Observational Study

The Effects of Abdominal Obesity and Sagittal Imbalance on Sacroiliac Joint Pain After Lumbar Fusion

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Background: Postoperative sacroiliac joint pain (SIJP) is a common manifestation of failed back surgery syndrome after a posterior lumbar interbody fusion (PLIF). However, there is currently no consensus on the risk factors for SIJP after PLIF.

Objectives: We explored the effects of abdominal obesity and sagittal imbalance on SIJP after PLIF.

Study Design: This is a prospective observational cohort study.

Setting: This study occurred at the Department of Spinal Surgery at a hospital affiliated with a medical university.

Methods: A total of 401 patients who underwent PLIF from June 2018 to June 2021 were enrolled in this study. 36 patients experienced postoperative SIJP. In contrast, a matched group comprised 72 non-SIJP patients. We used 1:2 propensity score matching to compare obesity features and sagittal spine parameters in the 2 groups. Inflammatory cytokines and visual analog scale (VAS) scores were measured in the SIJP group.

Results: A total of 36 patients (8.98%) experienced SIJP during the follow-up. Compared with the non-SIJP group, patients with postoperative SIJP had a higher body mass index (BMI), greater abdominal obesity, a higher incidence of pelvic incidence-lumbar lordosis greater than 10°, and a higher incidence of a sagittal vertical axis greater than 5 cm ($P < 0.05$). Receiver operating characteristic curve analysis showed that the area under the curve for waist circumference was greater than that for BMI (0.762 vs. 0.650, $P = 0.049$). Logistic regression analysis revealed that the risk factors for SIJP were abdominal obesity, a pelvic incidence-lumbar lordosis of greater than 10°, and a sagittal vertical axis greater than 5 cm ($P < 0.05$). In patients with SIJP, interleukin 6, tumor necrosis factor-α, and VAS scores were higher in the abdominal obesity group than in the non-abdominal obesity group ($P < 0.05$).

Limitations: There was no uniform diagnosis of SIJP, so the incidence rate of SIJP might not be accurate.

Conclusions: The significant predictors of SIJP were abdominal obesity and sagittal imbalance. Patients with abdominal obesity showed higher levels of inflammatory markers and pain intensity. More attention should be paid to body shape and the angle of correction of lumbar lordosis before lumbar surgery.

Key words: Posterior lumbar interbody fusion, sacroiliac joint pain, abdominal obesity, sagittal imbalance, pelvic incidence-lumbar lordosis, sagittal vertical axis, inflammatory cytokines, visual analog scale

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The prevalence of low back pain is increasing with the aging of the population and changes in our life and work style. It is reported that 37% of adults suffer from low back pain, and that the incidence of patients with low back pain in the population is between 60% to 85% (1). Low back pain places a tremendous economic burden on families and the society (2). Sacroiliac joint pain (SIJP) is a clinically common type of low back pain that can occur in people of any age (although mainly in the elderly and in young athletes) with an incidence of about 15% to 30% (3). SIJP is characterized by pain in the posterior superior iliac spine region, mainly caused by sacroiliac joint inflammation, trauma, degenerative changes, pregnancy, and lumbar fusion surgery (4).

Posterior lumbar interbody fusion (PLIF) is a quintessential treatment strategy for lumbar diseases. However, it has been reported that some patients have residual or persistent new SIJP after surgery, with an incidence of about 16% to 43% (5). The direct reasons for this frequent reoccurrence of SIJP after lumbar fusion surgery include preoperative misdiagnosis, stress changes in the sacroiliac joint after lumbar fusion, and iliac autogenous bone grafting (6). Furthermore, due to low back pain, lumbar fusion is often subject to sagittal imbalance and pelvic parameter changes (7). However, the relationship between SIJP and lumbopelvic sagittal alignment is unclear.

