A Novel Method for the Quantitative Evaluation of Lumbar Spinal Stenosis

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Abstract *Study design:* A retrospective study of computed tomography (CT) myelographic images in patients with degenerative lumbar spinal stenosis (LSS). *Objectives:* To introduce a new technique for the quantitative evaluation of LSS. *Background:* Advances in hardware and software technology now permit inexpensive digitalization of radiological images, and enable methodologies for quantifying space available for neural elements in spinal canal. However, a valid method with quantitative evaluation of spinal stenosis in living patients has not been developed yet. *Methods and materials:* Preoperative CT myelographic scans of 50 patients with degenerative LSS were collected for retrospective investigation. The patients subsequently underwent lumbar decompressive surgery. They included scans from thoracic vertebra 12 (T12) to sacrum (S1), in which each segment was scanned through both the vertebral body and disk. All CT scan films were digitized using a high-resolution digital camera. ImageTool™ software was used to measure three parameters: cross-sectional area of dural sac at disk level (A), cross-sectional area of spinal canal at midpedicular level (B), and cross-sectional area of vertebral body (C). The dural sac canal ratio (DSCR) was calculated as $A/B \times 100\%$. Low DSCR implied severe dural sac compression with a high degree of stenosis. The spinal canal vertebral ratio (CVR) was also calculated as $B/C \times 100\%$. Low CVR implied a low baseline of canal capacity for neural elements. They were calculated from T12 to S1. *Results:* The study consisted of 26 male and 24 female patients, with an average age of 68.4 (35–97) years. A total of 295 segments were evaluated, of which 118 (40%) were surgically decompressed. There were wide ranges of canal cross-sectional areas (140–475 mm²) and dural sac cross-sectional area (54–435 mm²). Male patients had a slightly larger canal cross-sectional area than female patients at

each level. The mean CVR was found decreased from T12 (26.1%) to L4 (18.3%). This was higher in female than in male patients, especially from T12 to L2 ($P < 0.01$). There were significant correlations between spinal canal and dural sac cross-sectional area ($r = 0.55$, $P < 0.001$), and also between CVR and DSCR ($r = 0.31$, $P < 0.001$). Of the levels decompressed, 82% was performed from the level L2 to L5, in which there was no significant difference in canal cross-sectional area and CVR between decompression and nondecompression ($P > 0.05$). There was a good correspondence between decreasing mean DSCR and increasing percentile of levels decompressed. *Conclusion:* DSCR represents a useful method for the quantitative diagnosis of lumbar spinal canal stenosis. ImageTool™ software is a useful tool in measuring spinal morphometry.

Key words lumbar spinal stenosis · quantitative diagnosis · ImageTool™

Degenerative lumbar spinal stenosis (LSS) is the most common disorder afflicting the human spine. Evaluation of the severity of LSS can be difficult. Surgeons and physicians determine the severity of stenosis and make the decision of which level decompressed based on clinical symptoms, signs, radiology findings, and experience. Clinically, radiologic studies are assessed qualitatively, a process that lacks methodologic rigor to permit a strong conclusion in the diagnostic accuracies [19]. These limitations result in a considerable amount of subjective judgment for decision making in decompressive surgery, and level decompressed among surgeons. Studies found that agreement in deciding the severity or level of stenosis and the classification of stenosis among surgeons was poor [5]. Some studies even reported that there was a poor correlation between clinical symptoms and signs, and radiology findings [2, 12]. Unfavorable surgical outcome for LSS varies from 20% to 40%, and revision related to recurrent stenosis is up to 20% [1, 4, 13, 15–18, 28, 29, 31].

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Using dry vertebra, two-dimensional radiographs, and even computed tomography (CT) scan dimensional measurement, normal and abnormal lumbar spinal canal size have been established, and provided for further study [7–9, 24, 30]. Advances in hardware and software technology now permit inexpensive digitalization of radiographic images, and enable methodologies for quantifying space available for neural elements in spinal canal. Unfortunately, most studies using advanced techniques such as CT, MRI, and CT myelography do not perform a quantitative evaluation. Using a coding index for grading the degree of stenosis, Drew et al. [5] suggested that CT scans were not a reliable method to identify the severity of LSS.

