Special type of distal junctional failure exhibits pelvic incidence changes: sacroiliac joint-related pain following lumbar spine surgery

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Background: Currently, change in pelvic incidence (PI) in patients after spinal surgery have not been associated with clear clinical symptoms. This study sought to compare changes in the sagittal parameters of different patients before and after thoracolumbar spine surgery, the relationship between PI change and sacroiliac joint pain (SIJP) after surgery was clarified, and the correlation between PI change and sacroiliac joint (SIJ) activity was verified.

Methods: This study retrospectively analyzed the data of patients who underwent thoracolumbar fusion at Sun Yat-sen Memorial Hospital from January 2019 to June 2021. The spinal and pelvic parameters [including pelvic tilt (PT), sacral slope (SS), PI, lumbar lordosis (LL) angle, etc.] of 409 patients with standard standing lateral radiographs before and after surgery were compared and analyzed. Postoperative follow-up of all patients with standardized SIJP assessment. The incidence of postoperative SIJP, and its correlation with sagittal parameters of the spine and pelvis, surgical methods, and the basic characteristics of patients were analyzed. The Chi-square test was used for categorical variables, the independent-sample *t*-test was used for generally conformed normally distributed continuous variables. Risk factors associated with the development of SIJP were analyzed using logistics regression. Correlations among SS, PI, and the 4 other sagittal parameters were analyzed using the Pearson correlation coefficient (r).

Results: Postoperative PI changes tended to be larger in the lowest instrumented vertebra (LIV) (L4 and above: 1.63°; L5: 2.43°; S1: 3.83°; $P<0.05$) and longer fixed segment. The risk factors for SIJP included a PI >4° [odds ratio (OR) =13.051; $P<0.001$], LIV S1 (OR =3.378; $P=0.023$), and fixed total segment ≥3 (OR =2.632; $P=0.038$). ΔPI was significantly correlated with ΔSS in patients with non-S1 distal fixation vertebrae ($R^2=0.388$; $P<0.01$), but no such correlation was found in patients with S1 distal fixation vertebrate.

Conclusions: Changes in PI values after thoracolumbar spine surgery can correctly reflect the motion state of the SIJ. Excessive changes in PI (>4°) are similar to the mechanism of distal junctional kyphosis (DJK), while such changes make patients prone to SIJP following lumbar spine surgery.

Keywords: Distal junctional kyphosis (DJK); sacroiliac joint (SIJ); pelvic incidence (PI); sacroiliac joint pain (SIJP)

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Introduction

Complications due to mechanical stress abnormalities in the adjacent segments after spinal fusion have been extensively examined and described in the literature, but distal junctional kyphosis and failure (DJK/DJF) have received less attention in the literature (1). DJK is defined as a distal junctional angle of more than 10 degrees and 10 or more degrees compared to the preoperative measurement, as measured from the caudal endplate of the lowest instrumented vertebra (LIV) and the caudal endplate of 1 vertebra below (2). The main risk factors for the development of DJK in patients after surgery are currently considered to include: improper distal fixed vertebral selection, the neglect of the overall sagittal balance, the misalignment of spinal-pelvic parameters with pelvic incidence (PI), surgical access, and improper intraoperative manipulation (3-7). However, the current definition of DJK/DJF is not sufficient to explain the problems associated with internal fixation failure that occurs in some cases where S1 fixation has been performed (8).

Previously, PI was considered constant in adulthood (9). However, several studies have reported that PI changes with age and that spinal surgery can also change PI (10-13). PI values may increase with age for a number of reasons, including sacroiliac joint (SIJ) laxity, hip joint deformation, and the long-term weight-bearing morphology of the ilium. Additionally, the magnitude of PI may also change after spinal surgery, and the main cause of its change is SIJ.

The SIJ is a typical diarthrodial synovial joint that is considered the most mechanically stable joint in the entire spinal-pelvic region (14). In adults, the SIJ is a minimally mobile joint; however, its mobility is not negligible in physiological and pathological states. This SIJ motion occurs mainly in the sagittal plane, which is defined as nutation and counternutation, and often ranges from 1–4° and has a translation from 0.5–2 mm (15,16). The PI is the angle between the perpendicular to the upper plate of S1 in its middle and the line joining this point to the bi-coxo-femoral axis. However, as its measurement line passes through the SIJ, the nutation and counternutation motion of the SIJ affect the PI value anatomically (17-19).

