spine, including pedicle width, lateral mass thickness, and laminar thickness[9,16-26]. However, the specific morphology and differences between patients with and without CSM remain unclear.

The purpose of this study was to compare the morphological features of the cervical spine seen on reconstructed CT scans between patients with and without CSM.

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Table 1. Characteristics of Patients with and without Cervical Spondylotic Myelopathy.

	Men			Women		
	CSM	Normal	P-value	CSM	Normal	P-value
Patients, n	63	106		34	106	
Age (years)	65.1±11.2	64.8±12.2	0.97	63.6±13.4	60.2±12.0	0.09
Body weight (kg)	61.0±8.2	64.6±9.2	0.08	55.0±8.8	53.4±8.3	0.38
Height (cm)	160.5±7.2	165.1±5.7	‡	151.1±7.7	153.3±5.8	0.14

Data are expressed as the mean and standard deviation. ‡Significant difference between men and women, P<0.001. CSM, cervical spondylotic myelopathy.

Materials and Methods

The ethics committee at our institution approved this study. In total, 309 patients (97 with CSM, 212 controls) underwent axial reconstructed CT of 1545 cervical vertebrae. The CSM group included 63 men (mean age 65.1 [range, 39-82] years) and 34 women (mean age 63.6 [range, 37-79] years). The control group comprised 106 men (mean age 64.8 [range, 30-87] years) and 106 women (mean age 60.2 years [range, 32-82] years; Table 1). The controls were patients who underwent enhanced CT at other departments in our hospital for asymptomatic brain diseases, such as cerebral aneurysm, brain tumor, and occult cerebral infarction. Exclusion criteria for the control group were age < 30 years and abnormal height (standard height≦-2SD) or body weight (BMI≧35), ossification of the posterior longitudinal ligament, rheumatoid arthritis, spinal tumor, a past history of consulting a spine surgeon, prior spinal trauma, or previous spinal surgery. There was no significant difference in body weight between the two groups. However, the mean height of the men in the CSM group was significantly lower than that of those in the control group (Table 1). All patients with CSM underwent cervical decompressive surgery at our hospital.

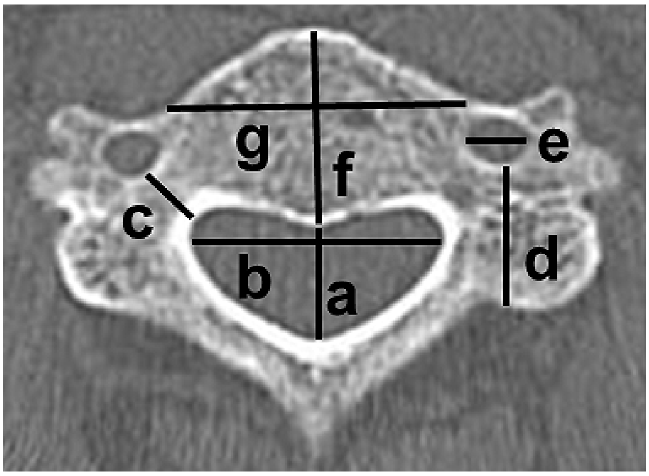

Figure 1. Axial reconstructed computed tomography image showing the following bony cervical spine parameters: (a) sagittal spinal canal diameter; (b) transverse spinal canal diameter; (c) pedicle width; (d) lateral mass thickness; (e) transverse foraminal diameter; (f) sagittal vertebral body diameter; and (g) transverse vertebral body diameter.

Radiographic assessment

Axial images parallel to the endplates of each vertebral body were obtained from C3 to C7. The following parameters were measured on images with an optimal pedicle diameter: sagittal and transverse spinal canal diameters; pedicle width; lateral mass thickness; transverse foraminal diameter; and sagittal and transverse vertebral body diameters (Fig. 1)[15]. The following ratios were calculated using these values: the sagittal-transverse ratio (sagittal spinal canal diameter divided by the transverse spinal canal diameter) and the canal-body ratio (sagittal spinal canal diameter divided by the sagittal vertebral body diameter).

