The Radiological Characteristics of Degenerative Cervical Kyphosis with Cervical Spondylotic Myelopathy

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Abstract:

Introduction: In this study, we aim to describe the radiological characteristics of degenerative cervical kyphosis (DCK) with cervical spondylotic myelopathy (CSM) and discuss the relationship between DCK and the pathogenesis of spinal cord dysfunction.

Methods: In total, 90 patients with CSM hospitalized in our center from September 2017 to August 2022 were retrospectively examined in this study; they were then divided into the kyphosis group and the nonkyphosis group. The patients' demographics, clinical features, and radiological data were obtained, including gender, age, duration of illness, cervical Japanese Orthopaedic Association (JOA) score, cervical lordosis (CL), height of intervertebral space, degree of wedging vertebral body, degree of osteophyte formation, degree of disc herniation, degree of spinal cord compression, and anteroposterior diameter of the spinal cord. In the kyphosis group, kyphotic segments, apex of kyphosis, and segmental kyphosis angle were recorded. Radiological characteristics between the two groups were also compared. Correlation analysis was performed for different spinal cord compression types.

Results: As per our findings, the patients in the kyphosis group showed more remarkable wedging of the vertebral body, more severe anterior compression of the spinal cord, and a higher degree of disc herniation, while the posterior compression of the spinal cord was relatively mild when compared with the nonkyphosis group. CL was related to the type of spinal cord compression, as cervical kyphosis is an independent risk factor for anterior spinal cord compression.

Conclusions: DCK might play a vital role in the pathogenesis of spinal cord dysfunction. In patients with DCK, it was determined that the anterior column is less supported, and more severe anterior spinal cord compression is present. The anterior approach is supposed to be preferred for CSM patients with DCK.

Keywords:

degenerative cervical kyphosis, cervical spondylotic myelopathy, radiography, compression

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Introduction

To maintain horizontal gaze, humans have developed physiological cervical lordosis. Cervical kyphosis is the loss of physiological lordosis with the formation of a reverse arc to the back, which can affect an individual's quality of life. With the increase use of electronic devices in recent years, prolonged neck flexion is seen to increase the incidence of cervical kyphosis[1)].

Cervical spondylotic myelopathy (CSM) has been identified as the most common cause of spinal cord dysfunction among the elderly[2)], accounting for 25% of cases[3)]. Therefore, the number of patients with concurrent degenerative cervical kyphosis (DCK) and CSM is expected to grow in the future, which spine surgeons should focus on. However, to the best of our knowledge, there are yet no research studies describing the radiological characteristics of DCK with CSM.

In patients with DCK, the cervical spinal cord is shifted anteriorly and abutted on the posterior wall of the apical vertebral body[4)]. When the segmental kyphosis angle exceeded 7.5°, the intramedullary pressure would increase sig-

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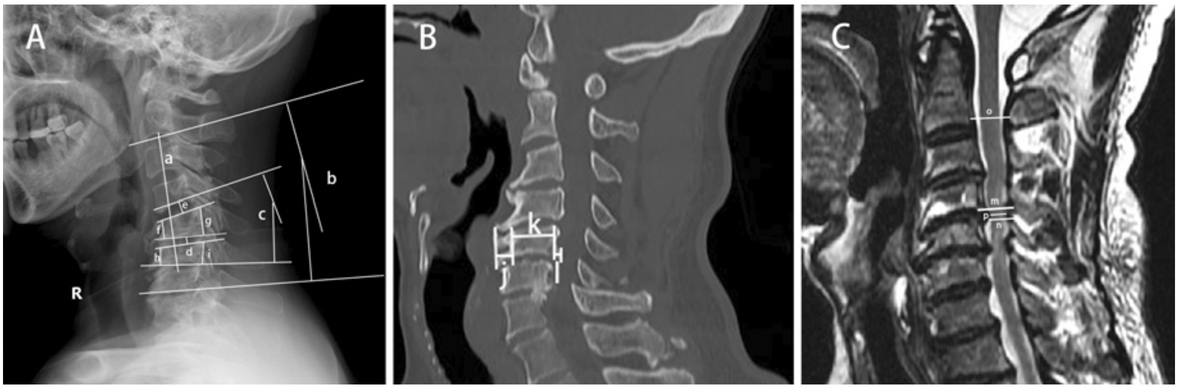

