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Original Article

The pelvic radius technique in the assessment of spinopelvic sagittal alignment of degenerative spondylolisthesis and lumbar spinal stenosis☆

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ABSTRACT

Background: Degenerative spondylolisthesis (DS) and lumbar spinal stenosis (LSS) are the most common degenerative spinal diseases. The evaluating of spinopelvic sagittal alignment of the two diseases using pelvic radius (PR) technique have not been reported. The purpose of this study was to use PR measurement technique to compare the differences in spinopelvic sagittal alignment between DS and LSS.
Methods: A total of 145 patients with DS or LSS were retrospectively reviewed. Seventy patients with DS (DS group) and 75 age-matched patients with LSS (LSS group) were enrolled. Spinopelvic parameters including pelvic angle (PA), regional lumbopelvic lordosis (PR—L1, PR—L2, PR—L3, PR—L4 and PR—L5), total lumbopelvic lordosis (PR—T12), pelvic morphology (PR—S1), sagittal vertical axis from the C7 plumb line (SVA), lumbar lordosis (LL), thoracic kyphosis (TK), L4 slope and L5 slope were assessed in the two groups. Several parameters of DS and LSS group were compared with the normal population (NP).
Results: The PR—L4, PR—L5 and PR-S1 in the DS group were significantly smaller than those in the LSS group. There was no difference in PR—T12 between the DS group and NP ($p > 0.05$), while PR—T12 of the LSS group were significantly lower ($p < 0.01$). Degree of correlations among spinopelvic parameters differed between the two groups. PR—T12 of the DS group was more strongly correlated with PA ($r = -0.829$, $p < 0.001$) than with LL ($r = 0.664$, $p < 0.001$), TK ($r = 0.582$, $p < 0.001$). PR-T12 of the LSS group was more strongly correlated with LL ($r = 0.854$, $p < 0.001$), TK ($r = 0.616$, $p < 0.001$) than with PA ($r = -0.582$, $p < 0.001$).
Conclusions: PR—L4 and PR—L5 may be the predisposing factors for DS development. Spinopelvic morphology differed in patients with DS and LSS compared to NP. The compensatory mechanisms to maintain spinopelvic sagittal alignment in DS and LSS patients may be different.

1. Introduction

The evaluation of whole spinal sagittal alignment plays an increasingly important role in assessing the pathomechanisms of degenerative spinal diseases. Better methods for evaluating spinal balance and treating spinal diseases are needed. Currently, two principal methodologies for evaluating the spinal sagittal balance are the pelvic radius (PR) technique [1,2] and the technique based on the pelvic incidence (PI) and the spinosacral angle (SSA) [3,4]. PI was initially described by Duval-Beaupère et al. [5] as an invariable morphologic angle that is not affected by posture or tilting of the pelvis. However, the pelvic parameters reflect only local changes in pelvic morphology and do not consider the spinal compensatory action for pelvic changes. Jackson et al. [2] described the PR technique, which takes into account the spinal orientation and pelvic morphology compared with the pelvic parameters [1,2]. Jackson et al. [6] noted that measures of spinopelvic morphology using the PR technique were more reliable than spinal balance techniques that involved the use of plumb lines.

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DS and LSS are the most common clinical presentations of degenerative spinal diseases. They are the main causes of low back pain and symptoms related to nerve root compression. Previous studies have attempted to evaluate the characteristics of spinopelvic alignment and compensatory mechanisms associated with the two diseases. Lim et al. [7] reported that patients with DS have a propensity toward sagittal imbalance compared with LSS patients. Funao et al. [8] demonstrated different compensatory mechanisms for the maintenance of spinopelvic sagittal alignment in DS vs. non-DS patients. However, the pathomechanisms and compensatory mechanisms of the two disease entities have not yet been fully clarified. To the best of our knowledge, few studies have focused on evaluating spinopelvic sagittal alignment of patients with DS and LSS using the PR technique.

The purposes of the present study were to use PR measurement techniques to compare the differences in spinopelvic sagittal alignment between patients with DS and LSS and to elucidate patients' compensatory mechanisms to maintain spinal sagittal balance in each of the two disorders.

