SS/PT and SS-PT as indicators for identification of compensatory sagittal balance in patients with degenerative disc disease

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Abstract

Study design

A retrospective study

Background

To determine whether radiological parameters such as maximal lumbar lordosis-maximal thoracic kyphosis (maxLL-maxTK), sacral slope-pelvic tilt(SS-PT) and sacral slope/pelvic tilt (SS/PT) could be used as indicators for the diagnosis of degenerative disc disease (DDD) in compensatory sagittal balanced patients.

Methods

Medical records of compensatory sagittal balanced DDD patients and asymptomatic adults in our hospital from July 2019 to November 2019 were reviewed retrospectively. General characters and radiological parameters were evaluated between the two groups. Analysis of covariance with age as a covariate was conducted, followed by receiver operating characteristic (ROC) analysis and areas under the curve (AUC) calculation. The max Youden index was calculated to identify the optimal sensitivity specificity pairs.

Results

A total of 42 DDD patients and 199 asymptomatic adults were included. For those parameters that showed significant differences between the two groups, AUC for SS/PT and SS-PT were the largest, reaching 0.919 and 0.936, respectively. The sensitivity was 0.749, the specificity was 0.952 and the max Youden index was 0.701 when SS/PT = 1.635 was used as threshold. The max Youden index was found for a threshold of SS-PT = 8.500, for which the sensitivity increased to 0.854, while the specificity decreased to 0.857.

Conclusions

Both SS/PT and SS-PT were significantly different between compensatory sagittal balanced DDD patients and asymptomatic adults. SS/PT < 1.6 and SS-PT < 8.5 could be used as indicators for the diagnosis of DDD patients with compensatory sagittal balance.

Background

Degenerative disc diseases (DDD) is a spectrum of diseases, which may present as disc herniation, spinal stenosis, spondylolisthesis, facet joint arthropathy, or their combination. Recent studies suggest that sagittal balance is important in DDD in which it closely associated with the patient quality of life (QOL)[1, 2]. T1 tilt, thoracic kyphosis (TK), lumbar lordosis (LL), sacrum slope (SS), pelvic tilt (PT), pelvic incidence

(PI) and sagittal vertical axis (SVA) have been identified as important spinopelvic parameters in maintaining spinal sagittal balance[3], and proven to be essential and effective referremce in spinal fusion surgery[1]. Many studies have reported a significant loss of LL in patients with DDD, especially after spinal fusion surgery, resulting in a compensative increase in PT[4–6]. The increase of PT represents the pelvis is in a backward rotation, which is a kind of compensatory mechanism of sagittal balance. The backward rotation of the pelvis can continue to a certain extent, the femoral head is forward result from the increasing tilt of the pelvis, meanwhile, the sacrum and the spine are backward. This causes the C7 plumb line to stay behind the perpendicular line passing through the middle of the femoral head, and the gravity line to fall between the feet. As a result, the full body is balanced, but it is a kind of uneconomic compensatory balance ,in which the posterior spinal muscle can be used as a tension band, trying to recover some lumbar lordosis. Moreover, this is a process of energy consumption, pain occurs quickly, explaining a certain degree of low back pain.

Schwab et al.[7] find a correlation between a high PT (threshold 20°) and a poor health-related QOL, and between a low PT and a good clinical outcome. So PT < 20° means the pelvis is in a state of balance. However, a high absolute value of PT does not necessarily represent increased retroversion, PT > 20° can also be an anatomic trait and simply reflect a large PI, in a similar way, the PT threshold may need to be lower than 20° for patients with a smaller PI[8]. Futher more, the normal range of those spinopelvic parameters is so wide due to individual differences[9] and measurement errors that it is challenging to differentiate a compensatory from a normal state of balance by using a single radiographic parameter alone. In the present study, we designed several composite parameters including maximal lumbar lordosis-maximal thoracic kyphosis (maxLL-maxTK), sacral slope-pelvic tilt(SS-PT) and sacral slope/pelvic tilt (SS/PT) to reduce the measurement errors and improve the accuracy and also attempt to find their diagnostic value in distinguishing compensatory balance from normal balance.