Figure 1. Radiological data: (A) Data in the cervical X-ray film. (a) Connecting midpoint on the inferior surface of C2 vertebra and midpoint on the superior surface of C7 vertebra. (b) Cervical lordosis: the angle between the two vertical lines of the two tangent lines under the inferior endplates of C2 and C7 vertebrae. (c) Segmental kyphosis: the angle between the two vertical lines of the two tangent lines under the inferior endplates of the first and the last vertebrae. The angle was deemed positive if the two tangents crossed behind the cervical spine, whereas it was negative if they crossed in front of the spine. (d) Middle disc height of the target level. (e) Middle disc height of the normal adjacent level. (f) & (h) Anterior heights of the degenerative vertebrae. (g) & (h) Posterior heights of the degenerative vertebrae. (B) Data in the cervical CT (sagittal reconstruction). (j) Length of the anterior osteophyte dimension. (k) Anteroposterior diameter of the vertebral body. (l) Length of the posterior osteophyte dimension. (C) Data in the cervical MRI. (m) Length between the posterior aspect of the vertebra and the spinous process root at the apex or responsible level. (n) Length between the anterior aspect of the spinal cord and the spinous process root at the apex or responsible level. (o) Length between the posterior aspect of the vertebra and the spinous process root at C2 level. (p) Length between anterior and posterior aspects of the spinal cord at the apex or responsible level. d/e=Height of intervertebral space. (f/g+h/i) /2=Degree of wedging vertebral body. j/k=Anterior osteophyte dimension. l/k=Posterior osteophyte dimension. (m-n) /o=Anterior spinal cord compression dimension of the spinal cord. (n-p) /o=Posterior spinal cord compression dimension of the spinal cord. p/o=Anteroposterior diameter of the spinal cord.

nificantly[5]. However, there is still no conclusive evidence on whether kyphotic deformity would affect the spinal cord compression behavior in CSM. Moreover, cervical alignment has been identified to be an essential factor in determining the surgical approach, and whether anterior or posterior approach is more beneficial for CSM patients with DCK remains controversial[6-8]. Thus, the attention to DCK should be focused in the treatment of CSM.

Based on the abovementioned issues, we examined 30 CSM patients with DCK and 60 CSM patients without DCK; we then compared the radiological features between the two groups and described the effect of cervical alignment on spinal cord compression conditions. The aim is to illustrate the radiological characteristics of CSM patients with DCK, potentially providing insights into elucidating the pathogenesis of spinal cord dysfunction and determining the surgical approach.

Materials and Methods

Subjects

In total, 90 patients who had spinal cord dysfunction as the chief complaint and diagnosed as CSM in our institute from September 2017 to August 2022 were randomly enrolled in this study.

The inclusion criteria were as follows: (1) those who are above 40 years old and (2) those with complete cervical radiological records, including X-ray films, computed tomography (CT), and magnetic resonance imaging (MRI).

Meanwhile, the exclusion criteria were as follows: (1) ossification of the posterior longitudinal ligament (PLL), (2) history of cervical spine trauma or surgery, (3) evidence of cervical neoplastic or infectious disease, (4) atlantoaxial disorders, and (5) osseous developmental anomaly, such as Klippel-Feil syndrome and developmental cervical stenosis.

As per the classification of cervical alignment, patients were divided into the kyphosis group (30 patients) and the nonkyphosis group (60 patients). In detail, *line a* was defined as the connecting line between the midpoint of C2 inferior endplate and the midpoint of C7 superior endplate (Fig. 1A). Patients with any centroids of C3-C6 vertebrae located ≥2 mm posterior to *line a* were classified as the kyphosis group, while the nonkyphosis group consisted the remaining patients.

The demographics (including gender, age, and duration of illness), cervical Japanese Orthopedic Association (JOA) score, and radiological data (as described below) were collected. The project was reviewed and approved by the Institutional Review Board of our institute.

Radiological data

Three spine surgeons measured the following radiological data three times at different times; thereafter, data with significant discrepancies in terms of measurement results were judged by a fourth experienced spinal surgeon. The average was used for statistical analysis to avoid measurement bias.

