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ORIGINAL ARTICLE

The characteristics of spinopelvic sagittal alignment in patients with lumbar disc degenerative diseases

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Abstract
Purpose A comparative study of the spinopelvic sagittal alignment in patients with lumbar disc degeneration or herniation (LDD/LDH) in normal population was designed to analyse the role of sagittal anatomical parameter (pelvic incidence, PI) and positional parameters in the pathogenesis and development of the disease. Several comparative studies of these patients with asymptomatic controls have been done. However, in previous studies without lumbar MRI, a certain number of asymptomatic LDD patients should have been included in the control group and then impacted on the results.
Methods Based on MRI findings, we divided 60 LDD or LDH patients and 110 asymptomatic volunteers into the normal group (NG) and the degeneration group (DG), which was further subdivided into the symptomatic (SDG) and asymptomatic (ADG) subgroups according to patients' symptoms. Standing full spine radiographs were used to measure sagittal parameters, including PI, sacral slope (SS), pelvic tilt (PT), lumbar lordosis (LL), thoracic kyphosis (TK), sagittal vertical axis (SVA), and sacrum-bicoxofemoral distance (SFD).
Results The PI, SS and LL in DG were significantly lower than NG, while the SVA and SFD were significantly greater ($P < 0.05$). PI correlated well with the SS and LL in all subjects. However, the trend lines of SS or LL over PI were downward in DG. PI was similar in SDG and ADG ($P = 0.716$) but SS and LL were significantly lower and SVA was significantly greater ($P < 0.05$).
Conclusions PI may play a predisposing role in the pathogenesis of lumbar disc degenerative diseases. The secondary structural and compensatory factors would lead to a straighter spine after disc degenerative change.

Keywords Spinopelvic · Sagittal alignment · Lumbar disc herniation · Lumbar disc degeneration

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Introduction

In the normal population, there is a great variation in the sagittal spinopelvic alignment, and even there were wide range of normal values of the sagittal parameters for an individual [1–4]. In the absence of a standard pattern of individual sagittal spinopelvic curvature, an ideal sagittal alignment would enable the individual to maintain the standing posture with minimum energy expenditure [2, 4–6].

Ever since the pelvic incidence (PI) was described by During and Duval-Baeaupere et al. [7, 8] increasing attention has been devoted to the important role of pelvic shape as well as orientation in the individual global sagittal curvature. The PI was an anatomic parameter which represented the morphology of the pelvis. The value of PI was constant at the end of the bone growth, and unaffected by the individual posture or position [2, 7, 9]. The PI determines pelvic orientation represented by the sacral slope (SS) and pelvic tilt (PT) as well as the size of the lumbar lordosis (LL). Indeed, the PI plays a fundamental role in the individual sagittal spinopelvic alignment [3, 4, 10, 11].

A series of studies correlated the sagittal alignment with several lumbar degenerative diseases, such as degenerative spondylolisthesis (DS), lumbar disc degeneration (LDD) or lumbar disc herniation (LDH) [12–17]. The results indicated that the PI was a predisposing factor in the pathogenesis and development of DS [12, 13, 16], supporting the theory that a greater PI implied a greater SS and as a result of a greater LL. The increased LL resulted in greater shear forces at the lumbosacral junction which may increase the risk of presenting or developing spondylolisthesis.

Relatively few published studies discussed the characteristics of sagittal alignment in patients with lumbar disc degenerative diseases [13–15]. Ragnics and Endo et al. [14, 15] reported a common pattern of spinopelvic sagittal alignment in patients with LDH, which is characterized by lower SS, lower LL, and anterior translation of the C7 plumb line. However, the studies showed no difference in the value of PI between these patients and the asymptomatic control population unlike the study of Barrey et al. [13] who reported that the mean PI value for their patients with LDD or LDH was significantly lower than the asymptomatic volunteers. In fact, the correlation between the PI and lumbar disc degenerative diseases is still unclear. The previous studies were associated with a critical defect in the selection of the control population in that asymptomatic volunteers with no visible defect on X-films were included in the control group. However, MRI was not used to distinguish the condition of their lumbar discs. Several studies reported a high prevalence (20–28 %) of the lumbar disc degenerative changes in the asymptomatic individuals [18–21]. It suggests that the "normal control population" in previous studies included several patients undiagnosed with LDD, and this may be a reasonable explanation of their contradictory results.