The biomechanics of the sacroiliac joint may influence the incidence of SIJP. Obese people may bear a greater mechanical load on their joints because of weaker lumbar muscle strength and reduced lumbar motion, which increases their risk of developing low back pain (8). At the same body mass index (BMI), abdominal obesity places a greater load on the spine, increasing the likelihood of vertebral fatigue compression fractures by 3 to 7 times (9). The complications of obesity are more closely related to the abnormal distribution of body fat, which refers more to the excessive accumulation of visceral fat in certain regions, than to the absolute degree of obesity according to BMI. El-Wakkad et al (10) showed that the levels of proinflammatory adipocytokines (such as tumor necrosis factor-α, interleukin 1β, and leptin) are significantly increased in people with abdominal obesity. Some inflammatory cytokines are involved in the initiation and persistence of pain as they directly activate nociceptive neurons, which hints at their role in SIJP in obese patients (11).

This study explores whether the incidence of SIJP after lumbar fusion surgery is associated with abdominal obesity and sagittal parameters by measuring the inflammation and pain intensity levels in patients with SIJP. We analyzed whether pain intensity was related to abdominal circumference and inflammatory cytokines, aiming to provide a new understanding of the treatment and management of SIJP.

Methods

Study population

Our study included a total of 401 patients who underwent PLIF for lumbar degenerative diseases from June 2018 to June 2021. Among the 401 patients, 36 were diagnosed with SIJP after surgery. All patients were treated by the same team of physicians and anesthesiologists who used the same surgical implant instruments for all surgeries. Intervertebral, intertransverse, and posterolateral bone grafts were used for fusion without the choice of iliac bone graft harvesting. All patients were followed-up with for at least one year post-surgery.

The inclusion criteria were as follows: 1) patients presented with lumbar degenerative diseases (lumbar disc herniation, degenerative lumbar spondylolisthesis, and lumbar spinal stenosis) treated in our hospital with PLIF surgery; 2) new postoperative SIJP must meet the following diagnostic criteria: A) the sacroiliac joint was the pain center, B) at least 2 SIJP provocation tests (Gaenslen test, Patric test, and the SIJ shear test) were positive, and C) after a sacroiliac joint block for 15 to 45 min (2 mL, 2% lidocaine), the visual analog scale (VAS) improvement rate was more than 70%; and 3) pain was not caused by other diseases of the lumbar spine (12).

The exclusion criteria were the presence of the following: 1) preoperative lumbosacral pain; 2) congenital deformity of the lumbar spine, trauma, malignancy, spinal infection, or revision surgery; 3) chronic systemic diseases, such as rheumatoid arthritis, ankylosing spondylitis, mental illness, or severe cognitive impairment; and 4) lost follow-up or incomplete imaging data.

The 36 patients who developed SIJP (SIJP group) were matched in a 1:2 ratio (by gender, age, hypertension, diabetes, the number of operative segments, and fusion/non-fusion to the sacrum) with enrolled patients who underwent PLIF but did not develop SIJP (non-SIJP group). The ethics committee of our hospital approved this study.

Data Collection

Data such as gender, age, BMI, waist circumference, preoperative diagnosis, fusion segment, operation time, and postoperative length of stay were collected. When the patients were diagnosed with SIJP during follow-up, the VAS (0-100 scores) of the sacroiliac joint and the serum levels of inflammation markers were measured and used to assess the severity of SIJP (13). The measurements were taken on one week preoperative and postoperative standing lateral radiographs, comprising the following sagittal spinopelvic parameters: sagittal vertical axis, lumbar lordosis, pelvic incidence, sacral slope, pelvic tilt, and pelvic incidence-lumbar lordosis (Fig. 1). Schwab's criteria for the balance of spinopelvic parameters were used: a sagittal vertical axis of less than 5 cm, a pelvic incidence-lumbar lordosis of less than 10°, and a pelvic tilt of less than 20° (14). Abdominal obesity was based on China's latest definition: a waist circumference ≥ 90 cm for men and ≥ 85 cm for women (15).