Cervical X-ray film (lateral radiograph)

(1) Kyphotic segments: vertebrae with centroids located ≥ 2 mm posterior to *line a*.
(2) Apex of kyphosis: the cervical vertebra or intervertebral disc farthest from *line a*.
(3) Segmental kyphosis angle: the Cobb angle between the superior endplate of the first kyphotic vertebra and the inferior endplate of the last one.
(4) Cervical lordosis (CL): the Cobb angle between the C2 inferior endplate and the C7 inferior endplate.
(5) Height of intervertebral space[6]: the height ratio between degenerative and normal intervertebral space. In the kyphosis group, the target disc was the apex disc, while in the nonkyphosis group, the target disc was the most degenerated intervertebral space.
(6) Degree of wedging vertebral body: the ratio of anterior height to posterior height of the target vertebra. In the kyphosis group, the target vertebra was the apex vertebra or the average value of the two vertebrae adjacent to the apex disc, while in the nonkyphosis group, the target vertebra was the vertebra corresponding to the kyphosis group.

(1)-(3) were collected only in the kyphosis group, whereas (4)-(6) were collected in both groups (Fig. 1A).

Cervical CT (sagittal reconstruction)

Degree of osteophyte formation[7]: the ratio of the length of anterior or posterior osteophyte to the anteroposterior diameter of the corresponding vertebral body in the most degenerated level (Fig. 1B).

Cervical MRI

(1) Degree of disc herniation[8]: 0, disc without herniation; I, the nucleus pulposus herniated through the annulus fibrosus but not PLL; II, herniated through the PLL but not dura mater; III, herniated through the dura mater; or IV, herniation is no longer contiguous with the disc.
(2) Degree of spinal cord compression: the ratio of the depth of anterior or posterior spinal cord compression to the anteroposterior diameter of the spinal canal at C2 level.
(3) Anteroposterior diameter of the spinal cord: the ratio of the diameter of the spinal cord at the most severely compressed level to the anteroposterior diameter of the spinal canal at C2 level (Fig. 1C).

Statistical analysis

Quantitative variables were presented as the mean±standard deviation. The Kolmogorov-Smirnov test was used to confirm a normal distribution. Normally distributed variables were analyzed using Student's t-test, whereas non-normally distributed ones were analyzed using Mann-Whitney U test. Qualitative data were presented as percentages and analyzed using χ^2 tests. The correlations between the degree of spinal cord compression and demographics and radiological data were analyzed using linear correlation or rank correlation. Furthermore, multivariate regression was performed for statistically significant variables. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) (version 26.0; SPSS Inc., Chicago, IL, USA). P<0.05 was considered as statistically significant.

Results

Demographics and clinical features

As per our findings, there were 23 males and 7 females in the kyphosis group, while 38 males and 22 females were in the nonkyphosis group. The ratio of gender was not significantly different between the two groups (P=0.202). The age of patients in the kyphosis group ranged from 40 to 81 (58.10±10.77) years old, whereas the age in the nonkyphosis group ranged from 42 to 76 (59.78±8.38) years old (P=0.417). The duration of illness was 3.81±6.19 years in the kyphosis group and 1.73±2.06 years in the nonkyphosis group (P=0.083). The cervical JOA score was 15.07±1.05 and 15.23±1.05 in the kyphosis group and the nonkyphosis group, respectively (P=0.204) (Table 1).

Characteristics of kyphosis

CL was (−9.90±12.18)° and (21.36 ±9.72)° in the kyphosis group and nonkyphosis group, respectively (P<0.001, Fig. 2A). In the kyphosis group, segmental kyphosis angle was (−13.10±10.34)°. The kyphotic segments lie in the C3-C4 in 6 of 30 cases (20.0%), C3-C5 in 11 cases (36.6%), C3-C6 in 8 cases (26.6%), and C4-C6 in 5 cases (16.6%). The apex of kyphosis lies in the C3 in 2 cases (6.7%), C3/C4 in 3 cases (10.0%), C4 in 14 cases (46.7%), C5 in 10 cases (33.3%), and C5/C6 in 1 case (3.3%) (Table 1).