In the present study, all the subjects were screened with MRI to assess the condition of their lumbar discs and select the normal population. We thereby attempted to discover the differences in the sagittal spinopelvic alignment between the patients with lumbar disc degenerative diseases (i.e. LDD and LDH) and the genuinely normal population, and identified the correlation of the morphologic sagittal parameter (i.e. PI) or positional sagittal parameters (e.g. SS and LL) with the lumbar disc degenerative diseases.

Materials and methods

We included 60 patients with single-level lumbar disc degenerative disease (i.e. LDD or LDH) from the outpatient or physical examination centre of our hospital and another 110 asymptomatic volunteers in this study, from January 2011 to September 2012. The inclusion criteria were as follows: (1) age between 20 and 50 years; (2) no history of any spinal surgery (including simple lumbar discectomy); (3) no spinal deformities (including scoliosis,

Table 1 Data of degeneration and normal groups

	DG	NG	*P* value
No. of subjects (*n*)	80	80	–
Age (years)	36.4 ± 6.9	36.9 ± 7.2	0.933
Gender (*n*)			
Female	32	30	0.746
Male	48	50	
BMI (kg/m^2)	23.1 ± 2.9	23.0 ± 2.7	0.602
PI (°)*	40.0 ± 9.8	48.7 ± 9.5	0.000
SS (°)*	28.5 ± 8.8	38.1 ± 7.0	0.000
PT (°)	11.3 ± 6.7	10.6 ± 5.9	0.774
LL (°)*	40.3 ± 12.8	53.0 ± 9.6	0.000
TK (°)*	33.1 ± 9.8	36.0 ± 7.3	0.028
SVA (cm)*	0.3 ± 3.0	−1.1 ± 2.3	0.001
SFD (cm)*	4.0 ± 1.5	3.0 ± 1.3	0.000

DG degeneration group, including intervertebral disc degeneration or herniation, *NG* normal group, *BMI* body mass index, *PI* pelvic incidence, *SS* sacral slope, *PT* pelvic tilt, *LL* lumbar lordosis, *TK* thoracic kyphosis, *SVA* sagittal vertical axis, *SFD* sacrum-bicoxofemoral distance

* Means significant difference

Table 2 Data of symptomatic and asymptomatic degeneration groups

	SDG	ADG	*P* value
No. of subjects (*n*)	45	35	–
Age (years)	36.5 ± 7.4	36.2 ± 6.5	0.812
Gender (*n*)			
Female	19	14	0.512
Male	26	21	
Level (*n*)			
L4–5	28	25	0.267
L5–S1	17	10	
BMI (kg/m^2)	23.0 ± 2.7	23.1 ± 3.2	0.753
PI (°)	39.3 ± 9.4	40.4 ± 10.4	0.716
SS (°)*	26.3 ± 8.9	31.3 ± 8.0	0.01
PT (°)*	12.9 ± 7.5	9.1 ± 4.9	0.009
LL (°)*	37.7 ± 13.8	43.7 ± 10.7	0.022
TK (°)	33.4 ± 10.9	32.7 ± 8.3	0.727
SVA (cm)*	1.0 ± 3.3	−0.6 ± 2.3	0.016
SFD (cm)	4.0 ± 1.7	3.9 ± 1.3	0.267

SDG symptomatic degeneration group, *ADG* asymptomatic degeneration group, *Level* degenerative level, *BMI* body mass index, *PI* pelvic incidence, *SS* sacral slope, *PT* pelvic tilt, *LL* lumbar lordosis, *TK* thoracic kyphosis, *SVA* sagittal vertical axis, *SFD* sacrum-bicoxofemoral distance