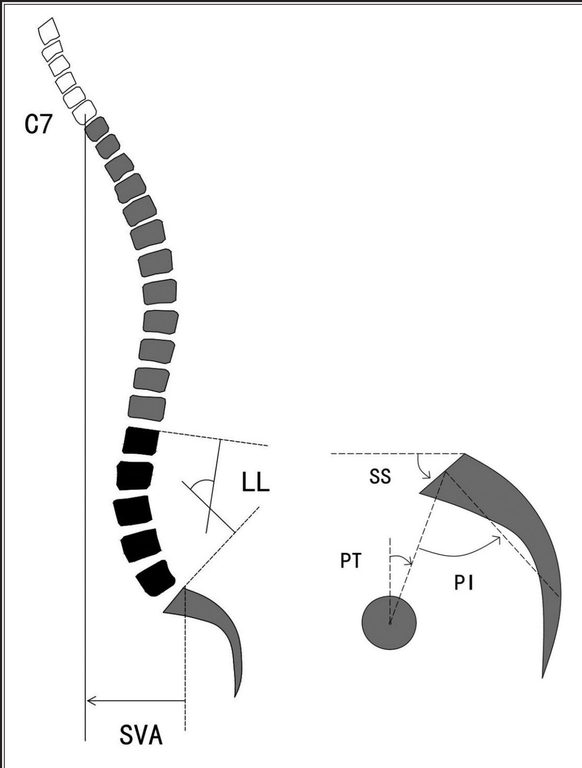

Fig. 1. *Methods for measuring the sagittal spinopelvic alignment. Sagittal vertical axis (SVA): the vertical distance between the central plumb line of the C7 vertebra and the posterior upper margin of the sacrum. Pelvic incidence (PI): the angle between the perpendicular to the sacral plate at its midpoint and the line connecting this point to the middle axis of the femoral heads. Lumbar lordosis (LL): the angle between the upper endplate of L1 and S1. Sacral slope (SS): the angle between the end plate and the horizontal line on S1. Pelvic tilt (PT): pelvic incidence-sacral slope.*

Statistics

The SPSS 27.0 software was used for data analysis. A 1:2 propensity score matching was performed to control for confounders and eliminate bias. Covariates included age, gender, hypertension, diabetes, fusion segment, and fusion location, and the clamp value was set to 0.2. SIJP patients were matched with non-SIJP patients, and the matching data were used for subsequent analysis. Student's t-tests, Chi-square tests, and Fisher exact tests were used to compare the differences in variables between the 2 groups. After univariate logistic analysis, statistically significant variables were included in a multivariate logistic regression analysis to determine the risk associated with postoperative SIJP. Correlations between VAS scores, interleukin 6, and the waist circumference of the SIJP group were confirmed by using the Pearson correlation coefficient. The receiver operating characteristic curve and the area under the curve were used to evaluate the ability of waist circumference and BMI to predict SIJP. The method of DeLong was used to compare the area under the curve (16). A P-value < 0.05 was considered statistically significant.

Results

Patient characteristics

A total of 36 patients (8.9%) developed SIJP during a mean follow-up duration of 18.9 months. The SIJP group included 20 women and 16 men, averaging 63.89 years of age (Table 1). Before the propensity score matching, there were no significant differences between the groups with respect to age, gender, smoking, drinking, hypertension, diabetes, and type of disease. Compared to no more than 2 segments, a fusion of multiple segments increased the SIJP incidence rate (P = 0.024). A higher fusion rate to the sacrum was also observed in the SIJP group (P = 0.017). Additionally, the operating time in the SIJP group was higher than that in the non-SIJP group (P < 0.001). However, there was no statistical difference in the postoperative length of stay. BMI and waist circumference were greater in the SIJP group than in the non-SIJP group (P < 0.05). Furthermore, the level of abdominal obesity was higher in the SIJP group compared with the non-SIJP group (69.4% vs. 27.9%, P < 0.001). To control for confounding factors (such as gender, age, hypertension, diabe-

Table 1. *Patient demographics before and after propensity score matching (PSM).*