Degree of cervical degeneration

In 80% of patients, the kyphotic apex was noted to lie in the C4-C5 in the kyphosis group; thus, C4 and C5 were selected as representatives to measure the degree of the wedge and then averaged. The degree of wedging vertebral body was 0.82±0.08 and 0.93±0.06 in the kyphosis group and the nonkyphosis group, respectively (P<0.001, Fig. 2C). The height of intervertebral space was 0.72±0.19 and 0.79±0.13 in the kyphosis group and the nonkyphosis group, respectively (P=0.071, Fig. 2B). The degrees of anterior and posterior osteophyte were 0.32±0.16 and 0.12±0.04 in the kyphosis group, while they were 0.26±0.10 and 0.13±0.07 in the nonkyphosis group, both of which were not statistically different (P=0.082 and 0.360, Fig. 2D-E). Disc herniation was determined to be II degree in 7 of 30 cases (23.3%), III degree in 14 cases (46.7%), and IV degree in 9 cases (30.0%) in the kyphosis group; meanwhile, in the nonkyphosis

Table 1. Comparing the Data between the kyphosis Group and the Nonkyphosis Group.

		All cases	Kyphosis group	Nonkyphosis group	P-value
		$\bar{x}$±SD/n (%)	$\bar{x}$±SD/n (%)	$\bar{x}$±SD/n (%)	
Gender	Male	61 (67.8%)	23 (76.7%)	38 (63.3%)	0.202
	Female	29 (32.2%)	7 (23.3%)	22 (36.7%)	
Age (years)		59.22±9.22	58.10±10.77	59.78±8.38	0.417
Duration of illness (years)		2.42±4.03	3.81±6.19	1.73±2.06	0.083
Cervical JOA score		15.18±1.04	15.07±1.05	15.23±1.05	0.204
Cervical lordosis (°)		10.94±18.18	−9.90±12.18	21.36±9.72	0.000**
Segmental kyphosis angle (°)			−13.10±10.34		
Height of intervertebral space		0.77±0.16	0.72±0.19	0.79±0.13	0.071
Degree of wedging vertebral body		0.89±0.09	0.82±0.08	0.93±0.06	0.000**
Degree of anterior osteophyte		0.28±0.13	0.32±0.16	0.26±0.10	0.082
Degree of posterior osteophyte		0.13±0.07	0.12±0.04	0.13±0.07	0.360
Degree of disc herniation	II	32 (35.6%)	7 (23.3%)	25 (41.7%)	
	III	37 (41.1%)	14 (46.7%)	23 (38.3%)	0.214
	IV	21 (23.3%)	9 (30%)	12 (20%)	
Degree of anterior spinal cord compression		0.31±0.13	0.42±0.09	0.32±0.12	0.000**
Degree of posterior spinal cord compression		0.26±0.13	0.18±0.10	0.30±0.12	0.000**
Anteroposterior diameter of the spinal cord		0.39±0.15	0.43±0.14	0.37±0.15	0.103
Segment with the most serious compression	C3/C4		7 (23.3%)		
	C4/C5		13 (43.3%)		
	C5/C6		10 (33.3%)		
Kyphotic segments	C3–C4		6 (20%)		
	C3–C5		11 (36.6%)		
	C3–C6		8 (26.6%)		
	C4–C6		5 (16.6%)		
Apex of kyphosis	C3		2 (6.7%)		
	C3/C4		3 (10%)		
	C4		14 (46.7%)		
	C5		10 (33.3%)		
	C5/C6		1 (3.3%)		

SD: standard deviation; ** P<0.01

group, the disc herniation was II degree in 25 of 60 cases (41.7%), III degree in 23 cases (38.3%), and IV degree in 12 cases (20%) (P=0.214) (Table 1).

Spinal cord compression

The degree of anterior spinal cord compression was noted to be more severe in the kyphosis group than that in the nonkyphosis group (0.42±0.09 vs. 0.32±0.12, P<0.001, Fig. 2F). Meanwhile, the degree of posterior spinal cord compression was milder in the kyphosis group than that in the nonkyphosis group (0.18±0.10 vs. 0.30±0.12, P<0.001, Fig. 2G). Anteroposterior diameter of the spinal cord was 0.43±0.14 and 0.37±0.15 in the kyphosis group and nonkyphosis group, respectively (P=0.103, Fig. 2H). In the kyphosis group, C3/C4, C4/C5, and C5/C6 were compressed most seriously in 7 (23.3%), 13 (43.3%), and 10 (33.3%) cases (Table 1). The consistency was considered as the apex the same as or adjacent to the segment with the most seriously compressed level, and the consistency rate was found to be 83.3%.