* Means significant difference

isthmic spondylolisthesis, irregular endplate, sacralization or lumbarization); (4) no spinal trauma or tumours; and (5) absence of arthropathy in the lower limbs. Written informed consent was obtained from all the subjects along with approved by the Ethics Committee of West China Hospital of Sichuan University. MRI was used for assessing the condition of the lumbar intervertebral discs in all subjects by one attending spinal surgeon and another attending radiologist not involved in the study. Each reader evaluated twice at different time points. The final result of MRI depended on their comprehensive views. Single-level LDD or LDH was found in 20 of 110 asymptomatic volunteers, who were then considered patients with lumbar disc degenerative diseases, while multi-level LDD was found in another ten volunteers, who were excluded from the study. Subsequently, the two groups were divided based on Pfirrmann grading system [26]: (1) Normal group (NG), contained 80 asymptomatic volunteers with normal lumbar intervertebral disc (Pfirrmann grade I–II); and (2) Degeneration group (DG), contained 80 patients with single-level LDH or LDD (Pfirrmann grade III–V) (Table 1). The degenerative patients included two subgroups: (1) Symptomatic degeneration group (SDG), contained 45 patients with low back pain; (2) Asymptomatic degeneration group (ADG), contained 35 patients without any low back pain in the last 5 years (Table 2).

Spinopelvic sagittal parameters were measured on the lateral standing full spine X-ray by the multi-purpose Digital R/F System (Sonialvision Safire 17, Shimadzu Corporation). The subjects were asked to stand in a relaxed erect position with the knees held in extension and hands placed on supports. The distance between the subject and the radiographic source was constant. The X-ray was taken from the skull to the proximal femora. A 17 × 14-inch film was then prepared for each subject. All radiological parameters were measured by two attending spinal surgeons and their average value adopted.

The study included a total of 7 relative sagittal parameters: pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), lumbar lordosis (LL), thoracic kyphosis (TK), sagittal vertical axis (SVA), and sacrum-bicoxofemoral distance (SFD) (Fig. 1a, b). The PI was defined as the angle between the vertical line of the sacral plate and the line connecting the midpoint of the sacral plate to the midpoint of the bilateral femoral head centre [2, 7]. In adults, the PI is a constant parameter which describes the shape of the individual pelvis. The SS was defined as the angle between the sacral plate and the horizontal plane [22]. The PT was defined as the angle between the plumb line and the line connecting the midpoint of the sacral plate to the midpoint of the bilateral femoral head centre [2, 7, 23]. Both the SS and PT were positional parameters which depended on the spatial position of the pelvis.

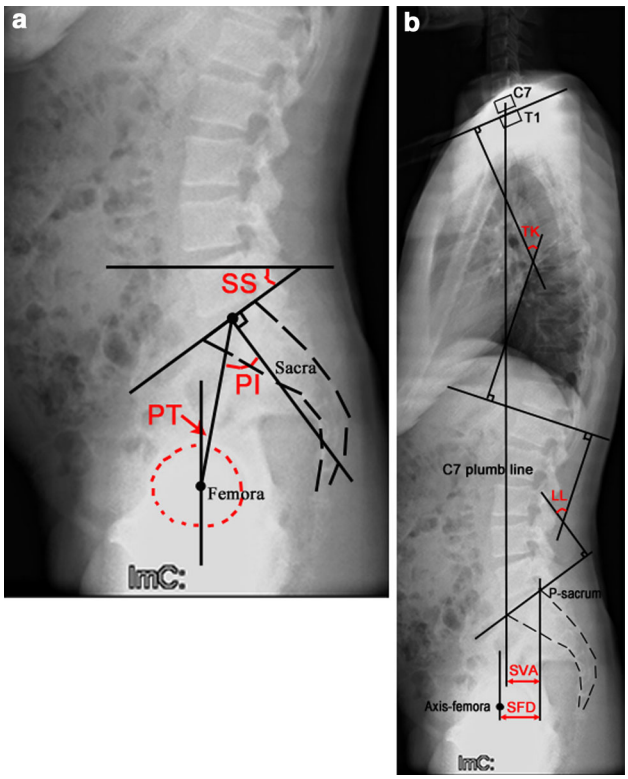

Fig. 1 **a** Sagittal parameters (PI, SS and PT). **b** Sagittal parameters (LL, TK, SVA and SFD)

However, the following algebraic relationship exists between the PI, SS, and PT: PI = SS + PT [22]. The LL was defined as the Cobb angle between the upper endplate of the L1 and S1, while the TK was defined as the Cobb angle between the upper endplate of the T1 and L1. The SVA was defined as the horizontal distance between the posterior corner of the sacrum and the C7 plumb line. A positive value was defined when the sacral posterior corner landed in front of the C7 plumb line. The SFD was defined as the horizontal distance between the sacral posterior corner and the midpoint of the bilateral femoral head centre [7]. The SFD was a distance parameter which partly reflected the pelvic space position because of the constant pelvic morphology. For example, the increasing value of SFD meant that the individual's pelvis became back-tilted (more upright pelvis), while the decreasing of SFD implied front-tilting pelvis.