	Before PSM		*P*	After PSM		*P*
	Non-SIJP group (n = 365)	SIJP group (n = 36)		Non-SIJP group (n = 72)	SIJP group (n = 36)	
Age, Years	62.53 ± 9.83	63.89 ± 4.3	0.413	64.01 ± 4.08	63.89 ± 4.3	0.883
Gender (M/F)	195/170	16/20	0.303	34/38	16/20	0.896
BMI, kg/m^2	24.37 ± 3.36	25.88 ± 3.20	0.010	24.44 ± 3.61	25.88 ± 3.20	0.042
Waist circumference, cm	83.41 ± 6.62	93.53 ± 9.09	< 0.001	84.49 ± 8.66	93.53 ± 9.09	< 0.001
Body type			< 0.001			0.003
Abdominal obesity	27.9%	69.4%		38.9%	69.4%	
Nonabdominal obesity	72.1%	30.6%		61.1%	30.6%	
Smokers (%)	22.7%	19.4%	0.651	18.1%	19.4%	0.861
Drinking (%)	34.2%	30.6%	0.655	27.8%	30.6%	0.764
Hypertension (%)	28.5%	38.9%	0.192	33.3%	38.9%	0.569
Diabetes (%)	12.6%	22.2%	0.107	18.1%	22.2%	0.606
Number of operative segments			0.024			0.785
≤ 2 segments (%)	71.0%	52.8%		55.6%	52.8%	
> 2 segments (%)	29.0%	47.2%		44.4%	47.2%	
Fusion / non-fusion to sacrum	23.6%/76.4%	41.7%/58.3%	0.017	38.9%/61.1%	41.7%/58.3%	0.781
Type of disease			0.366			0.440
Lumbar spondylolisthesis	30.1%	27.8%		27.8%	27.8%	
Lumbar stenosis	36.7%	27.8%		38.9%	27.8%	
Lumbar disc herniation	33.2%	44.4%		33.3%	44.4%	
Operative time (min)	138.79 ± 22.50	155.63 ± 20.61	< 0.001	153.54 ± 19.75	155.63 ± 20.61	0.803
Postoperative length of stay (days)	5.35 ± 1.48	5.83 ± 2.37	0.083	5.93 ± 1.67	5.83 ± 2.37	0.608

Values are presented in mean ± standard error (SE) or percentages.

tes, number of operative segments, and fusion/nonfusion to the sacrum), the SIJP group was matched in a 1:2 ratio with the non-SIJP group. After the propensity score matching, there still were significant differences between the 2 groups in BMI, waist circumference, and body type ($P < 0.05$, Table 1).

Relationship between SIJP and Spinal Parameters Based on radiologic Outcomes

Preoperative radiologic measurements of the preexisting rate of lumbar spondylolisthesis, lumbar stenosis, and lumbar disc herniation did not significantly differ between the SIJP and non-SIJP groups (Table 1). Among the preoperative and postoperative spinal parameters, the pelvic incidence and the pelvic tilt (the degree of sagittal tilt of the pelvis) were greater in the SIJP group compared to the non-SIJP group ($P < 0.05$). Sagittal spinal parameters in both classifications (sagittal vertical axis and pelvic incidence-lumbar lordosis mismatch) showed significantly greater imbalance preoperatively and postoperatively in the SIJP group than in the non-SIJP group ($P < 0.05$, Table 2).

Association between Waist Circumference, Inflammatory Cytokine Levels, and Pain Outcomes

Among the SIJP group, 11 (30.56%) and 25 (69.44%) patients were assigned to the nonabdominal obesity and abdominal obesity groups, respectively. Abdominal obesity patients had higher VAS scores, interleukin 6 levels, and tumor necrosis factor-α levels than the nonabdominal obesity group ($P < 0.05$, Table 3). Levels of other inflammatory markers (erythrocyte sedimentation rate, C-reactive protein, neutrophils, white blood cells and lymphocytes) were not significantly different between the 2 groups ($P > 0.05$). Pearson's correlation analysis revealed a significant positive correlation between the VAS scores and waist circumference ($r = 0.464$, $P = 0.004$). VAS scores were also positively correlated with interleukin 6 levels in the SIJP group ($r = 0.489$, $P = 0.002$; Fig. 2).

Logistic Regression and Receiver Operating Characteristic Curve Analysis

In univariable logistic regression analysis, the factors of BMI, abdominal obesity, pelvic tilt, pelvic incidence, pelvic incidence-lumbar lordosis, and sagittal vertical axis showed statistically significant differences between the 2 groups ($P < 0.05$). These factors were also included in a multivariate logistic regression analysis to determine the relative risk factors of SIJP. After these adjustments, the variables that were associated with the development of SIJP were abdominal obesity (Odds ratio [OR] = 4.36, $P = 0.010$), a pelvic incidence-lumbar lordosis greater than 10° (OR = 4.05, $P = 0.015$), and a sagittal vertical axis greater than 5 cm (OR = 8.25, $P < 0.001$) (Table 4). The receiver operating characteristic curve analysis for BMI and waist circumference revealed that cutoff values of 22.76 kg/m^2 and 84.17 cm, respectively, were able to distinguish between the 2 groups with the highest sensitivity (37.50% vs. 51.39%) and specificity (97.22% vs. 94.44%). The area under the curve for waist circumference was larger than that for BMI (0.762 vs. 0.650, $P = 0.049$) (Fig. 3).