2. Materials and methods

2.1. Patients

We retrospectively reviewed 70 DS and 75 LSS patients who were treated with lumbar interbody fusion surgery at our institution from June 2013 to August 2017. The DS group included 6 men and 64 women with an average age of 61.14 years (range, 46–83 years). The LSS group included 43 men and 32 women, and their average age was 60.57 years (range, 40–81 years). The NP group included 36 men and 44 women, and their average age was 37 years (range, 20–60 years) [9]. Patients in the NP group were excluded from the study if they had one or more of the following: history of any spinal surgery or disease (trauma or tumor), scoliosis, deformities or severe osteoarthritis in the lower limbs, or history of low back pain [9].

The levels involved in the DS group were L4–L5 in 59 patients (84.3%) and L5–S1 in 11 patients (15.7%). The slippage grade was evaluated according to Meyerding's classification and was determined to be 64.3% (45/70) grade I and 35.7% (25/70) grade II. The levels involved in LSS were L4–L5 in 44 patients (58.7%), L5–S1 in 24 patients (32.0%), and L4–L5–S1 in 7 patients (9.3%).

All patients had symptoms that were unresponsive to conservative treatment for at least 6 months. The exclusion criteria were as follows: (1) previous spinal trauma or surgery, (2) tumor or scoliosis, (3) isthmic lysis with or without spondylolisthesis, and (4) deformities or severe osteoarthritis in the lower limbs.

2.2. Spinopelvic parameters

Standing lateral radiographs of the whole spine were taken with patients' elbows bent to accommodate shoulder flexion to 30°, and the knees and hips were fully extended [10]. The following radiographic measurements were performed by two observers, including pelvic angle (PA), regional lumbopelvic lordosis (PR–L1, PR–L2, PR–L3, PR–L4, and PR–L5), total lumbopelvic lordosis (PR–T12), pelvic morphology (PR–S1), sagittal vertical axis from the C7 plumb line (SVA), lumbar lordosis (LL), thoracic kyphosis (TK), and L4 slope and L5 slope [2,8]. Briefly, Hip axis (HA) is defined as the midpoint between approximate centers of both femoral heads. PR line is defined as the line from HA to the posterior superior corner of the S1 endplate. PR–T12 is defined as the angle between the PR line and inferior endplate of T12. PR–L1, PR–L2, PR–L3, PR–L4 and PR–L5 is defined as the angle between the PR line and a tangent lines along the superior endplate of L1, L2, L3, L4 and L5, respectively. PR–S1 is defined as the angle between the PR line and the endplate of S1. PA is defined as the angle between the PR line and the plumb line (Fig. 1). SVA from the C7 plumb line is defined as the horizontal offset from the posterior superior corner of S1 to the C7 plumb line. TK is defined as the angle between the superior endplate of T1 and the inferior endplate of T12. LL is defined as the angle between the superior endplate of L1 and the superior sacral endplate. L4 slope is defined as the angle between the superior endplate of L4 and the horizontal plane. L5 slope is defined as the angle between the superior endplate of L5 and the horizontal plane (Fig. 2).

2.3. Statistical analysis

Statistical evaluation was performed with SPSS software version 17.0 (SPSS Inc, Chicago, IL, USA). All data were expressed as the mean ± standard deviation. The intraclass correlation coefficient (ICC) was used to evaluate the consistency of the measurements made by the two observers [11]. Student's *t* test was used to compare the parameters among the NP, DS, and LSS groups. Correlations among the spinopelvic parameters of DS and LSS groups were determined using the Pearson correlation coefficient. A p value <0.05 was considered to be statistically significant.

3. Results

There were no statistically significant differences in each of the parameters following two measurements in both the DS and LSS groups, as shown in Table 1. The ICC was calculated, and the results of the two observers are reported in Table 2. All the parameters were evaluated by the two measurements by two observers with good reliability.

