The Posterolaterally Oriented and Laterally Downward Sloping Facet Joint Is a Risk Factor for Degenerative Cervical Spondylolisthesis and Myelopathy

Hiromi Kumamaru[1)], Keiichiro Iida[1)2)], Takeyuki Saito[1)], Shingo Yoshizaki[1)], Yasuharu Nakashima[2)] and Katsumi Harimaya[1)]

1) Department of Orthopaedic Surgery, Kyushu University Beppu Hospital, Oita, Japan
2) Department of Orthopaedic Surgery, Graduate School of Medical Sciences, Kyushu University, Fukuoka, Japan

Abstract:

Introduction: Facet joints are anatomical structures that are known to be crucial for determining spinal biomechanical motion; however, the potential relationship between facet orientation and the development of cervical spondylolisthesis remains unclear. Thus, in this study, we aimed to explore the relationship between facet orientation and cervical spondylolisthesis as well as myelopathy.

Methods: Facet orientation in the cervical spine was investigated using computed tomography in 103 patients with cervical myelopathy, and facet inclination was measured on axial, coronal, and sagittal reconstructed images. Patients were divided into anterolisthesis, retrolisthesis, and no spondylolisthesis groups at each intervertebral level (C2/3-C6/7 levels).

Results: Facet joints in the anterolisthesis and retrolisthesis groups tended to slope posterolaterally and downward laterally compared with those in the no spondylolisthesis group at C3/4, C4/5, and C5/6 levels ($P<0.001$).

Conclusions: The posterolaterally oriented and laterally downward sloping facet at C3/4 and C4/5 levels may be a risk factor for the development of cervical spondylolisthesis as well as symptomatic myelopathy.

Keywords:

cervical degenerative spondylolisthesis, computed tomography, facet joint, myelopathy

Spine Surg Relat Res 2022; 6(4): 358-365
dx.doi.org/10.22603/ssrr.2021-0181

Introduction

Degenerative spondylolisthesis (DSL) is defined as a pathological condition caused by facet joint arthrosis, disc degeneration, and narrowing of the spinal canal, which could lead to spinal cord compression. Spinal cord compression at the cervical level causes progressive neurological deficit called myelopathy, which then hinders daily living activities. Degenerative cervical spondylolisthesis has been identified to be the primary cause of symptomatic myelopathy, especially in aged people[1)], and the number of degenerative cervical myelopathy (DCM) patients has been increasing with the advancement of an aging society worldwide.

Lumbar DSL is a common disease, while cervical DSL is considered a rare one. However, several recent studies have suggested that cervical DSL is more common than previously thought[2)]. The incidence of cervical DSL is reported to be 69% in elderly patients with DCM who underwent decompression surgery, and the authors concluded that more attention should be paid to cervical DSL[3)].

Facet joints are crucial anatomical structures in determining the biomechanical characteristics of the spine by guiding and restricting spinal motion[4)]. Since their orientation is reported to be correlated with spinal movements and clinical conditions[5)], their pathological changes could be associated with abnormal movement of the spinal segment, resulting in DSL. Facet joint orientation at the lumbar spine has been extensively studied, and many studies have indicated that sagittal orientation or facet tropism of the lumbar facet joints is a risk factor for lumbar DSL[6,7)]. However, at the cervical spine level, the relationship between facet orientation and DSL has not been examined to a great extent.

Thus, in this study, we, for the first time, addressed facet joint orientation on sagittal, axial, and coronal planes in patients with DCM using three-dimensional (3D) computed tomography (CT) data to explore the relationship between

Corresponding author: Hiromi Kumamaru, kumamaru.hiromi.849@m.kyushu-u.ac.jp
Received: September 17, 2021, Accepted: November 12, 2021, Advance Publication: December 27, 2021

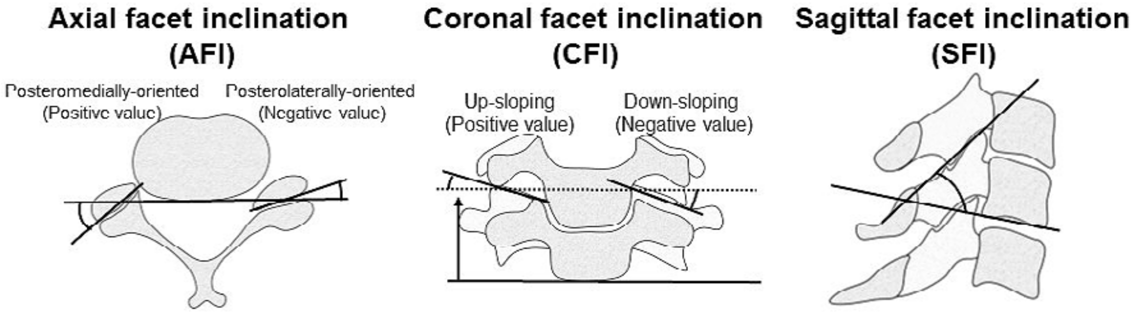

Figure 1. Schema showing the method of measuring the axial, coronal, and sagittal inclination.

facet joint orientation and cervical DSL.