DDD resulting in loss of lumbar lordosis, can lead to sagittal plane deformities[10].The loss of lumbar lordosis can be considered as the initiating event of sagittal imbalance[11]. Because of the potential mechanism of compensation, just like pelvic retroflexion, thoracolumbar hyperextension, knee flexion, ankle flexion, and finally cervical extension[12], the patients with DDD present with a compensatory sagittal balance. This not only influence the indication for spinal surgery[13], but also conceal the severity of the disease and mislead the treatment strategy. The recognition of compensatory sagittal balance has some clinical significance for the diagnosis and treatment of DDD. Nevertheless, few parameters have been used in the assessment of a state of compensatory sagittal balance, and comparison of these parameters between DDD patients with compensatory sagittal balance and asymptomatic adults without DDD has not been extensively explored. The purpose of this study was to explore possible correlations between the composite radiological parameters maxLL-maxTK, SS-PT, SS/PT and the diagnosis of DDD patients with compensatory sagittal balance, and identify which parameters could be used to discriminate DDD patients with compensatory sagittal balance from asymptomatic adults.

Methods

Patient selection

Adult patients(age ≥ 18 years) with compensatory sagittal balanced DDD including lumbar disc herniation (LDH), lumbar spinal stenosis (LSS), and with or without instability who scheduled for spine surgery in our hospital between July 2019 and November 2019 and met the inclusion and exclusion criteria were retrospectively reviewed as DDD group. The inclusion criteria were :1) a minimum 3-month history of low back pain and/or lower limb pain and/or lower limb numbness; 2) DDD grade 3 according to the Schneiderman classification on MRI showing a hypointense nucleus with disc space narrowing on at least one level[14]; 3) sagittal balanced patients (SVA ≤ 50 mm) [15]. The exclusion criteria were: 1) patients with red flag symptoms such as scoliosis, trauma or fracture ,ankylosing spondylitis, osteoporosis, pregnancy, or tumor; 2) patients with a previous history of spine surgery; 3) sagittal imbalanced patients (SVA > 50 mm). Asymptomatic adults (age ≥ 18 years)with no significant spinal diseases in the same time and space were used as the control(normal) group. X-ray films of the full-length spine were taken in both groups. This study was approved by the Institutional Review Board of our university, and all subjects involved provided written informed consent.

Data collection

Demographic data of all subjects including age and gender were collected. Then, radiographic parameters were measured on the standing full-spine lateral radiographs and evaluated (Fig. 1), including the angle between the horizontal and superior endplate of T1 (T1 tilt), the angle between the superior endplate of T1 and the inferior endplate of T12 using the Cobb method (T1-12 kyphosis, maxTK), the angle between the superior endplate of L1 and the superior endplate of S1 using the Cobb method (L1-S1 lumbar lordosis, maxLL) [16], the angle formed by a line drawn along the endplate of the sacrum and a horizontal reference line (sacral slope, SS), the angle formed by a line drawn from the midpoint of the sacral endplate to the center of the bicoxofemoral axis and vertical plumb line (pelvic tilt, PT), the angle formed by a line drawn between the center of the femoral head and the sacral endplate (pelvic incidence, PI) and the distance between the C7 plumb line and the posterior corner of the sacrum (sagittal vertical axis, SVA)[12, 17, 18].

The relationship between maxLL and maxTK was expressed as maxLL-maxTK (maxLL minus maxTK). The relationship between SS and PT was expressed as SS-PT and SS/PT (SS minus PT and SS divided by PT). The relationship between LL and PI was expressed as LL-PI (LL minus PI). Two surgeons with at least two years working experience measured all the radiographic parameters independently, and the mean values were used as final results for analysis. All the radiological data mentioned above were compared between the DDD group and the normal group. To identify the most important index for predicting the diagnosis of DDD with compensatory sagittal balance, receiver operating characteristic (ROC) analysis was also performed and the max Youden index was calculated.