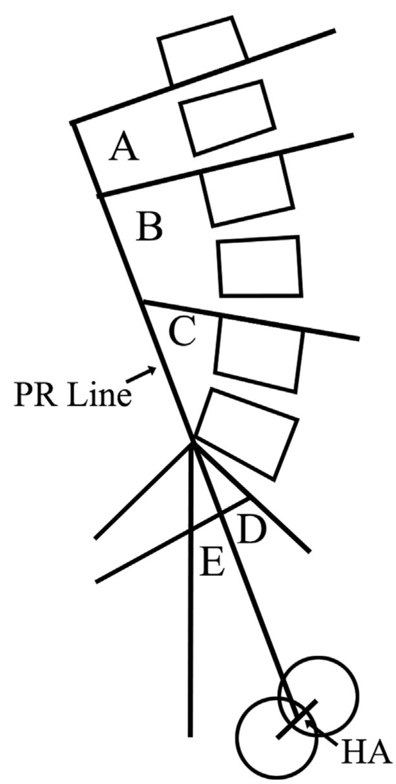

Fig. 1. The measurement methods of pelvic radius (PR) technique were demonstrated as follows. PR-T12 (*A*), PR-L2 (*B*), PR-L4 (*C*), PR-S1 (*D*), PA (*E*).

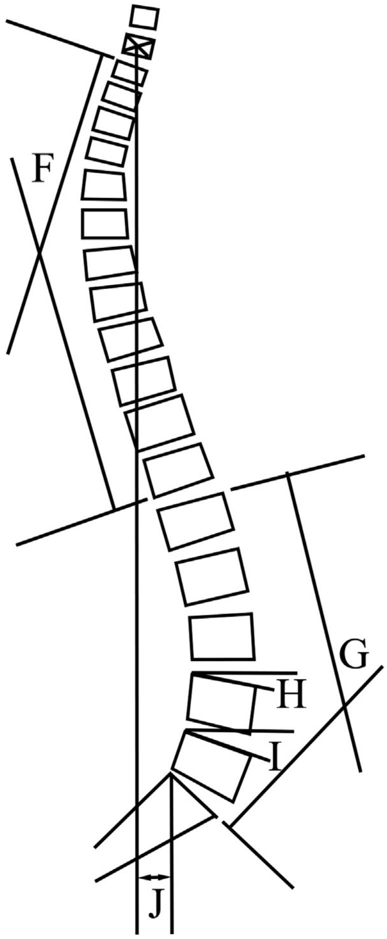

Fig. 2. The spinal parameters were measured as follows. TK (*F*), LL (*G*), L4 slope (*H*), L5 slope (*I*), SVA (*J*).

The differences in the spinopelvic parameters between the DS and LSS group are detailed in Table 3. There were no significant differences in age between the two groups. In the DS group, the L4 slope and the L5 slope were significantly greater than those in the LSS group. PR–L4, PR–L5, and PR–S1 in the DS group were significantly smaller than those in the LSS group. For SVA, PA, PR–T12, PR–L1, PR–L2, and PR–L3, there were no significant differences between the two groups.

The SVA and PA in the two groups were significantly greater than those in the NP group. Compared with NP, the DS groups showed significantly smaller PR–S1, and the LSS group showed significantly smaller PR–T12. There were no significant differences in PR–T12 between the DS and NP groups, as shown in Table 4.

Table 5 shows the significant correlations between several spinopelvic parameters in the DS and LSS groups. The degree of

Table 2
Intra-observer reliability between the two observers in DS and LSS group.

	Intra-observer reliability of the DS		Intra-observer reliability of the LSS	
	ICC	*p* value	ICC	*p* value
PA	0.796	0.000	0.919	0.000
SVA	0.958	0.000	0.990	0.000
L4 slope	0.907	0.000	0.928	0.000
L5 slope	0.827	0.000	0.854	0.000
PR-T12	0.920	0.000	0.957	0.000
PR-L1	0.883	0.000	0.947	0.000
PR-L2	0.974	0.000	0.968	0.000
PR-L3	0.966	0.000	0.894	0.000
PR-L4	0.912	0.000	0.932	0.000
PR-L5	0.906	0.000	0.764	0.000
PR-S1	0.953	0.000	0.888	0.000

Table 3
Comparison of the spinopelvic parameters between DS and LSS group.

