Prevalence and Definition of Multilevel Lumbar Developmental Spinal Stenosis

Marcus Kin Long Lai[1], Prudence Wing Hang Cheung, BDSc(Hons)[1] ,
Dino Samartzis, DSc[2,3] , and
Jason Pui Yin Cheung, MBBS, MMedSc, MS, PDipMDPath, MD,
FHKCOS, FHKAM, FRCSEd[1]

Abstract

Study Design: Cross-sectional study.

Objectives: To define multilevel lumbar developmental spinal stenosis (DSS) using a composite score model and to determine its prevalence.

Methods: This was a cohort study of 2385 openly recruited subjects with lumbosacral (L1-S1) MRIs. All subjects with previous spinal surgery or spinal deformities were excluded. The anteroposterior (AP) vertebral canal diameter was measured by two independent observers. Any associations between level-specific vertebral canal diameter and subject body habitus were analysed with non-parametric tests. Three or more stenotic levels, equivalent to a composite score of 3 or more, were considered as multilevel DSS. The median values of these subjects' AP canal diameters were used to construct the multilevel DSS values. Receiver operating characteristic analysis was utilized to determine the ability of these cut-off values to screen for DSS by presenting their area under curve, sensitivity and specificity.

Results: Subject body habitus was poorly correlated with AP vertebral canal diameter. Multilevel DSS was identified as L1<19 mm, L2<19 mm, L3<18 mm, L4<18 mm, L5<18 mm, S1<16 mm with 81%–96% sensitivity and 72%–91% specificity. The prevalence of multilevel DSS in this cohort was 7.3%.

Conclusions: Utilizing a large homogeneous cohort, the prevalence of multilevel DSS is determined. Our cut-offs provide high diagnostic accuracy. Patients with multiple levels that fulfil these criteria may be at-risk of spinal canal compressions at multiple sites.

Level of Evidence: III

Keywords

developmental spinal stenosis, lumbar spine, magnetic resonance imaging, multilevel, vertebral canal, prevalence

Introduction

Developmental lumbar spinal stenosis (DSS), as illustrated by Verbiest,[1] refers to a pre-existing narrowing of the lumbar bony canal. There is a lower threshold whereby patients are more susceptible to neural compression with mild degeneration, such as milder degrees of ligamentum flavum hypertrophy and disc herniation. It is important to differentiate DSS from degenerative lumbar spinal stenosis as they have different pathogenesis and treatments.[2] It was reported that spinal stenosis was associated with genetic mutations such as COL9A2, Trp2, and Trp3,[3,4] while LRP5 mutation is associated with DSS.[5] Hence,

[1] Department of Orthopaedics and Traumatology, The University of Hong Kong, Pokfulam, Hong Kong SAR, China
[2] Department of Orthopaedic Surgery, RUSH University Medical Center, Chicago, IL, USA
[3] International Spine Research and Innovation Initiative, RUSH University Medical Center, Chicago, IL, USA

Corresponding Author:
Jason Pui Yin Cheung, Department of Orthopaedics & Traumatology, The University of Hong Kong, Professorial Block, 5th Floor, 102 Pokfulam Road, Pokfulam, Hong Kong SAR, China.
Email: cheungjp@hku.hk

this is a result of spinal canal maldevelopment rather than a result of degenerative changes.

As DSS is considered to be a developmental event,[6] multi-level stenosis is expected and these patients are prone to developing neural compression at multiple levels.[7-9] This contributes to a high risk of reoperation up to 22% if levels with DSS are not decompressed in the initial surgery.[10-12] Therefore, it is crucial to identify any stenotic levels prior to the index surgery as they may also be indicated for prophylactic decompression. This can only be achieved by using a precise and accurate, standardized diagnostic tool. Over the years, numerous radiological cut-offs have been proposed to define DSS[7,13-16] without consensus. Some proposed cut-offs were of low sensitivity, indicating that many cases were underdiagnosed.[14] The imaging modalities were also inconsistent, ranging from axial or sagittal magnetic resonance imaging (MRI), to computed tomography (CT), myelography with contrast, and plain radiographs.[7-9,13-15,17-19] Furthermore, the orientation of patients during MRI or plain radiography also varied between studies, including supine and lateral standing.[7,9,13-16] In addition, the sample size in each individual study was very limited which is not representative of the overall population. Most importantly, the definition of DSS were based on single level measurements without consideration of multilevel involvement. With the above discrepancies, there is a need for a better definition of DSS.

