Analysis of sagittal curvature and its influencing factors in adolescent idiopathic scoliosis

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Abstract
This study aimed to explore the characteristics of changes in the sagittal arrangement of the spine between adolescent patients with idiopathic scoliosis (AIS) and normal adolescents, the risk factors for AIS and the factors affecting the progress of AIS.

X-ray images of the full length of the spine in standing position were taken in AIS patients and normal adolescents. Radiographic measurements made at intermediate follow-up included the following:C1 and C2 cervical lordosis and C2 - C7 curvature of cervical lordosis, C2-C7-sagittal horizontal distance (C2-C7SagittalVerticalAxis, C2-C7SVA), TS-CL, after thoracic lobe (Thoracic Kyphosis, TK), thoracic lumbar segment Angle (thoracolumbar kyphosis, [TLK]), lumbar lordosis Angle (Lumbar Lordosis, LL), sacral slope Angle (Sacrum Slope, SS), pelvic tilt Angle (Pelvic Tilt, PT), pelvic incidence (PI), L5 Incidence (Lumbar5 Slope (L5S), L5 incidence (Lumbar5 Incidence (L5)), sagittal horizontal distance (cSVA), lower depression Angle of the 2nd cervical spine. The difference of sagittal plane parameters between AIS group and normal adolescent group was compared. To evaluate the progress of AIS, correlation analysis was conducted between diagonal 2 and other parameters. The main risk factors of AIS were determined by binary Logistic analysis.

The cSVA of AIS patients was higher than that of healthy adolescents (AIS: 27.64 ± 15.56 mm). Healthy adolescents: (17.74 ± 12.8 mm), L5S (AIS: 19.93° = 7.07° and healthy adolescents: 15.38° = 7.78°, P = 0.024 < 0.05), C2 downward sag Angle (AIS: 15.12° = 2.7°; Healthy adolescents: 12.97° = 4.56°); AIS patients had lower TS-CL (AIS: 22.48 ± 6.09 and healthy adolescents: 28.26° ± 10.32°), PT (AIS: 10.42° = 4.53° and healthy adolescents: 15.80° = 7.68°), (AIS: 41.87° = 9.72° and healthy adolescents: 48.75° = 8.22°). The main risk factor for idiopathic scoliosis in adolescents was L5 (OR = 1.239, 95% CI = 1.049–1.463, P = 0.012 < 0.05).

L5S is a major risk factor for idiopathic scoliosis in adolescents. The larger PI is, the higher the risk of scoliosis progression is. In AIS patients, lumbar lordosis is increased, cervical lordosis is reduced, and even cervical kyphosis occurs.

Abbreviations: AIS = adolescent idiopathic scoliosis, L5 = lumbar 5, L5I = lumbar5 incidence, L5S = lumbar5 slope, LL = lumbar lordosis, PI = pelvic incidence, PT = pelvic tilt, S1 = sacrum 1, SS = sacrum slope, SVA = sagittal vertical axis, TLK = thoracolumbar kyphosis.

Keywords: adolescent idiopathic scoliosis, digital measurement, sagittal parameters

Editor: César Calvo Lobo.

CZ and YW have contributed equally to this paper.

This work was supported by the National Natural Science Foundation of China (81460330,81860393,81560348,81260269); Natural Science Foundation of Inner Mongolia Autonomous Region (2020 ms08124, 2016 lh08021, 2016 ms08131); Follow-up Research Project of Inner Mongolia Medical University (2020); Science and Technology Achievement Transformation Project of Inner Mongolia Medical University, Huhhot, China. The Second Hospital of Ulanqab, Ulanqab, The Second Afiliated Hospital of Inner Mongolia Medical University, Huhhot, The First Hospital of Inner Mongolia Medical University, Huhhot, The Second Affiliated Hospital of Inner Mongolia Medical University, Huhhot, The Second Affiliated Hospital of Inner Mongolia Medical University, Huhhot, The Second Hospital of Ulanqab, Ulanqab, The First Clinical College of Inner Mongolia Medical University, Gansu Normal University, Gansu, The Second Affiliated Hospital of Inner Mongolia Medical University, Huhhot, The Second Hospital of Ulanqab, Ulanqab.