Currently, we do not know how much affect SIJ sagittal plane activity has in the occurrence of changes in PI, and the association of SIJ movement with PI changes has also not been reported (20). Previous research suggests that the possible adverse effects of such postoperative PI changes include preoperatively measured sagittal parameters, such as the optimal lumbar lordosis (LL) angle and the sagittal vertical axis, becoming inaccurate due to altered PI values (6,11). New local adverse symptoms of SIJ, such as the exacerbation of SIJ degenerative changes and the development of sacroiliac joint pain (SIJP), may occur. Usually, SIJP has a clear stimulus factor, and in the absence of trauma, tumor or metabolic disease, abnormal local biomechanical changes, including spinal surgery, lower extremity inequality, and pregnancy, are often the underlying causes of SIJP (5). This abnormal stress is often manifested in the sagittal position as abnormal SIJ activity (21). However, no study has clarified the pattern of PI alterations after lumbar spine surgery or its association with SIJ dyskinesia. This study sought to establish the association between postoperative PI changes and SIJP and to verify the correlation between PI changes and SIJ activity. We present the following article in accordance with the STROBE reporting checklist (available at https://atm.amegroups.com/article/view/10.21037/atm-22-2413/rc).

Methods

Subjects

The clinical research design used a cross-sectional study. We performed a retrospective review of the data of consecutive Chinese Han patients who underwent posterior thoracolumbar fusion at Sun Yat-sen Memorial Hospital from January 2019 to June 2021. To be eligible for inclusion in the study, the patients had to meet the following inclusion criteria: (I) be aged >20 years; (II) have preoperative and 3-month postoperative lumbar lateral radiographs in the standing position in which the bilateral femoral head is clearly visualized; and (III) have undergone a single successful surgery with ideal screw placement and no revision or infection. Patients were excluded from the study if they met any of the following exclusion criteria: (I) had significant inequality in both lower extremities, severe injuries, or had undergone bone and joint surgery; (II) had structural damage to the SIJ caused by trauma, surgery, tumors, or other diseases; (III) had been classified as suffering preoperative SIJP based on our diagnostic criteria; and/or (IV) had sacralization and sacral lumbarization.

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Medical Ethics Committee of Sun Yat-sen Memorial Hospital of Sun Yat-sen University (No. SYSEC-KY-KS-2022-091) and written informed consent was obtained from all patients.

Radiographic measurements

The imaging data of the patients in this cross-sectional study had to meet the following criteria: include standing lateral radiographs of the spine and pelvis in which the bilateral femoral head was clearly visualized. These radiographs were made with the patient in a natural standing position with the knees in natural flexion for adaptive balance to the kyphosis and the hands overlying the ipsilateral clavicles. A senior resident orthopedist and another resident orthopedist with special training performed the measurements of all the parameters, and the average value was taken as the final measurement. The measurement parameters included: (I) LL: the angle between the superior end plates of T12 and the inferior plates S1 [a negative value indicated kyphosis (22)]; (II) PI: the angle between a line perpendicular to the sacral plate and a line joining the middle of the sacral plate and the hip axis (23); (III) pelvic tilt (PT): the angle between a vertical line from the hip axis and a line from the middle of the sacral plate [PT was positive if the hip axis was located anteriorly to the middle of the sacral plate and was negative if it was located posteriorly (23)]; (IV) sacral slope (SS): the angle between a line along the sacral plate and a horizontal line from the posterior corner of the sacral plate (23); (V) ΔPI: the difference between the postoperative PI and the preoperative PI (ΔPI was positive if the PI value increased postoperatively and was negative if it decreased postoperatively); (VI) ΔSS: the difference between postoperative SS and preoperative SS; and (VII) PI-LL.

Diagnosing of postoperative SIJ-related pain

Patients were diagnosed with SIJ-related pain following lumbar spine surgery if they: (I) experienced pain within 2 years of surgery below the L5 spinous process, buttocks, posterior thighs and groin area, and had a SIJ score based on (i) one-finger test (3 scores), (ii) groin pain (2 scores), (iii) pain while sitting on a chair (1 score), (iv) SIJ shear test (1 score), (v) tenderness of posterosuperior iliac spine (1 score), or (vi) tenderness of sacrotuberous ligament (1 score) (24,25), the scores, ranging from 0 to 9 points, had a cutoff value of 4; (II) had no residual compression findings of the nerve roots and cauda equina on lumbar magnetic resonance imaging; and (III) had 3 or more provocation tests that were positive in 6 specialized physical diagnostic tests [i.e., the FABER (flexion, abduction, external rotation), gapping test/distraction test, compression test/approximation test, thigh thrust test/femoral shear test, Gaenslen test/pelvic torsion test, and sacral thrust test/sacral base spring test] (26,27). If necessary, an SIJ intra-articular block was performed for patients with a difficult final diagnosis, and SIJP was diagnosed as 70% pain relief within 3 hours (28-32).