Statistical analysis

We performed statistical analyses using SPSS 22.0 statistics software (SPSS Inc., Chicago, IL), and listed descriptive statistics in the form of mean and standard deviation (SD). Chi-square test was used for gender comparison between the DDD group and the normal group. Normal distribution test and homogeneity test for variance were performed before independent two-sample t-test was used to compare the differences of other measurement data between the two groups. The mean age was different between the two groups($P < 0.05$), so age was used as a covariate to perform comparisons between radiological parameters and the level of significance was set at $p < 0.05$.

For each parameter,true positive (TP), true negative (TN), false positive (FP), false negative (FN) values, sensitivity and specificity of different cut-off pointswere calculated. Sensitivity and specificity were determined by calculating the true positive rate ($\mathrm{TPR} = \mathrm{TP}/(\mathrm{TP} + \mathrm{FN})$, $\text{sensitivity} = \mathrm{TPR}$) and false positive rate ($\mathrm{FPR} = \mathrm{FP}/(\mathrm{FP} + \mathrm{TN})$,$\text{specificity} = 1 - \mathrm{FPR}$). ROC analysiswas performed and area under the curve (AUC) were calculatedfor radiological parameters to see which parameters had high discrimination performance with AUC being greater than 0.9 for the DDD with compensatory sagittal balance. Then the maximal Youden index ($\mathrm{maxYI} = \text{sensitivity} + \text{specificity} - 1$) of each parameter was also calculated. The cut-off point corresponding to it was taken as the threshold value that determine the optimal sensitivity-specificity pair.

Results

Of the 42 patients with DDD, 14 (33.3%) were male and 28 (66.7%) were female with a mean age of 58.88 years; of the 199 asymptomatic adults, 86 (43.2%) were male and 113 (56.8%) were female with a mean age of 42.78 years. There was no significant difference in gender and PI between two groups($p = 0.238$ and 0.669, respectively), while age and other residual parameters were significantly different between two groups(Table 1). The analysis of covariance using age as a covariate showed no significant difference in T1 tilt, maxTK and PI between the two groups ,while significant difference was found in maxLL, LL-TK, SS, PT, SS/PT, SS-PT, LL-PI, SVA (Table 2).

Table 1
General characteristics and radiographic parameters of subjects in two groups

Variables	DDD group	Normal group	*P* value
No. of subjects	42	119	——
Age(years)	58.88 ± 11.93	42.78 ± 15.88	< 0.001
Gender(%)	——	——	0.238
Male	33.3	43.2	——
Female	66.7	56.8	——
T1 tilt(°)	22.90 ± 6.34	19.73 ± 6.08	0.003
maxTK(°)	40.10 ± 11.25	36.15 ± 9.19	0.016
maxLL(°)	41.43 ± 9.80	49.50 ± 9.49	< 0.001
maxLL-maxTK(°)	1.33 ± 8.75	13.35 ± 9.22	< 0.001
SS(°)	24.14 ± 7.03	33.22 ± 7.40	< 0.001
PT(°)	24.19 ± 6.81	14.34 ± 7.15	< 0.001
PI(°)	48.33 ± 11.17	47.56 ± 10.56	0.669
SS/PT(°)	1.06 ± 0.36	3.04 ± 3.62	< 0.001
SS-PT(°)	-0.05 ± 8.18	18.88 ± 10.02	< 0.001
LL-PI(°)	-6.90 ± 9.76	1.94 ± 9.90	< 0.001
SVA(mm)	20.14 ± 20.84	2.4 ± 22.00	< 0.001

Table 2
Covariance analysis with age as covariate of radiographic parameters of subjects in two groups

