Original Article

Changing of Pelvic Incidence after Lumbosacral Fusion: A Retrospective Study in Bangkok Hospital

Chaidej Sasomboon, MD ; Kanoknard Jaisanuk, MD ; Porameth Charoentanakorn, MD ; Kanit Chamroontaneskul, MD ; Tayard Buranakarl, MD
Yodruk Prasert, MD ; Supreecha Kapiya, MD ; Yongsakdi Liengudom, MD ; Sarij Srisuparp, MD ; Phudhiphorn Thienprasit, MD, PhD, FACS

Chaidej Sasomboon, MD

Bangkok Spine Academy, Bangkok Hospital, Bangkok, Thailand

*Address Correspondence to author:
Chaidej Sasomboon, MD;
Bangkok Spine Academy,
Bangkok Hospital,
2 Soi Soonvijai 7 New Petchburi Road
Bangkok 10310, Thailand
email: csasomboon@gmail.com

Received: May 13, 2018
Revision received: May 21, 2018
Accepted after revision: July 20, 2018
BKK Med J 2018;14(2): 10-16.
DOI: 10.31524/bkkmedj.2018.09.003
www.bangkokmedjournal.com

Abstract

OBJECTIVE: To assess the changing of pelvic incidence in patients who received lumbar and lumbosacral fusion with pedicle screw fixation.

MATERIAL AND METHODS: This is a single-institute, retrospective study. From 2011-2016, 113 cases of lumbar and lumbosacral fusion with pedicle screw fixation were reviewed. Preoperative and postoperative (at 6-week, 1-year and latest follow-up) pelvic parameters including Pelvic incidence (PI), Pelvic tilt (PT), Sacral slope (SS) and Lumbar lordosis (LL) were measured in standing lateral view X-ray by 2 independent fellow-trained spine surgeon who were blind to the operation. Difference in preoperative and postoperative PI was defined as Pelvic incidence disparity (ΔPI). Other characteristic data of patients were also collected, including age, sex, body mass index, diagnosis, fusion technique, number of fusion levels and level of fusion.

RESULTS: Pelvic incidence disparity (ΔPI) was 3.2º ± 4.0 at 6-week postoperative, 3.3º ± 4.0 at 1-year postoperative and 3.2º ± 3.4 at last follow-up. This showed a significant change when compared to preoperative but did not change significantly over time after surgery. There was no correlation between ΔPI and fusion technique, L5-S1 fusion, diagnosis and number of fusion segments.

CONCLUSION: Lumbar and lumbosacral fusion with pedicle screw fixation can alter pelvic incidence parameters. This could be a consequence from increased stress and motion in SI joint after the surgery.

Keywords: pelvic incidence, spinopelvic parameter, lumbar fusion, sacroiliac joint

Pelvic incidence (PI) was known to be a constant parameter for a person individually. Theoretically pelvic incidence is an anatomical parameter, unique to each individual, independent of the spatial orientation of the pelvis.[1] Several studies indicate that the sagittal spinal imbalance may be a critical parameter associated with clinical symptoms and is important in surgical decision-making.[2,3] Radiological sagittal parameters that significantly correlate with pain, disability and health-related quality of life include the sagittal vertical axis (SVA), pelvic tilt (PT), and the mismatch between pelvic incidence minus lumbar lordosis (PI-LL).[4,5] Of all of them, PI-LL is especially valuable for preoperative planning in correction of spinal deformity. Because PI is considered as a constant anatomic parameter for each individual, thus a surgeon can estimate the proper amount of lumbar lordosis (LL) to match PI for appropriate sagittal balance. Schwab et al suggest an ideal PI-LL achievement within ± 10º for adult spinal deformity patients.[6,7] Rothenfluh et al[8] also shown the important of pelvic incidence and lumbar lordosis mismatch that exceed 9.8º degrees is associated with poor postoperative clinical outcome and increased chance to undergo revision surgery for adjacent segment disease. Zhang et al reported a significantly better surgical outcome and lower postoperative complications in adult degenerative scoliosis patients who had pelvic incidence minus lumbar lordosis mismatch between 10º and 20º after performing long posterior instrumentation and fusion.[9] For this reason, preoperative pelvic incidence is widely used to determine the proper lumbar lordosis angle which is the only intraoperative parameter that surgeons could adjust during the procedure such as osteotomy and lumbar fusion.[10]

PI is the angle measure from center of S1 endplate between perpendicular line of S1 endplate and center of hip joint. Although PI was considered as a constant parameter in each individual, theoretically it still could be changed if there is motion at the sacroiliac (SI) joint. Even the SI joint has a strong bony and ligament configuration structure. Recent studies show that the SI joint could have more motion in case of trauma, degeneration disease and post-surgery. Spinal surgery such as vertebral osteotomy and spinal fusion may also cause significant change in load transfer to the SI joint resulting in movement of SI joint and followed by a changing in PI. Therefore if PI is not a constant value, it could impact the preoperative planning when we want to achieve optimal PI-LL.

