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ORIGINAL ARTICLE

Changes in pelvic anatomy after long corrective fusion using iliac screws for adult spinal deformity

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Abstract

Purpose Long fusion to the sacrum with iliac screws can decrease pelvic incidence (PI). Considering the physiological range of movement of the sacroiliac joint, this decrease may be relatively extreme. The purpose of the study was to determine changes in pelvic morphology after orthopedic surgery using long fusion with iliac screws, and examine the relationship between changes in PI and morphology.

Methods We included data from 80 consecutive patients who underwent corrective surgery for adult spine deformity (72 female and 8 male; mean age: 71.1 years). We examined preoperative and early postoperative full-standing X-ray images and pelvic computed tomography of the patients and compared the following: (1) pre- and postoperative pelvic measurements including PI, (2) correlations between change of PI, iliac angle, and distance between posterior superior iliac spines (DPSIS).

Results After surgery, PI decreased significantly (−3.3°, 95% confidence interval [95%CI] −4.3° to −2.3°, $P<0.01$) and DPSIS increased significantly (+2.7 mm, 95%CI 1.7 to 3.8 mm, $P<0.01$). By contrast, iliac angle decreased significantly (−1.4°, 95%CI −2.1° to −0.7°, $P<0.01$). There were significant correlations between changes of PI and iliac angle ($r=0.34$, $P<0.01$) and between changes of DPSIS and iliac angle ($r=-0.44$, $P<0.01$).

Conclusions We observed changes in pelvic morphology associated with spinal pelvic correction surgery using iliac screws and changes in pelvic incidence related to these changes in pelvic morphology. We recommend selecting pelvic anchors and surgical procedures considering potential movement of the sacroiliac joint.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.

Keywords Pelvic · Pelvic incidence · Sacroiliac joint · Long fusion · Adult spine deformity

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Introduction

Posterior long fixation and fusion of the thoracic spine to the sacrum is one of the most common surgical treatments for adult spinal deformity (ASD) [1–4]. Pelvic incidence (PI) is regarded by many as the key parameter for estimating ideal lumbar lordosis to be restored in spinal long fusion in ASD because PI is considered to change little [5, 6]. Changes in PI reflect the movement of the sacroiliac (SI) joint [6, 7]. The physiological range of motion of the SI joint movement is 1–4° of rotation and 1–2 mm of translation [8–10].

Long fusion to the sacrum with iliac screws can decrease PI by 3.9° [11]. Considering the physiological range of movement of the sacroiliac joint, this change may be extreme. Nevertheless, to our knowledge, there is no report on the mechanism. Changes in PI after long fusion using iliac screws are possibly beyond the range of physiological changes. So why can such a large change occur? Perhaps because the strong correction force after using iliac screws, pedicle screws (PS), and rods, changes not only the SI joint, but also the pelvic morphology.

The purpose of the present study was to determine changes in pelvic morphology after orthopedic surgery using long fusion with iliac screws, and to examine the relationship between changes in PI and pelvic morphology.

Materials and methods

Design

After approval by our institutional review board (approval No. 1101), we conducted a retrospective observational study of a cohort of patients with a diagnosis of ASD who underwent corrective surgery.

Patients

Data from consecutive patients who underwent corrective surgery for ASD between January 2013 and July 2017 with pre- and early postoperative full-standing X-rays and pelvic computed tomography (CT) were included in this study. The inclusion criteria were a radiographic diagnosis of ASD defined by at least one of the following parameters: a C7 sagittal vertical axis (SVA), which is the distance between the C7 plumb line and the posterosuperior edge of S1, > 5 cm, or pelvic tilt (PT), which is the orientation of the pelvis with respect to the femurs and the rest of the body, > 30°, or both. Patients who underwent surgery without iliac screws were excluded. Basic demographic and surgical data: sex, age at surgery, area of fusion, and type of procedure were collected. Demographic and surgical data are reported in Table 1.

