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The Relationship between Disc Degeneration and Morphologic Changes in the Intervertebral Foramen of the Cervical Spine: A Cadaveric MRI and CT Study

A cadaveric study was performed to investigate the relationship between disc degeneration and morphological changes in the intervertebral foramen of cervical spine, including the effect on the nerve root. Seven fresh frozen human cadavers were dissected from C1 to T1, preserving the ligaments, capsules, intervertebral disc and the neural structures. The specimens were scanned with MRI and then scanned through CT scan in the upright position. Direct mid-sagittal and 45 degree oblique images were obtained to measure the dimension of the intervertebral disc height, foraminal height, width, area and segmental angles. Disc degeneration was inversely correlated with disc height. There was a significant correlation between disc degeneration and foraminal width (p<0.005) and foraminal area (p< 0.05), but not with foraminal height. Disc height was correlated with foraminal width but not with height. The segmental angles were decreased more in advanced degenerated discs. There was a correlation between nerve root compression and decreased foraminal width and area (p<0.005). This information and critical dimensions of the intervertebral foramen for nerve root compression should help in the diagnosis of foraminal stenosis of the cervical spine in patients presenting with cervical spondylosis and radiculopathy.

Key Words : *Cervical Vertebrae; Intervertebral Disk; Magnetic Resonance Imaging; Tomography, X-Ray Computed*

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INTRODUCTION

Degenerative changes in the cervical spine are an inevitable response to the aging process. Impairment of cervical nerve roots may result from instability, disc degeneration, herniation or spinal stenosis (1). In recent years, spinal stenosis has been understood better with respect to its clinical signs and symptoms, pathophysiology, pathoanatomy and treatment. Kirkaldy-Willis et al. (2) studied the spectrum of pathologic change in spinal stenosis. The three-joint complex, including the two posterior joints and the disc, is involved in the pathogenesis. Degenerative changes of the three-joint complex occur concurrently and result in instabilities, stenosis and even deformities.

In foraminal stenosis, the nerve root can be impinged in cephalad/caudad or anterior/posterior direction. Foraminal nerve root compression can occur secondarily to subluxation of the superior articular facet, a laterally-herniated disc or osteophyte from the posterolateral part of the vertebral body (3). Extensive research has been conducted to investigate the intervertebral foramen in the lumbar spine (4-7); however, there is limited data related to the cervical region.

The choice of imaging modality most appropriate for detecting foraminal stenosis remains the subject of data. Magnetic resonance imaging (MRI) is considered as the gold standard for soft tissue pathology, while computed tomography (CT) is still utilized for bony abnormalities.

The purpose of this study was to investigate the anatomic changes in intervertebral foramen and nerve root compression with degenerative changes of cervical spine in neutral position using both CT and MRI.

MATERIALS AND METHODS

Seven fresh cadavers (4 males, 3 females) with ages from 44 to 85 yr (mean=65.3) were used in this study. To rule out any gross pathology aside from cervical spondylosis, plain radiography were taken and analyzed. The extraneous soft tissues were removed carefully so that the ligaments, facet capsule and disc remained intact. And then, the cervical spines were removed with saw and osteotome, and C1-T1 motion segments were obtained. Extracted cervical spines were attached to base molds with resin in the erect position. The motion segments were frozen rapidly with liquid nitrogen, sealed in plastic bags to prevent dehydration and stored frozen in the