	DS (n = 70)	LSS (n = 75)	*p* value
AGE	61.14 ± 8.61	60.57 ± 9.67	0.795
PA	24.18 ± 7.63	24.58 ± 9.22	0.840
PR-L1	81.04 ± 12.57	76.10 ± 13.08	0.109
PR-L2	77.99 ± 13.58	76.10 ± 12.76	0.547
PR-L3	69.48 ± 14.65	72.15 ± 11.58	0.400
PR-L4	57.63 ± 13.44	65.48 ± 10.70	0.008
PR-L5	45.76 ± 10.92	56.33 ± 9.15	<0.001
PR-S1	27.91 ± 10.41	38.63 ± 7.29	<0.001
PR-T12	84.36 ± 11.93	79.72 ± 13.19	0.124
L4 slope	8.18 ± 9.98	3.32 ± 7.95	0.027
L5 slope	19.96 ± 8.33	10.87 ± 8.02	<0.001
SVA (mm)	21.59 ± 32.65	23.94 ± 50.30	0.816

Mean ± standard deviation.

Table 4
Comparison of the spinopelvic parameters among NP, DS and LSS group.

	NP	DS (n = 70)	*p* value	LSS (n = 75)	*p* value
PA	16.38 ± 6.23	24.18 ± 7.63	<0.001	24.58 ± 9.22	<0.001
PR-S1	40.05 ± 8.35	27.91 ± 10.41	<0.001	38.63 ± 7.29	0.259
PR-T12	86.28 ± 9.39	84.36 ± 11.93	0.341	79.72 ± 13.19	0.006
SVA (mm)	−2.66 ± 22.79	21.59 ± 32.65	<0.001	23.94 ± 50.30	0.004

Mean ± standard deviation.

Table 1
Comparison of spinopelvic parameters performed by the two observers in DS and LSS group.

	DS (n = 70)			LSS(n = 75)		
	Observer 1	Observer 2	*p* value	Observer 1	Observer 2	*p* value
PA	24.50 ± 7.22	23.85 ± 8.80	0.734	24.73 ± 9.19	24.42 ± 9.62	0.890
SVA	22.50 ± 30.12	20.69 ± 35.66	0.817	23.78 ± 48.42	24.09 ± 52.36	0.980
L4 slope	8.13 ± 9.87	8.24 ± 10.55	0.965	4.33 ± 7.75	2.31 ± 8.43	0.299
L5 slope	19.69 ± 8.23	20.23 ± 9.17	0.792	11.34 ± 7.85	10.40 ± 8.78	0.638
PR-T12	84.11 ± 11.70	84.61 ± 12.64	0.862	78.82 ± 12.50	80.61 ± 14.11	0.577
PR-L1	80.86 ± 11.61	81.22 ± 14.16	0.907	76.07 ± 12.47	76.13 ± 13.99	0.987
PR-L2	77.75 ± 13.52	78.23 ± 13.83	0.882	75.82 ± 12.61	76.38 ± 13.11	0.853
PR-L3	69.47 ± 14.95	69.50 ± 14.60	0.992	72.57 ± 11.23	71.72 ± 12.54	0.764
PR-L4	58.01 ± 13.19	57.25 ± 14.00	0.813	66.04 ± 10.47	64.91 ± 11.29	0.697
PR-L5	45.52 ± 10.96	46.01 ± 11.39	0.853	56.41 ± 9.08	56.26 ± 10.36	0.949
PR-S1	28.18 ± 10.08	27.63 ± 10.99	0.824	38.96 ± 6.69	38.30 ± 8.23	0.712

Mean ± standard deviation.

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Table 5
Correlation coefficients among the spinopelvic parameters in DS and LSS group.

