The influence of spinopelvic parameters on adjacent-segment degeneration after short spinal fusion for degenerative spondylolisthesis

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OBJECTIVE Spinopelvic parameters, such as the pelvic incidence (PI) angle, sacral slope angle, and pelvic tilt angle, are important anatomical indices for determining the sagittal curvature of the spine and the individual variability of the lumbar lordosis (LL) curve. The aim of this study was to investigate the influence of spinopelvic parameters and LL on adjacent-segment degeneration (ASD) after short lumbar and lumbosacral fusion for single-level degenerative spondylolisthesis.

METHODS The authors retrospectively reviewed the records of all short lumbar and lumbosacral fusion surgeries performed between August 2003 and July 2010 for single-level degenerative spondylolisthesis in their orthopedic department.

RESULTS A total of 30 patients (21 women and 9 men, mean age 64 years) with ASD after lower lumbar or lumbosacral fusion surgery comprised the study group. Thirty matched patients (21 women and 9 men, mean age 63 years) without ASD comprised the control group, according to the following matching criteria: same diagnosis on admission, similar pathologic level (≤ 1 level difference), similar sex, and age. The average follow-up was 6.8 years (range 5–8 years). The spinopelvic parameters had no significant influence on ASD after short spinal fusion.

CONCLUSIONS Neither the spinopelvic parameters nor a mismatch of PI and LL were significant factors responsible for ASD after short spinal fusion due to single-level degenerative spondylolisthesis.

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KEYWORDS pelvic incidence; pelvic tilt; sacrum slope; degenerative spondylolisthesis; adjacent-segment instability

THE long-term clinical outcomes of spinal fusion in degenerative spondylolisthesis are influenced by a variety of pathophysiological factors such as the recurrence of spinal canal stenosis, instability, lumbar kyphosis, nonunion, and adjacent-segment degeneration (ASD).¹⁵ The risk factors for ASD after short spinal fusion for degenerative spondylolisthesis include the aging process, sacrifice of the posterior ligament complex, excessive decompression during surgery, and poor sagittal balance after lumbar fusion.⁷ Over the past 15 years, sagittal balance analysis has gained importance in reconstructive surgery of the spine.^{6,21} With the increasing use of vertebral

fusion, deteriorative effects of surgery on sagittal balance have been reported.¹⁴ These effects on sagittal balance are related to the locked position of the fused vertebra; the consequence of fixed sagittal imbalance is a loss of normal lumbar curvature, with forward inclination of the trunk.^{8,9}

Use of the C7 plumb line, defined as a line dropped from the center of the C7 vertebra, is the most common method of identifying risk and prognosis associated with sagittal balance.²¹ The horizontal distance from the posterosuperior corner of the sacrum to the plumb line is recorded as the magnitude of the sagittal vertical axis (SVA), and the degree of the SVA indicates sagittal balance.¹⁸

ABBREVIATIONS ASD = adjacent-segment degeneration; LL = lumbar lordosis; PI = pelvic incidence; PT = pelvic tilt; SS = sacral slope; SVA = sagittal vertical axis; VAS = visual analog scale.

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Measurement of the C7 plumb line for evaluation of the SVA is often difficult and several studies have shown that pelvic parameters, especially the pelvic incidence (PI) angle, are an indirect method of checking sagittal balance.^{3,19} Spinopelvic parameters, such as the PI, sacral slope (SS) angle, and pelvic tilt (PT) angle, are important morphological and positional indices for determining the sagittal curvature of the spine and the individual variability of the lumbar lordosis (LL) curve.

Our aim is to investigate the influence of spinopelvic parameters and LL on ASD after short lumbar or lumbosacral fusion for single-level degenerative spondylolisthesis.

Methods

Study Population

Between August 2003 and July 2010, a retrospective database review was conducted to identify all patients who underwent short lumbar or lumbosacral fusion surgeries (≤ 2 levels) for single-level degenerative spondylolisthesis. All procedures were performed in the spine section of our orthopedic department. Inclusion criteria included primary spinal operations with short spinal fusion and decompression (≤ 2 levels) due to single-level degenerative spondylolisthesis. No revision surgery was performed except for the ASD during the follow-up period.