Table 1 Demographic and operative data

Parameter	$N = 80$
Age at surgery (years)	71.1 ± 7.1 (50–81)
Sex (M:F)	8:72
Location of UIV (*n*)	
T3	2
T4	9
T5	5
T6	2
T8	3
T9	23
T10	24
T11	1
L1	1

Interval and ratio values represent the mean ± SD. Numbers in parentheses are minimum–maximum values (range)

UIV upper instrumented vertebra

Surgical procedure

First, we selected an anterior approach to perform lateral interbody fusion (LIF) from the level of the L1-2 or L2-3 to L4-5 disks to obtain adequate coronal and sagittal global spine alignment in patients with ASD. Then the patient was moved to a prone position. We performed Ponte osteotomy and posterior lumbar interbody fusion (PLIF) at the level of the L5-S disk and correction of spinal kyphosis through cantilever force using bilateral S1 screws and bilateral single or dual iliac screws. In the case of loss of flexibility of spinal motion, we added Ponte, pedicle subtraction, or vertebral column osteotomy. Iliac screws were bound to the S1 pedicle screw using a rod on each side, resulting in 2 or 3 rigid anchors in the pelvis bilaterally [12]. Then iliac screws and a rod for pedicle screws were connected with an offset connector.

Radiographic measurements

Radiographs and CT of pelvis obtained pre- and postoperatively were examined. Preoperative radiographs and CT were obtained immediately before surgery, and postoperative radiographs and CT were obtained within a month after surgery. All digital radiographs were examined using a 3D image analysis system (Synaps Vincent, version 4.6, Fujifilm, Tokyo, Japan). In addition to spinopelvic parameters, measurements of the following four pelvic parameters were made from full-standing X-ray images: (1) intercristal diameter (ID), (2) transverse diameter of pelvic inlet (TDUP), (3) distance between the center of each femoral head (DBH), and (4) anatomical conjugate (AC) (Fig. 1a–d). The full-length X-ray images were obtained with the patient in a free-standing posture with fingers placed on the clavicles.

The following five parameters were measured using pelvic CT: (1) distance between posterior superior iliac spines (DPSIS), (2) iliac angle, (3) cranial protrusion of the sacrum, and (4) caudal protrusion of the sacrum (Fig. 2).

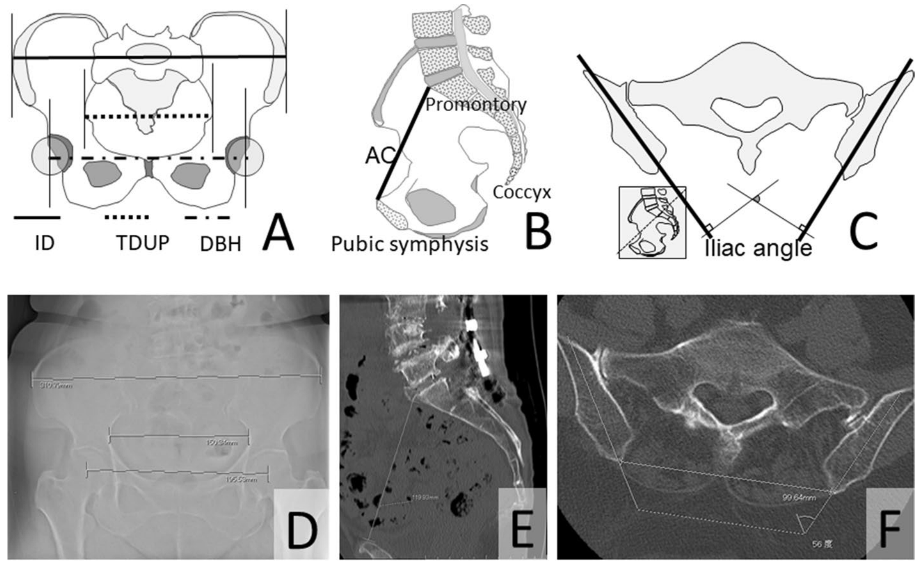

Fig. 1 Pelvic measurements on X-ray images and CT. ID, TDUP, DBH were measured as in figures **a** and **d**. AC was measured as shown in figures **b** and **e**. DPSIS and iliac angle were measured as shown in figures **c** and **f**. ID: intercristal diameter, TDUP: transverse diameter of pelvic inlet, DBH: distance between center of each femoral head, AC: anatomical conjugate, DPSIS: distance between posterior superior iliac spine