Statistical analysis

SPSS (version 25.0 SPSS Inc., Chicago, IL, USA) was used for the data analysis. The data obtained for lumbar-pelvic parameter generally conformed to a normal distribution. Inter-group differences were evaluated using the independent sample *t*-test. Differences in parameters among the groups were analyzed using the independent samples *t*-test and the least significant difference (LSD) *t*-test. Risk factors associated with the development of SIJP were analyzed using logistics regression. Correlations among SS, PI, and the 4 other sagittal parameters were analyzed using the Pearson correlation coefficient (r). A P value <0.05 was considered significant.

Results

Change in sagittal parameters with surgery

We enrolled 409 patients (see *Table 1*) in this study. Of the 409 patients, 23 (15 female and 8 male) were diagnosed with SIJP. The patients had a mean age of 61.3±11.2 years. The mean values of each preoperative spinal-pelvic parameter were not statistically different compared to the postoperative values (see *Table 2*).

We then examined the difference between the postoperative parameters of each patient compared to the preoperative parameters and found that the absolute value of the mean postoperative PI change for all patients was 3.11±2.76 (n=409). Grouped by LIV, the magnitude of the PI change was 1.63°±1.36° for L4 and above, 2.43°±2.00° for L5, and 3.83°±3.17° for S1 (P<0.05); thus, the closer the LIV was to S1, the greater magnitude of the change. There

Table 1 Patient information summary

Factors	Patients (n=409)
UIV	
T4	1
T9	2
T10	5
T11	1
T12	6
L1	18
L2	37
L3	95
L4	194
L5	50
LIV	
L2	5
L3	2
L4	16
L5	173
S1	213
Seg	
1	159
2	148
3	58
4	25
5	10
6	5
7	1
8	2
13	1
Age (years)	
20–40	22
41–60	139
61–75	215
>75	33
Gender	
Male	178
Female	231
Etiology	
Lumbar spinal stenosis	152
Lumbar disc herniation	126
Spinal deformity	23
Fracture of the spine	15
Lumbar spondylolisthesis	88
Spinal benign neoplasms	5

Table 1 (continued)

UIV, upper instrumented vertebra; LIV, lowest instrumented vertebra; Seg, segment.

was a tendency for the magnitude of the PI change to increase as the number of surgical fixed segments increased, and the difference in change between individuals increased, but this was not significant (P=0.145). The magnitude of the PI change in the female group was 3.38°±2.94°, which was greater than that in the male group (2.76°±2.48°; P<0.05). The magnitude of the PI change was significantly greater in patients with SIJP after surgery. Notably, 19 patients showed a positive change (i.e., the postoperative PI value was increased compared to the preoperative PI value). These patients had a mean value of 5.83±2.48. Conversely, 4 patients showed a negative change (i.e., the postoperative PI value was decreased compared to the preoperative PI value). These patients had a mean value of 8.3°±4.08°. The magnitude of positive change in PI was greater than the magnitude of negative change in SIJP patients, and the difference was significant (P<0.05; see *Table 3*).

SIJP patients

The prevalence of postoperative SIJP in all patients was 5.62% (23/409). There were no significant differences in terms of sex, age (P>0.05). The prevalence of SIJP with 3 or more segments fixed in total was 10.8%, which was significantly greater than single segment fixation (3.8%) and 2 segment fixation (4.1%) (P<0.01). Of the 23 patients who suffered SIJP after surgery, 18 had S1 LIV (8.5%), and 5 had L5 and above LIV (2.6%). However, it is worth noting that the LIV of all five patients was L5. The prevalence of postoperative SIJP was significantly greater in the S1 fixation group than the L5 fixation group (see *Table 4*). We performed a binary logistics analysis of risk factors (including

Table 2 Comparison of preoperative and postoperative mean values of individual parameters in all patients

Radiographic parameter	Preoperative	Postoperative	P value
PI	50.9±11.0	50.7±10.8	0.778
PT	17.6±8.9	17.0±8.2	0.308
SS	33.6±10.9	33.8±8.8	0.775
LL	44.9±15.6	45.1±12.8	0.797
PI-LL	6.0±12.5	5.6±9.8	0.549

Data was present as mean ± SD. A P value <0.05 was considered significant. PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis.