The aims of this study were: 1) identify the changing in pelvic incidence after lumbar and lumbosacral fusion, along with the impact of changed postoperative pelvic incidence, sacral slope and pelvic tilt; 2) to determine the relationship between various surgical techniques and changing in postoperative pelvic incidence.

Materials and Methods

This was a single-institute, retrospective study of patients who underwent lumbar posterior instrumentation and fusion treatment at Bangkok Spine Academy (Bangkok Medical Center) between 2011 and 2016. Inclusion criteria included 1) performed lumbar or lumbosacral fusion with pedicle screw fixation; 2) aged more than 18 years old at time of surgery; 3) a minimum 1-year follow-up. Patients who had had previous spinal surgery, suffered from congenital deformities, performed spinopelvic fixation, tumor and infection were excluded. Those whose radiographs did not meet standards were also excluded in order to discard measurement error. A total of 113 patients who met all the criteria were included in the study. Other characteristic data of patients were collected including age, sex, body mass index (BMI), diagnosis, fusion technique and number of fusion segments. This study was approved by the Institutional Review Board of Bangkok Spine Academy (Bangkok Medical Center).

Radiographic assessment

Preoperative and postoperative (at 6-week, 1-year and latest follow-up) radiological evaluations were investigated by standing lateral views x-ray. All radiographs were randomized and analyzed by two fellowship-trained spine surgeons (C.S. and K.J.). Each investigator performed measurement two times for intraobserver reliability. The degree of lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT) and pelvic incidence (PI) were measured.

The definition of lumbar lordosis (LL) is the angle between superior endplate of L1 and superior endplate of S1; sacral slope (SS) is the angle between the superior endplate of S1 and the horizontal line; pelvic tilt (PT) is the angle between the vertical line and the connecting the midpoint of superior endplate of S1 to hip axis; pelvic incidence (PI) is the angle between the perpendicular line of superior endplate of S1 and the line connecting the midpoint of superior endplate of S1 to hip axis (Figure 1).