Despite the inconsistency, it is well-recognized that the anteroposterior (AP) spinal canal diameter is significantly shorter in patients with DSS than the general "normal" population.[7,9,13,14] Therefore, due to a lack of consensus and weak significance in defining DSS as stated above, a cross-sectional study is conducted by utilizing population-based cohort to redefine the diagnostic criteria of DSS with a multilevel component and to determine the population-based prevalence of multilevel DSS. These new values provide better representation of a developmental origin, and is based on a large sample size with high sensitivity and specificity.

Materials and Methods

Study Design and Population

This was a cohort study assessing 2385 subjects[14,20-23] who were openly recruited from the general population via newspaper advertisement, posters and emails regardless of social or economic status between 2010-2015. Patients with previous lumbar surgery or history of scoliosis as a child were excluded. The selection was not based on the presence or absence of clinical symptoms. All subjects were of Chinese ethnicity, and underwent axial and sagittal MRI of the lumbosacral spine (L1-S1). Ethics review was conducted by a local institutional review board (UW 13-570). Written consent was obtained for every subject. As subjects were openly recruited from the population for MRIs without specifically targeting spinal stenosis, they were considered to be representative of the general population. Information regarding any low back pain or radicular
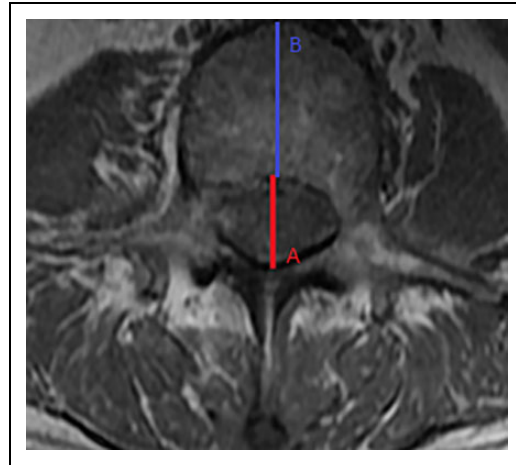

Figure 1. Axial magnetic resonance imaging: (A) Midline anteroposterior (AP) vertebral canal diameter; (B) Midline AP vertebral body diameter.

leg pain in the past month and year from the date of MRI was obtained. There was no missing data.

MRI Protocol

1.5 or 3 T HD MRI machines were used for imaging in all subjects in supine position. For axial scans, the field of view was 21 cm × 21 cm; for sagittal scans, the field of view was 28 cm × 28 cm. Slice thickness was 4 mm and 5 mm, and slice spacing was 0.4 mm and 1 mm for axial and sagittal scans respectively. The imaging matrix was 218 × 256 for axial scans and 448 × 336 for sagittal scans. For T1 and T2, the repetition time were 500-800 ms and 3320 ms respectively, and the echo time were 9.5 ms and 85 ms for T1 and T2 respectively. There were 11 slices per vertebral level and parallel slices were made according to the disc and pedicle levels.

Measurements

Two investigators were blinded to all clinical information and performed the measurements independently. Methods of measurements were standardized before data collection began. A subset of 40 subjects were randomly selected for intraobserver and interobserver reliability assessments prior to measuring the main cohort. The first and second round of measurements were performed at least 3 weeks apart. All images were measured using Philips DICOM Viewer 3.0 (Philips, Andover, MA, USA).

AP vertebral canal diameters and AP vertebral body diameters were obtained from T1-weighted axial MR images (Figure 1). The images were the cuts with the thickest pedicle diameter that also included the vertebral body, pedicle and lamina. The pedicle level was chosen to specifically measure the bony spinal canal diameter. This had been shown to be a useful and reproducible measurement for DSS.[14]

