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Thoracolumbar intervertebral disc area morphometry in elderly Chinese men and women: radiographic quantifications at baseline and changes at year-4 follow-up

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The manuscript submitted does not contain information about medical device(s)/drug(s).

No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this manuscript.

This study was partially funded by the National Institute of Health R01 Grant AR049439-01A1 and the Research Grants Council Earmarked Grant CUHK 4101/02 M.

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Study Design: A population-based study with longitudinal follow-up.

Objective: To develop a quantitative index for lumbar disc space narrowing (DSN) evaluation in elderly subjects; to quantify the areal loss of thoracic and lumbar disc space over four years in elderly; and to study whether osteoporosis is associated with faster disc degeneration than normal bone mineral density (BMD) subjects.

Summary of Background Data: There is paucity of research center on quantitative classification of lumbar DSN based on disc areal morphometry.

Methods: With the database of MrOS /MsOS (Hong Kong) and those who attended the year-4 follow-up (n = 1519 for men and n = 1546 for women), data of 491 women and 592 men were randomly selected. For each spine, the anterior, middle, and posterior heights, anteroposterior diameter and structure area of discs (T4T5 to L4L5) were measured on lateral radiographs. Disc Area Index for Lumbar Spine (DAIL, disc area divided by the mean of the sum of square of the adjacent upper and lower vertebrae anterior-posterior diameter) was developed and compared with semi-quantitative DSN grading.

Results: DAIL correlated with semi-quantitative grading, with sensitivity and specificity varying from 87.3% to 96.8% for grade-1 DSN, and 92.9 % to 100% for grade-3 DSN. The thoraco/lumbar disc area loss among men and women during 4 years' follow-up period varied between 6.31% and 8.64%, and it was greater for women (mean: 7.18%) than for men (mean: 6.20%, $p<0.001$). Majority of lumbar disc space narrowing progressions during 72 to 76 years old were from normal to grade 1. Osteoporosis was associated with disc area decrease, both for thoracic and lumbar discs.

Conclusion: Lumbar DSN can be quantified using DAIL. In elderly Chinese disc area lost faster in females than in males.

Key words: lumbar spine; osteoporosis; osteopenia; bone mineral density; intervertebral disc; vertebra

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Introduction

Spine degeneration is commonly associated osteophytes formation, decreased bone mineral density (BMD), decrease of vertebral body middle height (i.e. increase biconcavity), increase wedge of thoracic vertebral bodies, and osteoporotic fracture. Intervertebral disc degeneration can progress to disc herniation, spinal canal stenosis, and, in conjunction with facet joint arthrosis, degenerative spondylolisthesis [1-5]. Disc degeneration becomes apparent in men in the second decade of life, almost a decade earlier than in women [6, 7]. While young and middle-aged men are more likely to have lumbar disc degeneration than women, this trend is reversed in elderly subjects, with women tending to have more severe lumbar disc degeneration than men [8, 9], and this lead to increased low back pain incidence in postmenopausal women compared with age-match men [10].

Till now the areal loss of thoracic and lumbar disc space and their association with BMD in elderly subjects over a defined time span remain unknown. Osteoporotic Fractures in Men (Mr. OS) (Hong Kong) and Osteoporotic Fractures in Women (Ms OS) (Hong Kong) represent the first large-scale prospective cohort studies ever conducted on bone health in Asian men and women. Utilizing this database, the purpose of the current study was three-folds: 1) Till now, the diagnose of intervertebral disc space narrowing is subjective and uses a semi-quantitative grading, we aim to develop a quantitative index for lumbar disc space narrowing evaluation in elderly subjects; 2) to quantify the areal loss of thoracic and lumbar disc space over four years in elderly females and males; 3) to further confirm the previous observation that osteoporosis is associated with faster disc volume loss than normal BMD subjects [11].

Materials and methods

Osteoporotic Fractures in Men (Mr. OS) (Hong Kong) and Osteoporotic Fractures in Women (Ms OS) (Hong Kong) study design follows that of the osteoporotic fracture in men (MrOS) study performed in the United States [12]. At baseline, 2,000 Chinese men (mean age: 72.39 yrs) and 2,000 Chinese women (mean age: 72.58 yrs) in Hong Kong aged 65 to 98 years were recruited

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from the local communities between August 2001 and March 2003 [13, 14]. The recruitment criteria were established so that the study results from the cohort would be applicable to a broad population of similarly aged community-dwelling men and women. The project was designed primarily to examine the bone mineral density (BMD) of older Chinese adults prospectively for 4 years. All participants were community dwelling, able to walk without assistance, had no bilateral hip replacement and had the potential to survive the duration of a primary study based on their general medical health. The study protocol was approved by the Chinese University of Hong Kong Ethics Committee. 1,519 males (76.0%) and 1,546 females (77.3%) attended the year-4 follow-up study [15]. The remaining participants were unwilling or unable to attend for follow-up or were not contactable.

BMD (g/cm^2) at the total hip was measured by Hologic QDR 4,500 W densitometers (Hologic Inc., Waltham, MA). Standard Hong Kong Chinese reference data were used for the T-score calculations [16]. Spine radiographs were centered on T7 for the thoracic spine (T3-L1) and on L3 for the lumbar spine (T12-S1). Radiographs were digitized with spatial resolution of 300 dpi using VIDAR's DiagnosticPRO® Advantage film digitizer, and ClinicalExpress® 4.0 software (Vidar Systems Corporation, Herndon, USA).