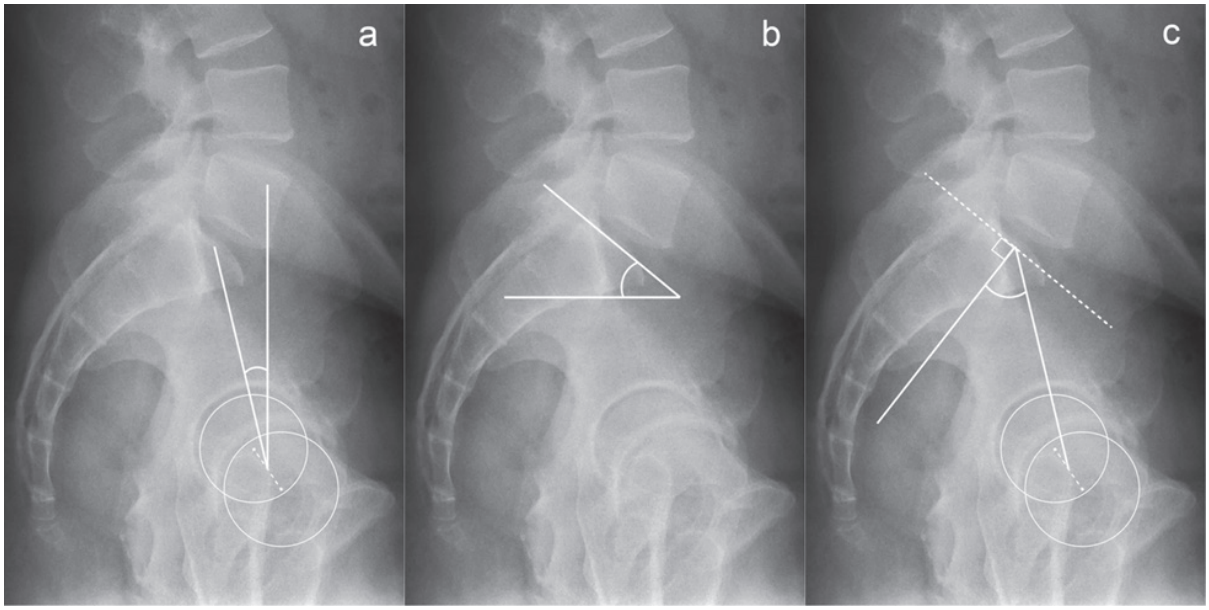

Figure 1: Methods for measuring pelvic parameters. Pelvic tilt (PT) is the angle between the vertical line and the connecting the midpoint of superior endplate of S1 to hip axis (a). Sacral slope (SS) is the angle between the superior endplate of S1 and the horizontal line (b). Pelvic incidence (PI) is the angle between the perpendicular line of superior endplate of S1 and the line connecting the midpoint of superior endplate of S1 to hip axis (c).

Statistical analysis

The data were analysed using the Stata software (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP). A repeated measure analysis of variance (ANOVA) test was performed for comparison between each dependent variable. Student's t test and Pearson's correlation coefficient were used for analysis of each radiological parameter. P-value less than 0.05 was considered to be statistically significant. The inter-observer reliability was calculated by intraclass correlation coefficient (ICC) for each radiographic measurement.

Results

Patient Baseline Characteristics

A total 113 patients were enrolled in this study, including 50 men and 63 women, with an average age of 57.6 ± 13.4 years (range 24-82 years). Mean time of latest follow-up was 23.6 ± 12.5 months with 64 from 113 patients were a follow-up of more than 12 months. The average BMI was 23.6 ± 12.5 kg/m^2 (Table 1).

Spondylolisthesis was diagnosed in 71 patients, spinal stenosis 8 patients, degenerative scoliosis 8 patients, degenerative disc disease (DDD) 22 patients, herniated nucleus pulposus (HNP) 2 patients and isthmic spondylolisthesis in 2 patients. Fusion technique was divided into six techniques: posterolateral fusion (PLF), posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), anterior lumbar interbody fusion (ALIF), direct lateral interbody fusion (DLIF) and oblique lumbar interbody fusion (OLIF). The number of patients in each group were 8, 2, 31, 19, 9 and 44 consecutively. Single level fusion was performed in 75 patients, 2-level in 29 patients and 3-level in 7 patients. Only one patient received 4 and 5-level of fusion. Fusion and pedicle screw fixation of L5-S1 was done in 72 patients but not in 41 patients (Table 2).

Spinopelvic parameter

The average preoperative PI was 52.3º ± 11.5, 52.3º ± 11.6 at 6-week postoperative, 52.4º ± 11.2 at 1-year postoperative and 53.0º ± 11.3 at last follow-up. The average preoperative SS was 32.1º ± 9.0, 31.5º ± 9.2 at 6-week postoperative, 32.9º ± 8.7 at 1-year postoperative and 32.6º ± 8.7 at last follow-up. The average preoperative PT was 20.3º ± 8.3, 20.8º ± 7.9 at 6-week postoperative, 19.7º ± 7.9 at 1-year postoperative and 20.8º ± 8.2 at last follow-up. The average preoperative LL was 46.5º ± 15.2, 46.6º ± 14.4 at 6-week postoperative, 49.0º ± 13.8 at 1-year postoperative and 48.2º ± 14.5 at last follow-up. The average difference between PI and LL (PI - LL) was 5.8º ± 14.3, 5.7º ± 11.8 at 6-week postoperative, 3.4º ± 11.1 at 1-year postoperative and 4.8º ±12.3 at last follow-up. (Table 3.)

Table 1: Patients' Demographic data

DemographicData	n (113)
Sex	
Male	50
Female	63
Age (years)	57.6 ± 13.4
BMI (kg/m^2)	26.3 ± 4.1
Total follow-up (months)	23.6 ± 12.5

Table 2: Summary of clinical data

Clinical data	n (%)
Diagnosis	
Spondylolisthesis	71 (62.8)
Spinal stenosis	8 (7.1)
Degenerative scoliosis	8 (7.1)
DDD	22 (19.5)
HNP	2 (1.8)
Isthmic spondylolisthesis	2 (1.8)
Fusion Technique	
PLF	8 (7.1)
PLIF	2 (1.8)
TLIF	31 (27.4)
ALIF	19 (16.8)
DLIF	9 (7.9)
OLIF	44 (38.9)
Number of fusion levels	
1	75 (66.4)
2	29 (25.7)
3	7 (6.2)
4	1 (0.9)
5	1 (0.9)
L5-S1 fusion include	
Yes	72 (63.7)
No	41 (36.3)