The authors have no conflicts of interests to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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How to cite this article: Zhang C, Wang Y, Yu J, Jin F, Zhang Y, Zhao Y, Fu Y, Zhang K, Wang J, Dai L, Gao M, Li Z, Wang L, Li X, Wang H. Analysis of sagittal curvature and its influencing factors in adolescent idiopathic scoliosis. Medicine 2021;100:23(e26274).

Received: 5 September 2020 / Received in final form: 20 March 2021 / Accepted: 24 May 2021

http://dx.doi.org/10.1097/MD.0000000000026274
1. Introduction

Adolescent idiopathic scoliosis (AIS) is the most common spinal deformity in adolescents.\(^1\) It is a three-dimensional deformity of the coronal, sagittal, and horizontal surfaces of the spine. Patients with thoracic scoliosis have a higher incidence of neck pain, back pain and low back pain due to the presence of coronal plane deformity and reduced thoracic kyphosis\(^2\) and abnormal spine biomechanics.\(^3,4\) The loss of physiological curvature leads to pathological changes in the spine and accelerated disc degeneration, affecting the health-related quality of life of patients.\(^5\) The incidence of sagittal imbalance in AIS patients is higher than that in healthy adolescents.\(^6\) Sagittal imbalance in patients with spinal deformity is closely related to quality of life. When this balance is broken, spinal function is restricted, and corresponding symptoms will occur.\(^7\) Glassman et al\(^8\) and Mac-Thiong\(^9\) found that when Sagittal Vertical Axis (SVA) \(>5\) cm, it was in a state of spinal imbalance, and the patients’ health-related quality of life score was reduced in this state. Themistocles et al.\(^10\) reported that postoperative recovery of cervical lordosis in patients with spinal deformity was associated with health-related quality of life. And the pelvis plays an important role in the regulation of sagittal compensatory balance.

Currently, there are few reports on the change characteristics of the sagittal plane of AIS. For this reason, we studied the imaging data of AIS patients and normal adolescents, analyzed the change characteristics of the sagittal curvature of AIS, and analyzed the reasons for the change and its clinical significance.

2. Materials and methods

2.1. Subjects

Collection 60 teenagers who visited the Imaging department of Inner Mongolia International Mongolian Hospital from April 2014 to November 2018 were taken orthographic and lateral X-ray images\(^11\) of the whole spine. Thirty (13 males and 17 females) were AIS patients with an Angle of \(40^\circ<\) Cobb \(<80^\circ\) was defined as cervical kyphosis. The control group was comprised of 30 normal adolescents, including 15 males and 15 females, aged 12 to 18 years, with an average of 15.2 years.

The protocol was approved by the medical ethics committee (YKD202001032) and all included patients expressed informed consent and participated in the study.

2.2. Hardware and software parameters

AIS patients and healthy adolescent volunteers took full-length frontal and lateral X-ray images of the standing spine (proximal over the anterior and posterior arch of the first cervical vertebra and distal to the femoral head 10 cm below). \(C_2-C_7 \leq 0^\circ\) was defined as cervical curvature straightening or lordosis, while \(C_2-C_7 >0^\circ\) was defined as cervical kyphotic. The measure processing of the (Joint Photographic Experts Group) data started using the “Mimics” (Materialise, Belgium). The linear and angular measurements were performed by 1 single examiner on the 2D pictures in Mimics. The measurement parameters are as follows:

1. Cervical sagittal alignment parameters: a. \(C_1-C_2\) Cobb angle \((C_1-C_2)\) was measured as the angle between the caudal endplate of cervical vertebra 1 and cervical vertebra 2. b. \(C_2-C_7\) Cobb angle \((C_2-C_7)\) was measured as the angle between the caudal endplate of cervical vertebra 2 and cervical vertebra 7. c. \(C_2-C_7\) Sagittal Vertical Axis \((C_2-C_7\ SVA)\) was defined as the horizontal distance between the vertical line through the center of \(C_2\) and posterior upper margin of \(C_7\). When \(C_2-C_7\ SVA\) was greater than 4 cm, the health-related quality of life of the patients would be affected.\(^11,12\) d. TS-CL: \(T_1\) Slope minus CL (Fig. 1).

2. Thoracic kyphosis and Lumbar lordosis parameters: a. Thoracic Kyphosis (TK) was measured as the angle between the superior endplate of \(T_4\) and the caudal endplate of \(T_{13}\). b. Thoracolumbar kyphosis (TLK) was measured as the angle between the superior endplate of \(T_{11}\) and the caudal endplate of \(L_1\). c. Lumbar Lordosis (LL) was measured as the angle between the upper edges of lumbar 1 (\(L_1\)) and sacrum 1 (\(S_1\)) (Fig. 2).