Correlation analysis of spinal cord compression

The correlations between the degree of spinal cord compression and other parameters were analyzed. As per our findings, CL and degree of wedging vertebral body were associated to the degree of anterior spinal cord compression (P <0.001 and P=0.021, respectively), while only CL was related to the degree of posterior spinal cord compression (P< 0.001) (Table 2). When the CL decreased, the degree of anterior compression increased and the posterior compression decreased. When the degree of wedging vertebral body increased, the degree of anterior compression was noted to increase.

Multivariate regression of spinal cord compression

Finally, the degree of anterior or posterior spinal cord compression was regarded as the dependent variable, and variables correlated to it were regarded as the independent ones. Multivariate regression demonstrated that small CL was an independent risk factor of severe anterior spinal cord compression (P<0.001), while large CL was an independent risk factor of severe posterior spinal cord compression (P<

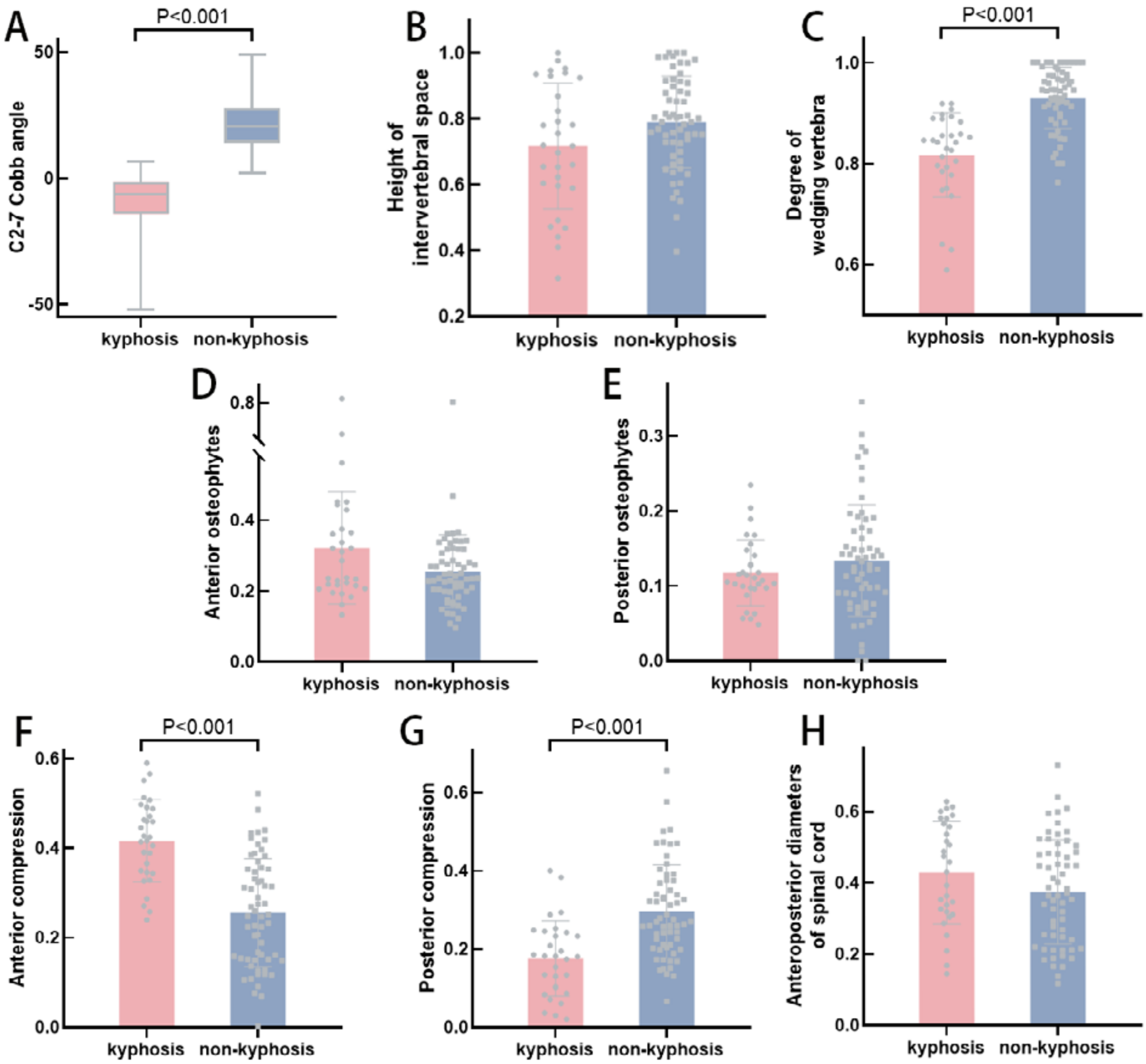

Figure 2. A: Cervical lordosis; B: Height of intervertebral space; C: Degree of wedging vertebral body; D: Anterior osteophyte dimension of degenerative vertebrae; E: Posterior osteophyte dimension of degenerative vertebrae; F: Anterior spinal cord compression dimension of the cervical spinal cord; G: Posterior spinal cord compression dimension of the cervical spinal cord; H: Anteroposterior diameter of the cervical spinal cord.

0.001) (Table 3).

Discussion

The cervical alignment in DCK usually presents with sagittal deformity and seldom coronal deformity. With the aggravation of DCK, some serious degenerations can appear simultaneously, for example, narrowed intervertebral space and osteophyte formation. Commonly, patients do outpatient visits for neck and shoulder pain and/or neurological impairment, whose head-up vision, breath, and swallow were rarely affected.

Cervical sagittal alignment was found to play a significant role in neck and shoulder pain, but the correlation between the loss of cervical lordosis and the clinical features of CSM is yet to be determined[9,10]. The flexion mechanical stress caused by segmental instability might lead to the development of myelopathy and neurological dysfunction when the cervical kyphosis exceeded 6.5° or 10°[5,11]. However, some researchers argue that there is no correlation between the Cobb angle and the severity of CSM[12]. The same degrees of posterior osteophytes and disc herniation in the two groups meant the same static spinal cord compression. However, in this study, the cervical JOA scores did not show any significant difference between the two groups, but the anteroposterior diameters of the spinal cord were noted to be narrower in the