Computed tomography, with its cross-sectional scan, not only provides the capability to visualize the impact of degenerative changes in the three-joint complex and the role of soft tissues in the stenosis, but also establishes measurement of the transverse area of the dural sac as the main criteria for central spinal stenosis [25–27], especially when myelography is employed. After studying several spinal measurements, Schönström et al. [26, 27] noted that the dural sac cross-sectional area shows the highest correlation to the degree of spinal stenosis, clinically and experimentally. Patients with greater reduction in the compression of cauda equina were found to have better surgical outcomes [1, 15]. On other hand, there are many reports about the poor relationship between the degree of narrowing and clinical symptom, and clinical outcome in conservative and surgical treatment patients [2, 10, 11, 14, 21, 22]. Previous studies focusing on spinal canal and dural sac area measurement did not consider the variety of spinal vertebra and its contents between individuals. It is still not known whether this relates to the poor agreement between radiologic findings and clinical significance.

To our knowledge, there has been no reported study on the use of noncommercial software to quantify and evaluate the degree of LSS. The purpose of this study was to introduce a new technique using the ImageTool™ software to assess spinal morphometry.

Methods and materials

Subjects

The study consisted of 50 patients with degenerative LSS who subsequently underwent decompression with laminectomy in a spine center from January 1998 to December 1999. Diagnosis, operative method, and level of decompression for each patient were collected from chart review.

Criteria for patient selection were: (1) degenerative LSS as the primary diagnosis, in which patients had radicular pain with or without back pain; (2) age greater than 35 years; (3) no history of prior lumbar spine surgery, vertebral fracture, congenital LSS, significant scoliosis, and with a single diagnosis of disk herniation.

Table 1. Canal cross-sectional area (CCA) and canal vertebra ratio (CVR) from the level T12 to L5 (mean $\pm$ SD)

	<i>N</i>	CCA (mm ²)	CVR (%)
T12	48	275 $\pm$ 46	26.1 $\pm$ 5.8
L1	49	282 $\pm$ 40	25.4 $\pm$ 5.0
L2	50	257 $\pm$ 42	21.7 $\pm$ 4.8
L3	50	247 $\pm$ 50	19.4 $\pm$ 4.1
L4	50	241 $\pm$ 52	18.3 $\pm$ 3.9
L5	48	252 $\pm$ 66	21.7 $\pm$ 5.6

Measurements on CT Myelography

Preoperative CT myelography scan films were collected for retrospective investigation. Ordinary myelography was performed with intrathecal instillation of 15 mL iohexol, 180 mg/mL (Omnipaque, Nycomed, Oslo, Norway). The CT machine used was a General Electric HiSpeed Advantage (Milwaukee, WI, USA) that was run with contiguous slices of 3-mm thickness from thoracic vertebra 12 (T12) to sacrum (S1).

All CT scan films (images captured from x-ray) were digitized to JPEG file format by using a high-resolution digital camera. A free image processing and analysis program, UTHSCSA ImageTool™ (IT) version 3.0 (downloaded from UTHSCSA Dental Diagnostic Science; San Antonio, TX, USA), was used for measurement of the following areas, from T12 to S1: cross-sectional area of dural sac at disk level (*A*), cross-sectional area of spinal canal at midpedicular level (*B*), and cross-sectional area of vertebral body (*C*). With the help of the IT software, the average value of each parameter was automatically obtained via mouse trailing in the cross-sectional area. At least three attempts of trailing were required in each measurement. They were calibrated for changes with the scale in the CT slice. The dural sac canal ratio (DSCR) was calculated as $A/B \times 100\%$. Low DSCR implied severe dural sac compression with a high degree of stenosis. The spinal canal vertebral ratio (CVR) was calculated as $B/C \times 100\%$. Low CVR implied a low baseline of canal capacity for neural elements.

Statistical analysis

Descriptive statistics and univariate analysis were performed with SPSS software (Version 8.00; SPSS, Inc., Chicago, IL, USA). Chi-square and *t*-test were used to test the difference when appropriate. Correlations were per-

Table 2. Dural sac cross-sectional area (DSCA) and dural sac canal ratio (DSCR) at disc level from T12–L1 to L5–S1 (mean $\pm$ SD)

	<i>N</i>	DSCA (mm ²)	DSCR (%)
T12–L1	48	258 $\pm$ 49	93.9 $\pm$ 12.0
L1–2	49	218 $\pm$ 47	77.4 $\pm$ 13.3
L2–3	50	166 $\pm$ 47	64.9 $\pm$ 16.1
L3–4	50	140 $\pm$ 42	58.5 $\pm$ 18.8
L4–5	50	132 $\pm$ 55	54.4 $\pm$ 18.3
L5–S1	48	170 $\pm$ 73	65.4 $\pm$ 20.1