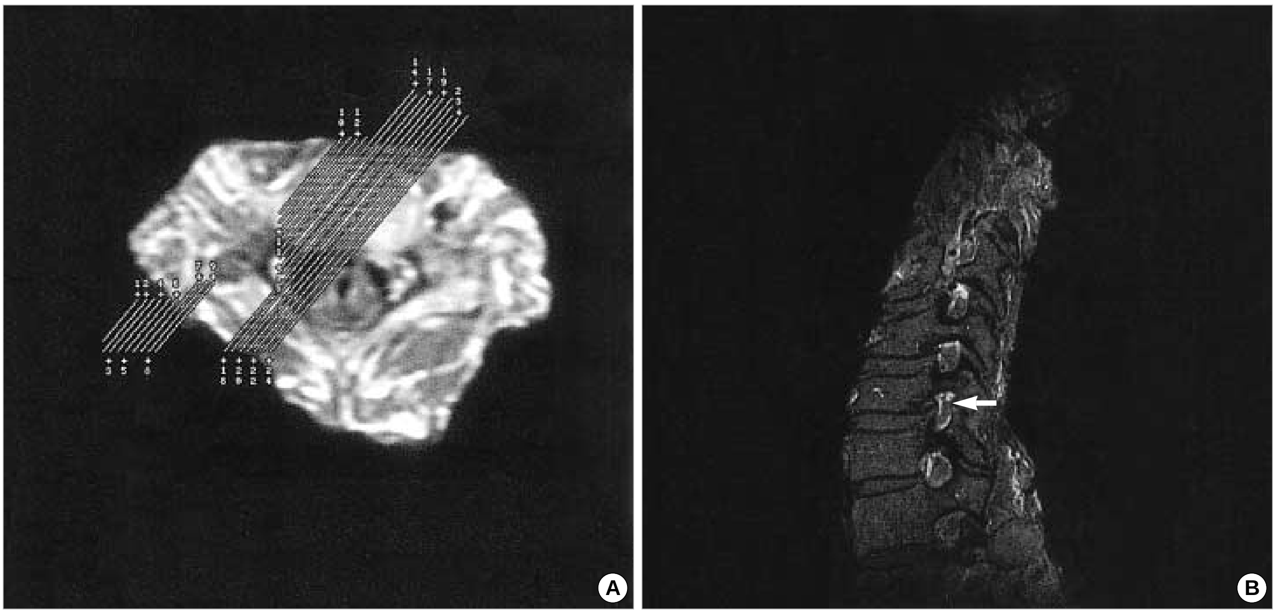

Fig. 1. (A) T1-weighted (500/16), 45 degree oblique projections of magnetic resonance imaging of the cervical spine, 1.0 mm slice thickness. (B) MRI shows decreased width and area at C5-6 intervertebral foramen (arrow), but relative conservation of foraminal height.

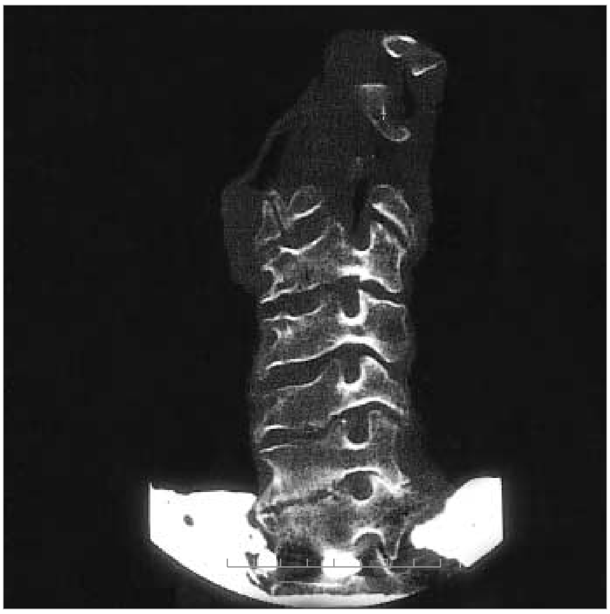

Fig. 2. Parasagittal oblique plane CT images of the cervical spine.