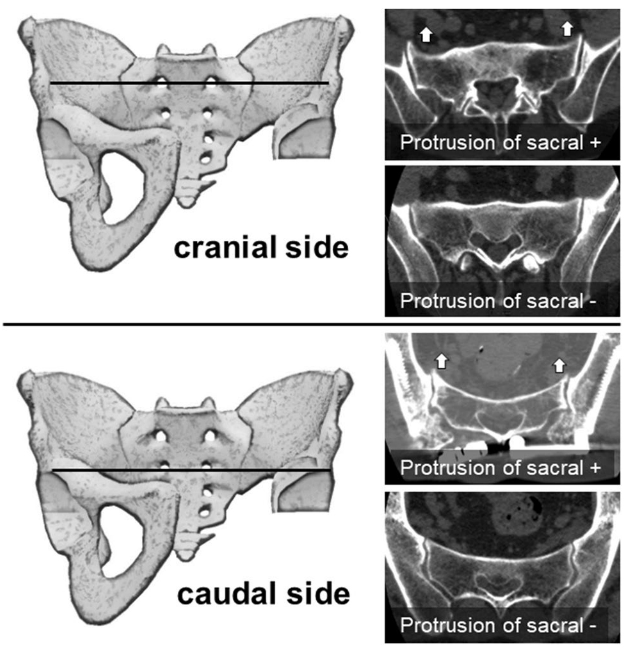

Fig. 2 Anterior protrusion of the sacrum. Patients in whom the anterior surface of the sacrum is located 3 mm or more anterior to the anterior surface of the ilium were defined as having anterior protrusion of the sacrum. We evaluated the protrusion using a slice horizontal to the end plate of S1. We evaluated the cranial and caudal thirds of the sacrum

Total measurement of pelvic morphology by CT was performed using an oblique axial slice reconstructed parallel to the S1 endplate. Measurements of parameters from images obtained before and after surgery were always performed at the same level. Based on these parameters, we compared the following: (1) preoperative and postoperative spinopelvic parameters including PI (Table 2), (2) preoperative and postoperative pelvic parameters (Figs. 3, 4, 5), (3) correlations between changes of PI, iliac angle, and DPSIS (Figs. 6 and 7), (4) preoperative and postoperative protrusion of the cranial and caudal sides of the sacrum (Tables 3, 4), and (5) PI decrease with and without protrusion of the cranial side of the sacrum (Table 5). Spinopelvic parameters including PT, SS, and PI were all measured using full-length X-ray lateral views with the patient in a standing position. The iliac angle was measured using imaging software and a horizontal slice from the S2 endplate. Measurements were taken at a level matching the S2 slice. Two observers each measured the angle three times, and the average value was used. We defined protrusion of the sacrum of 2 mm or more as being a sacral protrusion. When osteophytes were present, the apices of osteophytes were compared with each other.

Measurements were made by two spine certified physicians (H.O. and T.O.), and the mean value of the measurements by both was adopted. Protrusion of the sacrum was only judged as positive when there was a consensus. The intraclass correlation coefficient (ICC) (2, 1) for interobserver reliability of measurements of PI, DPSIS, and iliac angle was 0.86, 0.94, and 0.97, respectively. Cohen's kappa for protrusion of the cranial or caudal sides of the sacrum was 0.79 and 0.90, respectively. The measurements by the two observers were substantially consistent.

Clinical outcomes

Postoperative baseline patient health status was determined (for lumbar pain-related factors) using the Roland–Morris Disability Questionnaire (RDQ) [13] and Oswestry Disability Index (ODI) [14] measured on a 50-point scale preoperatively and 1 year postoperatively.

Table 2 Preoperative and postoperative spinopelvic parameters and clinical outcome

Parameter	Preoperative	Early postoperative	One year postoperative	P
PI (°)	50.8 ± 9.1 (31–76)	47.5 ± 8.9 (31–79)	49.7 ± 9.4 (34–81)	< 0.01[a]
PT (°)	31.7 ± 14.6 (− 8 to 57)	19.7 ± 9.1 (1–39)	23.6 ± 8.5 (6.5–43)	< 0.01[a]
SS (°)	16.3 ± 13.1 (− 19 to 54)	28.7 ± 8.3 (11–48)	27.7 ± 8.3 (11–49)	< 0.01[a]
LL (°)	8.4 ± 21.6 (− 52 to 52)	49.9 ± 10.3 (21–78)	49.3 ± 10.0 (24–77)	< 0.01[a]
SVA (mm)	120.1 ± 67.6 (− 7 to 293)	26.5 ± 39.4 (− 45 to 153)	26.5 ± 39.4 (− 45 to 153)	< 0.01[a]
GT (°)	52.4 ± 16.8 (13–89)	21.8 ± 12.1 (0–56)	26.2 ± 12.3 (5–63)	< 0.01[a]
TPA (°)	40.4 ± 14.2 (10–74)	16.4 ± 10.1 (− 6 to 46)	20.5 ± 9.9 (3–52)	< 0.01[a]
ODI (%)	45.9 ± 17.2 (11.1–91.1)	N.D	32.2 ± 16.1 (2.2–73.3)	< 0.01[a]
RDQ	12.6 ± 5.1 (0–23)	N.D	10.4 ± 2.7 (0–23)	0.01[a]