500 women and 600 men's data were randomly selected from those who attended both baseline and follow-up studies (Fig 1). Data from eight men and nine women were excluded due to inferior radiograph quality. Morphometric measurement was performed in each vertebra from T4 to L5 using a program written with Matlab (Matlab R2015a, Mathworks, USA). Eight digitized reference points were manually placed for each vertebra (Figure 2), and disc dimensions including anterior height (Ha), middle height (Hm), posterior height (Hp), anteroposterior diameter (AP) and disc areas from T4 to L5 were generated. For the correction of potential magnification differences between baseline and follow-up radiographs of the same participant, the coordinates of the points from follow-up radiographs was normalized with AP diameter of vertebral bodies at baseline. Based on past publications [17-19], the assumption was taken that vertebral AP

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diameter would not notably change during the 4-yrs follow-up. Similar to previous reports, disc space at L5S1 was not included, as assessment of disc narrowing at this level is less reliable [13, 16]. Understand the close supervision of an experienced radiologist (YXJW), two readers performed the morphometric measurement, Reader-1 (JQW) measured the radiographs of 491 females and 250 males, and reader-2 (ZK) measured the remaining 342 males. 50 randomly selected radiographs were measured for reproducibility assessment. The intraclass correlation coefficient (ICC) for intra-reader repeatability was 0.988 (Ha), 0.986 (Hm), 0.979 (Hp), and 0.990 (disc area), respectively; while ICC for inter-observer repeatability was 0.950 (Ha), 0.942 (Hm), 0.922 (Hp) and 0.985 (disc area), respectively.

Disc Area Index for Lumbar spine (DAIL) for each intervertebral level at baseline were calculated using the Equation (1).

$$DAIL_{L_iL_{i+1}} = \frac{A_{L_iL_{i+1}}}{\bar{\sigma}};\ \bar{\sigma} = \frac{AP_i^2 + AP_{i+1}^2}{2};\ \{i = 1, 2, 3, 4\} \quad (1)$$

Where A is the intervertebral disc area, $i = 1, 2, 3, 4$ is the vertebral level, AP is the anteroposterior diameter of vertebral body, $\bar{\sigma}$ is the mean of the sum of square of the adjacent upper and lower vertebrae *AP.* The reference standard grading was from a previous study with this dataset [13]. By experienced radiologists, lumbar disc space was classified into 4 categories: normal (grade 0), mild narrowing (grade 1 $<$ 30% reduction in disc height), moderate narrowing (grade 2 $=$ 30–60% reduction in disc height), and severe narrowing (grade 3 $>$ 60% reduction in disc height) [13, 16]. DAIL threshold criteria for defining severity of DSN from grade 1 to grade 2 and grade 3 were obtained from receiver operating characteristic (ROC) analysis (Fig 3, Supplement Fig 1-2).

Using these DAIL cutting off values, the lumbar spine radiographs obtained at year-4 follow-up were used to evaluate DSN progression, and then the results were visually confirmed by a radiologist (MD) who participated in the previous study [13].

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The statistical package IBM SPSS Statistics, V21.0 (IBM Corporation, IBM Corp, Armonk, New York, USA) was used for data processing. A probability level of 0.05 was used as the level of significance. The statistical method was indicated in result section.

Results

The demographic variables of study subjects are summarized in Table 1. There was no difference in age among the male and female groups, and there were more female subjects with osteoporosis than males (18.74% vs 3.72% at baseline, 24.24% vs 3.89% at year-4 follow-up).

The ROC analysis determined DAIL cut-off criteria for classifying lumbar DSN from grade 1 to grade 3 are shown in Table 2 and Supplement Figures 1-2. DAIL correlated well with semi-quantitative grading, with sensitivity and specificity varying from 87.3% to 96.8% for grade-1 DSN, and 92.9 % to 100% for grade-3 DSN. DAIL performed the best at grade-3 DSN, and the performance was slightly lower for grade-1 DSN.

At the year-4 follow-up, the agreement between DAIL-based DSN scoring and radiologist DSN scoring had a kappa value of 0.745 for women, and 0.732 for men. The major progression of lumbar DSN during 72 to 76 years were development from normal to grade 1 (Table 2). In females the proportion of normal spaced discs decreased from 45.1% at baseline to 36.6% at year-4 follow-up, while in males the proportion of normal spaced discs decreased from 49.2% to 40.8%.

Thoracic and lumbar lateral disc area decreases during 4-years follow-up period are shown in table 4. There was a statistically significant trend that lower hip BMD measured at baseline year was associated with greater disc area loss during the 4-year period. The thoraco-lumbar disc area losses among men and women during 4 years' follow-up period varied between 6.31% and 8.64%, and it was greater for women (mean: 7.18%) than for men (mean: 6.20%, $p<0.001$). An overall trend was note that caudal discs had higher percentage area decrease than cephalad discs. Both for females and males, in the thoracic spine there was a greater percentage disc area loss in mid-thoracic region than lower thoracic region.

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Discussion

This study is the first to investigate the influence of ageing and osteoporosis on the morphology of both thoracic and lumbar intervertebral discs, using quantitative radiographic data for both genders selected from an elderly population at baseline, and at year-4 follow-up. One strength of this study is that men and women of similar age and from the same community-based population were investigated, thereby enabling men and women to be directly compared. As expected there were more female subjects had osteoporosis than males.

The disc space narrowing has been traditionally semi-quantitatively scored by experienced radiologists [13, 16]. However, such semi-quantitative score is subjective, making it difficult for epidemiological study and longitudinal follow-up. Our study developed DAIL, which can quantitatively classify lumbar disc space into normal and DSN. The DAIL criteria was tested to compute the DSN progression at year-4 follow-up, and showed good agreement between results of DAIL-based reads and radiologist-based reads, with an overall kappa value of 0.745 for women, and 0.732 for men. These kappa values are similar to the inter-reader reproducibility of a kappa value of 0.72, which was obtained using the baseline L1/L2- L4/L5 radiographs [13]. Therefore, current study demonstrated the proof-of-principle of DAIL-based criteria in assessing lumbar disc narrowing for elderly subjects. Computer-aided segmentation for both vertebral body and disc area on lateral radiograph have been developed [20; 21], with underlining principles including edge-detection [22], graph-cut based methods [23, 24], and atlas-based methods [25, 26]. It is expected that this method will aid in advanced computerized disc segmentation and automatic disc space narrowing grading.