Table 3. Comparison of canal cross-sectional area (CCA) canal vertebra ratio (CVR) between compression and nondecompression at different level (mean $\pm$ SD)

Segments	N/N	CCA (mm ²)		CVR (%)	
		Decompression	Nondecompression	Decompression	Nondecompression
L1	7/42	267 $\pm$ 51	284 $\pm$ 38	22.7 $\pm$ 5.0	25.8 $\pm$ 4.9
L2	26/24	254 $\pm$ 49	260 $\pm$ 33	20.4 $\pm$ 4.9	23.3 $\pm$ 4.3*
L3	35/15	251 $\pm$ 52	240 $\pm$ 48	19.1 $\pm$ 4.1	20.0 $\pm$ 4.3
L4	37/13	240 $\pm$ 49	242 $\pm$ 62	18.5 $\pm$ 4.0	17.9 $\pm$ 3.7
L5	16/31	230 $\pm$ 50	262 $\pm$ 71	18.0 $\pm$ 3.8	19.8 $\pm$ 5.2

Difference was examined with independent *t* test, statistical significance was expressed as **P* < 0.05; ***P* < 0.01.

formed with Pearson correlation coefficients. A value of *P* < 0.05 was considered statistically significant.

Results

The study population comprised 26 male and 24 female patients with an average age of 68.4 (range, 35–97) years. A total of 295 segments were evaluated, of which 118 (40%) were subsequently surgically decompressed.

The canal cross-sectional area ranged from 140 to 475 mm², with a mean value of 259 $\pm$ 49 mm², with the largest deviation occurring at L5 (Table 1). Male patients had a slightly larger canal cross-sectional area than female patients at each level. A significant difference was found at L5 (*P* = 0.01).

The mean CVR gradually decreased from L1 (26.1%) to L4 (18.3%) (Table 1), in which females had a higher CVR than males. Significant differences were found at T12 (*P* = 0.002), L1 (*P* < 0.001), and L2 (*P* < 0.001).

The dural sac cross-sectional area ranged from 54 to 435 mm², with a mean value of 181 $\pm$ 52 mm², with the largest deviation found at L5–S1. The mean DSCR decreased from T12–L1 (93.9%) to L4–5 (54.4%) (Table 2). Both dural sac cross-sectional area and DSCR were not associated with gender in each segment.

There were significant correlations between canal cross-sectional area and dural sac cross-sectional area (*r* = 0.55, *P* < 0.001), and also CVR and DSCR (*r* = 0.31, *P* < 0.001). Of the levels decompressed, 0.8% was performed at T12–L1, 5.1% at L1–2, 21.2% at L2–3, 28.8% at L3–4, 31.4% at L4–5, and 12.7% at L5–S1. Overall, 82% was per-

formed from L2 to L5. There was a good correspondence between increasing percentile of levels decompressed and decreasing mean DSCR, and a significant internal correlation was found between the percentile of levels decompressed and DSCR of less than 70% from T12 to S1 (*r* = 0.94, *P* = 0.005).

There were no significant differences between the canal cross-sectional area and CVR between decompression and nondecompression from L1 to L5 (*P* > 0.05), but the dural sac cross-sectional area and DSCR were significantly smaller in decompression than nondecompression at each segment from L1–2 to L5–S1 (*P* < 0.05 to *P* < 0.001). (Tables 3 and 4).

Discussion

The measurement of image films in the computer involves two steps: digitization of the films using hardware equipment and measurement using computer software. The method previously used was carried out on films scanned with a computerized digitizer or scanner, and the area measurements were performed with a computer program [3, 11, 20, 21, 30]. With the method, Oland and Hoff [22] reported that the intraobserver variability was within the range of 10.7%. Meanwhile, in this study, we used a digital camera for the digitization of CT films. Area measurement was performed by using the ImageTool™ software, in which the average value is automatically obtained when the mouse trails the cross-sectional area as many times as possible.