Statistical analysis

Statistical analysis was performed using StatView version 5.0 software (SAS Institute Inc., Cary, NC) in the R computing environment (R Foundation for Statistical Computing, Vienna, Austria). The Mann-Whitney *U* test was used to analyze the differences between the CSM group and the control group. A P-value < 0.05 was considered statistically significant. The study dimensions were analyzed in both groups using receiver-operating characteristic (ROC) curves.

Results

The values for all spinal parameters measured are shown in Table 2. Most elements were significantly larger in men than in women in both study groups. Although the mean sagittal spinal canal diameter did not differ significantly between men (11.5 mm) and women (11.6 mm) in the CSM group, it was larger in men than in women in the control group.

Sagittal spinal canal diameter

The axial cervical spine parameters at each level are shown in Tables 3 and 4. The mean sagittal spinal canal diameter at all cervical levels was significantly smaller in the CSM group (range, 11.0-12.1 mm) than in the control group (range, 12.7-13.5 mm), regardless of sex. The smallest diameter was at C4 in both study groups.

Table 2. Sex-related Differences in Spinal Parameters between CSM Patients and Normal Controls *.

	Spinal canal				Pedicle		Lateral mass		Foramen		Vertebral body				Total transverse diameter of vertebra		Ratio			
	Sagittal		Transverse		Width		Thickness		Transverse		Sagittal		Transverse				Sagittal/ transverse		Canal/ body	
CSM																				
men (mm)	11.5±0.9		23.6±1.6	‡	5.7±1.0	‡	11.7±1.6	†	6.2±0.9	#	17.4±1.5	‡	26.0±3.2	‡	37.5±3.4	#	0.49±0.05	†	0.66±0.08	‡
women (mm)	11.6±1.3		23.0±1.9		5.2±1.0		11.3±1.9		6.1±0.9		16.0±1.5		23.5±2.8		35.1±3.2	$	0.51±0.08		0.74±0.14	
Normal																				
men (mm)	13.3±1.3	†	24.7±1.8	‡	5.7±1.0	‡	11.8±1.5	‡	6.5±0.7	‡	16.7±1.4	‡	26.2±3.1	‡	39.4±3.4	#	0.54±0.06	‡	0.79±0.11	‡
women (mm)	13.0±1.1		23.5±1.7		4.7±1.0		10.8±1.5		6.3±0.9		14.9±1.5		23.6±2.8		36.6±3.1	$	0.55±0.06		0.88±0.13	

* Data are expressed as the means±SD.
† Significant difference between sexes, P<0.05.
‡ Significant difference between sexes, P<0.001.
# No significant difference between CSM and normal in men, P=0.638
$ No significant difference between CSM and normal in women, P=0.416

Table 3. Summary of Cervical Spine Parameters in Men*.

		Spinal canal (mm)				Pedicle (mm)		Lateral mass (mm)		Foramen (mm)		Vertebral body (mm)				Ratio			
		Sagittal		Transverse		Width		Thickness		Transverse		Sagittal		Transverse		Sagittal/ transverse		Canal/body	
C3	CSM	11.7±0.8	‡	22.1±1.2	‡	5.4±1.0	†	11.7±1.6	†	6.1±0.9	‡	16.8±1.1	†	23.8±1.6	†	0.53±0.05	‡	0.70±0.07	‡
	Normal	13.4±1.2		23.0±1.2		5.1±0.7		11.9±1.5		6.5±0.7		16.4±1.1		24.2±1.4		0.58±0.05		0.82±0.11	
C4	CSM	11.0±0.9	‡	23.8±1.3	‡	5.2±0.8		11.5±1.4	†	6.2±0.9	‡	17.3±1.2	‡	23.7±1.6		0.46±0.05	‡	0.64±0.08	‡
	Normal	12.7±1.2		24.8±1.4		5.2±0.8		11.8±1.4		6.6±0.8		16.4±1.3		24.1±1.6		0.51±0.05		0.78±0.10	
C5	CSM	11.2±0.8	‡	24.5±1.2	‡	5.6±0.8		12.4±1.4		5.9±0.9	‡	17.1±1.4	‡	25.3±2.0		0.46±0.04	‡	0.66±0.08	‡
	Normal	13.2±1.2		25.9±1.6		5.5±0.8		12.3±1.3		6.4±0.7		16.2±1.3		25.2±2.0		0.51±0.05		0.82±0.11	
C6	CSM	11.5±0.9	‡	24.4±1.4	‡	5.8±0.9		12.3±1.4		6.3±1.0	†	17.9±1.7	‡	26.5±2.1		0.47±0.04	‡	0.65±0.10	‡
	Normal	13.3±1.3		25.5±1.6		5.8±0.9		12.5±1.4		6.6±0.7		17.1±1.3		26.8±2.1		0.52±0.05		0.78±0.11	
C7	CSM	12.0±0.9	‡	23.3±1.5	‡	6.6±0.9	†	10.4±1.3				18.2±1.6	†	30.7±2.0		0.52±0.05	‡	0.66±0.08	‡
	Normal	13.5±1.3		24.1±1.6		6.8±0.9		10.6±1.3				17.6±1.5		30.8±2.2		0.56±0.05		0.77±0.11	