3. Sagittal lumbosacral parameters: a. Sacrum Slope (SS) was measured as the angle between the superior endplate of \(S_1\) and the horizontal line. b. Pelvic tilt (PT) was measured as the angle between the line connecting. c. Pelvic Incidence (PI) was measured as the angle between a line perpendicular to the superior endplate of sacrum 1 (\(S_1\)) at its midpoint and a line connecting this point to the center of the femoral heads. If the femoral heads did not overlap in the radiograph, the midpoint of the line connecting the center of the femoral head was taken as a reference point. d. Lumbar 5 Slope (\(L_5S\)) was measured as the angle between the superior endplate of \(L_5\) and the horizontal line. e. Lumbar 5 Incidence (\(L_5I\)) was measured as the angle between a line perpendicular to the superior endplate of lumbar 5 (\(L_5\)) at its midpoint and a line connecting this point to the center of the femoral heads. If the femoral heads did not overlap in the radiograph, the midpoint of the line connecting the center of the femoral head was taken as a reference point (Fig. 3).

4. Global sagittal alignment parameters: a. Sagittal Vertical Axis (SVA) was defined as the horizontal distance between the vertical line through the center of \(C_7\) and posterior upper margin of \(S_1\). If the plumb line is located in front of the posterior upper margin of \(S_1\), then SVA is positive, otherwise it is negative. If SVA >5 cm, it is defined as unbalanced (Fig. 2).

Figure 1. Sagittal parameters of cervical spine and depression of the lower margin of the second cervical spine (1: \(C_1-C_2\); 2: \(C_2-C_7\); 3: \(T_1\); 4: Depression of the lower margin of the second cervical spine).
b. Thoracic Slope (T1S) was measured as the angle between the superior endplate of T1 and the horizontal line (Fig. 1).

5. The growth of AIS and healthy adolescent volunteers was evaluated. Depression of the lower margin of C2 (angle 2): the connection between the highest point at the bottom margin and the lowest point at the posterior margin of C2 vertebral body and the lowest point at the bottom margin of C2 vertebral body (Fig. 1).

2.3. Statistical analysis

The above parameters of each group of data were measured twice by the same person, and the mean value of the 2 results was used to represent the final value. SPSS25.0 software was used for statistical analysis. Descriptive statistical analysis was performed on AIS and healthy adolescent volunteers, and independent sample t-test was used to evaluate the differences between the 2 groups. Pearson correlation analysis was used for correlation analysis of diagonal 2 and other parameters to evaluate the progress of AIS. P < .05 was considered statistically significant.

3. Results

Compared with healthy adolescents, there were significant differences in T1S, TS-CL, cSVA, C2 downward depression Angle, SVA, L5S, LL, PI and PT in AIS patients (P < .05). The following parameters were higher in AIS patients than in healthy adolescents: cSVA: AIS (27.64 ± 19.56) mm; Healthy adolescents: (17.74 ± 12.8) mm, P = .024 < .05). L5S (AIS: 19.93 ± 7.07° and healthy adolescents: 15.38 ± 7.78°, P = .024 < .05), C2 downward recessed Angle AIS: 15.12 ± 2.7°. Healthy adolescents: 12.97 ± 4.56°, P = .03 < .05), the following parameters were small: TS-CL (AIS: 22.48 ± 6.09 and healthy adolescents: 28.26 ± 10.32°, P = .011 < .05), PT (AIS: 10.42 ± 4.53° and healthy adolescents: 15.80 ± 7.68°, P = .002 < .05), PI (AIS: 41.87 ± 9.72° and healthy adolescents: SVA (AIS: (3.53 ± 21.31) mm and healthy adolescents: (64.80 ± 72.51) mm, P = .014 < .05).

(Table 1).