Materials and Methods

Subjects

This study included 103 patients (60 men and 43 women; average age at the time of surgery: 72.5 years [range, 40-94 years]) who underwent expansive open-door laminoplasty for DCM from January 2014 to December 2018 at our institution. Patients with ossification of the posterior longitudinal ligament or the ligamentum flavum, cervical trauma, systemic inflammatory disease, infection, or tumor were excluded from this study. Of the young adults (control), 22 patients who underwent anterior or posterior cervical surgery for cervical disc herniation were included for analysis. There were 17 men and 5 women, and their average age was 43.2 years (range 29-48 years). These patients did not have spondylolisthesis.

This study was approved by International Review Board of the authors' affiliated institution.

Radiographic assessment

Before the surgery, standard plain radiographs of the cervical spine including anteroposterior and lateral radiographs were obtained with the standard tube-to-film distance (1.8 m) for all patients. Flexion-extension views were obtained from all patients. On lateral radiographs (standing neutral/flexion/extension lateral radiographs), horizontal displacement of one vertebral body relative to the one below it was measured by two independent observers, and the mean values (mm) were then calculated.

Anterior slippage was measured by measuring the distance from the posterior-inferior corner of the vertebra above the posterior tangent line along the posterior border of the vertebra below. Posterior slippage was measured in the same way from the posterior-superior corner of the vertebra below the posterior tangent line along the posterior border of the vertebra above. The criterion for static spondylolisthesis is considered to be a slip of >2 mm from the adjacent vertebrae on plain radiographs in a neutral position[8]. Using the same method, the slippage in the flexion and extension views was calculated to assess segmental instability, and slippage >3.5 mm was considered as dynamic spondylolisthesis according to the criteria by White et al.[9] and others[8,10-12]. In this study, spondylolisthesis was defined by static and dynamic spondylolisthesis, and the patients were divided into three groups at each intervertebral level according to spondylolisthesis as follows: anterolisthesis, retrolisthesis, and no spondylolisthesis groups.

CT assessment

CT was used to evaluate facet joint orientation in all patients. Using 3D CT imaging software (Aquarius Software, TeraRecon, Inc., San Mateo, CA), the cervical spine was reconstructed in each patient.

Axial images were obtained from the plane parallel to the superior end plate of the vertebral body. Coronal images were obtained from the plane perpendicular to both axial and sagittal planes. Sagittal images were then obtained from the plane bisecting the vertebral body. On the axial plane, the angles between the tangential line to the posterior vertebral wall and the line connecting the medial and lateral edges of the articular surfaces of the facet joints were measured bilaterally[13]. The mean value of right and left facet angles was calculated for each segment and defined as the axial facet joint inclination (AFI). Posteromedial orientation was defined as AFI>0, while posterolateral orientation was defined as AFI<0 (Fig. 1).

On the coronal plane, the angle between the tangential line to the inferior end plate of the vertebral body and the line connecting the superior and inferior edges of the superior articular surfaces was measured bilaterally, and mean values were defined as the coronal facet joint inclination (CFI). When CFI was >0, the facet sloped upward laterally, and when it was <0, the facet sloped downward laterally (Fig. 1).

On the sagittal plane, the angle between the parallel line of the inferior endplate and the line connecting the superior and inferior edges of the superior articular surfaces was measured bilaterally, and mean values were defined as the sagittal facet joint inclination (SFI; Fig. 1).

Magnetic resonance imaging assessment

Magnetic resonance imaging (MRI) was used to determine the location of the neurological compression. All patients were scanned using a 1.5-T MRI system (Siemens MAGNETOM ESSENZA). High signal intensity areas at the

Table 1. Cervical Anterolisthesis and Retrolisthesis by Level.

	C2	C3	C4	C5	C6	Total
Anterolisthesis	5 (4.9%)	12 (11.7%)	11 (10.7%)	5 (4.9%)	1 (1.0%)	34 (6.6%)
Retrolisthesis	0	25 (24.3%)	24 (23.3%)	25 (24.3%)	5 (4.9%)	79 (19.7%)
No spondylolisthesis	98	66	68	73	97	402

Table 2. Axial Facet Joint Inclination (AFI).