Relative estrogen deficiency may be contributing to the accelerated disc degeneration seen in postmenopausal women [8; 9; 27; 28], which in turn is associated increased prevalence of lower back pain [10]. The current study showed during the 4-years follow-up period there was greater lateral disc area loss in females, and during the period there were more disc space narrowing

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progresses in women than in men. This result differs from the report of Gambacciani *et al* [28]. Gambacciani *et al* reported after menopause disk space shows a progressive decrease that almost entirely occurs in the first 5–10 years since menopause; whereas after 60 years of age, no further significant decrease in disc space was evident. The results of this study, i.e. females have faster disc space narrowing than male even 20 years after menopause, concur with previous reports of Wang et al [13] and De Schepper EI et al [16]. Our results showed the lumbar DSN progression mainly occurred from normal disc space to grade-1 DSN in both genders during the follow-up period (7.7 % for women, 5.1 % for men). This is the first time that such an observation is reported.

An overall trend was note that caudal discs had higher lateral area decrease rate than cephalad discs (Fig 4). It has been well recognized that lumbar discs are more likely to undergo disc degeneration than thoracic discs [29], lower lumbar discs are more likely to undergo upper lumbar discs, and L4/L5 tend to have the most severe degeneration [30]. Therefore, greater disc degeneration is associated with greater disc area loss. Interestingly, both for females and males, in the thoracic spine there was greater disc area loss in mid-thoracic region than lower thoracic region. This result may be associated with curvature of the spine. The parts with greater curvature, i.e. mid-thoracic region and L4/L5, or the discs with greater wedge shape, tend to loss lateral disc area more than parts with less curvature or discs with less wedge shape. However, it is known that osteoporotic fractures are likely occur in the T12 and L1 vertebrae levels [31]. How to reconcile these differences which may be modified by biomechanics deserve further attention.

A trend was significant for a lower baseline BMD associated with and greater decrease of lateral disc areas, both for thoracic and lumber discs among females and males. Previous volumetric MR data suggested that although lower BMD is associated with greater disc middle height and increased biconvexity, it is accompanied by a decrease in lateral disc area, which translated to a decrease in disc volume [11]. Osteoporosis could add calcification and decrease the vascularization in the endplates adjacent to the degenerated discs, which subsequently exacerbated degeneration of the associated discs [32- 35]. Endplate fractures associated with osteoporotic spines may further contribute to disc vertical expansion. We expect the previous

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reports that ageing spine is associated with increased disc height was due to only the middle disc heights were measured [36-38]. Concurring with recent report [11], the current study suggests disc volume shrink as the spine ageing and developing osteoporosis.

There are a number of limitations of this study. The DAIL criteria was validated at year-4 follow-up and compared with radiologist read. However, radiologist DSN grading is itself subjective and could not be considered as golden standard. The DAIL criteria was only validated in elderly Chinese population, how it should be adjusted in younger population or other ethnic groups remain to be further studied. The year-4 follow-up quantification was based on the assumption that there was no change in vertebral middle horizontal diameter AP. Though this is a reasonable consideration for the 4-years follow-up period, this may not be absolutely true for individual cases. There is no perfect method to adjust the magnification difference between baseline radiographs and follow-up radiographs, which would be affected by the distance and the relative position of the X-ray tube to subject spines. Further studies with MRI may solve this difficulty.

In conclusion, the DAIL proposed in this study has a good performance in identifying disc space narrowing and may help to standardize automatic grading. Disc volume shrink as the spine ageing and developing osteoporosis. Elderly females have faster disc space narrowing than male even 20 years after menopause.