Compared with healthy adolescents, there were significant differences between AIS patients and healthy adolescents in T1S, TS-CL, cSVA, C2 downward depression Angle, SVA, L5S, LL, PI and PT (P < .05). The following parameters were higher in AIS patients than in healthy adolescents: cSVA: AIS (27.64 ± 19.56) mm; Healthy adolescents: (17.74 ± 12.8) mm, P = .024 < .05), L5S (AIS: 19.93 ± 7.07° and healthy adolescents: 15.38 ± 7.78°, P = .024 < .05), C2 downward recessed Angle AIS: 15.12 ± 2.7°. Healthy adolescents: 12.97 ± 4.56°, P = .03 < .05), the following param-
3.1. Correlations between progression of adolescent idiopathic scoliosis and other sagittal spinal parameters in AIS patients and normal controls

Correlation coefficient ($r$) is explained as follows: <.2 means weak correlation, 0.2 to 0.4 means weak correlation, 0.4 to 0.7 means moderate correlation, 0.7 to 0.9 means high correlation, and >0.9 means almost complete correlation. In the case group, the downward sag angle of C2 was moderately positively correlated with TS-CL and TLK. The downward sag angle of C2 is positively correlated with TK. The downward sag angle of C2 is negatively correlated with SVA. In the control group, the downward sag angle of C2 was negatively correlated with CSVA. The downward sag angle of C2 is negatively correlated with SVA. (Tables 2 and 3)

3.2. Binary logistic regression analysis

Binary logistic regression results showed that the main risk factors for idiopathic scoliosis in adolescents were L5 (odds ratio OR = 1.239, 95% (confidence intervals) CI = 1.049–1.463, $P = .012 < .05$). (Table 4)

4. Discussion

Adolescent idiopathic scoliosis is a three-dimensional deformity that affects the physical and mental health of patients,[13,14] among which the changes and matching of cervical vertebra, thoracic vertebra, lumbar vertebra and pelvis in sagittal deformity correction have attracted the attention of physicians.[15,16] It is widely believed that sagittal spinal dislocation plays a crucial role in the mechanism of spinal disease. Hu et al.[17] proposed that coronal deformity in AIS patients would lead to changes in sagittal parameters. Hwang et al.[18] concluded that the thoracic kyphosis angle of AIS patients with cervical kyphosis was significantly smaller than that of patients with cervical kyphosis.

Recently, more and more studies have been conducted on the changes of sagittal parameters of cervical spine,[19,20] in this study, it was observed that C1-C2 (-18.58° ± 9.72°) and C2-C3 (-12.30° ± 4.78°, $P < .05$) decreased, and CL (7.56° ± 2.08°, $P < .05$) increased. Chen et al.[21] measured the changes in sagittal curvature of cervical spine in 43 cases of Lenke type 5 after posterior correction and found that postoperative improvement of TLK may contribute to the improvement of CSA. In addition,
there was a significant difference in cervical curvature between the sexes. Machino et al. [23] found that the anterior convex Angle of cervical vertebra was larger in males than in females. The incidence of cervical sagittal abnormalities was higher in AIS patients, and Wang et al. [19] found that all patients had improved cervical sagittal abnormalities.

In our study, it was observed that SS in adolescent idiopathic scoliosis patients increased (34.37° ± 8.10° and 32.09° ± 8.11°, P < .05), PT (10.42° ± 4.53° and 15.80° ± 7.68°, P < .05), and PI (41.87° ± 9.72° and 48.75° ± 8.22°, P < .05).

Table 2

| Type  | Pearson correlation | Pearson significance (double-tailed) |
|-------|---------------------|-------------------------------------|
| C₂C₂  | AIS                  | −0.028                              | 0.883                              |
|       | Normal               | −0.056                              | 0.77                               |
| C₂C₇  | AIS                  | −0.368                              | 0.045                              |
|       | Normal               | 0.021                               | 0.913                              |
| T₁S   | AIS                  | 0.241                               | 0.199                              |
|       | Normal               | 0.002                               | 0.991                              |
| TS-CL | AIS                  | 0.426**                             | 0.019                              |
|       | Normal               | −0.012                              | 0.96                               |
| cSVA  | AIS                  | −0.325**                            | 0.08                               |
|       | Normal               | −0.544***                           | 0.002                              |
| PT    | AIS                  | −0.131                              | 0.491                              |
|       | Normal               | −0.114                              | 0.55                               |
| PI    | AIS                  | 0.274                               | 0.143                              |
|       | Normal               | 0.177                               | 0.35                               |
| SS    | AIS                  | 0.198                               | 0.295                              |
|       | Normal               | 0.316                               | 0.089                              |
| LL    | AIS                  | 0.023                               | 0.902                              |
|       | Normal               | −0.004                              | 0.984                              |
| TLK   | AIS                  | 0.455*                              | 0.012                              |
|       | Normal               | 0.302                               | 0.105                              |
| TK    | AIS                  | 0.497**                             | 0.005                              |
|       | Normal               | 0.259                               | 0.168                              |
| SVA   | AIS                  | −0.472**                            | 0.008                              |
|       | Normal               | −0.556**                            | 0.001                              |
| L₅S   | AIS                  | 0.131                               | 0.489                              |
|       | Normal               | 0.185                               | 0.357                              |
| L₇J   | AIS                  | −0.109                              | 0.567                              |
|       | Normal               | 0.06                                | 0.765                              |