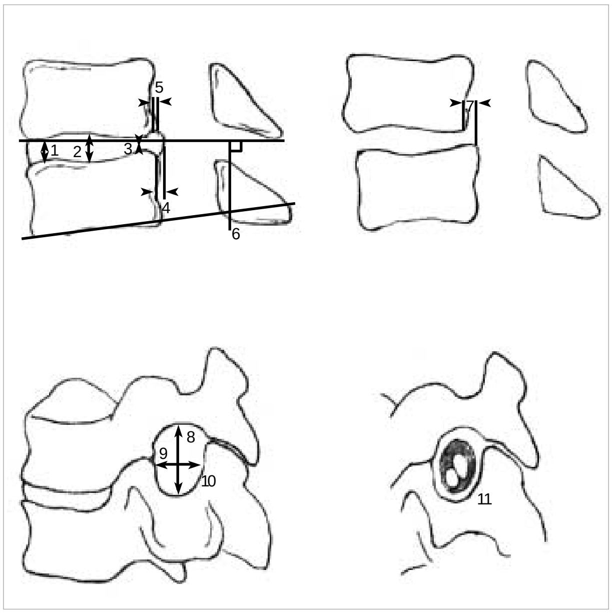

Fig. 3. Diagram showing the sagittal parameters of measurement. 1. Anterior disc height, 2. Midpoint disc height, 3. Posterior disc height, 4. Posterior bulging of disc, 5. Distance of spur, 6. Segmental angle of body, 7. Vertebral body translation, 8. Foraminal height, 9. Middle foraminal width, 10. Foraminal area, 11. Nerve root condition.

freezer at -20℃.

Total 35 motion segments from C2 to C7 were studied. Using a 1.5 T Signa scanner (GE Medical Systems, Milwaukee, WI, U.S.A.), sagittal images on T1 (TR: 500 ms, TE: 40 ms, FOV: 16×16 cm) and T2 (TR: 4,000 ms, TE: 90 ms, FOV: 16×16 cm) image condition were acquired to allow for measurement of disc degeneration. Criteria by Frymoyer and Gordon (8) were used in this study to clarify the degeneration of disc. The specimens were scanned in an erect position to make a lordotic curve of cervical spine, even though the head was absent. The medial edge of the foramen was identified and several images were taken progressing laterally through the foramen in 45 degree oblique projections (TR: 500 ms, TE: 16 ms, FOV: 16×16 cm, 1.0 mm slice thickness) (Fig. 1). The image included the medial margin of each pedicle, the isthmus of the foramen, and the lateral edge of the foramen and vertebral artery.

Nerve root compression was considered to be present when there was contact between the nerve root and adjacent tissue, and when there was deformation of the root. The appearance of the nerve was graded as normal, contacted or deformed by the bony margins of the foramen by the author.

The frozen cervical motion segments were imaged in the direct sagittal and oblique projections in a CT scanner (General Electric Medical Systems High-speed Advantage 9800; Milwaukee, WI, U.S.A.) using 120 kV, 200 mA and 1 mm slice thickness (Fig. 2). The CT gantry was oriented identically at each time. The midsagittal CT images and parasagittal oblique plane CT images in the middle of the pedicle were analyzed.

A total of 8 parameters were measured on the midsagittal and oblique plane CT images, including the disc height (anterior, mid-point, and posterior), foraminal height, foraminal middle width, posterior bulging of the intervertebral disc, distances of the posterior osteophyte from the endplate of the vertebral body, segmental angulation of vertebral body, vertebral body translation and the cross sectional area of the foramen (Fig. 3). The cross sectional area of the foramen, which was outlined by the facet joint, the 2 pedicles, the vertebral body and the posterior border of the disc was computed using National Institutes of Health image program software (Scion image, Scion Corporation, Frederick, MD, U.S.A.). All of the measurements were made independently by 3 investigators. The measurements were repeated twice and took the mean value to reduce the errors of measurements. The differences between the measurements of the groups at the different levels were analyzed by ANOVA, and regression analysis was performed to determine any correlation between each parameters.

Table 1. Incidence of disc degeneration

Level/Grade*	1	2	3	4	5
C2-3		1	5		1
C3-4		2	1	1	3
C4-5			4		3
C5-6				3	4
C6-7			1	2	4
	0	3	11	6	15

*Criteria by Frymoyer and Gordon (Ref. 8).