Interval and ratio values are presented as the mean ± SD. Numbers in parentheses are minimum–maximum values (range)

N.D. no data, *PI* pelvic incidence, *PT* pelvic tilt, *SS* sacral slope, *LL* lumbar lordosis, *SVA* C7 sagittal vertical axis, *GT* global tilt, *TPA* T1 pelvic angle

P value indicates comparison between preoperative and one year postoperative

[a] $P < 0.05$

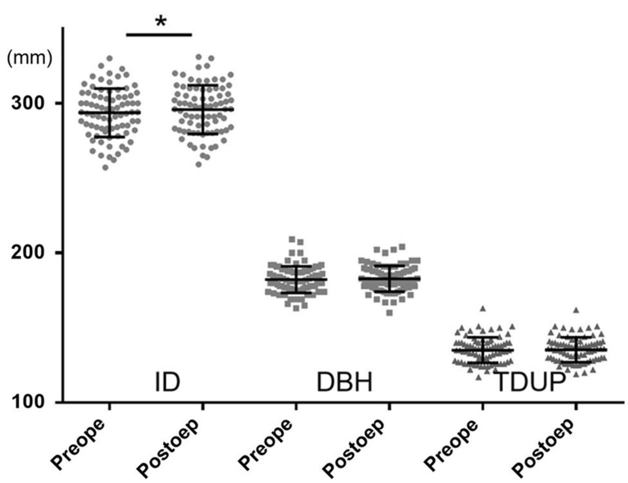

Fig. 3 Postoperative change in pelvic parameters. *$P < 0.05$. Error bars represent 95% confidence intervals. ID: intercristal diameter, TDUP: transverse diameter of pelvic inlet, DBH: distance between center of each femoral head, Preop: before surgery, Postop: after surgery

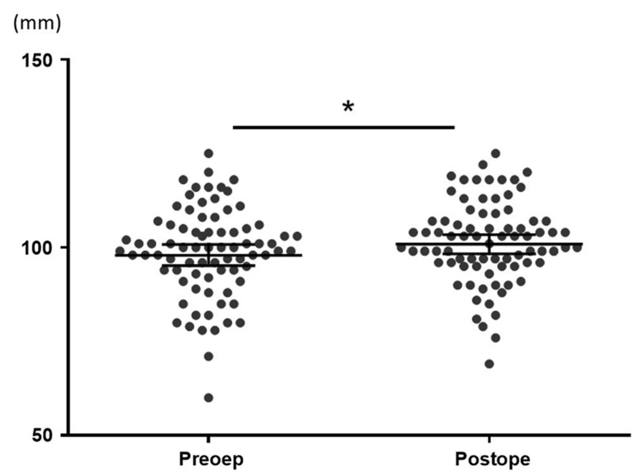

Fig. 4 Postoperative change of DPSIS. *$P < 0.05$. Error bars represent 95% confidence intervals. DPSIS: distance between posterior superior iliac spine, Preop: before surgery, Postop: after surgery

Statistical analysis

All data are reported as means ± SD. Comparisons of interval or ratio scale values were made using a Welch *t* test, ordinal scale data were assessed using a Mann–Whitney *U* test, and nominal scale data were compared using a Fisher exact test. All statistical calculations were performed using Prism (version 6.0, GraphPad Software, La Jolla, CA). $P < 0.05$ was considered significant.

Results

Patient population and changes in pelvic incidence

We included eligible data from 80 patients in this study. The baseline characteristics of the patients are summarized in Table 1. The mean preoperative, postoperative, and spinopelvic parameters and clinical outcome are summarized in Table 2. A significant postoperative improvement of spinal pelvic parameters and sagittal balance was identified. Postoperative PI was decreased significantly from the preoperative angle (− 3.3°, 95% confidence interval [95%CI] − 4.3° to − 2.3°, $P < 0.01$). ODI and