*Data are expressed as the means±SD.
† Significant difference between CSM patients and normal controls, P<0.05.
‡ Significant difference between CSM patients and normal controls, P<0.001.

Transverse spinal canal diameter

Mean transverse spinal canal diameter was 23.6 mm in men and 23.0 mm in women in the CSM group and 24.7 mm and 23.5 mm, respectively, in the control group. The sex difference was statistically significant in both study groups (Table 2). Mean transverse spinal canal diameter at each level in men was significantly different (P < 0.001) between the two groups, but not in women, except at C3.

Pedicle width

The mean pedicle width was significantly different between the sexes in both study groups (Table 2). The mean value was 5.1-6.8 mm in men and 4.1-6.0 mm in women. The smallest mean pedicle width was 5.2 mm in men and 4.6 mm in women at C4 in the CSM group and 5.1 mm in men and 4.1 mm in women at C3 in the control group. Mean pedicle width from C4 to C6 in men did not differ significantly between the two groups (Table 3); however, the mean pedicle width from C3 to C6 was significantly greater in women in the CSM group than in those in the control group (Table 4).

Lateral mass thickness

Mean lateral mass thickness from C5 to C7 was not significantly different in men between groups (Table 3). In contrast, the mean lateral mass thickness at all levels was significantly greater in women in the CSM group than in those in the control group (Table 4).

Transverse foraminal diameter

Mean foraminal diameter was significantly smaller in the CSM group than in the control group, except at C6 in women (Table 3, 4).

Table 4. Summary of Cervical Spine Parameters in Women*.

		Spinal canal				Pedicle		Lateral mass		Foramen		Vertebral body				Ratio			
		Sagittal		Transverse		Width		Thickness		Transverse		Sagittal		Transverse		Sagittal/ transverse		Canal/body	
C3	CSM (mm)	11.8±1.5	‡	21.1±1.3	‡	4.9±1.1	‡	11.5±1.7	†	5.9±0.6	‡	15.3±1.4	†	21.8±1.2		0.56±0.08	†	0.79±0.16	‡
	Normal (mm)	13.1±1.1		22.2±1.3		4.1±0.8		11.2±1.4		6.3±0.7		14.5±1.3		21.8±1.5		0.59±0.06		0.92±0.13	
C4	CSM (mm)	11.3±1.4	‡	23.1±1.8		4.6±0.8	‡	11.3±1.6	†	6.1±0.8	†	15.6±1.3	‡	21.4±1.4		0.49±0.07	†	0.73±0.13	‡
	Normal (mm)	12.7±1.1		23.5±1.3		4.2±0.8		10.9±1.2		6.5±0.9		14.7±1.4		21.7±1.8		0.54±0.06		0.87±0.13	
C5	CSM (mm)	11.5±1.2	‡	24.1±1.6		5.2±0.9	‡	11.6±2.0	†	6.1±1.2	†	15.7±1.4	‡	22.3±1.7		0.48±0.07	‡	0.74±0.12	‡
	Normal (mm)	12.9±1.2		24.4±1.5		4.7±0.7		11.1±1.5		6.3±0.9		14.5±1.5		22.7±1.8		0.53±0.05		0.90±0.13	
C6	CSM (mm)	11.5±1.2	‡	24.1±1.5		5.3±0.9	‡	12.2±1.8	‡	6.2±0.7		16.5±1.6	‡	24.1±1.6		0.48±0.05	‡	0.71±0.12	‡
	Normal (mm)	12.9±1.1		24.3±1.5		4.8±0.8		11.3±1.3		6.3±0.9		15.3±1.5		24.2±1.7		0.53±0.05		0.85±0.12	
C7	CSM (mm)	12.1±1.2	‡	22.4±1.3		6.0±1.0		9.9±1.4	†			16.7±1.6	‡	28.0±1.5		0.54±0.06	†	0.74±0.14	†
	Normal (mm)	13.2±1.0		22.9±1.5		5.8±0.8		9.5±1.1				15.6±1.3		27.7±2.0		0.58±0.05		0.85±0.10	

