Radiologic Factors for Predicting Dynamic Spinal Cord Compression in Conventional Cervical MRI

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Objective
Conventional cervical MRI is the gold standard exam for diagnosis of cervical myelopathy, but cannot detect dynamic cord compression. This study aims to evaluate radiologic factors suggesting dynamic spinal cord compression.

Methods
We retrospectively reviewed the patients who examined dynamic MRI in addition to conventional MRI. A total of 50 patients were included in this study, comprised of 36 in the group P (aggravation of spinal cord compression on dynamic MRI) and 14 in the group N (non-aggravation of spinal cord compression on dynamic MRI). Radiologic factors were compared.

Results
The following factors were analyzed: age, cervical canal diameter (CCD), spinal cord diameter (SCD), subarachnoid space (SAS), cervical lordosis (CL), cervical ROM, anterior length of cervical cord (ALCC), posterior length of cervical cord (PLCC), length of anterior column (LAC), and length of posterior column (LPC). Significant differences were found in age, CCD, SAS, CL, LPC (p<0.05). In ROC curves, age (AUC 0.813, cut-off value 54), CCD (AUC 0.858, cut-off value 10.32), and SAS (AUC 0.884, cut-off value 3.25) were a significant factor in predicting deterioration of spinal cord compression during the dynamic posture.

Conclusion
Dynamic MRI is more useful for the diagnosis of dynamic spinal cord compression in the following conditions: age is 54 years or older, CCD average is less than 10.32 mm, SAS average is less than 3.25 mm, CL is -1.98˚ or LPC is less than 105.45 mm.

Keywords: Dynamic MRI; Cervical spine; Cord compression; Risk factor

INTRODUCTION
In the previous literature, the pathophysiology of cervical compressive myelopathy is related to static cord compression and dynamic factors which aggravates central canal stenosis. Conventional MRI is a gold standard exam for diagnosis of cervical myelopathy, but cannot detect dynamic cord compression. Dynamic MRI is used to identify dynamic cord compression in cervical...
myelopathy patients whose cord compression was not found with conventional MRI. Risk factors of cervical myelopathy such as bulging disc and ligament flavum buckling which cause dynamic cord compression have been reported in the literature. However, Dynamic MRI after a routine MRI examination is still expensive and require additional time and patient who take dynamic MRI is placed in slightly uncomfortable positions. This study aims to evaluate radiologic factors suggesting dynamic spinal cord compression.

METHODS

Patients

Between January 2014 and December 2016, 89 patients examined dynamic MRI due to neck pain or neurological symptoms (radiating pain to upper extremities, tingling sensation of the upper limb, weakness of upper and lower extremities and gait disturbance) (Fig. 1). Thirty-nine patients were excluded since multi-level ossification of the posterior longitudinal ligament, cervical spinal cord tumor, history of trauma, history of spine surgery. A total of 50 patients were included in this study, comprised of 36 in the group P (aggravation of spinal cord compression on dynamic MRI) and 14 in the group N (non-aggravation of spinal cord compression on dynamic MRI).

Radiologic measurements

Central canal diameter (CCD) and spinal cord diameter (SCD) at each intervertebral disc level were measured at the extension of the midline of the intervertebral disc (Fig. 2). CCD and SCD on C1 level were measured at the line connecting C1 anterior arch and posterior arch. Subarachnoid space (SAS) was calculated with the following formula:

$$\text{SAS}_{\text{level}} = \text{CCD}_{\text{level}} - \text{SCD}_{\text{level}}$$

Anterior and posterior length of cervical cord (ALCC and PLCC) was defined as a line along the anterior and posterior spinal cord from line connecting C1 anterior and posterior arch to the extension of the midline of C7 intervertebral disc. Length of anterior column (LAC) was measured from apex of odontoid process to the midpoint of C7 lower endplate. Length of posterior column (LPC) was measured from C1 posterior arch to lower end of C7 lamina. Cervical lordosis was defined as the Cobb’s angle between C2 lower endplate and C7 lower endplate. Cervical lordosis (CL) on flexion and extension position was measured on dynamic MRI. Cervical range of motion (ROM) was calculated with the following formula:

$$\text{Cervical ROM} = \text{CL}_{\text{extension}} - \text{CL}_{\text{flexion}}$$

All measurements were performed using the INFINITT pro-
gram (INFINITT Healthcare Co. Ltd., Seoul, South Korea). All the radiological assessments were evaluated by two independent spine surgeons blinded to the study information, and average parameters were used in the analysis.

Statistical analysis
The statistical analyses were performed using the Student t-test for continuous variables and the Chi-square test or Fisher exact test for categorical variables. A receiver operating characteristics (ROC) curve analysis was performed to determine the cut-off value of the radiologic factor. The accuracy of the exam was evaluated by calculating the area under a curve (AUC). All statistical analyses were performed using R (Version 3.6.1, open-source software, www.r-project.org).