Table 3 Effects of different factors on the magnitude of postoperative PI change

Factors	Change of PI (°, n=409)	Positive PI (°, n=186)	Negative PI (°, n=223)
LIV			
L4 and above	1.63±1.36 [23]*	2.03±1.40 [12]*	1.21±1.23 [11]**
L5	2.43±2.00 [173]*	2.48±1.95 [78]*	2.39±2.06 [95]**
S1	3.83±3.17 [213]**	3.84±3.22 [96]**	3.81±3.15 [117]**
Seg			
1	2.80±2.38 [159]	2.73±2.43 [60]	2.84±2.36 [99]
2	3.28±2.62 [148]	3.19±2.57 [68]	3.35±2.67 [80]
≥3	3.35±3.43 [102]	3.55±3.24 [58]	3.10±3.69 [44]
Gender			
Male	2.76±2.48 [178]*	2.73±2.50 [79]	2.79±2.48 [99]
Female	3.38±2.94 [231]*	3.47±2.91 [107]	3.31±2.98 [124]
Age (years)			
≤65	2.96±2.55 [253]	3.01±2.68 [112]	2.92±2.45 [141]
>65	3.36±3.07 [156]	3.37±2.87 [74]	3.35±3.25 [82]
SIJP			
(–)	2.92±2.87 [386]*	2.85±2.62 [167]*	2.98±2.66 [219]*
(+)	6.26±2.64 [23]*	5.83±2.48 [19]*	8.3±4.08 [4]*

Data was present as mean ± SD [n]. A P value <0.05 was considered significant. *, statistical differences exist; **, statistically different from the other two. PI, pelvic incidence; LIV, lowest instrumented vertebra; Seg, segment; SIJP, sacroiliac joint pain.

gender, age, preoperative SS, preoperative PI, preoperative LL, weight, LIV, fixed total segment) for SIJP and similarly concluded that LIV [odds ratio (OR) =3.378; P=0.023], fixed total segment ≥3 (OR =2.632; P=0.038) was associated with postoperative SIJP. We further divided the patients into two groups for chi-square test by PI changes greater than or equal to 4° and less than 4° and concluded that the patients with PI changes greater than or equal to 4°have a higher prevalence of SIJP (OR =13.051; P<0.001) (see *Table 5*).

The relationship between PI and SIJ motion

Counting all patients, we found that there was a correlation between postoperative PI changes and SS changes. Specifically, we found that the PI value increases slightly with increasing SS (n=386; y = 0.531 + 48.189x; R^2=0.167;

Table 4 Multifactorial analysis of whether SIJP occurred after surgery

Factors	All patients (n=409)	Postoperative SIJP (+) (n=23)	Postoperative SIJP (–) (n=386)	P value
Age (years)	61.3±11.2	64.1±8.0	61.2±11.4	0.22
Gender				0.353
Male	178	8 (4.5)	170	
Female	231	15 (6.5)	216	
LIV				0.009*
L5 and above	196	5 (2.6)	191	
S1	213	18 (8.5)	195	
Seg				0.033*
1	159	6 (3.8)	153	
2	148	6 (4.1)	142	
≥3	102	11 (10.8)	91	

Data was present as mean ± SD/n/n (%). A P value <0.05 was considered significant. *, statistical differences exist. SIJP, sacroiliac joint pain; LIV, lowest instrumented vertebra; Seg, segment.

Table 5 Postoperative PI changes of more than 4° were more likely to result in SIJP

SIJP	|PI| ≥4°	|PI| <4°	Total
(+)	19	4	23
(–)	103	283	386
Total	122	287	

P<0.001. PI, pelvic incidence; SIJP, sacroiliac joint pain.