	C2/3		C3/4		C4/5		C5/6		C6/7	
	AFI	% of AFI (−)	AFI	% of AFI (−)	AFI	% of AFI (−)	AFI	% of AFI (−)	AFI	% of AFI (−)
Anterolisthesis	13.1±18.2	20%	−5.9±8.8	60%	−8.3±11.6	87%	−6.3±8.9	83%	27	0%
Retrolisthesis	N/A		−1.9±11.5	63%	−6.6±8.2	86%	−6.3±5.9	84%	−0.4±6.2	40%
No spondylolisthesis	21.5±10.4	3%	3.4±10.4	37%	1.4±13.0	39%	−2.1±11.8	57%	2.5±10.4	35%

C2/3-C6/7 levels of the spinal cord were recorded on sagittal and axial views of T2-weighted images (TR/TE 3500-4500/85-110 ms).

Statistical analysis

All values are shown as the mean±standard deviation. Multiple-group comparisons were made using two-way analysis of variance (ANOVA) with Bonferroni's multiple comparisons test. Fisher's exact test was used for categorical data. Statistical analyses were performed using JMP Pro 13 (SAS Institute, Cary, NC), and a p-value<0.05 was considered to be statistically significant.

Results

Radiographic evaluation for spondylolisthesis

Cervical DSL (anterolisthesis and retrolisthesis) was recorded in 66 patients (64.1%). In total, 30 patients had single-level DSL, while others had multiple-level DSL (two levels, 26 patients; three levels, 9 patients; four levels, 1 patient). Of these 113 cervical DSLs, 5 were at C2/3, 37 were at C3/4, 35 were at C4/5, 30 were at C5/6, and 6 were at C6/7 (Table 1). Anterolisthesis was the most common at the C3/4 and C4/5 levels, and retrolisthesis was the most common at the C3/4-C5/6 levels (Table 1). The incidence of spondylolisthesis was similar to that shown in a previous report[12]. Ten dynamic anterolisthesis (>3.5 mm anterior motion: C3,5; C4,4; C5,1) and five dynamic retrolisthesis (>3.5 mm posterior motion: C3,2; C4,3) were not visualized on plain neutral radiographs (<2 mm slippage). The other cervical vertebrae with anterior or posterior segmental instability slipped anteriorly or posteriorly (>2 mm) in the same direction on neutral position.

Evaluation of facet orientation in CT multiplanar reconstruction images

Three-dimensional CT has been determined as the most powerful tool for facet joint characterization[14] due to its sensitivity for assessing osseous anatomy. Thus, we measured facet inclinations of the vertebra at C2/3-C6/7 levels in the axial, coronal, and sagittal planes using CT multiplanar reconstruction images (Fig. 1).

AFI

AFI at each intervertebral level is shown in Table 2. Anterolisthesis and retrolisthesis groups showed significantly smaller AFI compared with the no spondylolisthesis group at the C3/4 and C4/5 levels (Fig. 2; ANOVA with Bonferroni correction; P<0.05). The facet joints of the posterior or anterior slipped vertebral bodies tended to slope posterolaterally compared with the non-slipped vertebral bodies from the C3/4-C5/6 level (Table 2).

CFI

The CFI at each intervertebral level is shown in Table 3. The anterolisthesis group showed significantly smaller CFI compared with others at the C3/4 level; meanwhile, the retrolisthesis group showed significantly smaller CFI compared with others at the C4/5 level (Fig. 3; ANOVA with Bonferroni correction; P<0.05). The facet joints of the posterior or anterior slipped vertebral bodies tended to slope downward laterally compared with non-slipped vertebral bodies at the C3/4 and C4/5 levels (Table 3).

SFI

The SFI at each intervertebral level is shown in Table 4. All facet joints sloped posteroventrally in this plane, and SFI was noted to be significantly larger in the retrolisthesis group than in the other groups at the C3/4 and C4/5 levels (Table 4 and Fig. 4).

We compared the proportion of both AFI negative and CFI negative facets at each level among the three groups. Interestingly, a significantly higher proportion of facets in the retro- and anterolisthesis groups showed negative AFI and CFI compared with those in the no spondylolisthesis