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Figures

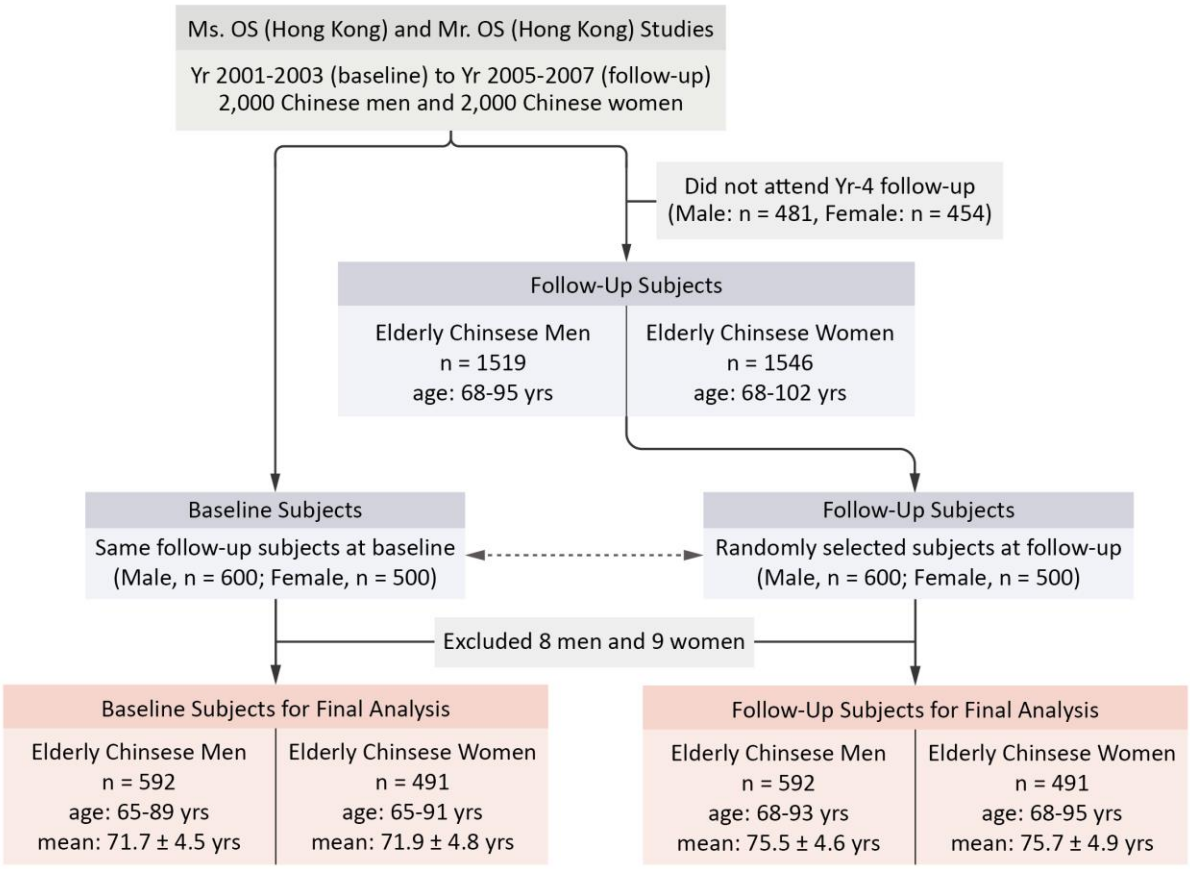

Figure 1. The flow chart shows the selection of study subjects.

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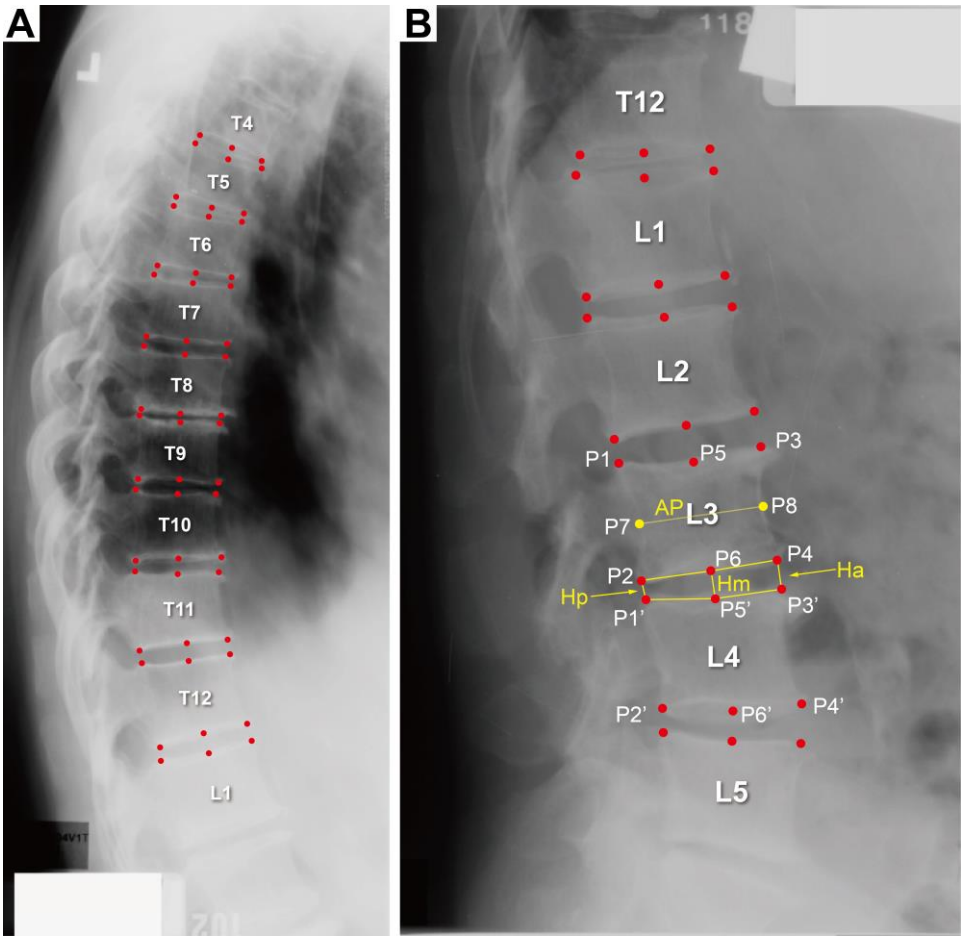

Figure 2. 8-point vertebral body and disc morphometry of spinal radiograph. Four contour points (P1-P4) were identified at the four corners of the vertebral body, two midpoints (P5 and P6) were marked at middle of the upper and lower endplates, and additional two points (P7 and P8) were positioned on the middle of the ventral (P1-P2) and dorsal (P3-P4) lines.