Patients were excluded due to scoliosis more than 10° ; preexisting disc degeneration of adjacent segments before primary surgery; anterior spine surgery; and preoperative vertebral compression fracture of the lumbar spine. During the study period, patients enrolled had to have a minimum follow-up period of 5 years and were divided into ASD and non-ASD groups. Radiographic criteria were used to define ASD: development of spondylolisthesis ≥ 4 mm, segmental instability $\geq 10^\circ$ on dynamic views, disc degeneration change of more than 1 grade according to the University of California at Los Angeles Grading Scale,¹² and disc degeneration of Modic type 2 or 3 (Fig. 1). A pairwise, retrospective, case-control study with 1-to-1 matching was performed between these two groups. Thirty patients were randomly selected from the ASD group as the study group.

A computer-generated list of potential controls was obtained from the non-ASD group database with a minimum follow-up period of 5 years. Controls were chosen according to the following matching criteria: same diagnosis on admission, similar pathologic level (≤ 1 level difference), similar sex, and similar age. The list of potential controls was reviewed for the best possible match, giving priority to diagnosis and similar pathological level, sex, and age. When multiple possible controls existed to match 1 case, the patient with the date of admission closest to that of the study patient was selected.

Data Collection

Medical records, imaging studies, laboratory data, neurological function data, and functional outcomes were reviewed and analyzed. Standard standing radiographs, including lumbosacral anterior-posterior, lateral, and dynamic views were obtained preoperatively, postoperatively (within 2 weeks after the operations), and at the

last follow-up. A single investigator checked the status of ASD and measured the degrees of LL angle, SS angle, PT angle, and PI angle, using standard lumbosacral lateral and dynamic views. SS is the angle between the horizontal line and the orientation of the sacral plateau. LL is defined using the Cobb L1–S1 method: the angle between the superior endplates of L1 and S1. PT is the angle between the vertical line through the femoral head and a line from the midsacral plateau and femoral head. By drawing a line through the center of the sacral plateau to that of the femoral head, this line and the perpendicular line dropped from the sacral plateau form the PI (Fig. 2).

Clinical outcomes were evaluated using patient-assessed quantitative measurements including a visual analog scale (VAS) for axial back pain as well as leg pain, and the Oswestry Disability Index. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The Chang Gung Medical Foundation IRB approved this study and waived the requirement for informed consent due to the retrospective nature of the study.

Statistical Analysis

A statistical software program (SPSS for Windows, version 12.0; SPSS Inc.) was used to analyze the preoperative and postoperative parameters in both groups. All data were presented as means $\pm$ standard deviations. The differences between the study and control groups in spinopelvic parameters and LL were evaluated using Fisher's exact test and Mann-Whitney U-test analyses. The clinical and spinopelvic parameters were compared at preoperative, postoperative, and follow-up time points. Multivariate analysis was performed using logistic multiple regression analysis. Statistical significance for all tests was set at a *p* value of 0.05.

Results

Between August 2003 and July 2010, a total of 978 patients with single-level degenerative spondylolisthesis who underwent short-segment spinal fusion were enrolled in this study. Patients underwent primary spine surgeries using the traditional midline open method with pedicle screw fixation as well as posterolateral fusion, interbody fusion, or both. Three hundred seventy-two patients were excluded who had less than 5 years follow-up. From the remaining 606 patients, 266 patients (43.9% of the patients with more than 5 years of follow-up) were defined as the ASD group and the other 340 patients (56.1%) were categorized as the non-ASD group. Thirty randomly selected patients (21 women and 9 men, mean age 64 years) in the ASD group made up the study group. Of those 30 study group patients, 6 patients underwent revision surgery due to symptomatic adjacent problems. Ten percent of the patients (20% of patients in the study group) underwent revision surgery due to symptomatic ASD problems with an average duration of 51.2 months.