Variables	DDD group	Normal group	*P* value
No. of subjects	42	119	——
T1 tilt(°)	22.90 ± 6.34	19.73 ± 6.08	0.065
maxTK(°)	40.10 ± 11.25	36.15 ± 9.19	0.411
maxLL(°)	41.43 ± 9.80	49.50 ± 9.49	< 0.001
maxLL-maxTK(°)	1.33 ± 8.75	13.35 ± 9.22	< 0.001
SS(°)	24.14 ± 7.03	33.22 ± 7.40	< 0.001
PT(°)	24.19 ± 6.81	14.34 ± 7.15	< 0.001
PI(°)	48.33 ± 11.17	47.56 ± 10.56	0.822
SS/PT(°)	1.06 ± 0.36	3.04 ± 3.62	0.001
SS-PT(°)	-0.05 ± 8.18	18.88 ± 10.02	< 0.001
LL-PI(°)	-6.90 ± 9.76	1.94 ± 9.90	< 0.001
SVA(mm)	20.14 ± 20.84	2.4 ± 22.00	0.001

It was found that the AUC for the composite indexes like SS-PT and SS/PT were the largest, reaching 0.919 and 0.936 respectively(as shown in Fig. 2 and Fig. 3). The optimal sensitivity-specificity pair was obtained, showing that the sensitivity was 0.749, the specificity was 0.952 and the maxYI was 0.701 when SS/PT = 1.635 was used as the threshold. The maxYI was found for a threshold of SS-PT = 8.500, when the sensitivity increased to 0.854, and the specificity decreased to 0.857.

Discussion

The aim of the present study was to find potential radiological parameters, especially the composite indexes, that could be used to distinguish between sagittal balanced patients with DDD and asymptomatic adults without DDD. It was found in previous studies that age was associated with the occurrence of DDD[19] and the mean age was different between the two groups($P < 0.05$). Therefore we used age as a covariate to perform analysis of covariance. Finally, we found that two composite indexes like SS/PT, SS-PT and some other parameters were significantly related to the occurrence of DDD. The analysis of ROC curves showed that both SS/PT and SS-PT had larger AUCs and could well tell sagittal balanced patients with DDD from asymptomatic adults without DDD. Finally, we set SS/PT > 1.6 and SS-PT > 8.5 as indicators for asymptomatic individuals without DDD, and SS/PT < 1.6 and SS-PT < 8.5 as indicators for the diagnosis of DDD patients with compensatory sagittal balance. Previous studies used to address the significant correlation between sagittal parameters and health-related QOL[20]. In this study, we introduced almost all common spinopelvic sagittal parameters, including morphological parameters (TK, LL and PI), position parameters (SS and PT) [21], and used maxTK and maxLL as representative of the global sagittal alignment of thoracic kyphosis and lumbar lordosis. Since these single parameters were of great variability during different postures and measurement, we alternatively introduced composite indexes of maxLL-maxTK, SS/PT, SS-PT and LL-PI.

The most important results found in this study were that decreased SS/PT and SS-PT are significantly correlated with the occurrence of DDD. Patients with DDD are characterized by decreased SS and increased PT as demonstrated in our illustrated cases in Table 1, whicn is a compensatory mechanism that allows the patient to maintain a balanced standing posture. SS and PT are thought to be associated with the compensatory mechanism in the pelvic area which is the keystone of equilibrium of the human body and gravity line[22]. During the compensatory process, as previously mentioned,the pelvis rotate around the femoral heads, called pelvic retroversion ,following the bicoxo-femoral axis, which is similar to that during hip extension. Due to the contraction of the hip extensor muscles, this motion of hip extension results in posterior positioning of the sacrum related to the bicoxo-femoral heads and increasing the sacro-femoral distance. The possibility of rotation of the pelvis around the bicoxo-femoral axis is one of the most important compensatory mechanisms of sagittal balance. This mechanism permits to compensate for the anterior translation of the axis of gravity[4]. A low SS means a low ability of pelvic tilting,conversely, a high SS means a higher possibilities of retroversion and when the pelvis rotates backward (retroversion), PT increases; when the pelvis rotates forward (anteversion), PT decreases[21]. In view of PI = SS + PT[23] and knowing that SS cannot be a negative value, a high PI have a much wider range for retroversion[10]. Based on what was mentioned above, we conclude that both SS/PT and SS-PT, as a pelvic regional mechanism of sagittal alignment, play an important role in maintaining sagittal balance. Although a compensatory state could maintain sagittal balance in DDD patients, it is still not theoretically a state of minimal energy consumption. In other words, the compensatory balance is less economical. The loss of lumbar lordosis can be considered as the initiating event of sagittal imbalance[11]. This loss of the normal lordosis pushes the C7 plumb line forward[24]. Then the pelvic compensatory mechanism is activated. LL should not be studied as a single curve and there is a strong correlation between SS and LL[25]. To obtain an ideal state of other indexes, efforts should be made to maintain a normal LL during the spinal surgery,in other words, high incidence high lordosis and low incidence low lordosis[6].