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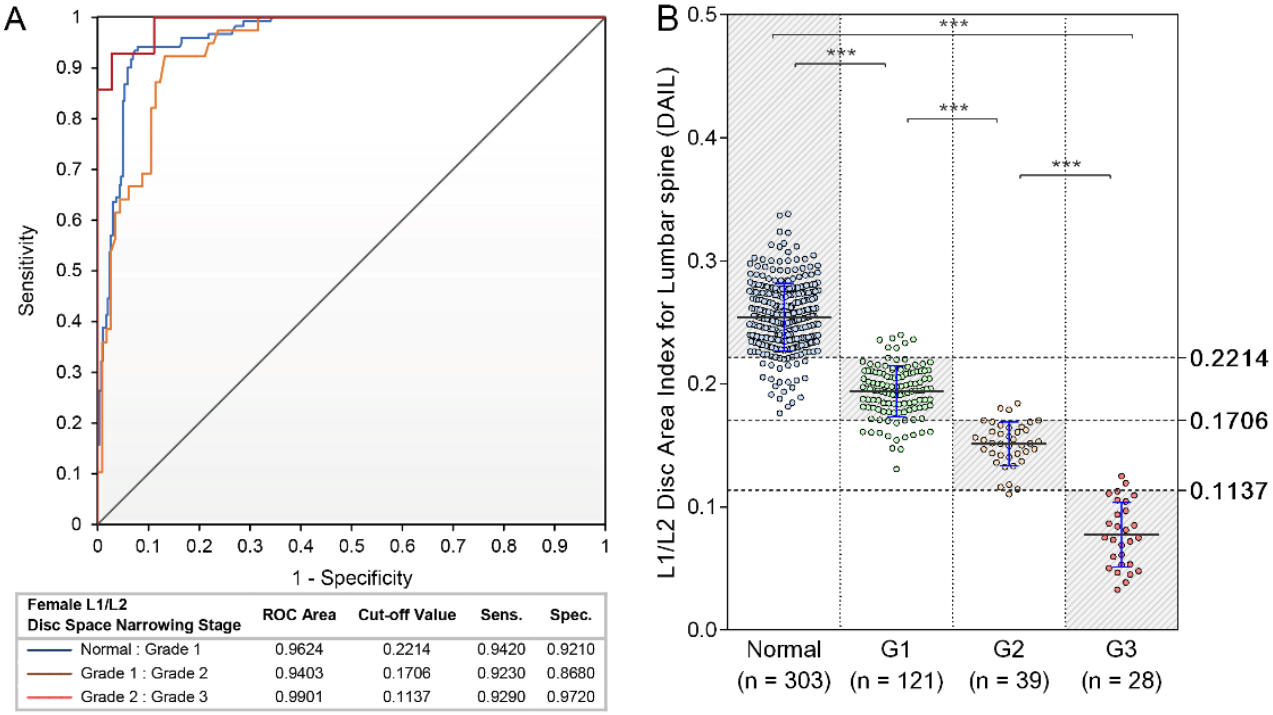

Female L1/L2 Disc Space Narrowing Stage	ROC Area	Cut-off Value	Sens.	Spec.
Normal : Grade 1	0.9624	0.2214	0.9420	0.9210
Grade 1 : Grade 2	0.9403	0.1706	0.9230	0.8680
Grade 2 : Grade 3	0.9901	0.1137	0.9290	0.9720

Figure 3. A: an example of ROC curve and diagnostic ability for L1L2 DSN in women; B: scatter plot of L1L2 DAILs which correlate with normal disc space, grade 1, 2 and 3 DSN. Defined optimal cut-off DAILs for DSN grading are indicated by horizontal dash line (more examples see supplementary Figures).

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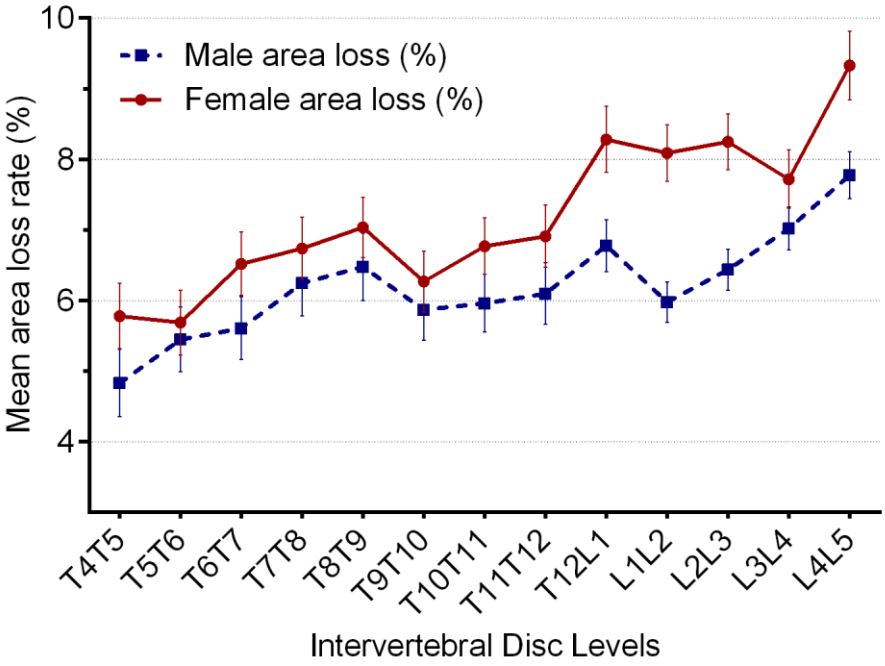

Figure 4. Mean lateral disc area decrease rate at individual levels during 4-years follow-up. The decrease rate is calculated by [(disc area at baseline- disc area at follow-up)/ disc area at baseline period]. Female subjects had a higher lateral disc area loss rate than males at each disc levels (r individual disc area measurement and standard deviation see supplementary table 4).

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TABLE 1. Demographics of Study Subjects

	Women (N = 491)		Men (N = 592)	
	BL	FU	BL	FU
Mean age (yrs) ± SD (range) #	71.9 ± 4.8 (65-91)	75.7 ± 4.9 (68-95)	71.7 ± 4.5 (65-89)	75.5 ± 4.6 (68-93)
Mean height (cm) ± SD	151.7 ± 5.2	151.1 ± 5.3	163.2 ± 5.5	162.8 ± 5.5
Mean weight (kg) ± SD	55.3 ± 8.3	54.5 ± 8.6	63.3 ± 8.8	62.5 ± 8.7
Normal BMD subjects	135/491 (27.49%)	120/491 (24.44%)	311/592 (52.53%)	297/592 (50.17%)
Osteopenia subjects	264/491 (53.77%)	252/491 (51.32%)	259/592 (43.75%)	272/592 (45.95%)
Osteoporosis subjects	92/491 (18.74%)	119/491 (24.24%)	22/592 (3.72%)	23/592 (3.89%)