The control group was chosen from the non-ASD

FIG. 1. A 60-year-old woman was diagnosed preoperatively with degenerative spondylolisthesis and lumbar spinal stenosis at the L4–5 level, as shown on radiography (A) and a T2-weighted MR image (B). She underwent posterior instrumentation and interbody fusion at L4–5 with immediate postoperative radiography (C). Five years after surgery, she was diagnosed with ASD at the L3–4 level with adjacent spondylolisthesis, spinal stenosis, and disc degeneration as seen on radiographs (D and E) and a T2-weighted MR image (F).

group according to the following matching criteria (i.e., 1-to-1 matching to the study group): same diagnosis on admission, similar pathologic level (≤ 1 level difference), sex, and age. The average follow-up period for both study and control groups was 6.8 years (range 5–8 years). Clinical and surgical data are shown in Table 1. Comparisons of LL and spinopelvic parameters (PI, PT, SS, and PI-LL mismatch between preoperative, immediate postoperative, and last follow-up time points) are shown in Table 2. There was no statistically significant difference in preoperative symptoms (e.g., low-back pain, claudication, sciatica, or

the duration), spondylolisthesis level, fusion length, LL, PI angle, PT angle, SS angle, and PI-LL mismatch between the study and control groups. The results remained the same after multivariate logistic regression analysis.

Discussion

The concept of “cone of economy,” first introduced by Jean Dubousset in 1994,¹¹ refers to a stable condition regarding standing posture. Within the center of the cone, the energy spent in stance is minimized, resulting from

FIG. 2. Measurement of LL and spinopelvic parameters. SS is the angle between the horizontal line and the orientation of the sacral plateau. LL is defined using the Cobb L1–S1 method (the angle between the superior endplates of L1 and S1). PT is the angle between the vertical line through the femoral head and a line from the midsacral plateau and femoral head. By drawing a line through the center of the sacral plateau to that of the femoral head, this line and the perpendicular line dropped from the sacral plateau form the PI. Copyright Fu-Cheng Kao. Published with permission. Figure is available in color online only.

a complex integration of physiological alignment of the spine in the coronal and sagittal planes, intrinsic paraspinal musculature activation, bone morphology, and balanced tension of the spinal ligaments. Ideal spinal alignment of the human body is set to maintain the center of gravity within the cone of economy with an extended pain-free and economical erect position. This requires precise interaction of spinal and spinopelvic parameters. Trunk imbalance is therefore the consequence when exceeding the center of the cone, and would cost further unnecessary energy spent to maintain one's standing position.

PI is the morphological parameter that plays a key role in the regulation of positional pelvic and spinal factors.^{3,29} The potential for variation of the spinal curves is associated with variation in pelvic positional parameters. For the same PI, SS and PT can vary, with the following relation among them: $PI \text{ (morphological)} = SS \text{ (positional)} + PT \text{ (positional)}$.²⁰ SS induces curves above the level of the pelvis, i.e., the spinal curves, and PT induces factors below the level of the pelvis, i.e., the angle of the coxofemoral joints in the upright posture. PI creates different lordosis

TABLE 1. Clinical and surgical data of all patients

Variable	Study Group	Control Group No. (%)	p Value
Males/females, n (%)	9/21 (30/70)	9/21 (30/70)	1.000
Mean age $\pm$ SD, yrs	64 $\pm$ 8.68	63 $\pm$ 10.05	0.505
Back pain, n (%)	30 (100.0)	29 (96.7)	1.000
Mean back pain duration $\pm$ SD, mos	12 $\pm$ 8.94	14 $\pm$ 11.39	0.958
Leg pain, n (%)	29 (96.7)	30 (100.0)	1.000
Mean leg pain duration $\pm$ SD, mos	11 $\pm$ 9.37	12 $\pm$ 11.66	0.607
Claudication, n (%)	27 (90.0)	25 (83.3)	0.706
Spondylolisthesis level, n (%)			0.661
L3–4	6 (20)	8 (27)	
L4–5	23 (77)	20 (67)	
L5–S1	1 (3)	2 (7)	
Fusion level, n (%)			0.718
1	25 (83)	26 (87)	
2	5 (17)	4 (13)	
Mean preop VAS score $\pm$ SD			
Back pain	8 $\pm$ 0.82	8 $\pm$ 0.74	0.465
Leg pain	8 $\pm$ 1.52	8 $\pm$ 1.00	0.731
Mean postop VAS score $\pm$ SD			
Back pain	2 $\pm$ 0.52	2 $\pm$ 0.63	0.619
Leg pain	1 $\pm$ 0.50	1 $\pm$ 0.49	0.601