Redefining DSS

To specifically address the issue of defining DSS with a multi-level component, we utilized previously established cut-off values of the midline AP canal diameter[14]: L1 < 20 mm, L2 < 19 mm, L3 < 19 mm, L4 < 17 mm, L5 < 16 mm, S1 < 16 mm. These values were defined by comparing axial MRIs of surgical cases with controls and thus were more clinically relevant. However, they were based on single level diagnoses and could only indicate a level that was sporadically narrower than others or subject to measurement variations. Using our 2385 subjects, we dichotomized the canal measurements of each vertebral level as having DSS (score of 1) versus non-DSS (score of 0). This scoring system indicated whether a spinal level was developmentally stenotic and we defined a DSS "composite score" which represented the sum of the 6 individual vertebral level scores. Such scoring system was developed for better illustration and easier communication in this study. Those with a composite score of 3 or above, representing 3 or more stenotic levels, were considered as multilevel DSS. This was decided as the definition as two operative levels of lumbar spinal stenosis would coincide with three vertebral levels (i.e. L3-5 decompression).

Statistical Analysis

Descriptive statistics were conducted and presented as mean and range. Intraobserver and interobserver reliability assessments were based on Cronbach α analysis. Excellent reliability was noted with α values of 0.90 to 1.00 and good reliability was noted with 0.80 to 0.89.[24] To investigate any relationship between the canal diameter at each vertebral level and parameters relevant to patient body habitus including age, sex, body mass index (BMI) and the AP vertebral body diameter, nonparametric correlation tests using Spearman's correlation and Kendall's tau-b were used for continuous and binary variables respectively. The results of any relationship found between AP canal diameter and various patient factors were taken into account when redefining the cut-off values for multi-level DSS. A correlation coefficient between −0.3 and 0.3 was noted to be poor, while a value of 0.3 to 0.5 or −0.3 to −0.5 was noted to have low correlation.[25]

The level-specific median AP spinal canal diameter measurements of subjects with a composite score of 3 or more were used as a reference to indicate any subjects with multilevel DSS. Any canal diameter that was smaller than the proposed values[14] was considered a DSS level. Receiver operating characteristic (ROC) curve and the area under curve (AUC) were used to assess the diagnostic property of these proposed values, as compared to previous values. The best cut-off value with optimal sensitivity and specificity was applied. An AUC of 0.8 to 0.9 was considered excellent, while AUC of more than 0.9 was considered outstanding.[26] A decrease in AUC suggested worse diagnostic accuracy. Lastly, these new values were used to screen for multilevel DSS in this cohort and to identify its prevalence. SPSS Statistics 26 (IBM SPSS Inc., Chicago, IL, USA) was used for analysis. A P-value of less than 0.05 was considered statistically significant.

Results

There were 913 males (38.3%) and 1472 females (61.7%) with mean age of 51.1 (range: 16.7-77.9) and 51.2 (range: 17.4-86.3) respectively. The mean body weight was 69.6 kg for males and 57.2 kg for females, mean body height was 1.69 m and 1.57 m respectively, and mean BMI was 24.2 kg/m^2 and 23.2 kg/m^2 respectively. The mean and range of AP vertebral canal diameters and AP vertebral body diameters are presented in Table 1. Correlations of canal diameter and age, sex, BMI, and AP vertebral body diameter were poor or statistically insignificant, with correlation coefficients within −0.3 and 0.3 (Table 2). Excellent interobserver (α = 0.90-0.96) and intraobserver reliability (α = 0.92-0.99 and α = 0.92-0.99) between the two independent observers were noted.

Table 1. Vertebral Canal and Vertebral Body Measurements.

Measurement	Mean (mm)	Range (mm)
Axial anteroposterior vertebral canal diameter		
L1	21.2	16.7-29.6
L2	20.8	15.3-30.2
L3	20.3	14.7-29.7
L4	20.1	14.1-28.9
L5	20.1	12.7-32.3
S1	18.6	9.4-30.3
Axial anteroposterior vertebral body diameter		
L1	25.8	18.5-39.0
L2	27.1	19.5-37.7
L3	28.6	20.2-39.5
L4	28.8	16.4-40.0
L5	29.2	20.2-42.3
S1	27.7	12.6-38.8

mm: millimetres.

Table 2. Correlation Between the Vertebral Canal Diameter and Various Parameters.