Discussion

The sacroiliac joint is the largest joint in the human body, with a surface area of about 17.5 cm^2. Its primary function is to transfer gravity between the lower extremities and the axial bones. The bony contours and strong interconnecting ligaments allow only minimal surface movement of the joint. Pain receptors in the sacroiliac joint are found throughout the joint capsules, ligaments, and subchondral bones. Surgical operations or inflammation can cause pain in these structures. Lumbar surgery changes the motor and biomechanical characteristics of the spine and compensates for adjacent segment activity, increasing stress and the risk of SIJP (17). The results of our study shows that the postoperative incidence of SIJP after PLIF was 9%, which is slightly lower than previously reported (5). Because of the atypical symptoms of SIJP, diagnosis depends on provocation tests and the sacroiliac joint block. The lack of unified diagnostic criteria may have resulted in a few patients with undetected SIJP.

Guan et al (18) noted that surgically fixed segments were positively correlated with the incidence of SIJP. Compared to the number of lumbar fusion segments, Maigne and Planchon reported more cases of SIJP in patients with fusion to the sacrum than in those without (6). Similarly, our study shows that the proportion of more than 2 fixed segments and lumbosacral fusion

Table 2. *Comparison of radiographic data of the SIJP group and the non-SIJP group.*

	Non-SIJP group (n = 72)	SIJP group (n = 36)	P
Preoperative			
LL (°)	41.02 ± 11.85	40.42 ± 9.49	0.793
SS (°)	29.29 ± 13.82	28.63 ± 11.37	0.805
PT (°)	19.56 ± 11.43	26.92 ± 11.06	0.002
PI (°)	48.85 ± 13.50	55.55 ± 11.34	0.012
PI-LL (°)			0.017
< 10	45.8%	22.2%	
> 10	54.2%	77.8%	
SVA (cm)			< 0.001
< 5	84.7%	25%	
> 5	15.3%	75%	
Postoperative			
LL (°)	44.11 ± 14.36	42.52 ± 13.51	0.583
SS (°)	32.38 ± 17.69	33.30 ± 15.38	0.790
PT (°)	17.74 ± 10.49	23.47 ± 12.92	0.015
PI (°)	50.12 ± 15.23	56.78 ± 15.23	0.035
PI-LL (°)			0.002
< 10	59.7%	27.8%	
> 10	40.3%	72.2%	
SVA (cm)			< 0.001
< 5	87.5%	36.1%	
> 5	12.5%	63.9%	

SVA, sagittal vertical axis; PI, pelvic incidence; LL, lumbar lordosis; SS, sacral slope; PT, pelvic tilt.

Table 3. *Pain intensity and inflammatory markers between the two groups of SIJP patients.*

	SIJP		P
	Non-abdominal obesity (n = 11)	Abdominal obesity (n = 25)	
VAS (0-100)	28.54 ± 5.76	33.80 ± 5.13	0.010
ESR, mm/1h	20.64 ± 11.20	18.96 ± 13.13	0.715
CRP, μg/mL	4.41 ± 0.38	4.33 ± 0.45	0.589
Neutrophils, count/l×109	2.49 ± 0.76	3.07 ± 1.12	0.131
WBC, count/l×109	6.13 ± 2.56	6.37 ± 1.69	0.737
Lymphocyte, count/l×109	1.49 ± 0.37	1.95 ± 1.89	0.428
TNF-α, pg/mL	4.21 ± 1.86	5.75 ± 1.51	0.013
IL-6, pg/mL	2.62 ± 0.96	4.03 ± 1.41	0.005
IL-1, pg/mL	0.88 ± 0.25	1.03 ± 0.19	0.057

VAS, visual analog scale; ESR, erythrocyte sedimentation rate; CRP, C-reactive protein; WBC, white blood cell.