nonkyphosis group. This result indirectly indicated that kyphosis was involved in the pathogenesis of CSM through aggravating dynamic compressions. For one thing, dynamic compression factors, such as stretch, shear, bend, and torsion, should not be ignored in patients with DCK[13]. For another, cervical segmental instability might be another factor affecting spinal cord function[14]. Thus, surgical treatment requires not only decompression, but also reconstruc-

Table 2. Correlation Analysis of the Degree of Spinal Cord Compression.

	P-value	
	Degree of anterior compression	Degree of posterior compression
Gender	0.408	0.361
Age	0.364	0.060
Duration of illness	0.440	0.407
Cervical lordosis	0.000**	0.000**
Height of intervertebral space	0.218	0.633
Degree of wedging vertebral body	0.008**	0.152
Degree of anterior osteophyte	0.122	0.050
Degree of posterior osteophyte	0.663	0.139

*P<0.05, **P<0.01

Table 3. Multivariate Regression of the Degree of Spinal Cord Compression.

Parameter	B	95% confidence interval	P-value
Degree of anterior compression			
Cervical lordosis	−0.003	−0.005 to −0.001	0.001**
Degree of wedging vertebral body	0.050	−0.408 to 0.309	0.783
Degree of posterior compression			
Cervical lordosis	0.003	0.001 to 0.004	0.000**

**P<0.01

tion of cervical lordosis.

Correction of cervical kyphosis should be considered when planning decompression surgery for CSM patients[15]. Anterior approach was recommended for patients with inflexible kyphosis or flexible kyphosis with 3 segments, while the posterior approach was recommended for flexible kyphosis with 4 levels or more[16]. Several clinical trials demonstrated a better prognosis in CSM patients with DCK treated via anterior surgeries[11,17,18]. And yet, fewer complications after posterior approach might be an advantage. Upon comprehensive consideration, the anterior approach would be the first choice of many surgeons for DCK patients.

Besides abnormal cervical sagittal alignment, CSM patients also had other radiological features closely related to DCK. In this study, it was found that the degree of wedging vertebral body was more serious in the kyphosis group than that in the nonkyphosis group. Although there was no significant difference, patients in the kyphosis group tend to be more severely degenerated, including height loss of intervertebral space and anterior osteophyte formation. All the above mentioned changes reminded us of insufficient anterior column support in CSM patients with DCK, which was consistent with previous research[19]. This might be a vital rationale to select an anterior approach for these patients. At the same time, the consistency rate of apex segment region and the most compressed segments of the spinal cord was 83.3%, suggesting that kyphosis could be corrected simultaneously with decompression through anterior approach.