Parameters	L1	L2	L3	L4	L5	S1
Age	-0.094**	-0.031	-0.045**	-0.006	-0.036	-0.006
Sex	0.090**	0.015	-0.014	0.061**	0.101**	0.233**
BMI	-0.034	-0.041	-0.071**	-0.033	-0.007	0.052
AP Vertebral Body Diameter	-0.009	-0.007	-0.003	0.014	0.035	0.018

**Statistically significant at the 0.05 level.
BMI: Body mass index, AP: anteroposterior.

By using previously defined DSS values, subjects with DSS were identified and composite scores were calculated (Table 3). The median AP vertebral canal diameter for subjects with a composite score of 3 or more (n=155) was also calculated (Table 4).

By comparing the AUCs of previously defined DSS values and the new multilevel DSS values, all levels had larger AUCs for multilevel DSS values with a range of 0.812-0.977 (p<0.001), suggesting excellent to outstanding diagnostic accuracy (Table 5). Therefore, we implemented the new multilevel DSS values for L1-S1. Based on the ROC analysis, multilevel DSS values were refined with best sensitivity and specificity for each vertebral level (Table 5). By using the new values on the same cohort, 173 subjects had multilevel DSS, which was equivalent to a prevalence of 7.3%. Multilevel stenosis involving L4+L5+S1 (17.3%) was most common, followed by L2+L4+L5 (6.9%) (Figure 2). Comparing between the 173 subjects with multilevel DSS and 2212 subjects without

multilevel DSS, there was a greater likelihood for radicular leg pain (Table 6).

Discussion

Multilevel involvement is one of the most distinctive features in patients with DSS.[7-9] This is an inborn defect rather than a degenerative change because it is considered as a maldevelopment during fetal and post-natal period. The current study showed that different demographics are poorly correlated with the canal size, and such correlations were negligible,[25,27] which adds evidence to a developmental origin. In addition, patients with DSS are reported to have high risk of reoperation especially at the adjacent levels.[10-12,28,29] This may be contributed by the presence of multilevel stenosis because pre-existing narrowed canals that are asymptomatic tend not to be investigated and operated. Furthermore, it is well-recognized that the lamina is significantly shorter in patients with DSS which contributes to a shorter AP canal diameter.[7,9,13,14,30] The narrowed vertebral spinal canal predisposes patients to neural compression even with only mild degeneration. As current available evidence[7-9,13-15,17-19] fails to reach consensus on defining DSS, this study redefined the cut-offs for DSS with a large-scale population-based cohort, and found the prevalence of multilevel DSS in southern Chinese. Our proposed values are different from previous proposed critical values, below which patients required surgery.[1,14] However, our results reflect the involvement of multilevel stenosis in the general population, and provides a guideline to which patients should be screened to better identify those at-risk of multilevel compression and risk of reoperation. Nevertheless, DSS is an important consideration during pre-operative assessment with nearly four times greater odds of adjacent level reoperation after the index decompression surgery.[10] Surgeons should consider whether pre-emptive decompression is warranted especially in those with pre-existing degeneration. Further studies are required to determine whether this practice is justifiable.

Many studies assessed the prevalence of lumbar spinal stenosis and degenerative lumbar spinal stenosis, but failed to address DSS specifically.[21,31,32] Our study reported a prevalence of 7.3%, suggesting that multilevel DSS is not an uncommon pathology in the general population. We redefined new

Table 3. Distribution of Composite Scores.

Composite Score	Number of Subjects	Most Prevalent Level(s)
0	1473	N/A
1	542	L3 (n=193)
2	215	L1+L3 (n=57)
3	107	L1+L2+L3 (n=55)
4	35	L1+L2+L3+S1 & L1+L2+L3+L4 (n=14 each)
5	11	L1+L2+L3+L4+S1 (n=5)
6	2	L1+L2+L3+L4+L5+S1

Table 4. Median Anteroposterior Vertebral Canal Diameter in Patients With Composite Score of 3 or More.

Vertebral Level	Mean (range)
L1	18.9 mm (16.7-19.9)
L2	18.3 mm (15.3-19.6)
L3	18.0 mm (14.7-19.0)
L4	16.6 mm (14.9-17.0)
L5	15.4 mm (14.4-15.9)
S1	14.6 mm (11.8-16.6)

mm: millimeters

Table 5. Comparison of Receiver Operating Characteristic Analysis for DSS Values.