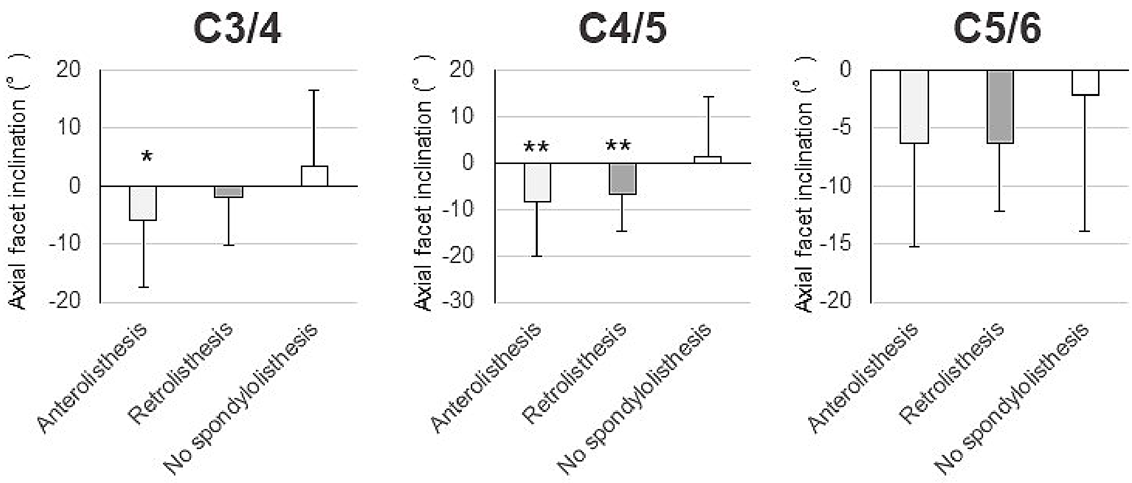

Figure 2. Axial facet joint inclination (AFI) from C3/4 to C5/6 levels.
*P<0.05 **P<0.01

Table 3. Coronal Facet Joint Inclination (CFI).

	C2/3		C3/4		C4/5		C5/6		C6/7	
	CFI	% of CFI (−)	CFI	% of CFI (−)	CFI	% of CFI (−)	CFI	% of CFI (−)	CFI	% of CFI (−)
Anterolisthesis	10.7±15.2	20%	−3.6±6.1	67%	−1.9±9.3	73%	−6.3±8.7	83%	12.5	0%
Retrolisthesis	N/A		−0.2±9.8	52%	−4.0±9.2	76%	−3.3±6.5	68%	4.1±11.4	40%
No spondylolisthesis	17.6±9.4	4%	3.5±8.5	26%	0.5±7.8	38%	−1.5±8.7	60%	2.8±9.0	32%

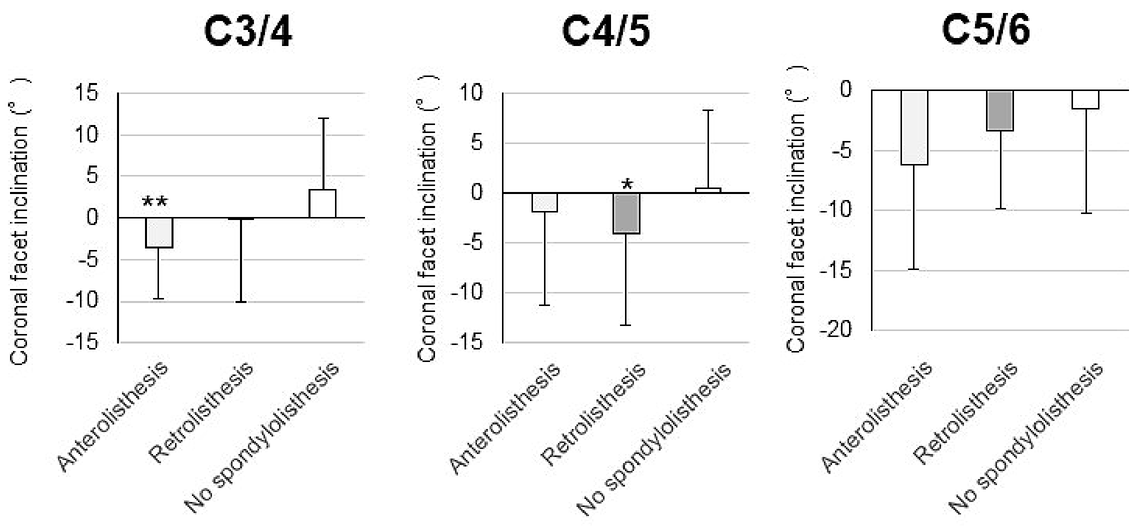

Figure 3. Coronal facet joint inclination (CFI) from C3/4 to C5/6 levels.
*P<0.05 **P<0.01

Table 4. Sagittal Facet Joint Inclination (SFI).