P<0.01). The patients were divided into two groups with LIV of S1and above. There was a significant correlation between the postoperative PI changes and SS changes in patients whose selected L5 and above as the LIV (y = 0.672 + 97.452x; R^2=0.388; P<0.01). When we added the exclusion of SIJP-positive patients, this correlation was stronger in female patients, (y = 0.249 + 88.682x; R^2=0.457; P<0.01), but there was no correlation in the S1 group (n=195; y = 0.297 + 30.046x; R^2=0.086; P<0.01).

Discussion

Research has shown that approximately 10–25% of the time, low back pain or leg pain originates from the SIJ (33-35). Because of the strong correlation between the occurrence of SIJP and local biomechanical changes, easily to associate it with common postoperative spinal adjacent segment degeneration/disease (ASD) in patients who develop SIJP after spinal surgery.

We analyzed the pre- and postoperative sagittal parameters of patients who had undergone posterior thoracolumbar fusion surgery and found that while there was no significant difference in the mean values of PI before and after surgery in all patients, there was a definite magnitude of change in PI after surgery. In the results of our analysis, the magnitude of this change was significantly affected by the lower LIV and gender. The closer inferiorly fixed vertebra is to the sacrum means that the greater postoperative structural stress changes around the SIJ. Notably, when fixed distally to the sacrum, the stress of the internal fixation will act directly on the SIJ and alter the important surrounding structures associated with the SIJ, such as the iliolumbar ligament, anterior/posterior sacroiliac ligament, and the erector spinae musculature. Further, the additional force exerted during pedicle screw insertion and the fixation of the connecting rods may intraoperatively strain and damage the ligaments around the SIJ. In patients with long-segment (≥3) fixation, there is a tendency for the value of PI change to become larger, and for the difference in the magnitude of PI change between individuals to increase, which may be related to the significant reconstruction of sagittal balance after long-segment fixation, the reduced compensatory mobility of the adjacent segment, and the excessive stripping of tissues, such as muscles, leading to excessive nutation or counternutation of the SIJ (36). The magnitude of PI changes was greater in female patients than in males, which is consistent with the greater normal physiological activity of the SIJ in females than in males due to reproductive demands (15,37).

We analyzed the risk factors for the development of SIJP after surgery and found that they included 3 or more fixed segments (P<0.05) and the selection of S1 as the distal fixed vertebra (P<0.05), which were similar to the risk factors for the development of DJK/DJF after spinal fusion previously reported in the literature (36). The SIJP is consistent with the factor of a larger postoperative PI change, which confirms that the occurrence of SIJP after spine surgery is usually due to abnormal sagittal stress in the SIJ.

The relationship between PI and SIJ activity was further verified. Normally, in natural standing, the gravity generated by the upper trunk produces an external torque along the superior sacral edge, which is the main reason why the SIJ is

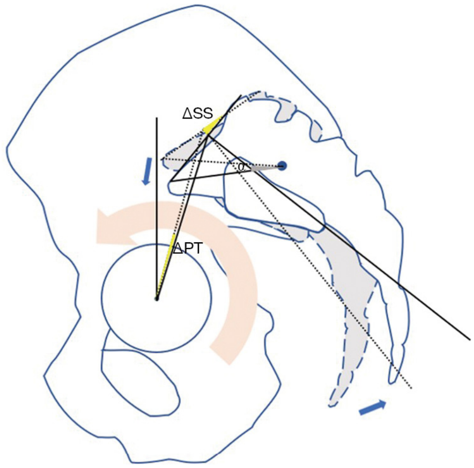

Figure 1 In the standing position the pelvis rotates anteriorly around the hip axis and the SIJ will nutation. Orange arrow: direction of hip joint movement; blue arrow: direction of SIJ movement. When the pelvis as the stationary reference, the SIJ is sagittally rotated at an angle of α with S2 as the sagittal axis, and the PT and SS increase at the same time, ΔPT + ΔSS = ΔPI, ΔPI ≈ α ± 0.5°, postoperative PI' = PI + ΔPI. SS, sacral slope; PT, pelvic tilt; SIJ, sacroiliac joint; PI, pelvic incidence.

always in the "nutation" position in the standing position (38); the internal torque generated by the ligaments, muscle tension, and joint friction in the posterior oppose it. These results confirm that the postoperative change by which the external torque acts on the sacrum is significantly correlated with the SIJ rotation angle around S2 (see *Figure 1*). There is a gender difference in the form of SIJ motion, such that the nutation is predominantly translational in male and predominantly rotational in female, and thus the correlation between PI and SS changes was further elevated in female patients with non-S1 fixation. When the spinal fusion involves S1, this correlation disappears, as the screw rod system directly involves the bony structure of the SIJ, and the sacrum and the overlying vertebrate form a strong internal fixation unit through the screw rod system, and gravity no longer acts directly on the sacrum to produce shear forces (see *Figure 2*).