values to allow conditions conducive to standing posture and gait, according to the principle of biomechanical economy. Every individual has his or her own standard and appropriate lordosis value. The lordosis assigned to the morphological pelvis, evaluated by PI (which determines the spine and pelvis positional parameters, $LL = PI \pm 9^\circ$), determines the predicted (theoretical) lordosis.¹⁷

Spinal arthrodesis with instrumentation has become a widely used treatment for spinal instability nowadays. After rigid fixation and solid spinal fusion, adjacent loading stress in mobile segments changes, causing adjacent-segment diseases in patients postoperatively, which is now considered one of the common long-term complications. In our study, radiographic ASD was found in 43.8% of total patients. In other papers that have conducted this review, an incidence rate more than 30% was reported for radiographic ASD,⁵ and there were several risk factors for its development. Fusion length, decompression level, facet capsule violation, and alignment of fusion level were considered as surgical factors, causing higher risk in developing postoperative ASD. Beyond surgical factors, patient factors, however, were strongly related to diathesis of each patient and could not be modified during the operations. Older age, the medical condition of obesity, menopause, preexisting ASD, and the morphology of pelvic inclination were patient factors found to be related to postoperative ASD.³⁰ However, in our study, there was no statistically significant difference in age, sex, preoperative symptoms, level of spondylolisthesis, length of fusion, or decompres-

TABLE 2. Difference of spinopelvic parameters between the two groups

Parameter	Study Group	Control Group	p Value
Preop			
SS	33° ± 10.51°	32° ± 11.60°	0.610
PI	54° ± 12.51°	53° ± 11.58°	0.982
PT	21° ± 9.03°	22° ± 11.62°	0.871
LL	48° ± 11.74°	47° ± 16.28°	0.918
No. w/ PI–LL mismatch, ≥10°	14 (46.7%)	13 (43.3%)	0.795
Immediate postop			
SS	32° ± 8.76°	30° ± 8.23°	0.657
PI	54° ± 12.51°	53° ± 11.58°	0.982
PT	22° ± 9.24°	23° ± 10.70°	0.807
LL	42° ± 11.02°	42° ± 12.28°	0.935
No. w/ PI–LL mismatch, ≥10°	18 (60.0%)	17 (56.7%)	0.793
Last follow-up			
SS	33° ± 9.09°	32° ± 8.62°	0.929
PI	54° ± 12.51°	53° ± 11.58°	0.982
PT	21° ± 10.03°	21° ± 12.15°	0.767
LL	45° ± 14.19°	47° ± 11.99°	0.636
No. w/ PI–LL mismatch, ≥10°	17 (56.7%)	16 (53.3%)	0.795

All data given as mean ± SD unless otherwise indicated.

sion between all groups. In addition, due to our highly selective criteria of single-level spondylolisthesis and only 1- or 2-level fusion, there was no preexisting degeneration of the adjacent disc in our population.