Statistical analysis was performed using the SPSS17 software (IBM, Inc., New York, USA). Quantitative data were analysed by *t* test or Mann–Whitney test as appropriate (including age, BMI, and all sagittal parameters). Categorical data were analysed by χ^2 test (including gender and degenerative level). Correlations between the morphological and positional parameters were analysed by Pearson's correlation coefficient (including PI with SS, and PI with LL). $P < 0.05$ was considered significant.

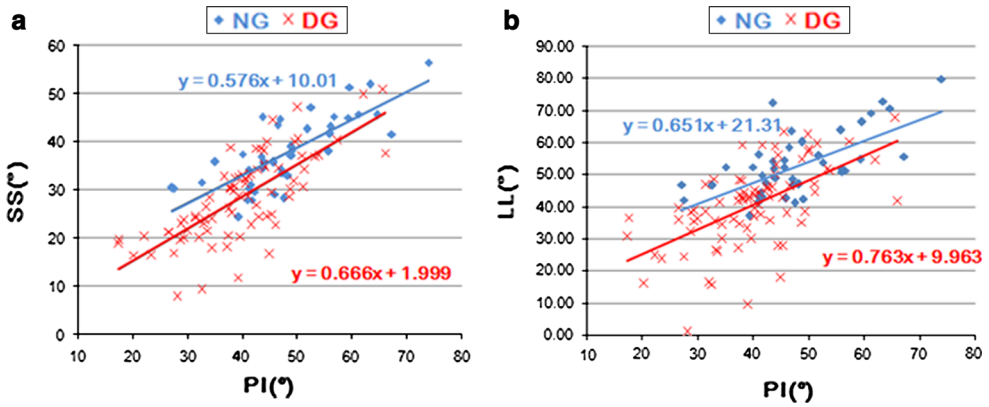

Fig. 2 **a** Correlation between PI and SS in both normal group (NG, *blue label*) and degeneration group (DG, *red label*). The *red line* is below the *blue line*, which suggests the *trend line* of SS over PI in degenerative patients was downward when compared with the normal population. **b** Correlation between PI and LL in both normal group (NG, *blue label*) and degeneration group (DG, *red label*). The *red line* is below the *blue line*, which suggests the *trend line* of LL over SS in degenerative patients was also downward when compared with the normal population

Results

No significant differences in the age, gender, or BMI between the DG and NG were noticed. The mean PI value for the DG was 40.0° ± 9.8° and significantly lower than 48.7° ± 9.5° for the NG. Compared with the NG, the mean SS, LL, and TK values for the DG were significantly lower, while the mean SVA and SFD values were significantly greater. The PT was not significantly different between these two groups (Table 1). With regard to the relationship between PI and positional parameters, SS and LL correlated well with PI in both the NG ($r = 0.78$ and 0.646, respectively) and DG ($r = 0.745$ and 0.607, respectively). However, the trend line of SS over PI in degenerative patients was markedly downward as compared to the normal population (Fig. 2a). The trend line of LL over PI in degenerative group was also markedly below the NG (Fig. 2b). The results suggested that in addition to the low PI, other factors derived from the degeneration of lumbar intervertebral disc may contribute to such lower SS or LL in this degenerative population.

Comparison of the symptomatic degeneration group (SDG) with asymptomatic degeneration group (ADG) yielded no significant differences in age, BMI, gender, degenerative level, BMI, PI, TK, or SFD. However, the mean SS and LL values for the SDG were significantly lower than the ADG, while the mean PT and SVA values were significantly greater (Table 2).