Table 4. Comparison of dural sac cross-sectional area (DSCA) dural sac canal ratio (DSCR) between compression and nondecompression at different segment (mean $\pm$ SD)

Segments	N/N	DSCA (mm ²)		DSCR (%)	
		Decompression	Nondecompression	Decompression	Nondecompression
L1–2	7/42	169 $\pm$ 55	226 $\pm$ 41*	62.6 $\pm$ 13.5	79.8 $\pm$ 11.6*
L2–3	26/24	142 $\pm$ 35	192 $\pm$ 45**	57.1 $\pm$ 14.7	73.3 $\pm$ 13.2**
L3–4	35/15	127 $\pm$ 36	173 $\pm$ 37**	52.2 $\pm$ 16.6	73.4 $\pm$ 15.3**
L4–5	37/13	121 $\pm$ 41	163 $\pm$ 77	50.2 $\pm$ 15.0	66.2 $\pm$ 22.1*
L5–S1	16/31	128 $\pm$ 57	183 $\pm$ 57**	55.1 $\pm$ 19.3	70.7 $\pm$ 18.7*

Difference was examined with independent *t* test, statistical significance was expressed as **P* < 0.05; ***P* < 0.01.

Spinal morphometric studies showed that the size of spinal vertebra and its contents changes with gender and race, and varies with level [6, 7, 9, 25]. However, previous studies focusing on spinal canal or dural sac cross-sectional measurement did not consider the varieties between individuals. This resulted in considerable variation in the results of area measurement between normal individuals [25], which limited their application. This study introduces the use of CVR and DSCR to increase the agreement in area measurement among individuals, which would make them better clinical predictors. Indeed, both spinal canal and dural sac cross-sectional areas were found with a wide range of difference, and canal cross-sectional area and canal vertebral ratio are significantly gender-related and vary with level. The narrowest canal was located at L2, L3, and L4 (Table 1), where degenerative LSS mostly occurs. Research showed that this was related to antenatal factor [23].

Early study found that canal cross-sectional area measurement in CT scans for the diagnosis of spinal stenosis was reliable, and was more sensitive than anteroposterior (AP) and interpedicular measurement [30]. Ullrich et al. [30] defined lumbar spinal stenosis as a condition where the canal transverse area is less than 145 mm². In degenerative spinal stenosis, compressive factors include bulging intervertebral disk, disk herniation, osteophyte formation, facet joint degeneration and hypertrophy, and ligament flavum infolding and hypertrophy. The narrowest dural sac is located at the level of intervertebral disk and facet joint [3], whereas the canal area at midpedicular level remains constant. The dural sac cross-sectional measurement has been found to be more reliable than osseous canal in diagnosing LSS [3]. Schönström et al. [27] confirmed that patients with spinal stenosis had a surprisingly normal size of bony canal when compared with the normal control. In this study, canal cross-sectional area and CVR showed no significant differences between decompression and non-decompression at each level. As expected, AP and interpedicular measurements in CT or radiography do not provide any evaluation in degenerative LSS. There was a good correspondence between decreasing mean DSCR and increasing percentile of levels decompressed.

The CVR may provide quantitative evaluation for developmental (congenital) stenosis, although it was not included in this study. In addition, we found there were significant correlations between canal cross-sectional area and dural sac canal cross-sectional area, and between CVR and DSCR, implying that narrow osseous canal may increase the risk of degenerative LSS. We selected the canal cross-sectional area at midpedicular level as the baseline of spinal canal capacity for neural elements in order to assess the degree of stenosis that expressed as DSCR. DSCR may represent a useful method for the quantitative evaluation of LSS in future studies.

There are several limitations in the current study. (1) For technique development, a study with retrospective design may not be sufficient, especially when it only considers patients from a single spine center. Further study will be needed to compare stenotic and normal subjects, as well as a

longitudinal investigation in multiple centers including patients treated with conservative and surgical treatment with a long-term follow-up. (2) As well known, the dural sac cross-sectional area reduces when the position is changes from flexion to extension. In this study, we supposed that the position of our 50 patients remained the same during CT myelography examination from January 1998 to December 1999. (3) Area measurement is significantly influenced by the level scanned and the level selected. Any uneven scanning in the end plate would influence the results. However, we observed that the largest deviation in the measurements occurred at L5 and L5–S1, which may relate to the less parallel scanning because of the slanting angle at the lumbosacrum area.

Key points

- A retrospective study of CT myelographic images including 295 levels in 50 patients with degenerative LSS was conducted. These patients subsequently underwent lumbar decompression.
- Adjusted canal cross-sectional area and dural sac canal ratio were introduced for the quantitative evaluation of LSS using a new technique.
- The dural sac canal ratio may as a useful method for the quantitative diagnosis in future studies.
- ImageTool™ is a convenient and effective software for the quantitative evaluation of spinal canal stenosis.

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