	C2/3	C3/4	C4/5	C5/6	C6/7
	SFI	SFI	SFI	SFI	SFI
Anterolisthesis	47.6±6.2	43.7±5.2	37.5±8.8	45.4±8.5	34
Retrolisthesis	N/A	50.1±6.0	48.7±5.8	47.4±8.2	53.7±3.1
No spondylolisthesis	49.3±8.3	46.9±7.2	40.4±6.8	45.4±7.7	55.1±8.1

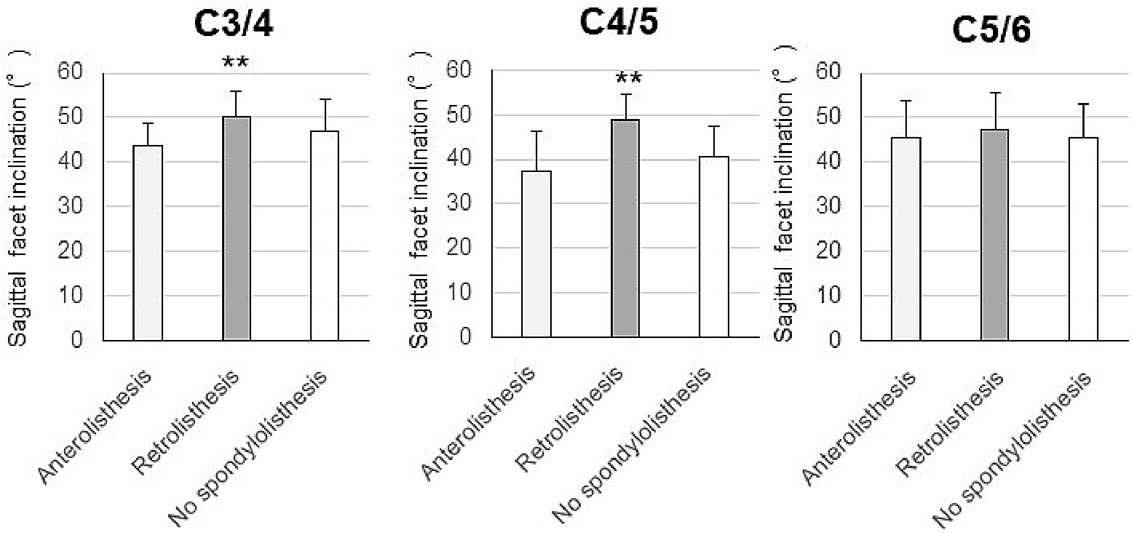

Figure 4. Sagittal facet joint inclination (SFI) from C3/4 to C5/6 levels.
**P<0.01

Table 5. Proportion of AFI (−)/CFI (−) Facets.

	C2/3	C3/4	C4/5	C5/6	C6/7
Anterolisthesis	20%	60%***	73%***	83%***	0%
Retrolisthesis	N/A	52%***	79%***	68%***	40%
No spondylolisthesis	1%	21%	26%	49%	1%

Axial facet joint inclination, AFI; coronal facet joint inclination, CFI
***P<0.001

group at the C3/4, C4/5, and C5/6 levels (Table 5; Fisher's exact test, P<0.001).

The proportion of the negative AFI and CFI facet in young adults without spondylolisthesis

In young adults without spondylolisthesis, the negative AFI and CFI facets were observed in 9.1% (2/22) at C2/3, 27.3% (6/22) at C3/4, 45.5% (10/22) at C4/5, 68.2% (15/22) at C5/6, and 31.8% (7/22) at C6/7.

Facet orientation for intramedullary signal intensity on T2-weighted MRI

A high intramedullary signal on T2-weighted MR images represents edema, inflammation, and ischemia in the spinal cord and thus is a diagnostic marker for the spinal segments of myelopathy[15]. To clarify the association of negative AFI and CFI with the development of symptomatic cervical myelopathy, we investigated axial and coronal facet orientation at the spinal segments with intramedullary spinal changes. Intramedullary spinal change was recorded in 106 spinal segments (C2/3, 2 cords; C3/4, 34 cords; C4/5, 35 cords; C5/6, 27 cords; C6/7, 8 cords). In addition, 45.1% of the anterolisthesis segment and 37.0% of the retrolisthesis segment showed intramedullary spinal changes compared with 11.6% of the segment without spondylolisthesis, indicating that not only anterolisthesis but also retrolisthesis causes symptomatic myelopathy.

In the spinal segments with intramedullary spinal changes, a significantly higher proportion of facets at C3/4 and C4/5 levels showed negative AFI and CFI in the retro- and anterolisthesis groups compared with those of the no spondylolisthesis group (Fig. 5; Fisher exact test, P<0.05). In addition, 71.9% and 68.4% of spinal segments with intramedullary spinal changes in the retrolisthesis and anterolisthesis groups had negative AFI and CFI, respectively (retrolisthesis: C2/3, 0%; C3/4, 44.4%; C4/5, 84.6%; C5/6, 80.0%; C6/7, 0%; anterolisthesis: C2/3, 0%; C3/4, 66.7%; C4/5, 62.5%; C5/6, 100%; C6/7, 0%), although only 27.3% of spinal segments with intramedullary spinal changes in the no spondylolisthesis group had both negative AFIs and CFIs (C2/3, 0%; C3/4, 6.3%; C4/5, 21.4%; C5/6, 60.0%; C6/7, 25.0%). These results indicated that the posterolaterally oriented and laterally downward sloping facet caused the development of cervical myelopathy by the development of retrolisthesis or anterolisthesis (Fig. 6).