Spinopelvic harmony is a posture for individuals to maintain sagittal balance with minimal energy consumption in a stable standing position. To further precisely fulfill the concept of spinopelvic harmony in clinical practice, the following parameters are known to be maintained: SVA < 50 mm, PT < 20°, and LL = PI ± 9°.²⁶ Aoki et al. stated that postoperative PI–LL mismatch causes greater residual low-back pain, and surgeons should pay attention to the sagittal spinopelvic balance even when treating spinal stenosis or spondylolisthesis.¹ Rothenfluh et al. showed that, in degenerative disease of the lumbar spine, a high PI with a diminished LL appears to predispose a patient to ASD. Patients with such PI–LL mismatch exhibit a 10-fold higher risk of undergoing revision surgery if sagittal malalignment is maintained after lumbar fusion surgery.²³ Patients with PI–LL mismatch are at a higher risk for sagittal imbalance; they are therefore treated using other spinal parameters for compensation, which may lead to increased rates of ASD. In our study, there was no significant difference in the PI–LL mismatch rate in preoperative, immediate postoperative, and last follow-up observation between the study and control groups. However, the study group included patients with only radiographic ASD and patients who underwent revision spine surgery. This might be the reason that PI–LL mismatch did not achieve statistical significance in our study as it did in previous studies.

The PT is also an important factor influencing spinal

alignment and adjacent-segment disease. According to a study conducted by Di Martino et al., patients with a PT greater than 20° and an SS less than 40° fall into a higher-risk group for clinically evident ASD and subsequent reintervention. Pelvic retroversion and hypolordosis are the two main mechanisms of compensation that create an unbalanced spine.¹⁰ Yamasaki et al. found greater PT results with decreased LL, flexion contracture of the hip and knee, and nerve or muscle disorders. Compensatory pelvic retroversion restores a mechanically efficient posture; the risk of ASD is 5.1 times greater in patients with a preoperative PT more than 22.5°. In our study, there was no statistical difference in PT or LL at preoperative, immediate postoperative, and last follow-up observation between the study and control groups.

In a study conducted by Barrey et al., loss of lordosis was more common in patients with a lower PI. When patients experience loss of lordosis, a significant anterior displacement of the C7 plumb line occurs.² Loss of lordosis is not only structural, secondary to segmental discopathy and loss of disc height, but also postural, secondary to the posture the patient adopts to relieve pain and avoid posterior discal hyperpressure. This loss causes a predisposition to disc degeneration and pathologic change. Rajnics et al. showed that patients with disc herniation have a relatively straight spine in the sagittal plane, with a significant decrease in both LL and SS.²² An increased PI may lead to a higher contact force on the lower facet joints and cause facet joint arthritis, along with a more sagittal facet joint orientation. Individuals with an increased PI may therefore be at high risk for facet joint arthritis at the lower lumbar spine.¹⁶ A significantly greater pelvic incidence indicates that the shape of the pelvis is a main predisposing factor for degenerative spondylolisthesis.² In the normal population, a high PI is usually associated with a pronounced SS and more LL.²⁴ The degree of lordosis noted in these patients generates forces on the posterior articular joints and probably causes excessive mechanical stresses on the posterior facets, accelerating arthrosis change. According to our study, there is no correlation between the size of the PI and the incidence of ASD caused by short-segment spinal fusion, including disc degeneration, segmental instability, and spondylolisthesis.

In this case-control study, we did not report SVA for global spinal alignment assessment because of the retrospective nature of the study, as routine full-length spine radiography was not obtained in patients undergoing short lumbar spinal fusion surgery in our practice. Instead, we assessed spinopelvic parameters to investigate sagittal balance and its relationship to radiographic ASD in this retrospective study. In the general population, the PI angle measures approximately 54° with a range from 34° to 84°; the positional angles, SS and PT, measure approximately 40° with a range of 20°–65° and 12° with a range of 5°–30°, respectively.^{27,28} Preoperatively, the patients in our study showed normal PI angles with decreased SS angles. Based on the study and classification system of Roussouly et al.²⁴ that identified sagittal alignment in a group of 160 asymptomatic individuals, most of our patients belonged to type I and type II with SS less than 35° and a relatively short lordotic curve of the total thoracolumbar spine. The