Table 2. Values for midsagittal parameters according to the degeneration

Parameter/Grade*	2	3	4	5
Mid. disc height (mm)	5.17±0.65	5.76±0.85	5.46±0.61	3.02±1.07
Spur (mm)	0.59±0.52	0.82±0.47	1.44±1.37	1.86±0.97
Disc bulging (mm)	0.56±0.12	1.31±0.81	1.83±0.97	1.63±0.86
Rt. foramen height (mm)	10.46±0.72	11.73±2.22	10.39±0.46	9.96±1.70
Lt. foramen height (mm)	9.30±0.96	11.05±1.35	10.87±0.93	9.50±0.79
Rt. foramen width (mm)	5.58±1.63	5.97±2.14	3.95±0.82	3.05±1.25
Lt. foramen width (mm)	5.48±1.11	5.16±1.36	4.35±1.40	2.89±1.03
Rt. foramen area (mm^2)	5.36±0.69	6.29±2.18	4.72±0.43	3.68±1.04
Lt. foramen area (mm^2)	4.35±0.82	5.70±1.25	5.19±1.47	3.48±0.71

*Criteria by Frymoyer and Gordon. Rt., right; Lt., left.

RESULTS

In terms of disc degeneration, 0% had grade I, 8.6% had grade II, 31.4% had grade III, 17.1% had grade IV and 42.9% had grade V according to criteria by Frymoyer et al. because of these cadavers are old aged group (Table 1). Disc degeneration was inversely correlated with disc height (r=0.714 for middle height, r=0.677 for anterior height, r=0.578 for posterior height). It meant that if disc degeneration was more severe, disc space was more narrowed. There was a significant correlation between disc degeneration and foraminal width ($p<0.005$) and foraminal area ($p<0.05$), but not with foraminal height.

The segmental angles were decreased in more advanced degenerated disc and there was no statistical significance between segmental angles and other parameters.

There was a significant correlation between spur formation and disc degeneration ($p<0.005$) and foraminal area ($p<0.005$) (Table 2).

Table 3. Incidence of nerve root condition

Level/R.C*	Normal Rt/Lt	Contacted Rt/Lt	Deformed Rt/Lt
C2-3	5/4	1/1	1/2
C3-4	1/1	2/0	4/6
C4-5	2/0	1/1	4/6
C5-6	1/0	1/1	5/6
C6-7	1/1	2/3	4/3
	10/6	7/6	18/23

*R.C, Root Condition; Rt, right; Lt, left.

Table 4. Values for midsagittal parameters according to the nerve root condition

Parameter/R.C*	Normal	Contacted	Deformed
Disc height (mid.) (mm)	5.38±0.96	4.79±1.99	4.04±1.44
Spur (mm)	0.74±0.65	1.20±0.78	1.64±1.06
Segmental angle (°)	26.84±27.34	25.32±53.16	24.57±50.95
Disc bulging (mm)	1.14±0.74	1.56±0.86	1.57±0.89
Foramen height (mm)	11.08±1.88	10.35±1.61	10.18±1.38
Foramen width (mm)	5.69±1.91	4.92±1.63	3.40±1.31
Foramen area (mm^2)	5.61±1.83	5.32±1.43	4.12±1.34

*R.C, Root Condition.

Table 5. Values for midsagittal parameters according to the level of cervical spine