Thus, we conclude that the change in PI after spinal fusion reflects the sagittal activity of the SIJ to a greater extent, which can predict the occurrence of SIJP of surgical origin to a certain extent. We analyzed the risk factors and

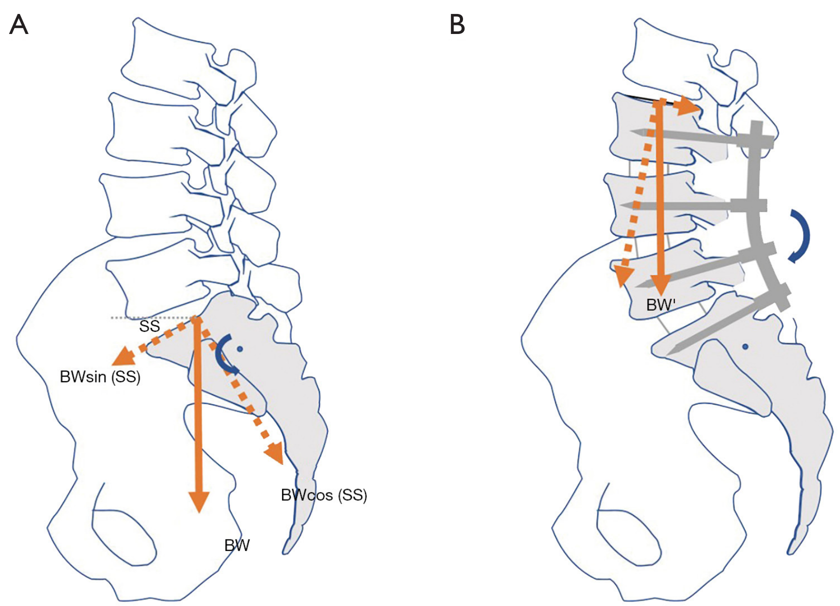

Figure 2 Effect of internal fixation on SIJ motion. (A) In the standing position, the gravity of the upper body leads the SIJ nutation and the SIJ tends to stabilize. (B) The upper body gravity no longer acts directly on the sacrum when the fixation concludes S1, which may even allow the SIJ to counternutation if the slope of the superior edge of the superior vertebrate is negative at this time. Orange arrow: the gravity generated by the upper body and its component forces; blue arrow: direction of SIJ movement. BW: the upper body gravity acting to the upper edge of the sacrum; BW': the upper body gravity acting to the upper edge of the superior vertebrate; $BW_{sin(SS)}$: forward shear force of the upper body gravity acting horizontally on the upper edge of the sacrum; $BW_{cos(SS)}$: the upper body gravity acting perpendicular to the upper edge of the sacrum. SS, sacral slope; SIJ, sacroiliac joint.

concluded that the characteristics of SIJP of surgical origin are consistent with the mechanism of DJK/DJF, which is defined as a posterior convexity of >10° in the distal junction area after orthopedic surgery and an increase of >10° compared to the preoperative period. The difference is that due to the limitations of the joint itself, the sacrum does not have as much mobility in the sagittal position as the vertebrae above it; however, our analysis showed that the magnitude of the change in PI reflects the sagittal mobility of the SIJ to some extent. These quantifiable results make the sagittal activity of the SIJ measurable on radiograph, and a change in PI of >4° was determined to be a high-risk factor for the development of SIJP. Thus, the DJK in a lower fixed spine of S1 can be defined as a change in PI of >4° from the preoperative value, or DJF if the patient has a new postoperative SIJP. The SIJP caused by spine surgery has been shown in some studies to be prevented by iliac screws; however, further studies on individualized surgical protocol development and the effects of iliac screws on SIJ activity and stress need to be conducted (6,11,39). For patients with a change in PI measurements >4° after surgery, appropriate non-surgical interventions should be considered first, such as standardized anti-osteoporotic treatment and muscle strength training to increase the stability of the SIJ (40,41).