This study had some limitations that should be addressed. First, our study was a single-center study and the sample size was relatively small. Second, the subjects in the two groups were not matched to the age factor. Since degeneration of the intervertebral disc naturally occur in older people, it is difficult to match well. Alternatively, we did analysis of covariance with age as a covariate to reduce the bias. Therefore, large-scaled and multicenter studies should be performed to make a more comprehensive investigation into the effectiveness of SS/PT and SS-PT in assessing compensatory sagittal balance in DDD.

Conclusions

Both SS/PT and SS-PT were significantly different between compensatory sagittal balanced DDD patients and asymptomatic adults. SS/PT < 1.6 and SS-PT < 8.5 could be used as indicators for the diagnosis of DDD patients with compensatory sagittal balance.

Abbreviations

maxLL-maxTK: maximal lumbar lordosis-maximal thoracic kyphosis; SS-PT: sacral slope-pelvic tilt; SS/PT: sacral slope/pelvic tilt; DDD: degenerative disc diseases; ROC: receiver operating characteristic; AUC: areas under the curve; QOL: quality of life; TK: thoracic kyphosis; LL: lumbar lordosis; SS: sacrum slope; PT: pelvic tilt; PI: pelvic incidence; SVA: sagittal vertical axis; LDH: lumbar disc herniation; LSS: lumbar spinal stenosis; LL-PI: lumbar lordosis-pelvic incidence; SD: standard deviation; TP: true positive; TN: true negative; FP: false positive; FN: false negative; TPR: true positive rate; FPR: false positive rate; maxYI:maximal Youden index

Declarations

Acknowledgments

Not applicable.

Authors’ contributions

CWY and MIL were corresponding authors and contributed to the study conception and design. SBN drafted the manuscript, XZ and YYC performed data collection and statistical analysis, SBN , XZ and YYC were co-first authors. HY draw the tables and figures. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used or analyzed during the study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Changhai Hospital, Naval Medical University, (the committee’s reference number is not applicable), and all patients provided written informed consent to participate before enrollment.

All procedures performed in studies involving human participants, human material and data were in accordance with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent for publication

A statement of consent to publish from the patient is not applicable.

Competing interests

The authors declared no competing non-financial/financial interests.