Parameter/Level	C2-3	C3-4	C4-5	C5-6	C6-7
Ant. disc height (mm)	4.67±0.95	4.67±1.55	3.71±0.57	3.38±1.57	2.84±1.14
Mid. disc height (mm)	5.35±1.39	4.59±1.47	4.60±1.15	3.92±1.89	3.97±1.81
Post. disc height (mm)	2.91±0.57	2.47±0.91	2.34±0.80	2.13±0.98	1.78±1.10
Spur (mm)	0.69±0.63	1.64±0.85	1.49±1.15	1.75±1.22	1.20±0.95
Translation (mm)	0.37±0.47	1.09±1.05	1.01±1.16	0.57±0.65	0.13±0.58
Segmental angle (°)	21.78±42.40	54.66±50.04	26.22±50.14	1.41±7.86	22.09±40.17
Disc bulging (mm)	1.17±0.89	1.28±0.76	1.59±1.00	2.08±0.90	1.24±0.67
Rt. foramen height (mm)	12.39±2.52	10.70±1.01	10.34±2.00	10.00±0.82	9.73±1.25
Lt. foramen height (mm)	11.31±1.70	9.99±0.67	9.55±0.89	9.98±1.29	10.19±1.05
Rt. foramen width (mm)	6.97±2.28	3.59±1.67	3.73±1.50	3.47±1.05	3.95±1.06
Lt. foramen width (mm)	5.67±1.16	3.58±1.54	3.50±1.61	3.45±1.42	4.18±1.37
Rt. foramen area (mm^2)	7.14±2.19	4.36±1.20	3.89±1.35	4.24±0.73	4.49±1.21
Lt. foramen area (mm^2)	5.80±1.45	4.19±1.02	4.11±1.40	4.03±1.42	4.60±1.37

Rt., right; Lt., left.

Nerve roots were noted to be normal in 22.8% of specimens, contacted in 18.6%, and deformed in 58.6% (Table 3). There was a correlation between nerve root compression and decreased foraminal width and area ($p<0.005$). Critical values for nerve root contact ranged 2.9-8.5 mm (mean=4.92) for the foraminal width, 3.3-8.1 mm^2 (mean=5.31) for foraminal area and 0.8-3.5 mm (mean=1.67) for posterior disc height (Table 4).

The heights of intervertebral disc according to the level of disc were similar mostly and there was no correlation between the level and disc height and disc degeneration in this old age group of cadavers (Table 5). There was a significant correlation between the disc height and the foraminal area ($p<0.05$) but not with foraminal height. There was no statistical significance between the translation and other parameters and also between posterior disc bulging and other parameters.

DISCUSSION

Extensive research has been conducted to investigate the intervertebral foramen and nerve root in the lumbar spine. In the cervical spine, however, most studies have focused on the evaluation of the vertebral body, spinal canal and spinal cord (9-12).

The cervical foramen forms an angle of about 45 degrees with the anteroposterior axis of the spine and about 10-15 degree caudal inclination from horizontal. The cervical intervertebral foramen is located under the isthmus region and the cervical foramen was divided into three zones: medial, middle, and lateral. When compared with the other two zones, the medial zone was believed to play an important role in the etiology of cervical radiculopathy because it is bounded by the uncinate process anteriorly, the superior facet posteriorly, and the adjacent pedicles superiorly and inferiorly. And the foramen has been traditionally described as having an hourglass configuration because of its layer area at the entrance and exit zone.

The MRI is traditionally used to obtain imagies in the sagittal and axial planes; however, oblique MRI's may be obtained to provide a clearer view of certain anatomical structures not available with the conventional technique. Oblique MRI has begun to be adopted into the conventional technique for the cervical spine.

Pech (13) demonstrated that surface coil MR images in a plane perpendicular to the cervical nerve roots allowed their relationship to intraforaminal structures and the boundary of the foramen to be determined. Yenerich and Haughton (14) reported on the advantages of oblique MRI of the cerviclal spine for patients with radiculopathy. It was found that MR provided excellent visualization of the nerve roots and foramen. This method also showed the foramen at several levels in a single image. Additionally, Schnebel et al. (15) reported a 96.6% agreement between MR and contrast CT in the diagnosis of spinal stenosis. It was found that the two methods were comparable in detecting spinal stenosis, and that MRI was more sensitive in detecting disc degeneration.