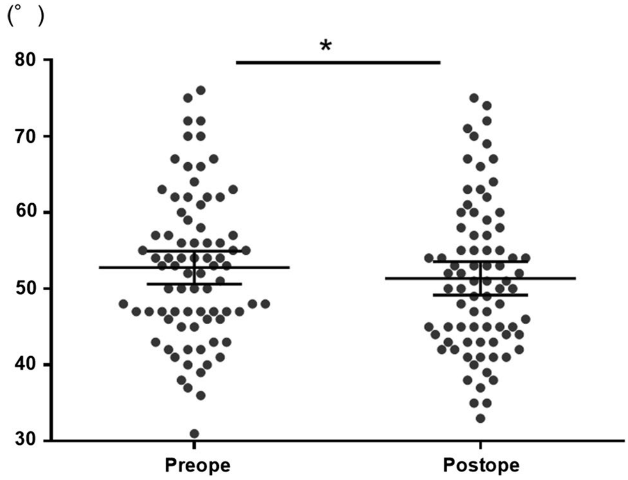

Fig. 5 Postoperative change of iliac angle. *$P < 0.05$. Error bars represent 95% confidence intervals. Preop: before surgery, Postop: after surgery

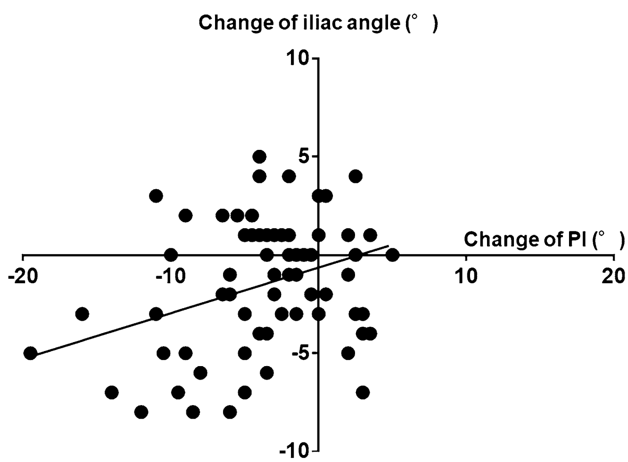

Fig. 6 Correlation between changes in PI and iliac angle. *$P < 0.05$. PI: pelvic incidence, $r = 0.34$, $P < 0.01$

RDQ were significantly improved 1 year postoperatively compared with their values preoperatively.

Changes in distance between the posterior superior iliac spine and iliac angle

Postoperative distance increased significantly from the preoperative distance (+2.7 mm, 95%CI 1.7 to 3.8 mm, $P < 0.01$; Fig. 4). By contrast, postoperative iliac angle decreased significantly from the preoperative angle (−1.4°, 95%CI −2.1° to −0.7°, $P < 0.01$; Fig. 5).

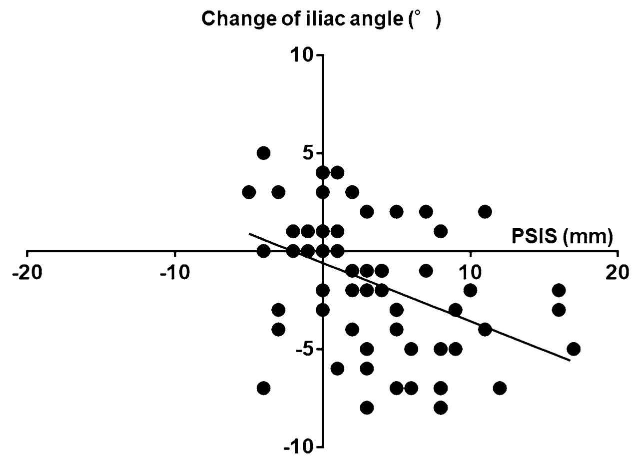

Fig. 7 Correlation between change of DPSIS and iliac angle. *$P < 0.05$. DPSIS: distance between posterior superior iliac spine

Correlations between change of PI, iliac angle, and DPSIS

The correlations between changes of PI and of iliac angle ($r = 0.34$, $P < 0.01$; Fig. 6) and between changes of DPSIS and of iliac angle were significant ($r = -0.44$, $P < 0.01$; Fig. 7).

Anterior protrusion of the sacrum

Before surgery, we planned 48 (60%) patients to have anterior protrusion of the sacrum, but after surgery this decreased slightly to 42 (53%) patients with protrusion of the cranial side (Table 3; Fig. 2). By contrast, on the caudal side, the anterior protrusion of the sacrum increased from 19 patients preoperatively to 37 patients postoperatively (Table 4; Fig. 2).