Table 3: Mean measurement of spinopelvic parameters

Radiographic parameter	Preoperative	6-week Postoperative	1-year Postoperative	Last follow-up
PI	52.3º ± 11.5	52.3º ± 11.6	52.4º ± 11.2	53.0º ± 11.3
SS	32.1º ± 9.0	31.5º ± 9.2	32.9º ± 8.7	32.6º ± 8.7
PT	20.3º ± 8.3	20.8º ± 7.9	19.7º ± 7.9	20.8º ± 8.2
LL	46.5º ± 15.2	46.6º ± 14.4	49.0º ± 13.8	48.2º ± 14.5
PI-LL	5.8º ± 14.3	5.7º ± 11.8	3.4º ± 11.1	4.8º ± 12.3

PI = pelvic incidence, SS = sacral slope, PT = pelvic tilt, LL = lumbar lordosis

ISSN 2287-0237 (online)/ 2287-9674 (print)

Pelvic incidence disparity (ΔPI)

PI can either increase or decrease after the surgery. It is better therefore to consider both increase and decrease of PI as the same meaning of disparity. Pelvic incidence disparity (ΔPI) is defined as the changing of PI in both increase (+) and decrease (-) value away from 0º when compared to preoperative value (Figure 2,3). Mean ΔPI was 3.2º ± 4.0 at 6-week postoperative 3.3º ± 4.0 at 1-year postoperative and 3.2º ± 3.4 at last follow-up. This showed a significant change when compared to preoperative ($p < 0.05$) but did not change significantly over time after surgery (Table 4).

Table 4: Preoperative comparison of pelvic incidence disparity (ΔPI)

	ΔPI	*p*
6-week Postoperative	3.2º ± 4.0*	< 0.001
1-year Postoperative	3.3º ± 4.0*	< 0.001
Last follow-up	3.2º ± 3.4*	< 0.001

*$p < 0.05$; significant difference between Postoperative and Preoperative parameter

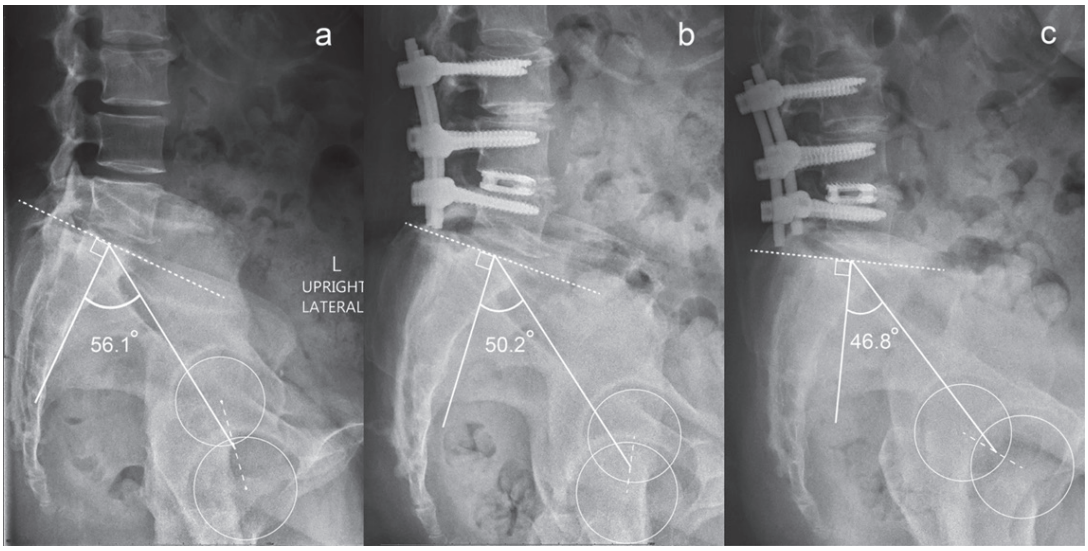

Figure 2: 68-year-old female received a L3-5 TLIF surgery for spinal stenosis. Preoperative (a), 6-week postoperative (b) and 1-year postoperative (c) standing lumbosacral lateral radiographs. Note the pelvic incidence (PI) reductions. Preoperative PI was 56.1º, 6-week postoperative PI was 50.2º with Pelvic incidence disparity (ΔPI) as 5.9º. PI at 1-year postoperative follow-up decreased to 46.8º with ΔPI 9.3º.