Discussion

DSL occurs due to age-related degenerative changes in the facet joints and discs of the cervical spine. In this present study, we showed that facet orientation in the cervical spine was related to spondylolisthesis in patients with symptomatic DCM requiring decompression surgery. The posterolaterally oriented facets and laterally down-sloping facets, especially at the C3/4 and C4/5 levels, are risk factors for spondylolisthesis development and symptomatic myelopathy (Fig. 6).

The pathophysiology of DCM is multifactorial, and several causative factors have been proposed for the development of DCM (e.g., degenerative processes, congenital cervical spine stenosis, and spinal alignment)[16]. Tani et al. described the functional importance of degenerative spondylolisthesis in DCM[3]. Consistent with their study, intramedul-

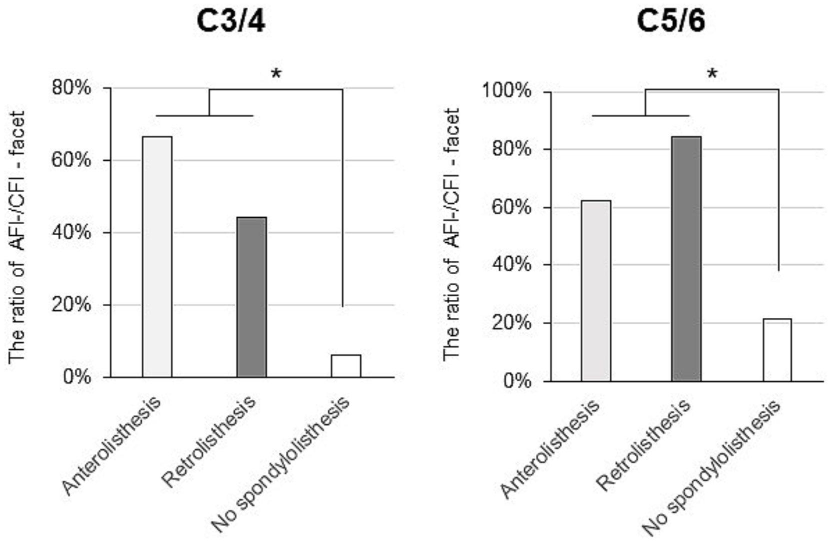

Figure 5. Proportion of AFI (−) /CFI (−) facets at spinal segments with intramedullary spinal changes.
Axial facet joint inclination, AFI; coronal facet joint inclination, CFI *P<0.05

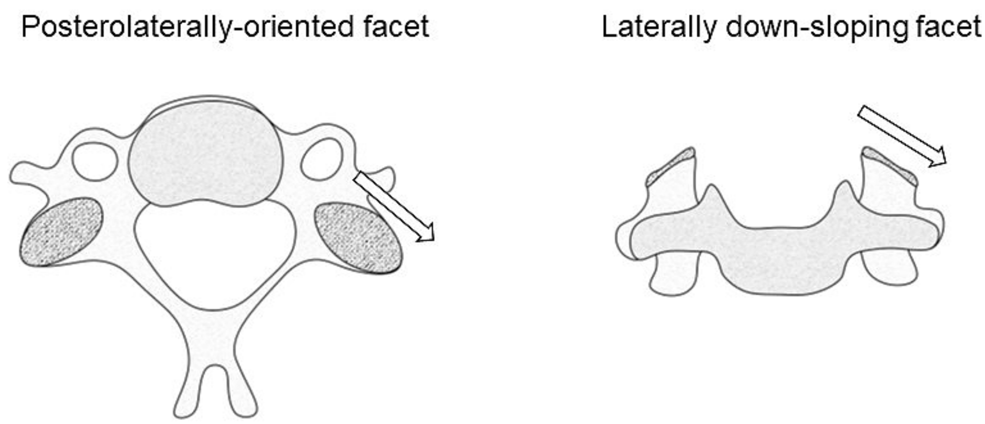

Figure 6. Posterolaterally oriented and laterally downward sloping facets are risk factors for developing spondylolisthesis and symptomatic myelopathy.

lary changes were recorded in approximately 40% of the spondylolisthesis segments in this study. Thus, degenerative cervical spondylolisthesis is considered to cause DCM, and we need to pay more attention to spondylolisthesis in the cervical spine as a causative factor for developing DCM.