As per our univariate and multivariate regression analyses, CL was indeed an independent factor affecting spinal cord compression behavior. In detail, the smaller CL was associated with more severe anterior spinal cord compression and, on the contrary, relatively milder posterior compression in CSM patients. So, it was probable that anterior approach could achieve adequate decompression for patients suffering from DCK.

Previous research revealed possible theories of how DCK affects spinal cord function. First, the presence of kyphosis could push the posterior osteophyte of the vertebral body directly against the spinal cord, thus significantly increasing the tension in the posterior aspect of the spinal cord[5,20]. Second, arteries around the anterior horn could be affected as the compression progressed. Even more, there could be progression of spinal cord atrophy and myelomalacia in patients with severe kyphotic deformity[21]. Third, kyphosis could lead to the loss of neurons and the demyelination of nerve fibers, which might be caused by continuous mechanical compression and changes in spinal cord vessels[22]. Lastly, the intramedullary pressure could be greater as the degree of kyphosis increases[5]. Therefore, the cervical alignment needs to be carefully evaluated for reconstruction when considering possible treatments.

In this study, we found insufficient anterior column support in the cervical vertebrae and obvious anterior spinal cord compression in the kyphosis group, providing theoretical basis for conducting an anterior approach. Because of the lacking authoritative guidelines for DCK with CSM, anterior approach was first considered for patients with severe or irreducible kyphosis[23-25]. Here, we provided sufficient quantitative data to support the selection of anterior approach. Anyway, surgeons should consider the condition of patients in all aspects when choosing the surgical plan. We illustrated the different sources of compression in CSM patients with different cervical curvatures using a quantitative data, to provide a theoretical basis for the selection of surgical approaches.

This study has several limitations. First, only one center was included in this study. Multicenter studies are expected to provide more reliable conclusions. In addition, the small sample size limited the interpretation of our results. Moreover, the significant difference in terms of the number of cases in the two groups might be another limitation. Finally, this was a retrospective study, which might have resulted in bias.

Conclusion

In patients suffering from DCK with CSM, there is less anterior column support in the cervical spine and more serious anterior spinal cord compression. With the loss of cervical lordosis, the spinal cord is more likely to be compressed anteriorly. DCK has been determined to be involved in spinal cord dysfunction. Thus, it is necessary to consider cervical alignment when patients plan to undertake surgical intervention, and anterior approach might reach a better outcome for patients suffering from DCK with CSM.

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

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Author Contributions: Hongwei Wang, Haocheng Xu, and Hongli Wang designed the study. Hongwei Wang and Xianghe Wang performed the experiments and analyzed the data. Hongwei Wang and Xianghe Wang provided the critical reagents. Ye Tian, Jianwei Wu, Xiaosheng Ma, Feizhou Lyu Jianyuan Jiang, and Hongli Wang supervised the experiments. Hongwei Wang and Haocheng Xu wrote the manuscript.

Hongwei Wang, Haocheng Xu and Xianghe Wang contributed equally to this work as co-first authors.

Ethical Approval: This project was reviewed and approved by the Institutional Review Board of Huashan Hospital, Fudan University (KY2022-683).

Informed Consent: Consent was not required because of the retrospective nature of this study.