	DS (n = 70)	*p* value	LSS(n = 75)	*p* value
PR-T12–PA	−0.829	<0.001	−0.582	<0.001
PR-T12–LL	0.664	<0.001	0.854	<0.001
PR-T12–TK	0.582	<0.001	0.616	<0.001
PR-T12–PR-S1	0.458	0.005	0.004	0.983
PR-T12–SVA	−0.570	<0.001	−0.784	<0.001
PA–LL	−0.474	0.003	−0.463	0.005
PA–TK	−0.231	0.175	−0.227	0.189
PA–PR-S1	−0.512	0.001	−0.081	0.642
PA–SVA	0.218	0.201	0.382	0.024
LL–TK	0.470	0.004	0.593	<0.001
LL–PR-S1	−0.312	0.064	−0.465	0.005
LL–SVA	−0.343	0.040	−0.606	<0.001
TK–PR-S1	0.188	0.273	−0.152	0.384
TK–SVA	−0.345	0.040	−0.264	0.125
PR-S1–SVA	−0.318	0.058	−0.129	0.461

correlations among the spinopelvic parameters differed between the DS and the LSS group. In the DS group, PR–T12 was more strongly correlated with PA ($r = -0.829$, $p < 0.001$) than with LL ($r = 0.664$, $p < 0.001$), TK ($r = 0.582$, $p < 0.001$). In the LSS group, PR–T12 was more strongly correlated with LL ($r = 0.854$, $p < 0.001$) and TK ($r = 0.616$, $p < 0.001$) than with PA ($r = -0.582$, $p < 0.001$).

4. Discussion

Since degenerative spondylolisthesis was initially described by Junghanns in 1930 [12], a number of studies have focused on the pathologic mechanisms of DS. Sex [13,14], pregnancy [15], body mass index [16], ligamentous hyperlaxity [13], and facet joint orientation [17] have been reported as factors that predispose patients to the development of DS. Recently, spinopelvic sagittal alignment has been emphasized and has become one of the most important consideration to be taken into account when physicians analyze the pathologic mechanism of many spinal disorders. Schuller et al. [16] reported that a high pelvic incidence (PI) and sacral slope (SS) might be risk factors for the development and progression of DS. Liu et al. [18] described the association between lumbar spine orientations and degenerative spinal diseases. The results showed that the value of the L5 slope was greater in the DS group than in the reference group [18], and the authors concluded that L5 slope may be a useful parameter to predict the risk of DS development. In present study, compared with the LSS group, the L5 slope was significantly greater in the DS group, which was similar to the observation by Liu. We also found in our study that there were no statistically significant differences in PR–L1, PR–L2, and PR–L3 between the two groups. However, PR–L5 and PR–L4 values in the DS group were significantly smaller than those in the LSS group. These findings suggest that the anterior shear force on L4 and L5 was greater in DS patients than in LSS patients. Meanwhile, the ligamentous structure between L4 and L5 is weaker compared to that between L5 and S1 [19,20]. As a result, vertebral slip generally occurs in either L4 or L5, especially L4. From our results, we conclude that the PR–L4 and PR–L5 values also can be used to predict the risk of DS development.

Sagittal balance is a condition in which the body maintains a stable standing position with minimal muscle effort [21]. Several angular parameters can be used to evaluate the spinal sagittal balance. The more frequently used parameter to measure the overall spinal sagittal balance is SVA [22], which measures the distance from the C7 plumb line to the posterior corner of the S1 endplate. In our study, the global sagittal balance was also maintained in the DS and LSS groups, and the mean SVA of the two groups was within the normal range when the SVA <50 mm. Furthermore, the SVA in the DS and LSS groups was significantly greater than that in the NP group. The SVA was not different between the two groups, which is similar to the observation by Funao [8], suggesting that both DS and LSS patients adopt a posture that involves a forward-leaning trunk in order to maintain sagittal balance compared with postures in the NP group. A leaning trunk inevitably leads to changes in pelvic morphology. Chanplakorn et al. [23] noted that the PA angle can be used to describe the pelvic morphology. In our study, compared with NP, PA values in the two groups were significantly greater, indicating that the pelvis of DS and LSS patients tilts backward compared with NP. Therefore, with an increasing degree of spinal degeneration, the DS and LSS patients showed characteristic spinopelvic alignments with backward pelvic tilts and the forward-leaning trunks in order to maintain global balance.