It is speculated that the number of cervical DSL patients will increase in the future because spondylolisthesis is secondary to degenerative changes in intervertebral structures, and the population has a longer lifespan than they did in the past. However, the etiology of spondylolisthesis is not well clarified in the cervical spine. A previous study showed that a high T1 slope is a predisposing factor for developing DLS[16]. In addition, the T1-T4 thoracic kyphosis angle was reported to affect DLS[17]. Most previous reports have focused on sagittal parameters, and only a few addressed the facet orientation on coronal and axial parameters. In this current study, we propose that coronal and axial facet parameters can significantly affect the development of cervical spondylolisthesis in addition to sagittal spinal alignment.

This present study determined that posterolaterally oriented facets and laterally downward sloping facets were associated with the development of retro- and anterolisthesis at C3/4 and C4/5 levels. This facet orientation may be a predisposing factor for degenerative cervical spondylolisthesis because young people without spondylolisthesis have the posterolaterally oriented and laterally downward sloping facets. These types of facets would be less resistant to vertebral slip due to less protection for intervertebral structures from physiological overload. Anatomically, cervical facet joints allow a greater degree of axial rotation and lateral bending than lumbar facet joints[4]. The posterolaterally oriented facet would then pose less restriction to the antero-posterior translation and could facilitate translation on the sagittal plane in the cervical spine[5]. Axial compressive or tensile loads may not be sufficiently transmitted to the lamina or vertebral body in the posterolaterally oriented facet joint. The laterally downward sloping facets are considered to provide limited bony restriction for axial rotation and lateral bending compared with the laterally upward sloping facet. A combination of these two facet orientations provides less bony restriction to all cervical movement (flexion/extension, axial rotation, and lateral bending), resulting in excessive movement of the intervertebral tissues, such as discs, capsules, and ligaments. Excessive stress on intervertebral soft tissues over a prolonged period could cause the spinal segment to loosen, thus making it unstable. Cervical DSL may then occur without sufficient restriction for the anterior or posterior translation by the posterolaterally oriented facet[5].

Pal et al. reported that the facet joints gradually or suddenly transition from posteromedial to posterolateral from C2/3 to C7/T1 levels; this was demonstrated by a detailed anatomical analysis of 30 dry macerated normal human male vertebral columns. Their important observation is that once the transition from posteromedial to posterolateral orientation had occurred, reversal of this pattern was never observed in subsequent lower vertebrae[18]. Similar results were reported using a detailed CT analysis[19]. However, this is not the case in this study. Many patients with symptomatic DCM showed a mixed pattern of posteromedially and posterolaterally oriented facets as well as laterally upward and downward sloping facets. Thus, this mixed pattern of cervical facet orientation is considered to be secondary remodeling rather than a pre-existing morphological feature. The remodeling process of facet joint arthritis may alter the morphological features of the facet joints, and the alteration of facet orientation with advancing age seemed to result in cervical DSL.

Facet tropism is defined as the angular asymmetry between the paired facet joint orientation, and it is a common phenomenon in the cervical spine[5]. Cervical facet tropism is reportedly associated with cervical spondylolisthesis[20] as well as cervical disc herniation[21,22]. In this study, no significant relationship was noted between cervical DSL and facet tropism in any planes (data not shown). However, cervical facet tropism may result in asymmetric motion and non-uniform pressure distribution at the intervertebral disc and facet joints, which accelerate disc and facet degeneration[5]. Their degeneration may further increase the mechanical stresses on the intervertebral disc and facet joints, leading to the instability of the vertebral motion segment, which causes cervical DSL. However, further studies would be needed to clarify the facet tropism and the development of cervical DSL.

In summary, this study is the first to investigate the relationship between facet orientation and cervical DSL using 3D-CT data. Our results show that the posterolaterally oriented and laterally downward sloping facet may be a predisposing factor for the development of cervical spondylolisthesis and symptomatic myelopathy. However, this study has several limitations. This was a retrospective single-centered study with a relatively small sample size. Young adult controls had cervical disc herniation. We focused on the facet orientation, especially on axial and coronal planes, though many other factors would influence the development of cervical DSL. Nevertheless, strong statistical significance in our study supports our conclusion. In the future, a prospective study is required to evaluate the role of facet orientation in the pathology and etiology of cervical DSL. Further longitudinal clinical studies and biomechanical studies will be necessary to elucidate the causal relationship between facet orientation and the incidence of spondylolisthesis and myelopathy.

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

Sources of Funding: The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Grant-in-Aid for Scientific Research (C), Teijin Pharma.