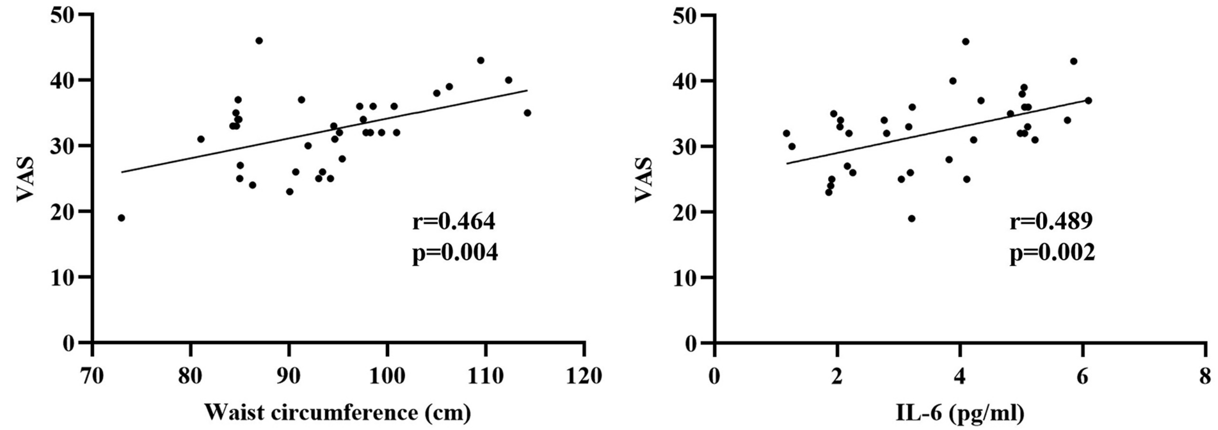

Fig. 2. *Receiver operating characteristic curves of waist circumference and BMI for differentiating SIJP patients. Waist circumference (WC): Area under the curve = 0.762, sensitivity = 51.4%, and specificity = 94.4%. BMI: Area under the curve = 0.650, sensitivity = 37.5%, and specificity = 97.2%. AUCWC vs. AUCBMI, P = 0.049.*

Table 4. *Results from the univariate and multivariate logistic regression analysis for the potential risk factors for SIJP.*

Variables	Univariate OR (95%CI)	*P*	Multivariate OR (95%CI)	*P*
Abdominal obesity	3.57 (1.52-8.38)	0.003	4.36 (1.42-13.39)	0.010
BMI (kg/m²)	1.13 (1.01-1.27)	0.045	1.18 (0.99-1.39)	0.052
Postoperative				
LL (°)	0.992 (0.96-1.02)	0.580	-	
SS (°)	1.00(0.98-1.02)	0.788	-	
PT (°)	1.05 (1.01-1.08)	0.017	1.01 (0.96-1.05)	0.812
PI (°)	1.03 (1.00-1.06)	0.039	1.02 (0.99-1.06)	0.230
PI-LL > 10 (°)	3.86 (1.62-9.19)	0.002	4.05 (1.31-12.56)	0.015
SVA > 5 (cm)	12.39 (4.67-32.83)	< 0.001	8.25 (2.65-25.68)	< 0.001

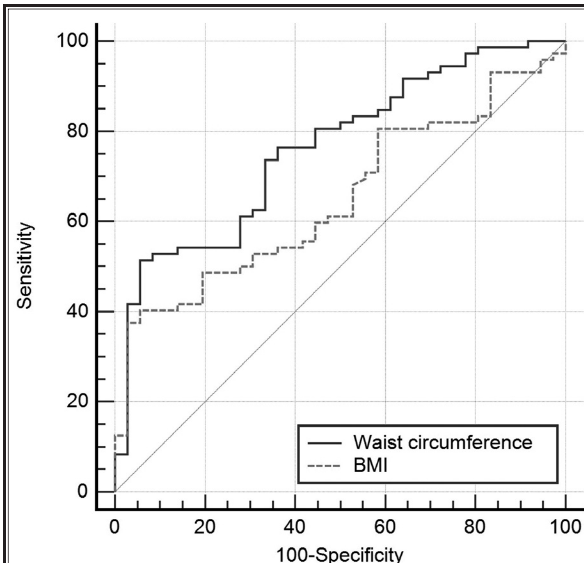

Fig. 3. *Correlation between visual analog scale (VAS) scores, waist circumference, and interleukin 6 in SIJP patients. Data was analyzed using the Pearson approach.*