PR–T12 is equal to the sum of the PR–S1 and the T12–S1 lordosis scores. Sergides et al. [24] demonstrated that the value of PR–T12 is relatively constant in healthy individuals, about $90° \pm 10°$. Gardocki et al. [25] described a strong correlation between PR–T12 and spinal sagittal balance. Sergides et al. [24] reported that congruent sagittal alignment is necessary in order to assess spinopelvic sagittal balance by means of PR–T12. These authors found that the ratio of the thoracic kyphosis to the lumbar lordosis (T4–T12/T12–S1) is a predictor of congruent sagittal alignment [24], which was also evaluated in our study. In the current study, the PR–T12 value was significantly lower in the LSS group compared with that in the NP group. However, there were no differences in PR–T12 between the DS group and the NP group. These observations suggested that DS and LSS patients present with different characteristic spinopelvic alignments compared to those in NP, because the PR–T12 assessment showed that the alignments in the two groups were not exactly the same as those in NP.

Spinal orientation and pelvic morphology work together to maintain the overall sagittal balance as adaptations to increasing degrees of degeneration of the DS and LSS. However, the compensatory mechanism associated with these two kinds of disorders remains unclear. Funao et al. [8] reported that the pelvic parameter PI in DS patients correlated more strongly with SS, and non-DS patients had a stronger correlation with pelvic tilt (PT), so they demonstrated that SS was the major factor that compensated for greater PI in DS patients and PT in non-DS patients. However, these observations overlook the manner in which the spine compensates for pelvic changes when the spinopelvic sagittal balance was assessed by pelvic parameters alone. As mentioned previously, the PR technique reflects a combined measure of pelvic morphology and lumbar lordosis. PR–T12 is a useful parameter for rapidly assessing the spinopelvic sagittal balance. In the current study, the degree of correlations among the spinopelvic parameters differed between the DS and LSS groups. In the DS group, the correlations between the PR–T12 and PA were stronger than LL, TK. In contrast, the correlations between the PR–T12 and LL, TK were stronger than PA in the LSS group. The spinopelvic parameters of the two disorders revealed that an increased PA was the major compensatory factor for maintaining global sagittal balance in DS patients, and changing the curvature of the thoracic and lumbar spine was a major compensation mechanism in patients with LSS. The previous studies of sacro-pelvic alignment using the PR technique have demonstrated that when the PR–S1 increases, the sacrum has tends to have a more vertical orientation, but it tends increasingly to the horizontal as the PR–S1 decreases [23]. Chanplakorn and Roussouly et al. [23,26] reported a negative correlation between the PR–S1 and the PA angle, and the PA angle tended to increase when the PR–S1 was decreased. In contrast, the PA angle decreased when the PR–S1 increased (Fig. 3). However, we believe that this correlation is not

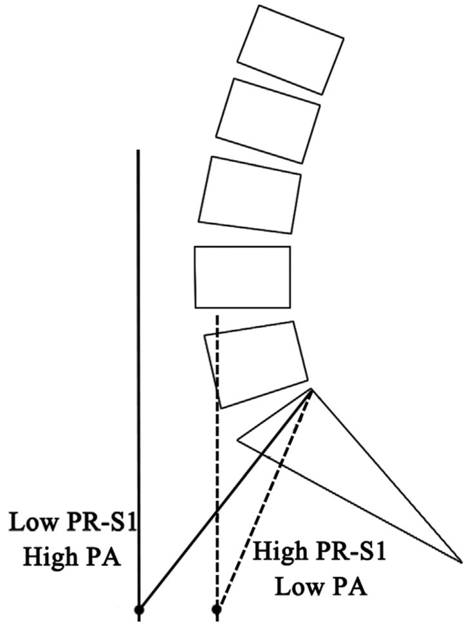

Fig. 3. Drawing describes the relationship between PR-S1 and PA angle. The *black dots* represent the HA in high and low PR-S1. The *straight lines* indicate the PR line in low PR-S1 or high PA angle. The *dashed lines* indicate the PR line in high PR-S1 or low PA angle.

always constant because of the geometric relationship: PA + SS + PR −S1 = 90° (Fig. 4). Therefore, PR−S1 is negatively correlated with PA when SS is constant, but, in fact, SS is constantly changing in order to maintain spinopelvic sagittal balance during spinal degeneration. In the present study, the PR−S1 in the DS group was significantly smaller than in the LSS group, and the SS in the DS group was significantly greater than that in the LSS group (37.83 ± 9.17 vs. 28.18 ± 9.02). This explains why the PA values show no statistical differences between the two groups in the present study. In