Vertebral Level	Multilevel DSS Cut-off Values	Sensitivity, %	Specificity, %	Area Under Curve of Diagnosing Multilevel DSS Using Prior[(12)] DSS Values (P-value)	Area Under Curve of Diagnosing Multilevel DSS Using New Multilevel DSS Values (P-value)
L1	19 mm	95.7	90.9	0.906 (< 0.001)	0.977 (< 0.001)
L2	19 mm	92.8	87.9	0.934 (< 0.001)	0.965 (< 0.001)
L3	18 mm	94.5	90.9	0.933 (< 0.001)	0.951 (< 0.001)
L4	18 mm	80.9	78.8	0.875 (< 0.001)	0.892 (< 0.001)
L5	18 mm	84.7	71.9	0.814 (< 0.001)	0.882 (< 0.001)
S1	16 mm	80.7	73.1	0.772 (< 0.001)	0.812 (< 0.001)

DSS = Developmental lumbar spinal stenosis, mm: millimetres, %: percentage.
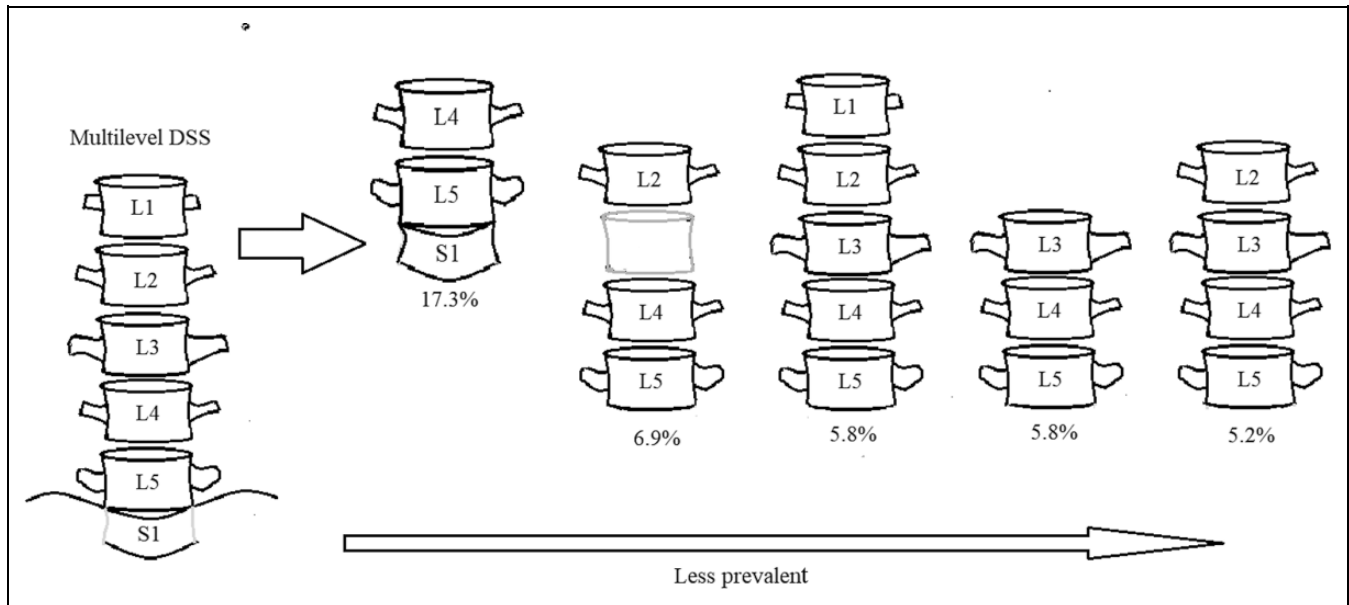
Figure 2. Patterns of Multilevel Lumbar Developmental Spinal Stenosis. L4+L5+S1 multilevel stenosis was most prevalent, followed by L2+L4+L5 multilevel stenosis.

Table 6. Prevalence of Pain.