* Data are expressed as the means±SD.
† Significant difference between CSM patients and normal controls, P<0.05.
‡ Significant difference between CSM patients and normal controls, P<0.001.

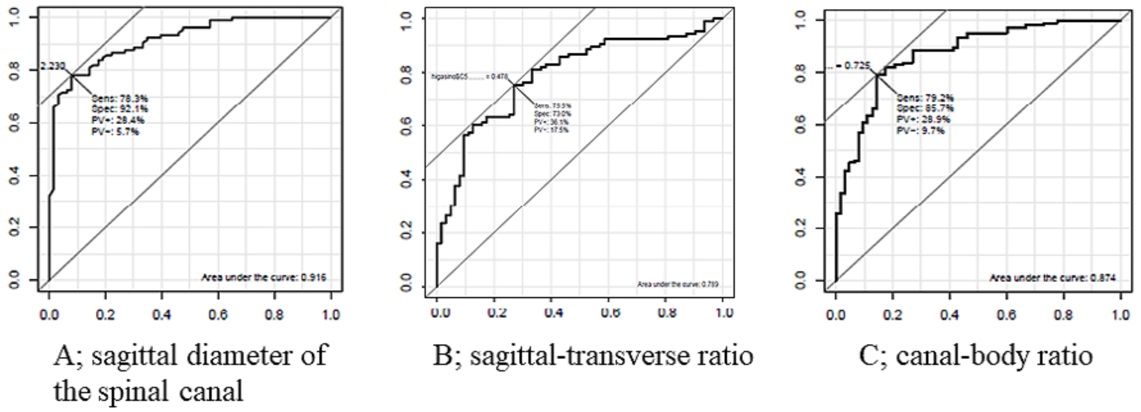

Figure 2. Receiver-operating characteristic curves at C5 in men. (A) Sagittal spinal canal diameter. (B) Sagittal-transverse ratio. (C) Canal-body ratio.

Sagittal vertebral body diameter

Overall mean sagittal vertebral body diameter differed significantly between the sexes in both groups (Table 2). This diameter was significantly greater at all levels in the CSM group than in the control group (Table 3, 4).

Transverse vertebral body diameter

Overall mean transverse vertebral body diameter differed significantly between the sexes in both groups (Table 2). However, there was no significant between-group difference at any level, except at C3 in men (Table 3, 4).

Sagittal-transverse and canal-body ratios

Overall mean sagittal-transverse and canal-body ratios differed significantly between the sexes in both groups (Table 2). Both ratios were significantly smaller at all levels in the CSM group than in the control group (Table 3, 4).

Total transverse diameter of vertebra

The overall mean total transverse diameter of vertebra did not differ significantly between the CSM group and the normal group in both sexes (Table 2).

ROC curves

ROC curves were constructed for the sagittal spinal canal diameter and the sagittal-transverse and canal-body ratios to determine their diagnostic value in CSM. The ROC curves for the C5 level in men are shown as an example in Fig. 2. When a sagittal spinal canal diameter of < 12.2 mm was used as the threshold to indicate CSM, the sensitivity was 78.3%, and the specificity was 92.1%. When a sagittal-transverse ratio of < 0.48 was used as the threshold to indicate CSM, the sensitivity was 75.5%, and the specificity was 73.0%. When a canal-body ratio of < 0.73 was used as the threshold to indicate CSM, the sensitivity was 79.2%, and the specificity was 85.7%. Table 5 shows the results for the thresholds overall, the sensitivity and specificity at the point

Table 5. Cut-off Points for Cervical Spine Parameters.