Table 3

| Type  | Pearson correlation | Pearson significance (double-tailed) |
|-------|---------------------|-------------------------------------|
| C₂C₂  | AIS                  | −0.154                              | 0.415                              |
|       | Normal               | 0.324                               | 0.099                              |
| CL    | AIS                  | 0.137                               | 0.47                               |
|       | Normal               | 0.414*                              | 0.032                              |
| T₁S   | AIS                  | −0.173                              | 0.36                               |
|       | Normal               | −0.29                               | 0.142                              |
| TS-CL | AIS                  | −0.212*                             | 0.261                              |
|       | Normal               | −0.432**                            | 0.024                              |
| cSVA  | AIS                  | 0.089                               | 0.642                              |
|       | Normal               | −0.276                              | 0.163                              |
| PT    | AIS                  | 0.078                               | 0.681                              |
|       | Normal               | −0.421*                             | 0.029                              |
| PI    | AIS                  | 0.448                               | 0.013                              |
|       | Normal               | 0.496**                             | 0.009                              |
| SS    | AIS                  | 0.494**                             | 0.005                              |
|       | Normal               | 0.841**                             | 0.000                              |
| LL    | AIS                  | 0.297                               | 0.111                              |
|       | Normal               | 0.622**                             | 0.002                              |
| TLK   | AIS                  | −0.14                               | 0.46                               |
|       | Normal               | −0.312                              | 0.113                              |
| TK    | AIS                  | −0.068                              | 0.72                               |
|       | Normal               | −0.312                              | 0.113                              |
| SVA   | AIS                  | −0.056                               | 0.769                              |
|       | Normal               | −0.526**                            | 0.005                              |
| L₇J   | AIS                  | −0.144                              | 0.448                              |
|       | Normal               | −0.568***                           | 0.002                              |

L₅ = lumbar5 incidence, L₅S = lumbar5 slope, LL = lumbar lordosis, PI = pelvic incidence, PT = pelvic tilt, SS = sacrum slope, SVA = sagittal vertical axis, TLK = thoracolumbar kyphosis.
* At the level of 0.05 (double-tailed); the correlation was significant.
** Significant correlation at 0.01 level (double tails).
*** Significant correlation at 0.001 level (double tails).

The study results of Yuan et al. (Yuan et al., 2019) showed that in patients with Lenke type 1 AIS, compared with non-segmental fusion, selective fusion not only has an important value in maintaining lumbar mobility, but also retains the compensatory function of the posterior rotation of the pelvis from the standing position to the sitting position. In combination with previous studies, we suggest that PI maintains the sagittal balance of the spine by affecting the degree of Sacrum Slope (SS) and thus the degree of lumbar lordosis.[25] The experimental results showed that the LL value of adolescent idiopathic scoliosis patients significantly increased LL (49.69° ± 8.83° and 41.32° ± 12.47°, P < .05). LL is very important for maintaining the upright posture of human body. Qiu et al. [24] reported that LL value of healthy adolescents was close to (49.3° ± 7.07°, 4.37° ± 8.11°, and 15.38° ± 7.78°, P < .05).
sagittal parameters, such as PI and SS, L5S, and PI (AIS: \( r = 0.448, P = .013 < .05 \), normal adolescents: \( R = 0.496, P = .009 < .05 \), L5S and SS (AIS: \( r = 0.494, P = .005 < .05 \), normal adolescents: \( r = 0.841, P = .000 < .05 \)). Zhang et al.\(^ {28} \) found that PI is closely related to disc degeneration of L3/S1. We concluded that with an increase in L5S, biomechanical factors would cause accelerated disc degeneration, leading to an increase in PI, an increase in sacral inclination, and a change in the spin-pelvis sagittal plane. In order to maintain the gravity balance of the spine, the lumbar lordosis Angle would be compensated.