after lumbar fusion was significantly higher in the SJIP group. A biomechanical study demonstrated that after lumbosacral fusion, ligament surge or reduction could easily lead to a ligament sprain or strain, especially of the iliosacral ligament and the ileal ligament, resulting in SIJP (19). Therefore, we used propensity score matching to exclude surgical factors and more accurately study the influence of other factors on SIJP.

Compared to men, women are more likely to develop osteoarthritis. After menopause, women's estrogen levels decrease, and the subchondral bone conversion rates increase, resulting in cartilage damage and thus increasing the risk of osteoarthritis (20). After lumbar fusion, the force of the sacroiliac joint changes significantly, and this mechanical change will inevitably accelerate the injury of the articular cartilage. Therefore, women may be more prone to SIJP following surgery. In addition, women have wider, more uneven and less curved pelvises compared to men's longer and narrower pelvises. Furthermore, women have higher sacroiliac joint mobility, greater pressure, greater load, and more pelvic ligament strain because of different pelvic morphology and the secretion of the hormone relaxin. Thus, women are also more likely to develop SIJP and pelvic pain (21). In our study, female gender was not a risk factor for SIJP after lumbar fusion, possibly because most of the patients were elderly and their hormone levels were relatively stable. Similarly, Guan et al (18) found no gender difference in SIJP after lumbar surgery.

Obesity is a low-grade inflammatory condition associated with multiple comorbidities such as metabolic syndrome, osteoarthritis, and chronic pain (22). High BMI and waist circumference also increase the risk of low back pain, intervertebral disc degeneration, and sciatica (23). Razieh et al (8) surveyed 160 patients undergoing lumbar fusion surgery and found that the obese group had significantly more adverse outcomes (including nonfusion, surgical site infection, pain, and disability) than the nonobese group. Our results show that patients with abdominal obesity are more likely to have SIJP after lumbar fusion, and waist circumference is a better predictor of SIJP than BMI.

Adipose tissue is an essential endocrine organ responsible for producing and releasing proinflammatory cytokines called adipokines. In obese people have significantly increased cytokines and inflammatory markers such as C-reactive protein, interleukins, tumor necrosis factors, and leptin (24). There is growing evidence that inflammation is closely associated with obesity and pain. Inflammation can lead to a lower threshold of nerve excitation and an enhanced nociceptor response to supranational stimuli, which then leads to peripheral and central pain sensitization (25). We also found that patients with higher abdominal obesity had higher VAS scores, interleukin 6 levels, and tumor necrosis factor-α levels. Ultimately, waist circumference and interleukin 6 levels positively correlated with the VAS scores.

Increased mechanical load is also one of the potential mechanisms associated with obesity and pain. Abdominal obesity increases spinal stress and the risk of vertebral compression fractures (9). Similarly, obese people have greater peak knee compressive forces leading to knee arthritis (26). Therefore, joints and soft tissues in obese patients are more likely to accumulate mechanical stress damage, and the resulting tissue destruction products can also trigger the release of inflammatory factors. The release of cytokines by immune cells in these tissues can cause nociceptor hypersensitivity and aggravate obesity-induced pain.

People with abdominal obesity accumulate fat in the waist. Therefore, the strength of their waist muscles is weakened, and the range of motion of their lumbar spine is significantly reduced. This can cause an imbalance in the strength of the trunk flexor and extensor muscles. The muscles in the waist and back need to bear a greater load to maintain the mechanical balance of the body. Weight loss and an exercise program can increase trunk muscle strength and spinal range of motion, significantly reducing chronic low back pain in patients (27). Nevertheless, the accumulation of abdominal fat leads to compensatory hyperlordosis of the spine, which counteracts the flexion torque applied to the lumbar spine, resulting in an increased spinal load. This spinal load makes people with high pelvic incidence and lumbar lordosis more prone to lumbar spondylolisthesis and low back pain (28). Obese patients have a significantly increased sagittal spine imbalance and thus have altered pelvic mechanics (increased pelvic retroposition) (29). These factors may be the reason for the prevalence of in SIJP in patients with abdominal obesity.