By using both CT and MRI, we were able to measure bony dimensions of the disc height, intervertebral foramen, spur, translation, disc degeneration, including the nerve root morphology and surrounding structures in the foramen. A multiplanar technique was used to obtain the oblique images. Oblique images may also be obtained using a volume acquisition technique in which thin slices are obtained and then reformatted into an oblique plane using a post processor. The method used in this study reduced scanner time and provided a good signal to noise ratio.

The dimensions of the foramen are of clinical importance in the diagnosis of foraminal stenosis and radiculopathy. Various studies have reported that the oblique MRI can provide information not available from the conventional technique. It was reported that delineation of disease in the lateral aspects of the spinal canal and foramen on sagittal images is more difficult because of the oblique course of the foramen with respect to the sagittal plane (16-19).

Intervertebral foraminal width is narrowed by degenerative change (spondylosis) and the nerve root is compressed. In a previous study, Ebraheim et al. (20) reported measurement of the cervical nerve root groove and the intervertebral foramen. It was found that the foraminal height and width increased from the cephalad to the caudal except at the C2-C3 level and the minimum width for all levels ranged 1-2 mm. In our study, intervertebral disc height and foraminal height decreased from the cephalad to the caudal and foraminal width and foraminal area decreased from C2 to C6 and slightly increased on the C6-7 level and the minimum width for all levels ranged 3.5 mm. We think that this result is different from Ebraheim's result due to soft tissue shadow and degenerative change of intervertebral disc on the imaging film.

Traction spurs have been proposed as an indicator of instability by Macnab (21). He suggested that the traction spur resulted from tensile stresses on the outermost annular fibers. The traction spur develops 2-3 mm away from the disc edge of the vertebral body and projects horizontally. In our study, the presence of traction spur was associated with translational instabilities. Furthermore, bulging of the disc was found to be associated with translational instabilities. Whether the bulging disc precedes or follows instability is not known from this study.

Each of the foramen was graded as normal (no or slight contact with the foramen), contact (20-40% of the nerve being contacted by the foramen) or obviously deformed. Results showed that the nerves with minimal or no contact at the isthmus region had significantly greater foraminal widths as compared with those with significant contact. The larger foraminal width would allow for additional space for the nerve.

The dimensions of the foramen are of clinical importance in the diagnosis of foraminal stenosis and radiculopathy. Previous studies reported that the dimension of spinal canal and intervertebral foramen on the lumbar spine can be changed significantly on flexion and extension motion (22-24). Yoo et al. (25) determined that flexion of the cervical spine increased the dimensions of the foramen whereas extension of the cervical spine decreased foraminal dimensions by 10% and 13% with 20 and 30 degrees of extension. On the study of an analysis of neuroforaminal pressures with varying head and arm position by Farmer and Wisneski (26), increasing neck extension led to significant pressure changes at each root tested. Our study is performed on the static neutral position but we think that dynamic study of cervical spine will be needed to evaluate the dynamic spinal stenosis in forth.

However, several limitations were inherent in our study design. Firstly, the cadaveric specimen without skull did not transfer the compression loading to the cervical spine, so we could not measure the dimension accurately. Secondly, the number of specimens was small in that when one analyzes data of the same level, the statistical significance decreases. Finally, the morphologic study using cryomicrotome should be added to determine the correlation of our data.

Facet overgrowth, herniated lateral disc, and uncinate process osteophytes may all reduce available room in the foramen. Conventional sagittal and axial images may miss or under represent pathology in the foramen because of its obliquity. Oblique MRI should be added to conventional methods when the physician's clinical examination is suggestive of cervical radiculopathy and conventional MR images are not diagnostic.

In conclusion, this information and critical dimensions of the intervertebral foramen for nerve root compression should help in the diagnosis of foraminal stenosis of the cervical spine in patients presenting with cervical spondylosis and radiculopathy. In addition to static anatomical changes, careful dynamic studies may be required to better evaluate the central canal and the foramen, subtle changes such as bulging disc, traction spur, and translation may make the neural structures more susceptible to compression.

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