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Figures

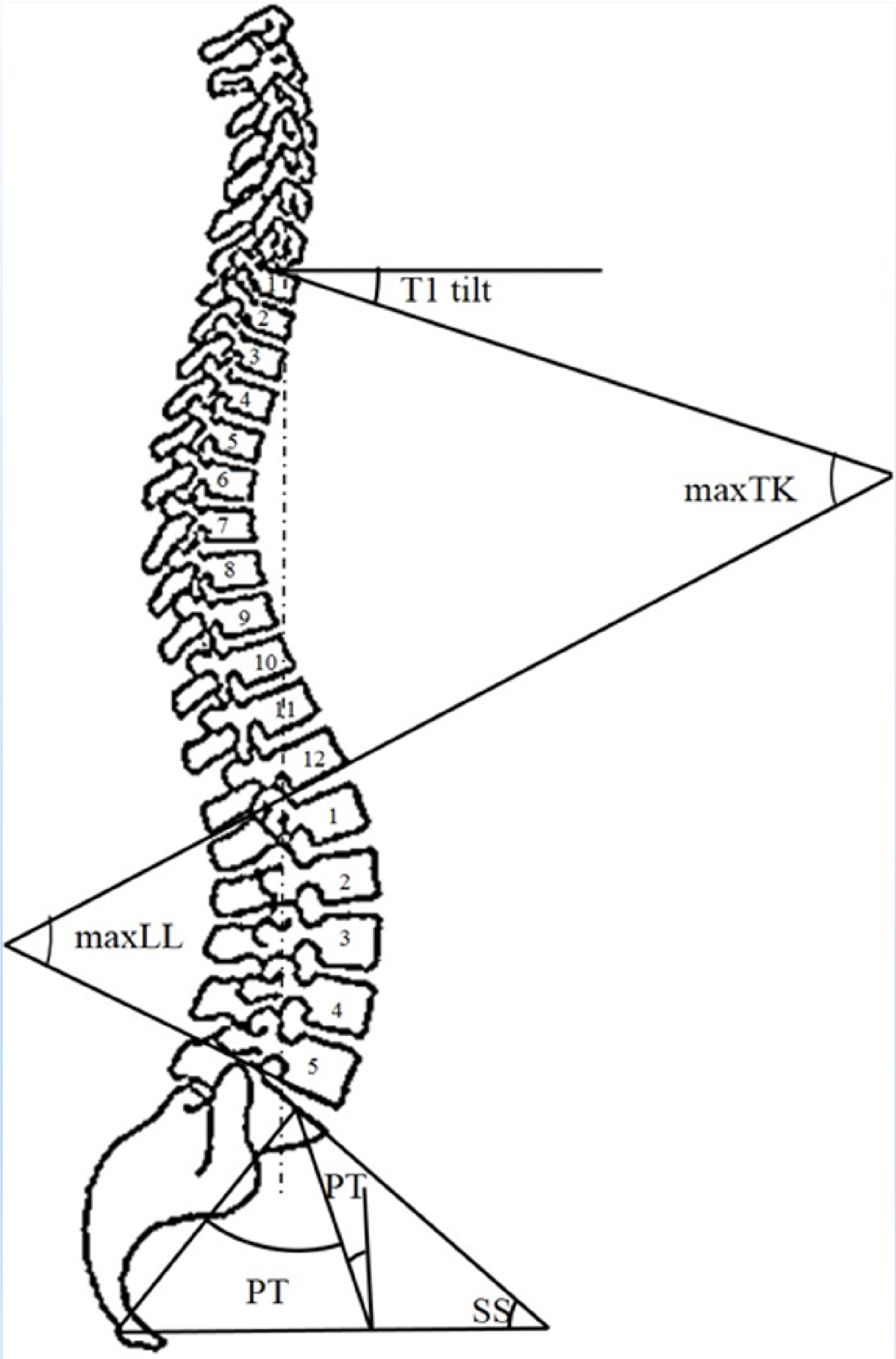

Figure 1

Radiographic parameters measured on the standing full-spine lateral radiographs (T1 tilt; maxTK, maximal thoracic kphyosis; maxLL, maximal lumbar lordosis; SS, sacral slope; PT, pelvic tilt; and PI, pelvic incidence; SVA, sagittal vertical axis)