	Men					Women			
	Cut-off value	Sensitivity (%)	Specificity (%)	AUC		Cut-off value	Sensitivity (%)	Specificity (%)	AUC
	Sagittal spinal canal diameter (mm)					Sagittal spinal canal diameter (mm)			
C3	12.4	79.2	81.0	0.87	C3	12.7	65.1	76.5	0.75
C4	11.8	74.5	87.3	0.89	C4	11.1	90.6	55.9	0.77
C5	12.2	78.3	92.1	0.92	C5	11.4	90.6	61.8	0.81
C6	12.2	84.9	87.3	0.90	C6	12.5	60.4	94.1	0.82
C7	12.9	64.2	88.9	0.84	C7	12.5	75.5	70.6	0.75
	Sagittal/ transverse ratio					Sagittal/ transverse ratio			
C3	0.57	64.2	79.4	0.77	C3	0.54	81.1	47.1	0.62
C4	0.49	70.8	73.0	0.78	C4	0.47	89.6	44.1	0.68
C5	0.48	75.5	73.0	0.79	C5	0.49	79.2	67.6	0.75
C6	0.48	84.0	69.8	0.80	C6	0.50	75.5	73.5	0.78
C7	0.54	72.6	68.3	0.73	C7	0.57	60.4	70.6	0.69
	Canal/body ratio					Canal/body ratio			
C3	0.74	77.4	74.6	0.83	C3	0.75	90.6	55.9	0.76
C4	0.74	68.9	93.7	0.87	C4	0.69	93.4	55.9	0.78
C5	0.73	79.2	85.7	0.87	C5	0.74	91.5	64.7	0.82
C6	0.69	82.1	71.4	0.83	C6	0.72	89.6	67.6	0.83
C7	0.73	67.0	85.7	0.79	C7	0.75	87.7	61.8	0.77

AUC, area under the curve.

nearest to the upper left corner of the graph, and the area under the curve (AUC) (Table 5). The sensitivity of all parameters in both sexes was >60%, and the specificity of all parameters in men was >68%.

Discussion

The main findings of this study were as follows: sagittal spinal canal narrowing was a static bony anatomic factor and a critical morphologic feature of CSM; the sagittal-transverse ratio was useful for assessment of spinal canal stenosis, and pedicle width and lateral mass thickness were larger in women in the CSM group than in women in the control group.

The bony component of the cervical spine was larger in men than in women in both groups. On the other hand, the sagittal spinal canal diameter was almost the same in men and women in the CSM group. Our AUC results indicate that the sagittal spinal canal diameter is a critical morphological feature when screening for spinal canal stenosis and risk factor for myelopathy. The mean sagittal spinal canal diameter was ≤ 12 mm in all patients in the CSM group, except at C7 in women.

Our findings indicate that the sagittal-transverse ratio is also a useful measurement for detecting spinal canal stenosis and a risk factor for myelopathy in both sexes. A sagittal-transverse ratio < 0.5 at C4 to C6 may predict cervical myelopathy, although the AUC showed that this ratio is not as useful as the sagittal spinal canal diameter or the canal-body ratio.

The pedicle width and lateral mass thickness were larger at all levels in women in the CSM group than in those in the control group but not significantly different in men. The transverse foraminal diameter was smaller in both men and women in the CSM group. All osseous parameters, including the pedicle, lateral mass, and vertebrae, were larger at most cervical levels in women in the CSM group than in those in the control group (Fig. 3).