Discussion

Spinopelvic sagittal alignment accompanied with biomechanical changes has been demonstrated in previous studies in the pathogenesis and development of lumbar degenerative diseases [12–17, 24]. Several studies have compared the sagittal spinopelvic alignment in LDD or LDH patients with the asymptomatic volunteers, suggesting that the sagittal profile in these patients was characterized by a straight spine (lower LL and TK), vertical sacrum (lower SS and greater SFD) with an anterior displaced C7 plumb line (greater SVA) [13–15]. In these studies, the selection of control subjects merely depended on the clinical symptoms and X-films without considering findings from a lumbar MRI. As a consequence, the studies failed to recognize the high prevalence (20–28 %) of the disc degenerative change in the asymptomatic individuals [18–21].

In the present study, all the subjects were screened with MRI to assess and grade lumbar intervertebral disc degeneration. The normal asymptomatic volunteers were then demarcated from the symptomatic or asymptomatic patients with LDD. We found that the patients with lumbar disc degenerative diseases had a significantly lower PI as well as a more vertical sacrum, flat spine, and anterior translation of the C7 plumb line as compared to the normal subjects (Fig. 3), consistent with previous studies, except for the significantly lower PI which has only been found by Barrey et al. [13]. It was not unreasonable to suspect that the asymptomatic subjects with lumbar disc degenerative change had been included in the control population in previous studies, which then reduced the average value of PI for the normal subjects.

The PI was an important pelvic morphological parameter which maintained a constant value after the end of growth [2, 7, 9]. Patients with LDD or LDH were found to have a lower PI value, which suggested that the low PI may be a predisposing factor of these lumbar disc degenerative

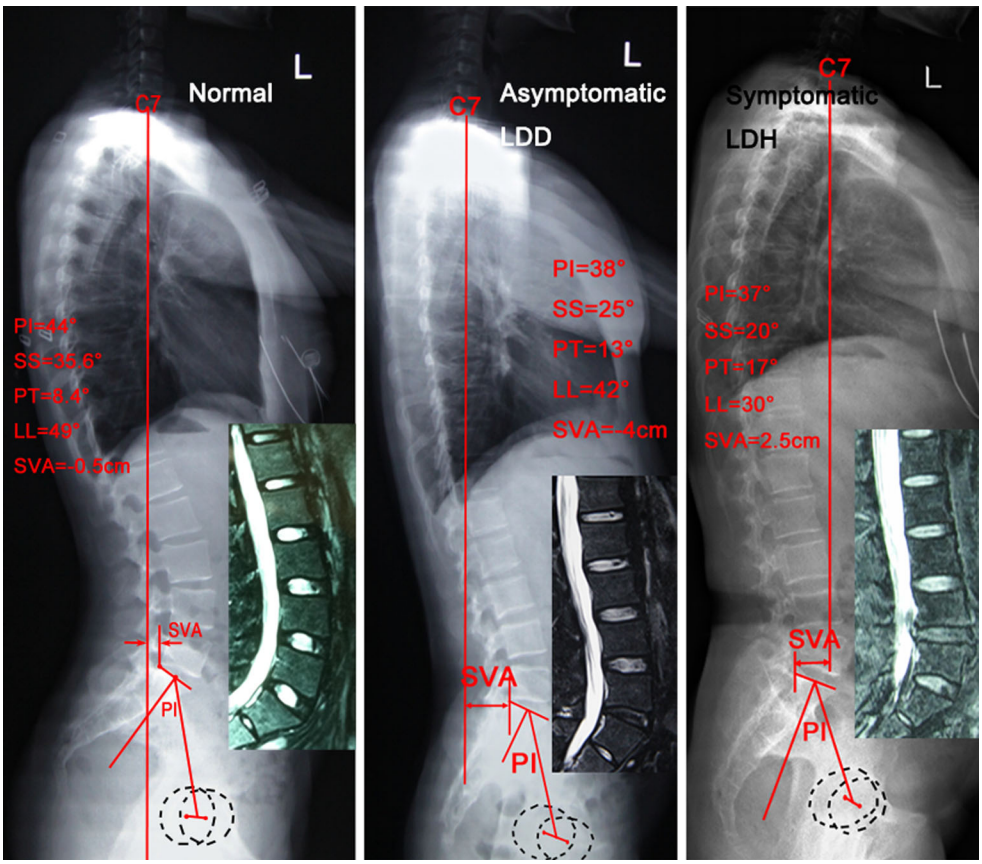

Fig. 3 Sagittal alignment in different populations. From *left* to *right* the normal population, the asymptomatic patient with lumbar disc degeneration and the symptomatic patient with lumbar disc herniation respectively. Compared with normal subjects, patients with LDD or LDH have a similar sagittal profile characterized by lower PI as well as more vertical sacrum and flat spine. In addition, the symptomatic LDH patient has a straighter spine and a forward gravity axis when compared with the asymptomatic LDD patient