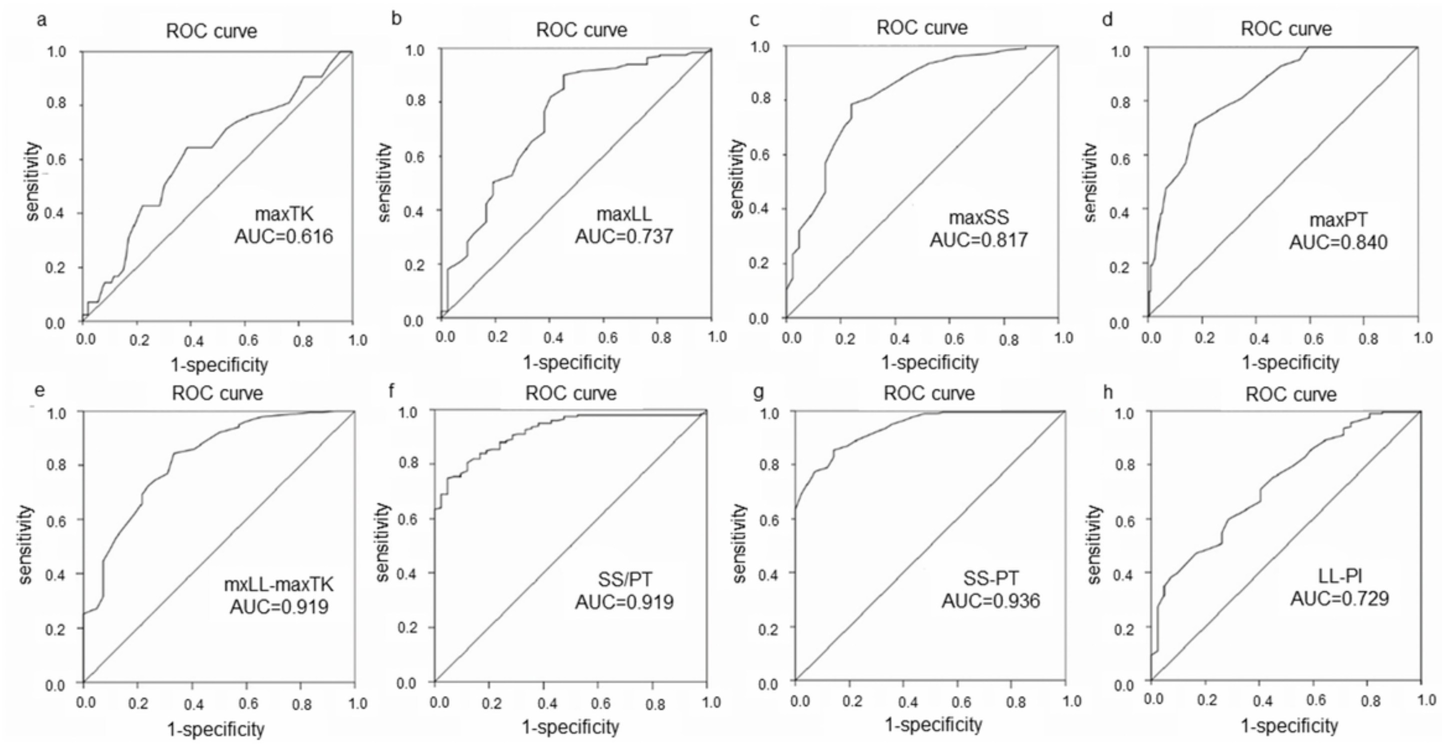

Figure 2

Prediction of degenerative disc disease by receiver operating characteristic (ROC) curves of radiological parameters. Areas under the curves (AUC) were 0.616 for maxTK(a), 0.737 for maxLL(b), 0.817 for SS(c), 0.840 for PT(d), 0.824 for maxLL-maxTK(e), 0.919 for SS/PT(f), 0.936 for SS−PT(g), 0.729 for LL−PL(h) (max TK, max thoracic kyphosis; max LL, max lumbar lordosis; SS, sacrum slope; PT, pelvic tilt; PI, pelvic incidence)