References

1. Shin Y, Han K, Lee YH. Temporal trends in cervical spine curvature of South Korean adults assessed by deep learning system segmentation, 2006-2018. JAMA Netw Open. 2020;3(10):e2020961.
2. Young WF. Cervical spondylotic myelopathy: a common cause of spinal cord dysfunction in older persons. Am Fam Physician. 2000;62(5):1064-70.
3. Moore AP, Blumhardt LD. A prospective survey of the causes of non-traumatic spastic paraparesis and tetraparesis in 585 patients. Spinal Cord. 1997;35(6):361-7.
4. Albert TJ, Vacarro A. Postlaminectomy kyphosis. Spine. 1998;23(24):2738-45. English.
5. Wu B, Liu B, Sang D, et al. The association between cervical focal kyphosis and myelopathy severity in patients with cervical spondylotic myelopathy before surgery. Eur Spine J. 2021;30(6):1501-8.
6. Walraevens J, Liu B, Meersschaert J, et al. Qualitative and quantitative assessment of degeneration of cervical intervertebral discs and facet joints. Eur Spine J. 2009;18(3):358-69.
7. Rydman E, Bankler S, Ponzer S, et al. Quantifying cervical spondylosis: reliability testing of a coherent CT-based scoring system. BMC Med Imaging. 2019;19(1):45.
8. Nouri A, Martin AR, Mikulis D, et al. Magnetic resonance imaging assessment of degenerative cervical myelopathy: a review of structural changes and measurement techniques. Neurosurg Focus. 2016;40(6):E5.
9. Scheer JK, Tang JA, Smith JS, et al. Cervical spine alignment, sagittal deformity, and clinical implications: a review. J Neurosurg Spine. 2013;19(2):141-59.
10. Lee SH, Hyun SJ, Jain A. Cervical sagittal alignment: literature review and future directions. Neurospine. 2020;17(3):478-96.
11. Uchida K, Nakajima H, Sato R, et al. Cervical spondylotic myelopathy associated with kyphosis or sagittal sigmoid alignment: outcome after anterior or posterior decompression. J Neurosurg Spine. 2009;11(5):521-8.
12. Mohanty C, Massicotte EM, Fehlings MG, et al. Association of preoperative cervical spine alignment with spinal cord magnetic resonance imaging hyperintensity and myelopathy severity: analysis of a series of 124 cases. Spine. 2015;40(1):11-6.
13. Davies BM, Mowforth O, Gharooni AA, et al. A new framework for investigating the biological basis of degenerative cervical myelopathy [AO spine RECODE-DCM research priority number 5]: mechanical stress, vulnerability and time. Global Spine J. 2022;12(1_suppl):78S-96S.
14. Henderson FC, Geddes JF, Vaccaro AR, et al. Stretch-associated injury in cervical spondylotic myelopathy: new concept and review. Neurosurgery. 2005;56(5):1101-13;discussion:1101-13.
15. Ames CP, Blondel B, Scheer JK, et al. Cervical radiographical alignment: comprehensive assessment techniques and potential importance in cervical myelopathy. Spine. 2013;38(22 Suppl 1):S149-60.
16. Yoshida G, Alzakri A, Pointillart V, et al. Global spinal alignment in patients with cervical spondylotic myelopathy. Spine. 2018;43(3):E154-62.
17. Zhu B, Xu Y, Liu X, et al. Anterior approach versus posterior approach for the treatment of multilevel cervical spondylotic myelopathy: a systemic review and meta-analysis. Eur Spine J. 2013;22(7):1583-93.
18. Sakai K, Yoshii T, Hirai T, et al. Impact of the surgical treatment for degenerative cervical myelopathy on the preoperative cervical sagittal balance: a review of prospective comparative cohort between anterior decompression with fusion and laminoplasty. Eur Spine J. 2017;26(1):104-12.
19. Ogura Y, Dimar JR, Djurasovic M, et al. Etiology and treatment of cervical kyphosis: state of the art review-a narrative review. J Spine Surg. 2021;7(3):422-33.
20. Buell TJ, Buchholz AL, Quinn JC, et al. Importance of sagittal

alignment of the cervical spine in the management of degenerative cervical myelopathy. Neurosurg Clin N Am. 2018;29(1):69-82.

21. Sakamoto T, Funaba M, Imajo Y, et al. The impact of anterior spondylolisthesis and kyphotic alignment on dynamic changes in spinal cord compression and neurological status in cervical spondylotic myelopathy: a radiological analysis involving kinematic ct myelography and multimodal spinal cord evoked potentials. Spine. 2021;46(2):72-9.

22. Shimizu K, Nakamura M, Nishikawa Y, et al. Spinal kyphosis causes demyelination and neuronal loss in the spinal cord: a new model of kyphotic deformity using juvenile Japanese small game fowls. Spine. 2005;30(21):2388-92.

23. Emery SE. Anterior approaches for cervical spondylotic myelopathy: which? When? How? Eur Spine J. 2015;24 Suppl 2:150-9.

24. Papavero L, Schmeiser G, Kothe R, et al. Degenerative cervical myelopathy: a 7-letter coding system that supports decision-making for the surgical approach. Neurospine. 2020;17(1):164-71.

25. Farrokhi MR, Ghaffarpasand F, Khani M, et al. An evidence-based stepwise surgical approach to cervical spondylotic myelopathy: a narrative review of the current literature. World Neurosurg. 2016;94:97-110.