RESULTS
Demographic data of both groups are shown in Table 1. There were no significant statistical differences in sex, SCD, ALCC, PLCC, LAC, and cervical ROM. The mean age of the group P was 62, and that of group N was 45 (p < 0.001). The mean CCD and CCD at the C1 level of group P showed significantly narrower than those of the group N (9.43 vs. 11.25, 13.58 vs. 14.79, respectively). The mean SAS and SAS at the C1 level of group P also showed significantly narrower than those of the group N (2.90 vs. 4.00, 5.54 vs. 6.87, respectively). The mean LPC of group P was significantly shorter than that of group N (96.46 vs. 106.51; p = 0.037). CL of group P was 11.16° (lordotic curve), but that of group N was -2.11° (kyphotic curve).

A ROC curve was generated. A cutoff point of 54-year-old predicts the occurrence of spinal cord compression in dynamic MRI with 73.3% specificity and 85.7% sensitivity (Fig. 3A). The ROC curve demonstrated an AUC of 0.813 (p < 0.001). A cutoff point of 10.319 mm in CCD predicts the occurrence of spinal cord compression in dynamic MRI with 80.0% specificity and 77.1% sensitivity (Fig. 3B). The ROC curve demonstrated an AUC of 0.858 (p < 0.001). A cutoff point of CCD at C1 level was 13.89 and AUC was 0.759 (p = 0.004). A cutoff point of 3.254 mm in SAS predicts the occurrence of spinal cord compression in dynamic MRI with 100.0% specificity and 71.4% sensitivity (Fig. 3C). The ROC curve demonstrated an AUC of 0.884 (p < 0.001). A cutoff point of 3.254 mm in SAS predicts the occurrence of spinal cord compression in dynamic MRI with 80.0% specificity and 80.0% sensitivity (Fig. 3D). A cutoff point of -1.98 degrees in CL predicts the occurrence of spinal cord compression in dynamic MRI with 53.3% specificity and 88.6% sensitivity (Fig. 3D). The ROC curve demonstrated an AUC of 0.688 (p = 0.037).

DISCUSSION
Conventional MRI is the gold standard exam for diagnosis of cervical myelopathy because it supplies more practical informa-

Table 1. Demographics of the patients

| Age (years) | group P | group N | p-value |
|-------------|---------|---------|---------|
| 62 (42-79)  | 45 (18-69) | <0.001 |
| Sex (male : female) | 20:16 | 5:9 | 0.345 |
| CCD (mm) | 9.43 (7.51-11.64) | 11.25 (9.52-14.10) | <0.001 |
| CCD at C1 (mm) | 13.58 (10.14-18.43) | 14.79 (12.34-18.39) | 0.041 |
| SCD (mm) | 6.61 (4.96-8.08) | 6.83 (6.10-7.65) | 0.087 |
| SCD at C1 (mm) | 7.68 (5.69-9.65) | 8.02 (6.80-9.07) | 0.360 |
| SAS (mm) | 2.90 (1.68-4.43) | 4.00 (3.26-6.50) | <0.001 |
| SAS at C1 (mm) | 5.54 (3.07-9.24) | 6.87 (4.30-9.92) | 0.004 |
| ALCC (mm) | 105.50 (87.56-125.80) | 110.91 (94.96-123.35) | 0.114 |
| PLCC (mm) | 99.94 (81.69-119.87) | 107.76 (88.17-120.56) | 0.099 |
| LAC (mm) | 113.14 (94.23-123.93) | 117.27 (105.17-126.84) | 0.290 |
| LPC (mm) | 96.46 (79.7-116.15) | 106.51 (83.73-118.38) | 0.037 |
| CL (°) | 11.16 (-22.30-32.28) | -2.11 (-17.34-20.65) | 0.014 |
| Cervical ROM (°) | 32.69 (12.19-56.36) | 32.35 (16.86-52.99) | 0.557 |