SIJP after lumbar fusion is often associated with changes in pelvic parameters and sagittal imbalance. Cho et al (30) investigated 452 patients who underwent lumbar surgery and found that the incidence of SIJP was 6%. Patients with SIJP had reduced sacral slope and a greater pelvic tilt. In our study, excessive sagittal vertical axis and pelvic incidence-lumbar lordosis values significantly increased the risk of postoperative SIJP, and the preoperative and postoperative pelvic tilt and pelvic incidence values were higher in the SIJP patient group. Usually, in the case of insufficient lumbar lordosis, the human body will compensate for the instability of the spinal sagittal position by changing the pelvic posture, which causes an increased pelvic tilt value. Studies have shown that an excessive pelvic tilt may lead to a decline in quality of life and can aggravate low back pain and SIJP. Furthermore, a decrease in pelvic tilt (back to normal) can improve lower limb motor function by increasing the range of motion of the hip (31). Previous studies have shown that low pelvic incidence is associated with chronic low back pain (32). On the other hand, there are reports that high pelvic incidence is associated with chronic low back pain, especially in women, which our results also suggest (33). However, neither study had clear inclusion criteria for low back pain, which can indicate SIJP (32,33). High pelvic incidence may cause SIJP because it causes a retraction of the shear line, which increases the pressure load on the posterior facet joints of the lower back. Theoretically, this high pelvic incidence may increase with facet joint pain after surgery.

Pelvic incidence-lumbar lordosis and the sagittal vertical axis are indexes proposed by Schwab to evaluate the sagittal balance of the spine and pelvis (14). The matching value of pelvic incidence-lumbar lordosis above 10° will lead to a sagittal spine imbalance and will significantly increase the incidence of disability (34). Senteler et al (35) showed that after lumbar fusion surgery, insufficient reconstruction of the lumbar lordosis resulted in a mismatch between pelvic incidence and lumbar lordosis, which significantly increased the shear stress near the small joints, leading to adjacent segment disease and the need for revision surgery. A study of 346 patients who underwent PLIF showed that the matching value of postoperative pelvic incidence-lumbar lordosis was larger in the SIJP group than in the non-SIJP group (14.45° ± 12.16° vs. 8.26° ± 9.12°) (36). It was concluded that lumbar pelvic sagittal imbalance represented by elevated pelvic tilt and inadequate lumbar lordosis recovery may play a central role in the development of SIJP after PLIF. One article noted that patients with a greater sagittal vertical axis were more likely to have low back pain and a decreased physical performance (37). It has been reported that chronic low back pain patients have difficulty adopting a neutral lumbar posture and that their static balance may have been destroyed (38). Whatever the cause of the breakdown of the static balance, the result is a forward tilt of the spine. The pelvic compensatory reserve is reduced, and the body swings around the edge of the "cone of economy," increasing the energy expenditure for posture maintenance (39). We speculate that, at a certain threshold, the failure of various compensatory functions leads to SIJP.

Limitations

There are several limitations to our study. First, the diagnostic criteria of SIJP are not consistent, inevitably leading to a small number of missed patients. Second, managing obesity and sagittal spinopelvic alignment must also account for differences in ethnicity, age, gender, and other variables. Finally, in addition to the risk factors involved in this study, future studies should further explore the role of the sacroiliac joint nerve anatomy, stress distribution, inflammation, and other factors of SIJP after lumbar fusion.

Conclusions

The occurrence of SIJP after lumbar fusion is strongly associated with abdominal obesity and sagittal imbalance. This association between abdominal obesity and SIJP may be mediated by inflammatory cytokines and abnormal biomechanics. To prevent SIJP, body type and sagittal spinopelvic alignment should be considered when selecting a surgical strategy.

Author Contributions

SJW initiated the idea, HWX and XYF wrote the assay, HC and SJC did the data analysis. CXR and XYG supervised and reviewed the manuscript. SJW gathered the data and helped with the data analysis. All authors read and approved the final manuscript.

Data Availability

The datasets generated for this study are available upon reasonable request to the corresponding author.

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