BL: baseline; FU: year-4 follow-up; # *p* for women vs men at BL=0.508

TABLE 2. Receiver operating characteristic (ROC) analysis of DAIL-based DSN Classification for lumbar discs at Baseline

	L1L2			L2L3			L3L4			L4L5		
Females	G1	G2	G3	G1	G2	G3	G1	G2	G3	G1	G2	G3
AUC	0.96	0.94	0.99	0.94	0.97	0.99	0.96	0.97	1.00	0.98	0.97	0.98
95% CI	0.946-0.979	0.910-0.977	0.976-1.00	0.919-0.967	0.955-0.994	0.985-1.000	0.947-0.980	0.960-0.990	0.994-1.000	0.964-0.992	0.951-0.984	0.951-1.000
p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Sensitivity (%)	94.2	92.3	92.9	87.3	92.5	94.9	93.8	95.1	100.0	96.8	92.3	94.9
Specificity (%)	92.1	86.8	97.2	94.2	95.2	98.0	88.6	90.5	97.4	94.3	89.0	97.7
DAIL cut-off value	0.2214	0.1706	0.1137	0.2378	0.1787	0.1147	0.2625	0.2025	0.1208	0.3008	0.2244	0.1253
Males	G1	G2	G3	G1	G2	G3	G1	G2	G3	G1	G2	G3
AUC	0.96	0.98	1.00	0.96	0.98	0.99	0.97	0.99	1.00	0.98	0.98	1.00
95% CI	0.950-0.979	0.962-0.999	1.000-1.000	0.937-0.976	0.971-0.998	0.976-1.000	0.954-0.984	0.984-0.999	0.995-1.000	0.966-0.991	0.967-0.992	0.989-1.000
p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Sensitivity (%)	92.3	92.9	100.0	90.5	96.4	92.9	92.3	95.5	100.0	95.2	92.0	97.9
Specificity (%)	91.2	96.4	100.0	91.0	92.6	100.0	95.6	97.1	97.0	92.7	95.2	96.9
DAIL cut-off value	0.2345	0.1775	0.1157	0.2662	0.1995	0.1208	0.2784	0.2185	0.1552	0.3194	0.2484	0.1574

p: asymptotic significance

DSN: disc space narrowing; AUC: area under the curve; G1 G2, G3: DSN of grade 1, 2, and 3, respectively.

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TABLE 3. Progress of Lumbar Disc Space Narrowing During the Four Years Follow-Up Period for Women and for Men (based on DAIL read)

Disc Level	DSN classification	Women Baseline (%)	Women Yr-4 (%)	Men Baseline (%)	Men Yr-4 (%)
Total (L1L2 – L4L5)	Grade 1	30.40%	38.14%	33.61%	38.72%
Total (L1L2 – L4L5)	Grade 2	17.57%	17.92%	13.22%	14.44%
Total (L1L2 – L4L5)	Grade 3	6.93%	7.38%	3.93%	6.04%
L1L2	Grade 1	25.66%	41.96%	28.55%	35.64%
	Grade 2	10.59%	12.22%	4.73%	6.93%
	Grade 3	5.50%	6.31%	1.52%	2.53%
L2L3	Grade 1	27.90%	37.07%	31.93%	38.34%
	Grade 2	11.41%	12.02%	9.46%	12.50%
	Grade 3	7.74%	8.15%	2.36%	3.38%
L3L4	Grade 1	31.57%	35.85%	35.14%	39.53%
	Grade 2	17.92%	18.53%	11.15%	12.50%
	Grade 3	6.11%	6.31%	3.72%	7.26%
L4L5	Grade 1	36.46%	37.68%	38.85%	41.39%
	Grade 2	30.35%	28.92%	27.53%	25.84%
	Grade 3	8.35%	8.76%	8.11%	10.98%

DSN: disc space narrowing.

TABLE 4. Female and Male Lateral Intervertebral Disc Area loss in 4 Years among normal BMD, Osteopenia, and Osteoporosis subjects

	Estimated Means of Disc Area Decline Rate*	
Female	Thoracic Discs	Lumbar Discs
Total (n = 491)	6.89% ± 0.07	8.64% ± 0.07
Normal BMD (n = 135)	5.85% (0.006)	7.38% (0.006)
Osteopenia (n = 264)	7.08% (0.004)	8.76% (0.004)
Osteoporosis (n = 92)	7.88% (0.008)	10.16% (0.007)
p in linear trend	0.0463	0.0069
Male		
Total (n = 592)	6.31% ± 0.08	7.09% ± 0.05
Normal BMD (n = 311)	5.79% (0.005)	6.82% (0.003)
Osteopenia (n = 259)	6.68% (0.005)	7.19% (0.003)
Osteoporosis (n = 22)	9.38% (0.017)	9.68% (0.011)
p in linear trend	0.0419	0.0166

***** disc area decline rate = [(baseline area-follow-up area)/ baseline area] × 100%; obtained using analysis of covariance (ANCOVA) with adjustment of BMI (body mass index) and age at baseline.