morphology of types I and II in the 4-part classification scheme revealed straighter lumbar curves with loss of lordosis in this type of patient. Thus, we found that the rate of PI-LL mismatch was high in both the study and control groups. Decreased LL could relieve excessive mechanical stress on the posterior facet joints, which avoids adjacent facet arthritis and lumbar foraminal stenosis.²² It would also decrease clinical symptoms (such as sciatica and claudication) secondary to ASD and reduce the reoperation rate. Sixty-three patients underwent reoperation due to ASD with clinical symptoms in this retrospective study. The total reoperation rate was 10.4% in this cohort. Compared to the 14% reoperation rate in the SLIP (Spinal Laminectomy versus Instrumented Pedicle Screw) study,¹³ 11% in the SPORT (Spine Patient Outcomes Research Trial) study,³¹ and 13.3% in the study by Brodke et al.,⁴ our reoperation rate was lower. Decreased SS and LL postoperatively was more likely to cause positive sagittal imbalance with a stooped posture.²⁵ Patients would compensate for this sagittal imbalance by hip extension, knee flexion, and ankle dorsiflexion. The compensated posture caused early muscle fatigue and poor exercise tolerance. However, in clinical practice, it was very difficult to distinguish low-back and buttock pain from postoperative muscle fibrosis or sagittal imbalance, although low-back soreness and pain must have been mentioned during the follow-up. Reoperation usually would not be performed because of simple low-back soreness and pain without sciatica.

A study by Rothenfluh et al.²³ reported that patients with high PI with diminished LL were predisposed to symptomatic ASD and a higher risk of undergoing reoperation. Higher PI would cause a relatively longer lordotic curve in the thoracolumbar spine²⁴ and lead to a higher contact force on the adjacent facet joints, causing facet joint arthritis.¹⁶ Adjacent facet joint arthritis is the main factor causing ligamentum flavum and facet capsule hypertrophy. Therefore, the resulting spinal stenosis and foraminal stenosis would lead to neurological symptoms and higher risk of reoperation. In our study, most of the patients had relatively straight lumbar spines with normal PI and diminished LL. Axial weight loading was evenly distributed on the vertebral disc and lower contact force was on the adjacent facet joint in this kind of morphology. Our focus was on the radiographic change but not on the clinical symptoms. In addition, most patients underwent only single-level spinal fusion in this study. Due to our highly restrictive inclusion criteria, there was no preoperative scoliosis, preexisting disc degeneration of adjacent segments, or vertebral compression fracture in our patients. Preoperative spinal degeneration might be less severe in our patient population.

Our study had several limitations. It was a retrospective, case-controlled study conducted in a diverse population. Additionally, some patients were lost to follow-up due to the nature of the retrospective study, and randomized selection of the control group was not used, which increased the risk for selection bias. Our results differed from previous studies because our study group included both participants with only radiographic ASD and participants who underwent revision spine surgery for symptomatic ASD. The definition of ASD varies from study

to study, not to mention the specific definition of radiographic ASD and clinical ASD. Patients with radiographic ASD may not have clinical ASD, and vice versa. Finally, observational bias may have resulted from intraobserver variability.

Conclusions

Spinopelvic parameters and mismatch of the PI and LL were not significant factors in the development of ASD after short spinal fusion performed for single-level degenerative spondylolisthesis. However, physiological curvature of the spine adopted for energy saving and pain relief is related to trunk balance and the spinopelvic parameters of PI, PT, and SS. Nonfused segments of the spine after short spinal fusion might compensate for the effect of the fused segments. Further studies related to radiographic and symptomatic ASD, such as the influence of spinopelvic parameters after long spinal fusion, the status of preexisting degeneration, preoperative thoracolumbar and spinopelvic morphology, and back muscle strength for compensation, are worth investigation.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: WJ Chen. Acquisition of data: WJ Chen. Analysis and interpretation of data: Kao. Drafting the article: Kao. Reviewed submitted version of manuscript: Wang. Statistical analysis: IJ Chen. Study supervision: Hsieh.

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