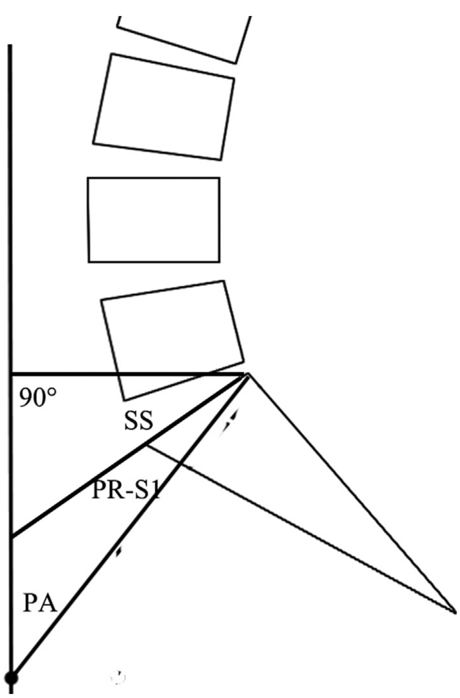

Fig. 4. The geometric relationship PA + SS + PR-S1 = 90°.

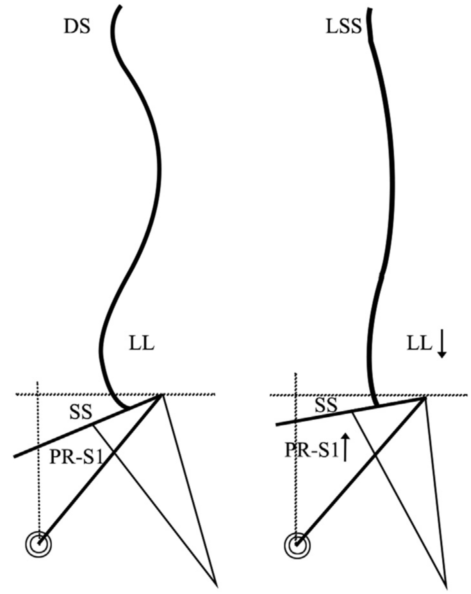

Fig. 5. Schematic drawing depicting the different mechanisms responsible for the maintenance of spinopelvic sagittal alignment in DS and LSS groups. There is a negative correlation between PR-S1 and PA in DS patients. It indicated that a lower PR−S1 possibly induced a compensatory increase in the PA of DS patients, and therefore pelvic retroversion was the major compensatory factor for maintaining global sagittal balance in DS patients. PR−S1 was negatively correlated with LL. This finding indicated that a higher PR−S1 value possibly induced a compensatory decrease in the LL of LSS patients, Thus, reducing spinal curvature may take a major compensatory factor for maintaining spinopelvic sagittal alignment in LSS patients.

addition, our results revealed a negative correlation between PR−S1 and PA in the DS group that is similar to the observations by Chanplakorn and Roussouly et al. [22,25]. These findings indicated that a lower PR−S1 possibly induced a compensatory increase in the PA of DS patients, and therefore pelvic retroversion was the major compensatory factor for maintaining global sagittal balance in DS patients. However, there was no correlation between PR−S1 and PA in the LSS group, but PR−S1 was negatively correlated with LL. This finding indicated that a higher PR−S1 value possibly induced a compensatory decrease in the LL of LSS patients, Thus, we hypothesized that reducing spinal curvature may take a major compensatory factor for maintaining spinopelvic sagittal alignment in LSS patients (Fig. 5).

There are several limitations in current study including small sample size, cross-sectional design, rather than a longitudinal study design and without sex-matched analysis. However, to the best of our knowledge, the compensatory mechanisms to maintain spinopelvic sagittal alignment in the DS and LSS patients have not yet been fully clarified. The findings obtained in this study may provide more information on the spinopelvic sagittal alignment for DS and LSS.

Conflicts of interest and source of funding

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