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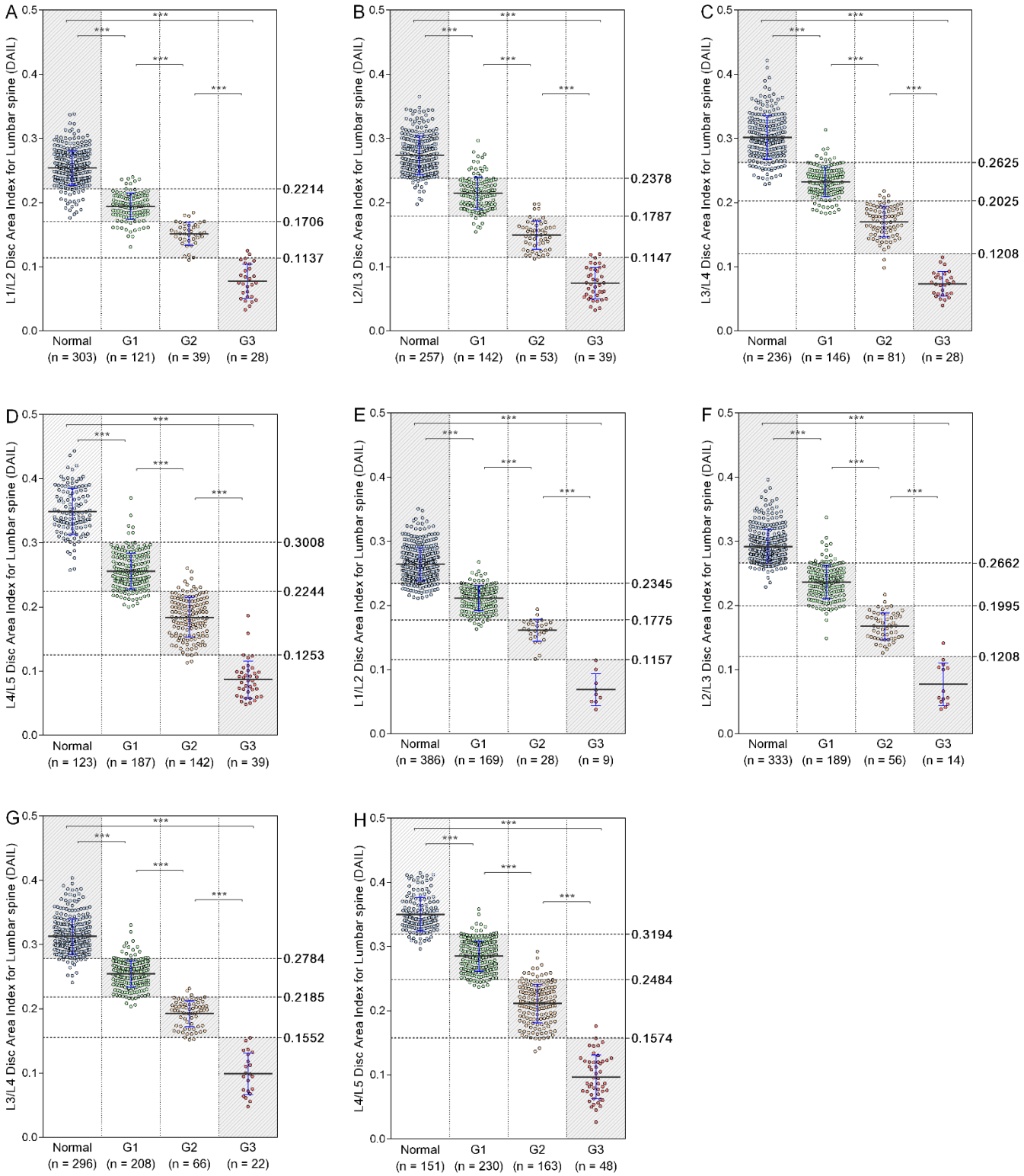
Supplement Figure 1. Correlations between each Individual DAIL (Disc Area Index for Lumbar Spine) and defined semi-quantitative grading at different disc Levels among women and men. A, Female L1/L2. B, Female L2/L3. C, Female L3/L4. D, Female L4/L5. E, Male L1/L2. F, Male L2/L3. G, Male L3/L4. H, Male L4/L5.



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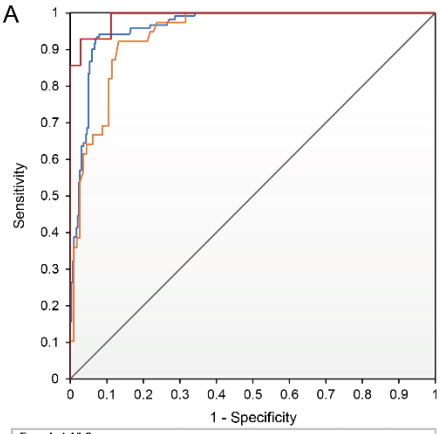
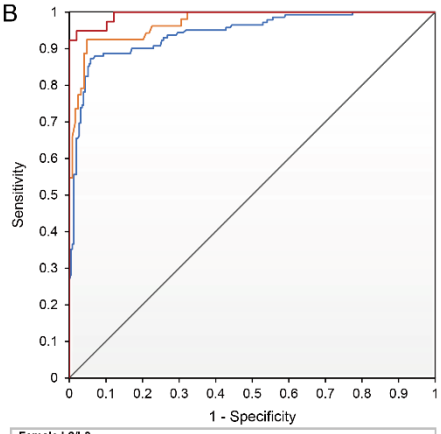
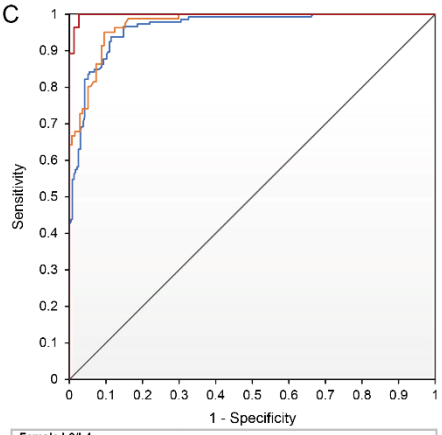
Supplement Figure 2. ROC analysis of the DAIL (Disc Area Index for Lumbar Spine) based classification ability for grading disc space narrowing among women and men. **A,** Female L1/L2. **B,** Female L2/L3. **C,** Female L3/L4. **D,** Female L4/L5. **E,** Male L1/L2. **F,** Male L2/L3. **G,** Male L3/L4. **H,** Male L4/L5.