Comparison of the decrease in PI with and without anterior protrusion of the cranial side of the sacrum before surgery

The decrease in PI between patients with and without anterior protrusion of the cranial side of sacrum before surgery was −4.4 ± 0.7° and −1.7 ± 0.7°, respectively. In the patients where the cranial side of the sacrum protruded anteriorly, the decrease in PI associated with surgery was significantly greater than the decrease in patients in whom it did not protrude (−2.7°, 95%CI 0.7° to 4.8°, $P < 0.01$).

Table 3 Preoperative and postoperative protrusion of cranial sacrum

	Postoperative					
	Protrusion		Nonprotrusion		Total	
Preoperative						
Protrusion	38	79.2%	10	20.8%	48	100%
Nonprotrusion	4	13.5%	28	87.5%	32	100%
Total	42		38		80	

Table 4 Preoperative and postoperative protrusion of caudal sacrum

	Postoperative					
	Protrusion		Nonprotrusion		Total	
Preoperative						
Protrusion	14	73.7%	5	26.3%	19	100%
Nonprotrusion	23	37.7%	38	62.3%	61	100%
Total	37		43		80	

Table 5 Comparison of clinical outcome and global alignment at one year postoperatively between groups of patients with early postoperative PI > 50° and PI ≤ 50°

Variable	Early postop PI > 50° (N = 25)	Early postop PI ≤ 50° (N = 48)	*P* value
1-year postoperative			
PT (°)	28.4 ± 1.7	21.2 ± 1.1	< 0.01[a]
SS (°)	31.6 ± 1.8	25.6 ± 1.0	< 0.01[a]
LL (°)	50.0 ± 2.4	48.9 ± 1.3	0.66
PI-LL (°)	8.7 ± 2.8	− 3.8 ± 1.4	< 0.01[a]
TK (°)	43.8 ± 3.2	49.2 ± 2.3	0.17
SVA (mm)	56.0 ± 10.2	27.9 ± 5.0	< 0.01[a]
GT (°)	33.5 ± 2.5	22.2 ± 1.6	< 0.01[a]
TPA (°)	26.8 ± 2.1	17.1 ± 1.2	< 0.01[a]
Complication			
PJK {cases (%)}	11 (44%)	18 (37%)	0.62
Iliac loosening {cases (%)}	8 (32%)	10 (21%)	0.39
S1 pedicle screw loosening {cases (%)}	6 (24%)	10 (21%)	0.77
Clinical outcome			
1y ODI (%)	30.5 ± 2.6	29.3 ± 3.7	0.78
1y RDQ	9.3 ± 1.2	10.0 ± 1.2	0.70

Interval and ratio values are presented as the mean ± standard error

Early postop early postoperative, *PT* pelvic tilt, *SS* sacral slope, *LL* lumbar lordosis, *PI-LL* pelvic incidence-lumbar lordosis, *PI* pelvic incidence, *SVA* sagittal vertical axis, *GT* global tilt, *TPA* T1 pelvic angle, *PJK* proximal junctional kyphosis, *ODI* Oswestry disability index, *RDQ* Roland–Morris disability questionnaire

[a] $P < 0.05$

Comparison of clinical outcome and global alignment at one year postoperatively between groups of patients with early postoperative PI > 50° and PI ≤ 50°

One year postoperatively, there was no significant difference in the frequency of proximal junctional kyphosis, or frequency of iliac screws loosening, or ODI, RDQ between the two groups of patients. PT, SS, PI-LL, SVA, GT, and TPA were significantly less in patients with PI ≤ 50° than they were in patients with PI > 50° (Table 5).

Discussion

SI joints connect the lowest end of the trunk skeleton with the lower limb skeleton. The perfectly interlocking SI joints have evolved to be generally stable and can effectively transfer large loads to the lower limbs [15–17]. The range of motion of the SI joint is 1–4° rotation and 1–2 mm translation [8–10]. Rough irregularities appear in the SI joints during adolescence and change the flexible joint to a type of fusion joint [17]. Degeneration appears in the SI joints in the fourth decade of life [18], and by 70 years of age, about 10% of individuals have fused SI joints [19, 20]. Although there is no term to perfectly describe the complicated movement of an SI joint, nutation and counternutation are used relatively often [21]. Nutation increases PI and counternutation decreases PI. The correlation between age and PI was found significant only for individuals > 60 years. The mean values of PI are significantly greater for these individuals than they are for younger people [22, 23]. As the center of gravity of the trunk moves anteriorly to the point where sagittal balance is exacerbated, humans generally attempt retroversion of the pelvis to compensate for this movement [24]. Both of these forces work toward nutation of the SI joint. Patients with ASD may have a larger than physiological PI. Because PI has large individual variation [23], it is difficult to judge whether SI joints are nutated by PI alone.