Number of Subjects	DSS n=173	Non-DSS n=2212	P-value
LBP in the past month	92 (53.2%)	1157 (52.3%)	0.351
LBP in the past year	120 (69.4%)	1468 (66.4%)	0.069
Radicular leg pain in the past month	61 (35.3%)	610 (27.6%)	0.008
Radicular leg pain in the past year	83 (48.0%)	820 (37.1%)	0.001

DSS: developmental spinal stenosis; LBP: low back pain.

cut-off values for DSS based on the presence of multilevel stenosis. This is an appropriate definition as multilevel stenosis is a significant radiological feature in DSS, and is a major factor for reoperation risk. By using ROC analysis, we were able to refine the cut-offs with the best sensitivity and specificity. These values allowed us to identify more underdiagnosed cases accurately. Any subject with a composite score of 3 or more should be closely followed up because they are prone to develop compressive symptoms when they age with degeneration. These cut-off figures are representative of multilevel involvement.

Based on our results, L4-S1 was the most common multilevel pattern. This was of great importance as many symptoms arise from stenotic L4-S1 such as low back pain and sciatica,[11,12,33] and many of the surgical cases are targeting these three levels.[10] Furthermore, 4 out of 5 patterns (Figure 2) and more than 50% of subjects with multilevel DSS in our cohort had narrowed lumbosacral levels in a consecutive manner, suggesting a possible consecutive involvement for this pathology. All newly proposed values had better AUCs than the previous established DSS values.[14] Similar to our study, the authors also used subjects from the general population and

without surgery to develop DSS cut-offs for L1-L3. However, our larger sample size and better AUCs indicated our proposed values were more appropriate for population screening. Conversely, the previous study only included values for L4-S1 in a surgical cohort. This is reflected by improved AUCs of L4-S1 in our study, suggesting better diagnostic accuracy. These refined criteria provide superior diagnosis of multilevel stenosis in the underlying population, which serves the purpose of this study.

It is important to obtain accurate and precise measurements to define DSS. The AP canal diameter was used in this study as it is proven to be one of the most reliable spinal canal parameters to reflect canal development.[7,9,13,14] Many authors have used both axial and midsagittal MRI to evaluate the canal size, but midsagittal images are prone to inaccuracies. The canal diameter can be affected by the posterior curvature of the vertebrae and endplate disease.[14,34] Moreover, poor positioning and spinal deformities such as scoliosis greatly affect the possibility of obtaining a good midline cut for measurements. Therefore, greater variability is expected for midsagittal measurements, while axial measurements are preferable and more reliable.

Although our study provides some insights upon the definition and prevalence of multilevel DSS in the general population, there are several limitations in this study. Our results are based on southern Chinese and thus may not be generalizable to other populations. Results should be validated in different populations. Having said that, focusing on one ethnicity allowed us to minimize confounders such as genetic variations. In addition, as our subjects were openly recruited from the general population, the amount of male and female participants in this analysis could not be controlled as with the age of subjects. We also only excluded patients with known history

of scoliosis, any deformities that are occult or unbeknownst to the subjects may have been present. This was also a cross-sectional study design. Prospective follow-up of subjects to determine how many patients develop spinal stenosis symptoms requiring surgery should be performed. This is necessary to determine the risk of life-time symptomatology. Future study should also examine the relationship of multilevel DSS with other potential developmental phenotypes such as Schmorl's nodes and degenerative disc disease, and its development through skeletal growth. Although the diagnostic criteria is based on bony parameters and should be static, our measurements were performed on supine MRIs. Whether changes alter with dynamic MRI should be studied.

This study provides a more comprehensive understanding of the scope of DSS in a population. The large-scale population-based study provides the population-based prevalence of multilevel DSS and a better justified imaging definition. Multilevel DSS is not an uncommon pathology with specific patterns of level involvement. By emphasizing the presence of multilevel stenosis, our proposed DSS values serve to identify patients with multilevel DSS for better characterization of patients at-risk of multilevel stenosis and provides a guideline for determining which spinal levels may require consideration for pre-emptive decompression.

Author Contribution

Marcus Kin Long Lai and Prudence Wing Hang Cheung are equal contributors.

Declaration of Conflicting Interests

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ORCID iD

Prudence Wing Hang Cheung, BDSc(Hons) https://orcid.org/0000-0002-3213-7373
Dino Samartzis, DSc https://orcid.org/0000-0002-7473-1311
Jason Pui Yin Cheung, MBBS, MMedSc, MS, PDipMDPath, MD, FHKCOS, FHKAM, FRCSEd https://orcid.org/0000-0002-7052-0875

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