Many authors have reported sex differences in cervical spine morphology[14,16,18,19]. In 1956, Wolf et al. pointed out that cord compression is likely to be present when the sagittal spinal canal diameter is ≤ 10 mm[1]. Payne and Spillane[2] reported that the initial size of the canal was a factor in myelopathy, while Hinck et al[4] defined "developmental stenosis" as a factor. Most patients with CSM have been found to have a small sagittal diameter of the cervical spinal canal[3-7,27,28]. However, DCS is still controversial in terms of its definition and period of onset because the specific bony morphology of the cervical spine has not been clarified in the average population or patients with cervical myelopathy. Therefore, the results of our study can be used to confirm the cervical spine morphology in patients with CSM and to determine the features of CSM in relation to those with a healthy spine.

Vertebral malformation occurs in humans when somitogenesis is disrupted at the embryonic stage. For example, congenitally fused cervical vertebrae are a primary malformation of the chorda dorsalis and are attributed to defects that take place during the development of the occipital and cervical somites[32]. Vertebral ossification occurs within one

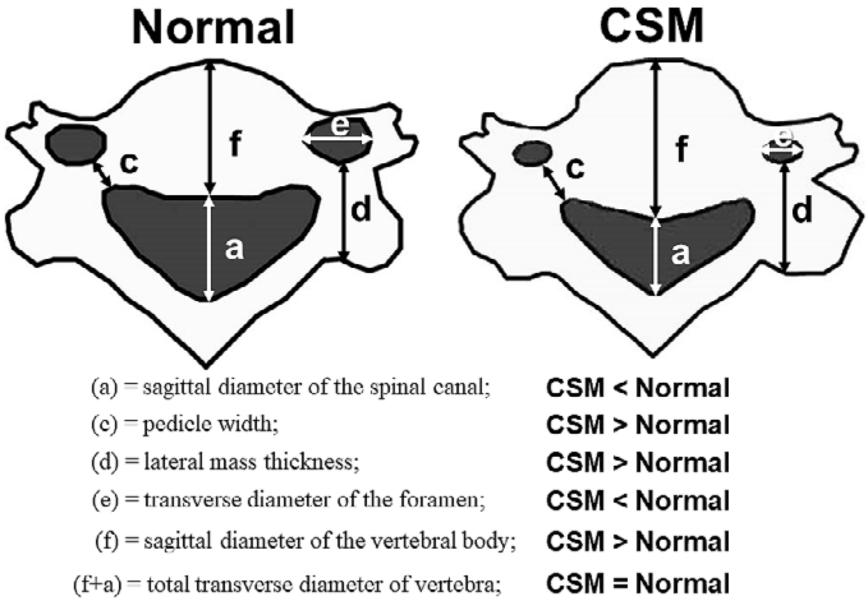

Figure 3. Specific differences in bony morphology in women with and without cervical spondylotic myelopathy.

center in the centrum and each half of the neural arch during bone formation in humans. Growth of the posterior elements of the vertebrae, such as the lamina and facet joint, is marked up to the age of approximately 13 years, at which time the osseous tissues finally fuse[29,30]. For example, stenosis of the spinal canal in achondroplasia is secondary to abnormalities of endochondral ossification, which is responsible for the formation of the vertebral bone structures[31]. Previous research in different ethnic groups has shown that patients with cervical myelopathy typically have a sagittal spinal canal diameter < 12 mm and that this diameter is 2.5 mm smaller in Japanese men than in Caucasian adults[1-5,12,13,18,19,26,27]. A previous study also indicated that spinal canal stenosis might have a genetic predisposition[13].

Conclusion

Our results suggest that the narrowing of the sagittal spinal canal diameter is a static bony anatomical factor that is a critical feature of CSM morphology. This study also demonstrated the value of calculating the sagittal-transverse ratio of the spinal canal on axial reconstructive CT images. Most osseous parameters in the cervical spine were larger in patients with CSM than in controls. The results of this study may be useful for determining the morphology and features of the cervical spine in patients with CSM.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

Ethical Approval: N/A

Author Contributions: Shunichi Toki, Kosaku Higashino and Hiroaki Manabe drafted this report. Kosuke Sugiura, Fumitake Tezuka, Kazuta Yamashita, Yoichiro Takata, Toshinori Sakai, and Toru Maeda collected the patient data. Natsuo Yasui and Koichi Sairyo made significant revisions to the manuscript. All authors approved the final version of the manuscript submitted for publication.

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