Lee et al. observed the progress of patients after lumbar spinal fusion surgery and reported that PI gradually increases by 11.4° [25]. It can be predicted that PI is exacerbated with the worsening of total alignment. Many of our patients who undergo surgery for ASD have extremely nutated SI joints. Nutation is sometimes beyond the physiological range. In other words, nutation may be a rotation subluxation. Richard et al. reported that PI decreased by 3.9° after long fusion surgery using iliac screws. This suggests that extremely nutated SIJs of patients with ASD could be corrected by surgery. The effect of PI correction on clinical outcomes has remained largely unknown. However, because surgery aims at restoring physiological alignment, we install a rod with lordosis between 2 iliac screws on one side and SIPS with consideration of SIJ correction. We initiated this research because we were concerned about the adverse effect of a strong PI correction force on the morphology of the pelvis.

We made three main observations: (1) changes in pelvic morphology associated with spinal pelvic correction surgery using iliac screws, (2) changes in PI were related to these changes in pelvic morphology, and (3) in patients where the cranial side of the sacrum protruded anteriorly, the reduction of PI by surgery was large.

We observed changes in pelvic morphology associated with spinal pelvic correction surgery using iliac screws. By contrast, we observed no significant postoperative change in TDUP, DBH, or AC. There may be no change in the true pelvis. Although we observed a slight increase in ID, this is suspected as the influence of posture during photography because of the postoperative decrease in PT. There was no instance in which the pubic symphysis was extended. By contrast, after surgery, PI decreased, DPSIS increased, and iliac angle decreased. Before surgery, there were 19 patients (23%) with anterior protrusion of the cranial side of the sacrum, but this was increased to 37 patients (46%) after surgery.

Changes in PI by surgery were associated with changes in pelvic morphology. Decrease in PI and decrease in iliac angle (Fig. 4), and increase in DPSIS and decrease in iliac angle were correlated (Fig. 5). For the corrective force used to counternutate the nutated SI joints to be effective, the posterior part of the ilium on both sides of the sacrum will widen and the iliac angle may decrease (Fig. 8).