Author Contributions: H.K. designed and interpreted results and wrote and prepared the manuscript. H.K., K.I., T.K., and S.Y. contributed to acquisition of data. Y.N. contributed to the conception of the project. K.H. contributed to the conception of the project and interpretation of results. All authors read and approved the final manuscript.

Ethical Approval: This study was approved by the Kyushu University Institutional Review Board (IRB approval No.29-411).

Informed Consent: All patients provided informed consent in this study.

References

1. Young WF. Cervical spondylotic myelopathy: a common cause of spinal cord dysfunction in older persons. Am Fam Physician. 2000;62(5):1064-70.
2. Jiang SD, Jiang LS, Dai LY. Degenerative cervical spondylolisthesis: a systematic review. Int Orthop. 2011;35(6):869-75.
3. Tani T, Kawasaki M, Taniguchi S, et al. Functional importance of degenerative spondylolisthesis in cervical spondylotic myelopathy in the elderly. Spine (Phila Pa 1976). 2003;28(11):1128-34.
4. Jaumard NV, Welch WC, Winkelstein BA. Spinal facet joint biomechanics and mechanotransduction in normal, injury and degenerative conditions. J Biomech Eng. 2011;133(7):071010.
5. Rong X, Liu ZY, Wang BY, et al. The facet orientation of the subaxial cervical spine and the implications for cervical movements and clinical conditions. Spine. 2017;42(6):E320-5.
6. Liu X, Zhao X, Long Y, et al. Facet sagittal orientation: possible role in the pathology of degenerative lumbar spinal stenosis. Spine (Phila Pa 1976). 2018;43(14):955-8.
7. Liu ZY, Duan YC, Rong X, et al. Variation of facet joint orientation and tropism in lumbar degenerative spondylolisthesis and disc herniation at L4-L5: a systematic review and meta-analysis. Clin Neurol Neurosur. 2017;161:41-7.
8. Kawasaki M, Tani T, Ushida T, et al. Anterolisthesis and retrolisthesis of the cervical spine in cervical spondylotic myelopathy in the elderly. J Orthop Sci. 2007;12(3):207-13.
9. White 3rd AA, Johnson RM, Panjabi MM, et al. Biomechanical analysis of clinical stability in the cervical spine. Clin Orthop Re-

lat Res. 1975;109:85-96.
10. Dean CL, Gabriel JP, Cassinelli EH, et al. Degenerative spondylolisthesis of the cervical spine: analysis of 58 patients treated with anterior cervical decompression and fusion. Spine J. 2009;9(6):439-46.
11. Shigematsu H, Ueda Y, Takeshima T, et al. Degenerative spondylolisthesis does not influence surgical results of laminoplasty in elderly cervical spondylotic myelopathy patients. Eur Spine J. 2010;19(5):720-5.
12. Park MS, Moon SH, Lee HM, et al. The natural history of degenerative spondylolisthesis of the cervical spine with 2- to 7-year follow-up. Spine (Phila Pa 1976). 2013;38(4):E205-10.
13. Cinotti G, Postacchini F, Fassari F, et al. Predisposing factors in degenerative spondylolisthesis. A radiographic and CT study. Int Orthop. 1997;21(5):337-42.
14. Lehman RA, Jr., Helgeson MD, Keeler KA, et al. Comparison of magnetic resonance imaging and computed tomography in predicting facet arthrosis in the cervical spine. Spine (Phila Pa 1976). 2009;34(1):65-8.
15. 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.
16. Jun HS, Kim JH, Ahn JH, et al. T1 slope and degenerative cervical spondylolisthesis. Spine (Phila Pa 1976). 2015;40(4):E220-6.
17. Murata K, Endo K, Suzuki H, et al. Spinal sagittal alignment and trapezoidal deformity in patients with degenerative cervical spondylolisthesis. Sci Rep. 2019;9(1):4992.
18. Pal GP, Routal RV, Saggu SK. The orientation of the articular facets of the zygapophyseal joints at the cervical and upper thoracic region. J Anat. 2001;198(4):431-41.
19. Ebraheim NA, Patil V, Liu JY, et al. Morphometric analyses of the cervical superior facets and implications for facet dislocation. Int Orthop. 2008;32(1):97-101.
20. Xu C, Lin BQ, Ding ZH, et al. Cervical degenerative spondylolisthesis: analysis of facet orientation and the severity of cervical spondylolisthesis. Spine J. 2016;16(1):10-5.
21. Huang XC, Ye LQ, Liu X, et al. The relationship between facet tropism and cervical disc herniation. J Anat. 2020;236(5):916-22.
22. Wang Y, Chen GL, Lin JJ, et al. The correlation between facet tropism and intervertebral disc herniation in the subaxial cervical spine. Spine. 2021;46(5):E310-7.