As for the progression of idiopathic scoliosis in adolescents, Chen et al.\(^ {29} \) found that the depression at the lower edge of the second cervical vertebra (Angle 2) was significantly correlated with wrist bone age (\( r = 0.86 \), that is, the depression at the second cervical vertebra could predict bone age. In addition, in this study, there was a highly negative correlation between C2 downward depression Angle and SVA (\( R = -0.472, P = .008 < .05 \)). Therefore, C2 downward depression Angle was used as a parameter index to predict the growth peak of adolescents and the progression of adolescents with idiopathic scoliosis. In the case group, the downward sag Angle of C2 was moderately positively correlated with TS-CL and TLK. The downward sag Angle of C2 is positively correlated with TK/C2 recesses downward. In the control group, C2 downward depression Angle and the downward sag Angle of C2 is negatively correlated with SVA. The correlation analysis showed that the depression of the lower margin of the 2nd cervical spine was moderately negatively correlated with cSVA (\( r = -0.544, P = .002 < .05 \)), and highly negatively correlated with SVA (\( r = -0.556, P = .001 < .05 \)) in normal adolescents. Since adolescent bones are at the peak of growth and development, the pelvic anatomical parameter PI increases with age and the degree of sacral inclination also increases, so the spin-pelvis sagittal plane balance plays a significant role in bone development.\(^ {30} \) But this article adolescent idiopathic scoliosis patients compared with normal adolescents showed no PI, SS and bone growth aspects, such as correlation, we suggest that patients with AIS spinal growth lost balance, spinal and pelvic sagittal balance, disappear for AIS progress adjustment, so we think that to maintain the spine - the pelvis in sagittal balance can prevent progress in AIS.

This paper has the following limitations: due to the small number of samples in the case group and the control group, the AIS patients were not followed up for investigation, and it was limited to the imaging measurement studies, resulting in errors in the measurement values of sagittal parameters. Moreover, due to the limitation of sample size, Lenke typing of AIS was not conducted, and differences between different types for experimental results were not discussed. Multicenter prospective studies with larger samples are still needed to further improve this system.

This study mainly analyzed the characteristics of spinal sagittal alignment changes between adolescent idiopathic scoliosis patients and normal adolescents and discussed the risk factors for AIS and related studies on the development of AIS. L5S is a major risk factor for AIS, and is strongly correlated to the LS, PI, SS L5S increases after the compensatory increase PI, SS, maintain the spine and pelvic sagittal balance, decompensation after lumbar lordosis Angle increases, such as 3 dimensional rotation of spine in thoracic vertebral protruding after decreases, and smooth back deformity, resulting in lumbar lordosis Angle increase jointly maintain sagittal balance, and upper cervical sequence C1C2 Angle decreases, and balance the forward-looking. The above studies are helpful to infer the causes of sagittal plane changes in patients with adolescent idiopathic scoliosis, delay the progress of AIS, and provide references for constructing the sagittal balance of AIS\(^ {12,31,32} \) in orthopedic surgery to improve patients’ quality of life.

### Table 4

Analysis of risk factors for adolescent idiopathic scoliosis.

| B          | Standard error | Wald | P     | OR   | 95% CI |
|------------|----------------|------|-------|------|--------|
| Lj         | 0.201          | 0.262| 0.585 | .444 | 1.222  | 0.731–2.043 |
| L2S        | 0.214          | 0.085| 6.381 | .012 | 1.239  | 1.049–1.463 |
| LL         | 0.039          | 0.051| 0.589 | .443 | 1.04   | 0.941–1.149 |
| PI         | –0.115         | 0.1  | 1.326 | .25  | 0.892  | 0.733–1.084 |
| SS         | 0.005          | 0.104| 0.002 | .962 | 1.005  | 0.82–1.232 |
| PT         | –0.133         | 0.2  | 0.443 | .506 | 0.875  | 0.591–1.296 |
| Constant   | 0.372          | 2.605| 0.02  | .886 | 1.451  |

CI = confidence intervals, Lj = lumbar5 incidence, L2S = lumbar5 slope, LL = lumbar lordosis; OR = odds ratio, PI = pelvic incidence, PT = pelvic tilt, SS = sacrum slope.

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