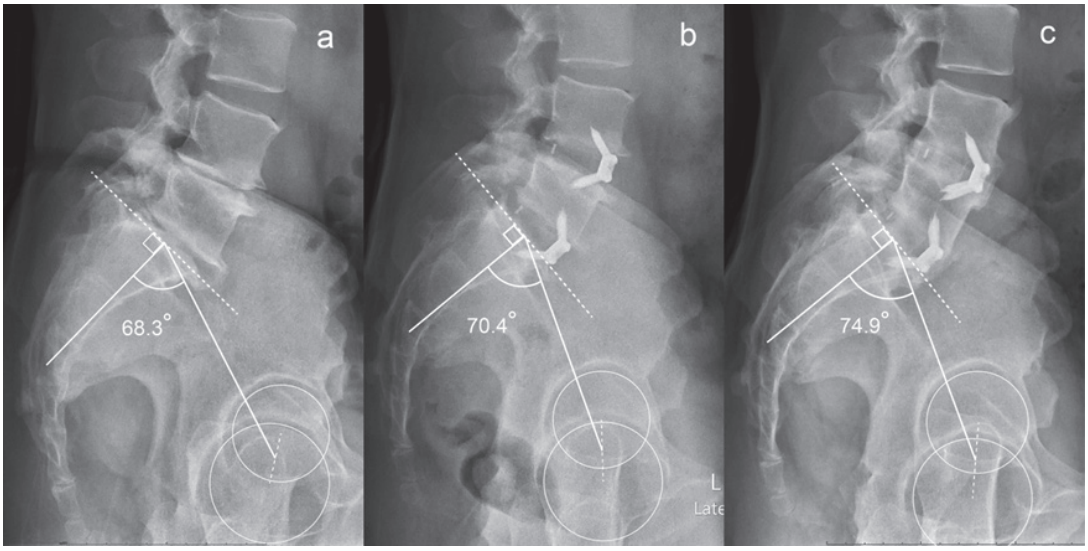

Figure 3: 52-year-old male received a L4-S1 ALIF surgery for degenerative disc disease. Preoperative (a), 6-week postoperative (b) and 1-year postoperative (c) standing lumbosacral lateral radiographs. Note the pelvic incidence (PI) increments. Preoperative PI was 68.3º, 6-week postoperative PI was 70.4º with Pelvic incidence disparity (ΔPI) as 2.1º. PI at 1-year postoperative follow-up increased to 74.9º with ΔPI 6.6º.

Single level fusion had ΔPI of 2.9º ± 2.3 at 6-week postoperative, 2.9º ± 2.5 at 1-year postoperative and 2.6º ± 2.0 at last follow-up. 2 levels fusion had ΔPI of 2.5º ± 2.6 at 6-week postoperative, 3.0º ± 2.6 at 1-year postoperative and 3.3º ± 2.6 at last follow-up. 3 levels fusion had ΔPI of 7.9º ± 12.8 at 6-week postoperative, 8.0º ± 12.1 at 1-year postoperative and 9.8º ± 12.0 at last follow-up. 4 levels fusion had ΔPI of 8.5º at 6-week postoperative, 7.8º at 1-year postoperative and 8.9º at last follow-up. 5 levels fusion had ΔPI of 10.0º at 6-week postoperative, 7.0º at 1-year postoperative and 5.1º at last follow-up. Statistic significant with p-value < 0.05 was observed in 3-level fusion when compare to single and double levels fusion (Table 5).

In L5-S1 fusion group, ΔPI was 3.1º ± 2.7 at 6-week postoperative, 3.1º ± 2.2 at 1-year postoperative and 3.5º ± 2.5 at last follow-up. Without L5-S1 fusion, ΔPI was 3.3º ± 4.6 at 6-week postoperative, 3.4º ± 4.7 at 1-year postoperative and 3.1º ± 3.9 at last follow-up. There is no significant difference in ΔPI between both groups (Table 6).