This study had some limitations. The study was a retrospective cross-sectional study and only analyzed sagittal parameters in the standing position; however, the real activity of the SIJ in different positions is quite complex (e.g., exceptionally, some patients may present with nutation on 1 side of the SIJ and counternutation on the opposite side). Further tests are needed to analyze the postoperative SIJ motion in 3 dimensions in different postures.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://atm.amegroups.com/article/view/10.21037/atm-22-2413/rc

Data Sharing Statement: Available at https://atm.amegroups.com/article/view/10.21037/atm-22-2413/dss

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://atm.amegroups.com/article/view/10.21037/atm-22-2413/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by Medical Ethics Committee of Sun Yat-sen Memorial Hospital of Sun Yat-sen University (No. SYSEC-KY-KS-2022-091) and written informed consent was obtained from all patients.

References

1. Zanirato A, Damilano M, Formica M, et al. Complications in adult spine deformity surgery: a systematic review of the recent literature with reporting of aggregated incidences. Eur Spine J 2018;27:2272-84.
2. Lowe TG, Lenke L, Betz R, et al. Distal junctional kyphosis of adolescent idiopathic thoracic curves following anterior or posterior instrumented fusion: incidence, risk factors, and prevention. Spine (Phila Pa 1976) 2006;31:299-302.
3. Lamartina C, Berjano P. Classification of sagittal imbalance based on spinal alignment and compensatory mechanisms. Eur Spine J 2014;23:1177-89.
4. Berjano P, Cecchinato R, Damilano M, et al. Preoperative calculation of the necessary correction in sagittal imbalance surgery: validation of three predictive methods. Eur Spine J 2013;22 Suppl 6:S847-52.
5. Langella F, Villafañe JH, Damilano M, et al. Predictive Accuracy of Surgimap Surgical Planning for Sagittal Imbalance: A Cohort Study. Spine (Phila Pa 1976) 2017;42:E1297-304.
6. Cecchinato R, Redaelli A, Martini C, et al. Long fusions