The values represent the means and ranges. Boldface type indicates statistical significance.
Group P: dynamic cord compression positive; Group N: dynamic cord compression negative; CCD: central canal diameter; SCD: spinal cord diameter; SAS: subarachnoid space; CL: cervical lordosis; ALCC: anterior length of cervical cord; PLCC: posterior length of cervical cord; LAC: length of anterior column; LPC: length of posterior column.
Fig. 3. Receiver operating characteristics (ROC) curves for predicting dynamic cord compression: (A) age, (B) central canal diameter, (C) subarachnoid space, (D) cervical lordosis, (E) length of the posterior column.
tion about spinal cord and central canal stenosis, which changes depending on the ligament and disc. Conventional cervical MRI is typically performed with the patient in a supine position and neck in a neutral position during examination. Thus, conventional MRI may not represent the physiologic neck motion and dynamic cord compression. Previous papers suggest that pathophysiologic changes of cervical myelopathy is related to static spinal cord compression and dynamic cord compression caused by dynamic factors such as vertebral column instability and aggravation of the spinal canal diameter in different postures. Since Dynamic MRI is performed in neck flexion and extension position with placing custom-built positioning sponges under the head and neck, it provides additional information on dynamic compression. Dynamic MRI seems to be more sensitive in detecting dynamic cord compression. Tykocki et al. reported that 50% of patients in their study were classified to a high grade in Muhle scale (grade 2 and 3) in extension, but only 35% in neutral position. They also reported that neutral MRI might underestimate the degree of cervical cord compression, because grade 0 in Muhle scale was three times more often in neutral position than in extension position. In study of Zeitoun et al., 22.5% of grade 3 cord compression levels in extension position were grade 1 in neutral position, and the difference was most significant from C3-4 level to C5-6 level. In preoperative study of flexion-extension MRI conducted by Zhang et al., functional cord impingement (grade 3 in Muhle scale) increased to 12% in flexion, 34% in neutral, and 74% in extension position. They also reported that the ratio of grade 3 to grade 1 nearly doubled comparing to neutral MRI. When dynamic MRI was used for planning the operation, the number of levels requiring surgery was significantly increased. Therefore, this exam can be useful for planning the surgery of cervical myelopathy patients. However, only T2 weighted sequence in sagittal image with/without axial image is included in dynamic cervical MRI since these images can be taken rapidly to avoid motion artifact from the patient placed in uncomfortable position. Dynamic MRI also requires patients who underwent conventional MRI to spend additional time and cost.

Age-related disc degeneration causes changes in the facet joint; these lead to segmental instability and aggravation of physiologic motion. Segmental instability and angular motion are related to dynamic stenosis by thickening ligamentum flavum. Ligamentum flavum of kyphotic segments may become thicker than that of the lordotic segment because the kyphotic segment may have more room for extension. Segmental kyphosis also causes spinal cord tethering with reduced cord mobility due to spinal stenosis, which cannot distribute axial strain throughout the cord leading to the accumulation of distracting forces and axonal injury. In present study, there was a significant difference in age between group P and group N. It was supposed that the difference between two groups correlates with disc degeneration according to age.

The sagittal diameter of the spinal cord is nearly constant in adults, averaging about 8 mm from C3 to C7. Therefore, patients with congenitally narrow central canals may be more susceptible to spinal cord compression with relatively minor pathologic changes such as disc bulging, osteophyte, folding of ligamentum flavum. Previous literature provides that a ratio of the congenital narrowness of the central canal in cervical myelopathy patient was 66–72%, and the most frequent anomaly was a short lamina. Hayashi et al. proposed that developmental stenosis defined as AP diameter of CSF area less than 13 mm at pedicle level is risk factor of missed dynamic stenosis. Chen et al. observed that out of all the patients they reviewed, 31% had functional cord impingement in extension posture, whereas only 3% had it in flexion posture. They considered that sagittal canal diameter of C7 less than 10 mm was severe central canal stenosis and the chance of demonstrating dynamic cord compression on extension position increased to 79%. Greenberg suggested that in the adults, spinal cord compression always occurred when the space available for the cord (SAC) was 14 mm or less, possible occurred when the SAC was 15-17 mm and never happened when the SAC was 18 mm or more at Dens level. In present study, CCD had significant difference between group P and group N, and dynamic cord compression was significantly demonstrated using dynamic MRI when CCD at C1 was 13.89 mm or less and CCD average was 10.32 mm or less. There was significant difference in SAS between the two groups; the chance of demonstrating dynamic cord compression using MRI was increased when SAS average was 3.25 mm or less. As a result, patients with congenital central canal narrowness and insufficient subarachnoid space were more susceptible to dynamic cord compression. A few previous studies also reported that the cervical canal widened by 10-15% on flexion position and narrowed by 10-25% on extension position. Disc bulging and folding of ligamentum flavum on extension position cause spinal cord compression. It was also reported that sagittal SCD decreased in flexion position and increased in the extension position. In other words, spinal cord elongate, narrow and unfold in neck flexion position and shorten, thicken, and fold in neck extension position. These changes reflect that the spinal cord becomes susceptible to injury in the presence of cervical stenosis. In this study, SCD had no significant difference between group P and group N. We thought that the difference of SCD according to posture is more important than SCD in static state.

The limitation of the present study was its retrospective design,
small sample size. The criteria for performing dynamic MRI had not been established. Further research for additional factors such as the severity of cord compression, disc degeneration, segmental and cervical angle is needed in a large number of patients with long-term follow-up.

CONCLUSION

Dynamic MRI is more useful for the diagnosis of dynamic spinal cord compression in the following conditions: age is 54 years or older, CCD average is less than 10.32 mm, SAS average is less than 3.25 mm, CL is -1.98˚ or LPC is less than 105.45 mm.

NOTES

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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