diseases. Indeed, a lower PI implies a lower SS and as a result of a lower LL. As a straight spine aligns with a vertical sacrum, the compressive force of gravity will increases and then accelerates the disc degeneration [1, 10, 14, 24]. On the other hand, the reduced absorption of the shaking component of the vertical movement increases the injury rate to the lumbar disc resulting in disc herniation.

The changing tendency of SS over PI and LL over PI were downward in the degenerative patients when compared with normal population, which suggested that in addition to lower PI, other factors play significant roles in decreasing the value of SS and LL in the patients with lumbar disc degenerative diseases. The LL will structurally reduce as a result of segmental discopathy and loss of disc height [13, 25]. Subsequently, the loss of lordosis potentially leads to the anterior translation of the gravity axis (increasing SVA). In compensation, pelvic backtilt (PT increasing and SS decreasing and SFD increasing), which is secondary to the action of the hip extensor muscles acts to limit the forward movement of the gravity axis in these patients [2, 13, 15, 16, 25].

Endo et al. [15] had found the loss of lordosis and anterior displacement of the gravity axis in the patients with LDH was restored after discectomy, and thereby inferred the important role of the analgesic posture in the sagittal alignment of these patients. Comparing the sagittal parameters between symptomatic LDD or LDH patients with asymptomatic ones, we found the PIs in both subgroups were similar (39.3 vs 40.4). However, the SS and LL in the symptomatic patients were significantly lower than the asymptomatic patients (23.3 vs 31.3, and 37.7 vs 43.7, respectively), while the SVA was significantly greater (1.0 vs −0.6 cm). It suggested that the spine and sacrum became straighter (SS and LL decreasing) and the gravity axis moved increasingly forward (SVA increasing) in patients with seriously symptomatic lumbar disc degenerative diseases (e.g. low back pain). In other words, the specific analgesic posture is another compensatory factor inducing the straight sagittal alignment in the patients [13, 15, 25].

In addition, the morphology of the spinal complex (such as the vertebral shape and the strength of the posterior spinal muscles) also affects individual sagittal alignment. The abnormal morphology of the lumbar vertebrae directly affects LL, with the weak erector spinae leading to a vertical sacrum and flat lordosis. The direct contribution of

these factors to the individual sagittal balance is very difficult to evaluate at present. In our study, we selected subjects without spinal deformities (including the irregular endplate) to minimize these impacts, as far as possible.

However, several limitations still exist. First, the relatively sample size, especially the NG, was associated with a huge cost due to the MRI screening used for selection. Second, we failed to divide the LDD patients into separate groups, again due to the small size, although they were documented to have a similar sagittal pattern as the LDH patients before. Finally, this is a cross-sectional comparative study which lacked longitudinal data to document the predisposing effect of the low PI in the occurrence and development of the disc degenerative diseases. In future, a long-term follow-up of the health volunteers in this study, or even another prospective multicenter study are required.

Conclusion

In this study, we used MRI to screen subjects for LDD in normal population. Our finding suggests that subjects with lumbar disc degenerative diseases had a similar sagittal alignment characterized by a lower PI than normal subjects. The PI may play a predisposing role in the pathogenesis of LDD. A lower PI would result in lower SS and PT, which lead to a flatter LL and TK. The compressive force of gravity would increase in such sagittal pattern and accelerate the degenerative changes in lumbar disc, followed by the secondary structural (i.e. loss of disc height) and compensatory (i.e. pelvic backtilt and analgesic posture) changes which would further reduce the value of LL and SS to achieve a new sagittal balance.

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Conflict of interest None of the authors has any potential conflict of interest.

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