to S1 with or without pelvic fixation can induce relevant acute variations in pelvic incidence: a retrospective cohort study of adult spine deformity surgery. Eur Spine J 2017;26:436-41.
7. Crawford CH 3rd, Bridwell KH, Cho W, et al. Extension of prior idiopathic scoliosis fusions to the sacrum: a matched cohort analysis of sixty patients with minimum two-year follow-up. Spine (Phila Pa 1976) 2010;35:1843-8.
8. Charles YP, Yu B, Steib JP. Sacroiliac joint luxation after pedicle subtraction osteotomy: report of two cases and analysis of failure mechanism. Eur Spine J 2016;25 Suppl 1:63-74.
9. Schwab F, Lafage V, Boyce R, et al. Gravity line analysis in adult volunteers: age-related correlation with spinal parameters, pelvic parameters, and foot position. Spine (Phila Pa 1976) 2006;31:E959-67.
10. Jean L. Influence of age and sagittal balance of the spine on the value of the pelvic incidence. Eur Spine J 2014;23:1394-9.
11. Lee JH, Na KH, Kim JH, et al. Is pelvic incidence a constant, as everyone knows? Changes of pelvic incidence in surgically corrected adult sagittal deformity. Eur Spine J 2016;25:3707-14.
12. Merrill RK, Kim JS, Leven DM, et al. Differences in Fundamental Sagittal Pelvic Parameters Based on Age, Sex, and Race. Clin Spine Surg 2018;31:E109-14.
13. Vrtovec T, Janssen MM, Likar B, et al. Evaluation of pelvic morphology in the sagittal plane. Spine J 2013;13:1500-9.
14. Cohen SP. Sacroiliac joint pain: a comprehensive review of anatomy, diagnosis, and treatment. Anesth Analg 2005;101:1440-53.
15. Walker JM. The sacroiliac joint: a critical review. Phys Ther 1992;72:903-16.
16. Nagamoto Y, Iwasaki M, Sakaura H, et al. Sacroiliac joint motion in patients with degenerative lumbar spine disorders. J Neurosurg Spine 2015;23:209-16.
17. Legaye J, Duval-Beaupère G, Hecquet J, et al. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998;7:99-103.
18. Vaz G, Roussouly P, Berthonnaud E, et al. Sagittal morphology and equilibrium of pelvis and spine. Eur Spine J 2002;11:80-7.
19. Roussouly P, Pinheiro-Franco JL. Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. Eur Spine J 2011;20 Suppl 5:609-18.
20. Cardwell MC, Meinerz CM, Martin JM, et al. Systematic review of sacroiliac joint motion and the effect of screw fixation. Clin Biomech (Bristol, Avon) 2021;85:105368.
21. Liliang PC, Lu K, Liang CL, et al. Sacroiliac joint pain after lumbar and lumbosacral fusion: findings using dual sacroiliac joint blocks. Pain Med 2011;12:565-70.
22. Kuklo TR, Potter BK, Schroeder TM, et al. Comparison of manual and digital measurements in adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 2006;31:1240-6.
23. Upasani VV, Tis J, Bastrom T, et al. Analysis of sagittal alignment in thoracic and thoracolumbar curves in adolescent idiopathic scoliosis: how do these two curve types differ? Spine (Phila Pa 1976) 2007;32:1355-9.
24. Kurosawa D, Murakami E, Ozawa H, et al. A Diagnostic Scoring System for Sacroiliac Joint Pain Originating from the Posterior Ligament. Pain Med 2017;18:228-38.
25. Murakami E, Aizawa T, Noguchi K, et al. Diagram specific to sacroiliac joint pain site indicated by one-finger test. J Orthop Sci 2008;13:492-7.
26. van der Wurff P, Buijs EJ, Groen GJ. A multitest regimen of pain provocation tests as an aid to reduce unnecessary minimally invasive sacroiliac joint procedures. Arch Phys Med Rehabil 2006;87:10-4.
27. Young S, Aprill C, Laslett M. Correlation of clinical examination characteristics with three sources of chronic low back pain. Spine J 2003;3:460-5.
28. Thawrani DP, Agabegi SS, Asghar F. Diagnosing Sacroiliac Joint Pain. J Am Acad Orthop Surg 2019;27:85-93.
29. Murakami E, Tanaka Y, Aizawa T, et al. Effect of periarticular and intraarticular lidocaine injections for sacroiliac joint pain: prospective comparative study. J Orthop Sci 2007;12:274-80.
30. Kurosawa D, Murakami E, Aizawa T. Referred pain location depends on the affected section of the sacroiliac joint. Eur Spine J 2015;24:521-7.
31. Gartenberg A, Nessim A, Cho W. Sacroiliac joint dysfunction: pathophysiology, diagnosis, and treatment. Eur Spine J 2021;30:2936-43.
32. Buchanan P, Vodapally S, Lee DW, et al. Successful Diagnosis of Sacroiliac Joint Dysfunction. J Pain Res 2021;14:3135-43.
33. Maigne JY, Planchon CA. Sacroiliac joint pain after lumbar fusion. A study with anesthetic blocks. Eur Spine J 2005;14:654-8.
34. Ebraheim NA, Elgafy H, Semaan HB. Computed tomographic findings in patients with persistent sacroiliac pain after posterior iliac graft harvesting. Spine (Phila Pa 1976) 2000;25:2047-51.
35. Frymoyer JW, Howe J, Kuhlmann D. The long-term effects of spinal fusion on the sacroiliac joints and ilium.

Clin Orthop Relat Res 1978;(134):196-201.
36. Berjano P, Damilano M, Pejrona M, et al. Revision surgery in distal junctional kyphosis. Eur Spine J 2020;29:86-102.
37. Fortin JD, Tolchin RB. Sacroiliac arthrograms and post-arthrography computerized tomography. Pain Physician 2003;6:287-90.
38. Vleeming A, Volkers AC, Snijders CJ, et al. Relation between form and function in the sacroiliac joint. Part II: Biomechanical aspects. Spine (Phila Pa 1976) 1990;15:133-6.
39. Yasuda T, Hasegawa T, Yamato Y, et al. Lumbosacral Junctional Failures After Long Spinal Fusion for Adult Spinal Deformity-Which Vertebra Is the Preferred Distal Instrumented Vertebra? Spine Deform 2016;4:378-84.
40. Snijders CJ, Hermans PF, Kleinrensink GJ. Functional aspects of cross-legged sitting with special attention to piriformis muscles and sacroiliac joints. Clin Biomech (Bristol, Avon) 2006;21:116-21.
41. van Wingerden JP, Vleeming A, Buyruk HM, et al. Stabilization of the sacroiliac joint in vivo: verification of muscular contribution to force closure of the pelvis. Eur Spine J 2004;13:199-205.

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