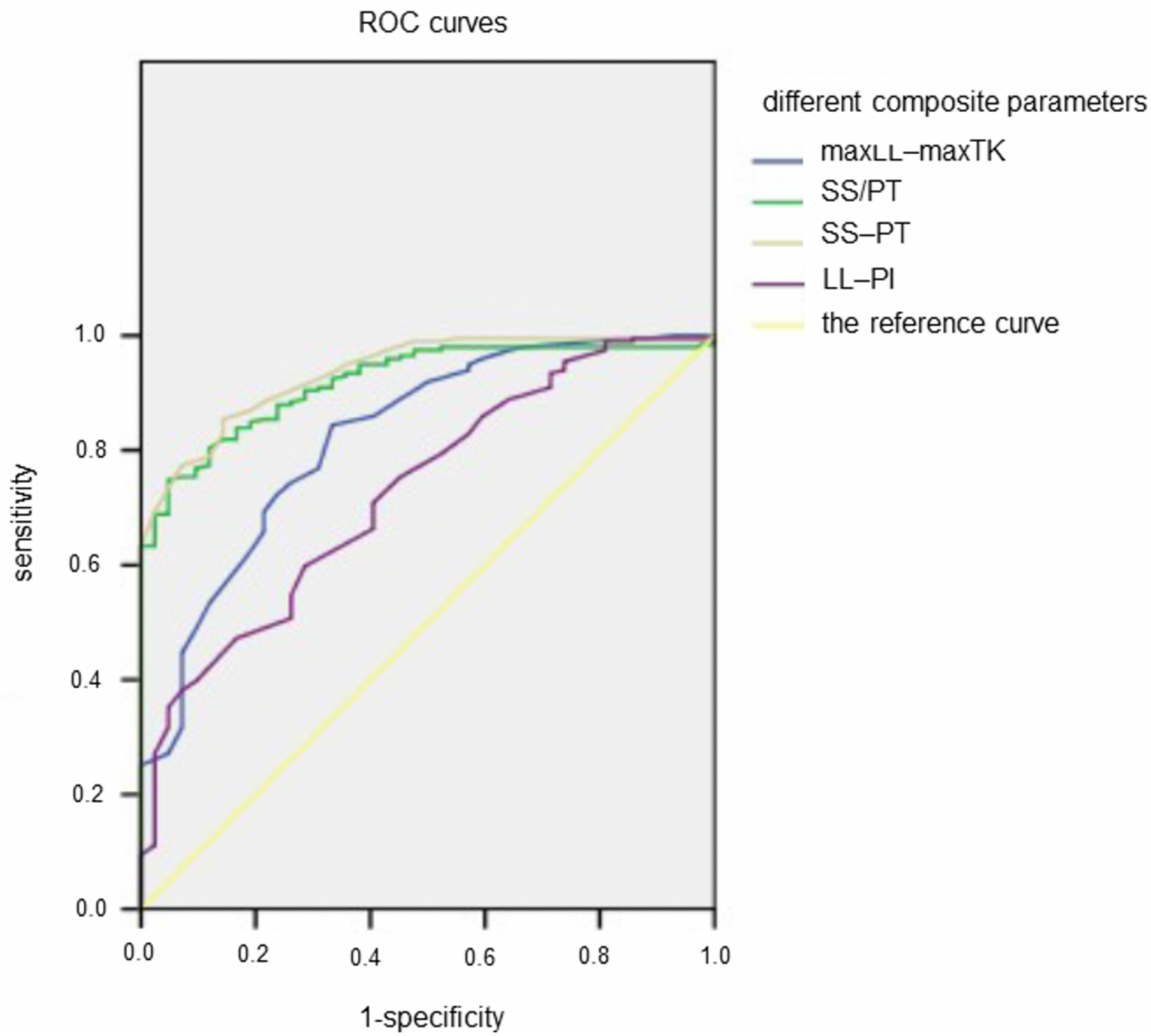

Figure 3

Comparison of areas under the curves (AUC) of different composite parameters. The results showed SS–PT and SS/PT had the largest AUC indicating high diagnostic value