ΔPI was not different when compared to each fusion technique. In PLF technique the ΔPI was 3.5º ± 3.0 at 6-week postoperative, 3.8º ± 2.2 at 1-year postoperative and 5.0º ± 2.5 at last follow-up. In PLIF technique the ΔPI was 4.4º ± 2.0 at 6-week postoperative, 2.5º ± 0.2 at 1-year postoperative and 3.6º ± 1.1 at last follow-up. In TLIF technique the ΔPI was 2.8º ± 2.0 at 6-week postoperative, 3.1º ± 3.2 at 1-year postoperative and 3.0º ± 2.5 at last follow-up. In ALIF technique the ΔPI was 2.1º ± 2.2 at 6-week postoperative, 2.4º ± 2.2 at 1-year postoperative and 2.6º ± 2.5 at last follow-up. In DLIF technique the ΔPI was 6.4º ± 11.5 at 6-week postoperative, 6.7º ± 11.1 at 1-year postoperative and 5.8º ± 8.8 at last follow-up. In OLIF technique the ΔPI was 3.2º ± 2.8 at 6-week postoperative, 3.1º ± 2.3 at 1-year postoperative and 2.5º ± 1.8 at last follow-up (Table 7.)

Discussion

Pelvic incidence (PI) was known to be a unique anatomical parameter individually. It is constant regardless of age, position and surgery only if the orientation between sacrum and pelvis is maintained.[11] Ozkunt et al.,[12] study the change of spinopelvic parameters in Lenke 5 Adolescent idiopathic scoliosis (AIS) patients who underwent surgical correction and posterior instrumentation. They found significant differences in PT, SS and LL but not PI when compared to preoperative.[12] Asai et al.,[13] analyzed the relationship between age and spinopelvic parameters in 1,461 participants. The results showed that SVA, PT and PI-LL increased with age, and LL decreases with age but showed there was no change in PI.

However it is still controversial that PI could be changed by the motion of sacroiliac joint in some situations. Even in some studies such as Kissling et al.,[14] rotation and translation movement of SI joints in healthy people could be found, but the amounts were very low (1.8º of rotation & 0.7 mm of translation in males and 1.9º of rotation & 0.9 mm of translation in females).

Another cause of SI joint hypermobility could be due to age and degenerative process. Mendoza-Lattes et al[15] also reported an increase in PI linearly with age throughout the lifespan. PI also has been found to be greater in patients with adult spinal deformity than in normal individuals by Cho et al.,[16] in 2010.

Table 5: Comparison of pelvic incidence disparity (ΔPI) and segment of fusion

	1-Level	2-Level	3-Level	*p*
6-week postoperative	2.9º ± 2.3	2.5º ± 2.6	7.9º ± 12.8*	0.0023
1-year postoperative	2.9º ± 2.5	3.0º ± 2.6	8.0º ± 12.1*	0.0089
Last follow-up	2.6º ± 2.0	3.3º ± 2.6	9.8º ± 12.0*	0.0028

* $p < 0.05$; significant difference between 3 Levels fusion and less

Table 6: Preoperative comparison of pelvic incidence disparity (ΔPI) with or without L5-S1 fusion

	Yes	No	*p*
6-week postoperative	3.1º ± 2.7	3.3º ± 4.6	0.7519
1-year postoperative	3.1º ± 2.2	3.4º ± 4.7	0.6985
Last follow-up	3.5º ± 2.5	3.1º ± 3.9	0.6982

Table 7: Comparison of pelvic incidence disparity (ΔPI) and fusion technique

	PLF	PLIF	TLIF	ALIF	DLIF	OLIF	*p*
6-week postoperative	3.5º ± 3.0	4.4º ± 2.0	2.8º ± 2.0	2.1º ± 2.2	6.4º ± 11.5	3.2º ± 2.8	0.1765
1-year postoperative	3.8º ± 2.2	2.5º ± 0.2	3.1º ± 3.2	2.4º ± 2.2	6.7º ± 11.1	3.1º ± 2.3	0.1338
Last follow-up	5.0º ± 2.5	3.6º ± 1.1	3.0º ± 2.5	2.6º ± 2.5	5.8º ± 8.8	2.5º ± 1.8	0.2768

PLF = posterolateral fusion, PLIF = posterior lumbar interbody fusion, TLIF = transforaminal lumbar interbody fusion, ALIF = anterior lumbar interbody fusion, DLIF= direct lateral interbody fusion, OLIF = oblique lumbar interbody fusion

ISSN 2287-0237 (online)/ 2287-9674 (print)

In 2014, Jean et al.,[17] reported the effect of age and sagittal imbalance as the key factor of increased PI and chronic low back pain. The explanation was sagittal disturbance by loss of LL from aging, being overweight and disc degeneration creating a lever arm inducing a forward tilt of the sacrum. Simultaneously, a compensatory backward rotation of the pelvis aim to partially correct this disturbance, leads to increasing the lever arm from SI joint to femoral heads. Accentuation of the sagittal spinal disturbance re-emphasizing the lever arm to rotate the sacrum forward result in twisting into SI joints. If these situations persist over time, it will lead to major disruptions of the complex ligaments structures followed by loss of mechanical stabilizing of SI joints. These will result in twisting mobilization of SI joints and thereby an increase of the PI value.