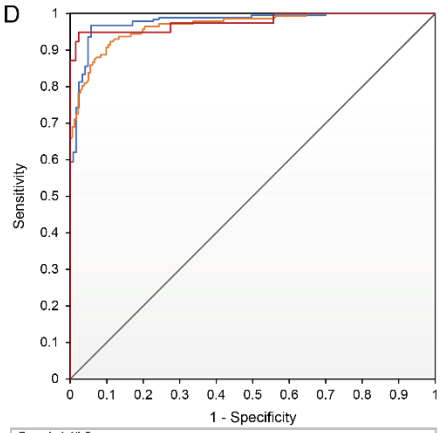
Female L1/L2 Disc Space Narrowing Stage	ROC Area	Cut-off Value	Sens.	Spec.
Normal : Grade 1	0.9624	0.2214	0.9420	0.9210
Grade 1 : Grade 2	0.9403	0.1706	0.9230	0.8680
Grade 2 : Grade 3	0.9901	0.1137	0.9290	0.9720



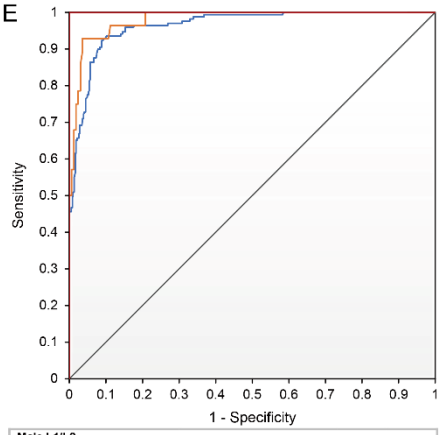
Female L2/L3 Disc Space Narrowing Stage	ROC Area	Cut-off Value	Sens.	Spec.
Normal : Grade 1	0.9431	0.2378	0.8730	0.9420
Grade 1 : Grade 2	0.9709	0.1787	0.9250	0.9520
Grade 2 : Grade 3	0.9937	0.1147	0.9490	0.9800



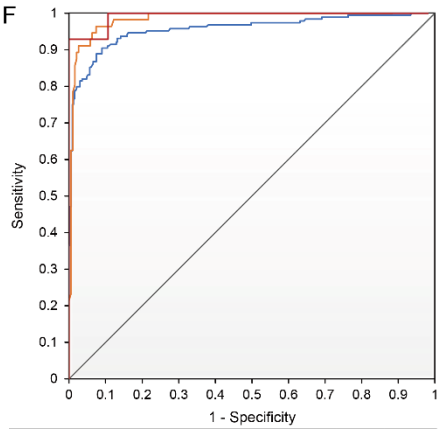
Female L3/L4 Disc Space Narrowing Stage	ROC Area	Cut-off Value	Sens.	Spec.
Normal : Grade 1	0.9636	0.2625	0.9380	0.8860
Grade 1 : Grade 2	0.9733	0.2025	0.9510	0.9050
Grade 2 : Grade 3	0.9981	0.1208	1.0000	0.9740



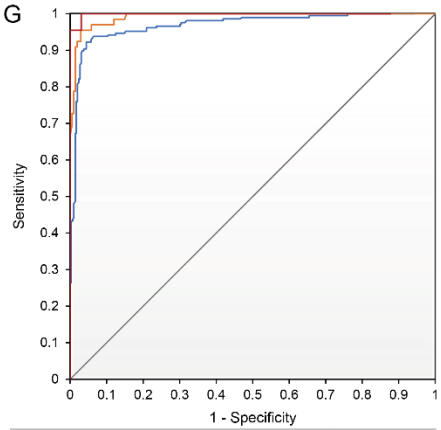
Female L4/L5 Disc Space Narrowing Stage	ROC Area	Cut-off Value	Sens.	Spec.
Normal : Grade 1	0.9780	0.3008	0.9680	0.9430
Grade 1 : Grade 2	0.9664	0.2244	0.9230	0.8900
Grade 2 : Grade 3	0.9773	0.1253	0.9490	0.9770



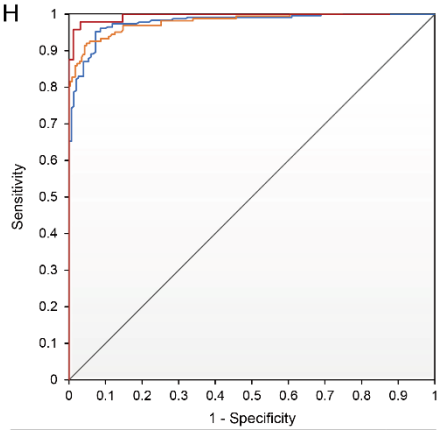
Male L1/L2 Disc Space Narrowing Stage	ROC Area	Cut-off Value	Sens.	Spec.
Normal : Grade 1	0.9646	0.2345	0.9230	0.9120
Grade 1 : Grade 2	0.9803	0.1775	0.9290	0.9640
Grade 2 : Grade 3	1.0000	0.1157	1.0000	1.0000



Male L2/L3 Disc Space Narrowing Stage	ROC Area	Cut-off Value	Sens.	Spec.
Normal : Grade 1	0.9565	0.2662	0.9050	0.9100
Grade 1 : Grade 2	0.9844	0.1995	0.9640	0.9260
Grade 2 : Grade 3	0.9923	0.1208	0.9290	1.0000



Male L3/L4 Disc Space Narrowing Stage	ROC Area	Cut-off Value	Sens.	Spec.
Normal : Grade 1	0.9691	0.2784	0.9230	0.9560
Grade 1 : Grade 2	0.9913	0.2185	0.9550	0.9710
Grade 2 : Grade 3	0.9986	0.1552	1.0000	0.9700



Male L4/L5 Disc Space Narrowing Stage	ROC Area	Cut-off Value	Sens.	Spec.
Normal : Grade 1	0.9785	0.3194	0.9520	0.9270
Grade 1 : Grade 2	0.9796	0.2484	0.9200	0.9520
Grade 2 : Grade 3	0.9953	0.1574	0.9790	0.9690