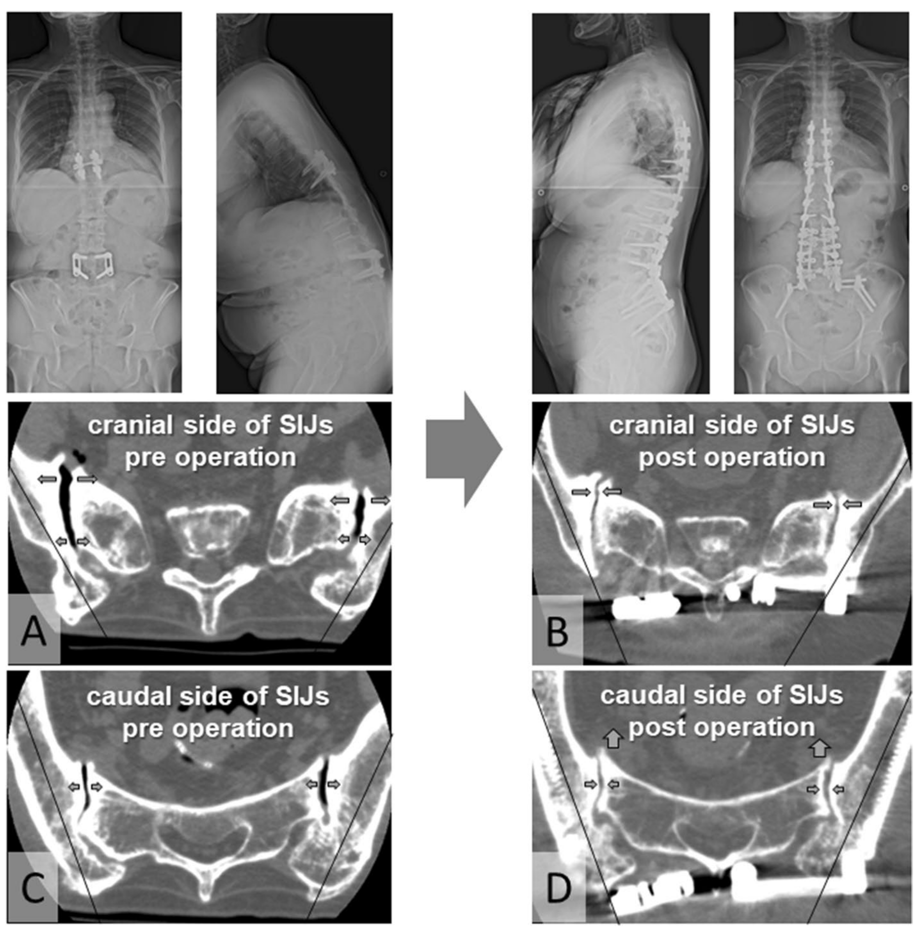

Fig. 8 Representative case of sacroiliac joint changes after long fusion using iliac screws. A 75-year-old woman with ASD. T8-iliac posterior correction surgery was performed. PI decreased from 60° to 46°, and the iliac angle decreased from 67° to 59°. The caudal side of the sacrum protruded anteriorly after surgery. SVA decreased from 257.5 mm to 27.0 mm

In patients where the cranial side of the sacrum protruded anteriorly, the reduction in PI by surgery was large. Changes in PI reflect movement of the SI joint [7, 26]. When the SI joint is nutated, PI increases, and when counternutated it decreases PI. A downward force because of body weight produces an anterior bending torque, which increases as the trunk tilts anteriorly. Therefore, older patients undergoing long fusion to the sacrum without pelvic fixation have an increase in PI postoperatively [25]. Patients who need surgery for ADS may have an extremely nutated SI joint. We can predict that SI joints nutated; this is associated with significant anterior protrusion of the cranial side of the SI in patients in whom the cranial side of the sacrum protrudes anteriorly. Furthermore, the increased protrusion of the caudal side of the sacrum observed in a number of patients after surgery may be the result of the SI joint counternutation.

The present study has some limitations. First, the present study is limited by its retrospective nature. We were therefore unable to examine the effect of changes in pelvic morphology on clinical outcome. The findings are limited because we were only able to measure parameters on images obtained within a month after surgery and so long-term outcomes were not examined. Second, spinopelvic and sagittal measurements and clinical outcomes were determined early postoperatively and one year postoperatively, but the pelvic morphology was only evaluated by CT at 1 month postoperatively. The present study shows pelvic changes due to surgical techniques. However, it has not been possible to examine what changes occur in the morphology of the sacroiliac joints in the subsequent course. Third, despite that most of the sacroiliac joints coalesce and lose their range of motion with aging, in the present study we have stated in the limitations that whether or not the sacroiliac joints are fused cannot be determined. Fourth, although it has been reported that the value of PI can differ depending on posture during image acquisition, we could not consider these differences in our present study. All spinopelvic parameters in our study were measured from full-length X-ray images with the patient standing, but DPSIS and iliac angle were measured from CT image with the patient supine [26, 27].

We observed that the correction of PI was associated with changes in pelvic morphology. The changes in the morphology of the pelvis such as in PI, iliac angle, and DPSIS are relatively small, and actual differences between the two groups are not recognized in clinical outcomes. However, while surgeons were probably not aware until now that the pelvic morphology changes, even slightly, after long fusion using iliac screws, we believe this finding will be a trigger for new discoveries that may change future clinical outcomes. Because these changes occur mainly around the SI joint, we suspect that a strong load is applied to the iliac screws. There is the possibility that the SI joint may nutate again if the iliac screws loosen. The correction between iliac and S1 screws may not be effected when sacral alar-iliac screws are used as the pelvic anchor. A future study of methods to ensure that the pelvic anchor does not loosen is warranted. We would like to compare PI correction when using sacral alar-iliac or iliac screws. We will also consider bone grafting for the SI joint.

Conclusions

We observed changes in pelvic morphology associated with spinal pelvic correction surgery using iliac screws and changes in PI after surgery related to these changes in pelvic morphology. In patients in whom the cranial side of the sacrum protruded anteriorly, the reduction of PI by surgery was relatively large. It may be necessary to select pelvic anchors and surgical procedures considering potential movement of the SI joint. Changes in the sacroiliac joints associated with long fusion did not significantly affect the complications and clinical outcome at 1 year after surgery.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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