Surgery of lumbar fusion with posterior instrumentation may alter the alignment of lumbar spine and patient might compensate a spinal alignment through lordosis or kyphosis of lumbar spine. Even the fusion did not include pelvis, a study from Skalli et al.,[18] in 2006 has shown the compensatory movement on the pelvis and changes in pelvic incidence of more than 5º after posterior spinal fusion in idiopathic scoliosis patients. Baek et al.,[19] analysed changes of spinopelvic parameters in long fusion after degenerative lumbar deformity and found a significantly increased PI at 3 months postoperative in long fusion with iliac fixation group. The study concluded that increased PI after iliac fixation might be explained by the movement of the SI joint. Therefore it is suggested that the PI is not a constant value, but a variable affected by long spinal fusion with iliac fixation.

Therefore the pelvis could possibly be the site of compensation also, this may cause motion at SI joint so it is possible for PI to change.

Increased stress on the SI joint after lumbar fusion could accelerate the degenerative process, resulting in an increased SI joint motion.[20] Regarding the changes in postoperative PI values, the concept of the SI joint motion remains controversial. Fromoyer et al.,[21] reported compensatory hypermobility of the SI joint after spinal fusion including the sacrum that could cause acceleration in degenerative change. Ha et al.,[22] also reported the concept of adjacent segment degenerative change of the SI joint after lumbosacral fusion. The result was that the SI joint degeneration was significantly higher in the S1 fusion group than the L5 fusion group without a link in the number of fusion segments and incidence of SI joint degeneration.

Kim et al.,[23] reported an average increase of PI of approximately 3º at the last follow-up relative to preoperatively period in the C7 plump line to S1 > 3 cm group, in long posterior lumbar instrumentation surgery patients. However this was not statistically significant.

Lee et al.,[24] also found an increase in mean PI disparity in patients who received pedicle subtraction osteotomy, anterior lumbar interbody fusion and posterior lumbar interbody fusion. This study also agreed with the concept of PI changing from the SI joint motion after long lumbar fusion and sacropelvic fixation.

In this study mean PI, SS, PT, LL and PI – LL were not significantly different between the preoperative and postoperative period. But when considered in terms of ΔPI, from a null hypothesis that ΔPI should be equal to zero because theoretically pelvic incidence should be constant and could not change in any situation, this study showed a statistically significant change of ΔPI after surgery of the lumbar and lumbosacral fusion. The ΔPI was 3.2º ± 4.0 at 6-week postoperative, 3.3º ± 4.0 at 1-year postoperative and 3.2º ± 3.4 at the last follow-up when compared to the preoperative period which was statistically significant. This study showed no change in ΔPI over a period of time after surgery.

The number of fusion segments seem to have a positive correlation with ΔPI. 3-level fusion groups had more ΔPI when compared to 1-level and 2-level fusion groups in all periods postoperative which was statistically significant. Unfortunately, there was only 1 case in each group of 4-level and 5-level fusion groups so we could not determine the different ΔPI between these two groups and another. What is more, the trend of ΔPI seems to increase subsequently with the number of fusion segments.

Fusion to L5-S1 did not show a difference in ΔPI compared with the non-fusion group. Even some studies showed an increase in stress on the SI joint after lumbosacral fusion that can lead to hypermobility and motion in the SI joint. Our study did not find different ΔPI from both groups in any period of time postoperatively.

Six techniques of fusion were performed at our institute in this study. There were no different ΔPI in each fusion technique. DLIF tended to have the most ΔPI but this was not statistically significant.

There are some limitations of this study. First of all this is a retrospective study that does not contain clinical outcome results. Further clinical studies are needed to establish a correlation between ΔPI and clinical outcomes such as Visual Analog Scale (VAS), Oswestry Disability Index (ODI) and functional score e.g. EQ-5D, SF-36 and HRQOL.

Second, the results were derived through follow-up for a relatively short period of time from among a relatively small number of patients. There is a need to conduct further analysis over a longer period of follow-up and a greater number of cases.

Conclusion

PI might not be a constant value for spinopelvic parameter. Recent studies showed that PI could change in case there is motion in SI joint from stress or shearing force such as degeneration and surgery. This study showed a significant change of PI in terms of ΔPI in patients on whom lumbar and lumbosacral fusion had been performed, with pedicle screws fixation by various fusion techniques.

References

1. Legaye J, Duval-Beaupere G, Hecquet J, et al. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. *Eur Spine J* 1998;7(2):99-103.
2. Glassman SD, Berven S, Bridwell K, et al. Correlation of radiographic parameters and clinical symptoms in adult scoliosis. *Spine* 2005;30(6):682-8.
3. Glassman SD, Bridwell K, Dimar JR, et al. The impact of positive sagittal balance in adult spinal deformity. *Spine* 2005;30(18):2024-9.
4. Schwab FJ, Blondel B, Bess S, et al. Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: a prospective multicenter analysis. *Spine* 2013;38(13):E803-12.
5. Smith JS, Klineberg E, Schwab F, et al. Change in classification grade by the SRS-Schwab Adult Spinal Deformity Classification predicts impact on health-related quality of life measures: prospective analysis of operative and nonoperative treatment. *Spine* 2013;38(19):1663-71.
6. Schwab F, Patel A, Ungar B, et al. Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. *Spine* 2010;35(25):2224-31.
7. Schwab F, Ungar B, Blondel B, et al. Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. *Spine* 2012;37(12):1077-82.
8. Rothenfluh DA, Mueller DA, Rothenfluh E, et al. Pelvic incidence-lumbar lordosis mismatch predisposes to adjacent segment disease after lumbar spinal fusion. *Eur Spine J* 2015;24(6):1251-8.
9. Zhang HC, Zhang ZF, Wang ZH, et al. Optimal pelvic incidence minus lumbar lordosis mismatch after long posterior instrumentation and fusion for adult degenerative scoliosis. *Orthop Surg* 2017;9(3):304-10.
10. Senteler M, Weisse B, Snedeker JG, et al. Pelvic incidence-lumbar lordosis mismatch results in increased segmental joint loads in the unfused and fused lumbar spine. *Eur Spine J* 2014;23(7):1384-93.
11. Lafage V, Schwab F, Patel A, et al. Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. *Spine* 2009;34(17):E599-606.
12. Ozkunt O, Karademir G, Sariyilmaz K, et al. Analysing the change of sagittal balance in patients with Lenke 5 idiopathic scoliosis. *Acta Orthop Traumatol Turc* 2017;51(5):377-80.
13. Asai Y, Tsutsui S, Oka H, et al. Sagittal spino-pelvic alignment in adults: The Wakayama Spine Study. *PloS one* 2017;12(6):e0178697.
14. Kissling RO, Jacob HA. The mobility of the sacroiliac joint in healthy subjects. *Bull Hosp Jt Dis* 1996;54(3):158-64.
15. Mendoza-Lattes S, Ries Z, Gao Y, et al. Natural history of spinopelvic alignment differs from symptomatic deformity of the spine. *Spine* 2010;35(16):E792-8.
16. Cho KJ, Suk SI, Park SR, et al. Risk factors of sagittal decompensation after long posterior instrumentation and fusion for degenerative lumbar scoliosis. *Spine* 2010;35(17):1595-601.
17. Jean L. Influence of age and sagittal balance of the spine on the value of the pelvic incidence. *Eur Spine J* 2014;23(7):1394-9.
18. Skalli W, Zeller RD, Miladi L, et al. Importance of pelvic compensation in posture and motion after posterior spinal fusion using CD instrumentation for idiopathic scoliosis. *Spine* 2006;31(12):E359-66.
19. Baek SW, Park YS, Ha KY, et al. The analysis of spinopelvic parameters and stability following long fusions with S1, S2 or iliac fixation. *Int Orthop* 2013;37(10):1973-80.
20. Ivanov AA, Kiapour A, Ebraheim NA, et al. Lumbar fusion leads to increases in angular motion and stress across sacroiliac joint: a finite element study. *Spine* 2009;34(5):E162-9.
21. 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.
22. Ha KY, Lee JS, Kim KW. Degeneration of sacroiliac joint after instrumented lumbar or lumbosacral fusion: a prospective cohort study over five-year follow-up. *Spine* 2008;33(11):1192-8.
23. Kim YJ, Bridwell KH, Lenke LG, et al. An analysis of sagittal spinal alignment following long adult lumbar instrumentation and fusion to L5 or S1: can we predict ideal lumbar lordosis? *Spine* 2006;31(20):2343-52.
24. 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(11):3707-14.

ISSN 2287-0237 (online)/ 2287-9674 (print)