Occupancy rate of pedicle screw below 80% is a risk factor for upper instrumented vertebral fracture following adult spinal deformity surgery

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Shin Oe, MD, PhD,[1] Yu Yamato, MD, PhD,[1] Tomohiko Hasegawa, MD, PhD,[2] Go Yoshida, MD, PhD,[2] Tomohiro Banno, MD, PhD,[2] Hideyuki Arima, MD, PhD,[2] Koichirou Ide, MD, PhD,[2] Tomohiro Yamada, MD, PhD,[2] Keiichi Nakai, MD,[2] Kenta Kurosu, MD,[2] Yukihiro Matsuyama, MD, PhD[2]

[1]Department of Orthopedic Surgery and Division of Geriatric Musculoskeletal Health Hamamatsu University School of Medicine

[2]Department of Orthopedic Surgery, Hamamatsu University School of Medicine, Hamamatsu, Japan

***Corresponding author:**

Shin Oe, MD

Department of Orthopedic Surgery and Division of Geriatric Musculoskeletal Health Hamamatsu University School of Medicine

1-20-1 Handayama Higashi-ku, Hamamatsu, Shizuoka 431-3192, Japan

Tel: 81-53-435-2299

Fax: 81-53-435-2296

E-mail: mecersior@gmail.com

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Abstract

Study Design: Single-center retrospective study

Objective: To clarify whether an occupancy rate of pedicle screw (ORPS) <80% in an upper instrumented vertebra (UIV) is a risk factor for UIV fracture (UIVF).

Summary of Background data: The ratio of the length of the pedicle screw to the anteroposterior diameter of the vertebral body at the UIV is defined as ORPS. Previous studies showed that the stress on the UIV is most reduced when ORPS is >80%. However, it remains unclear whether these results are clinically valid.

Methods: A total of 297 patients who had undergone adult spinal deformity surgery were included in the study. UIVF incidence was assessed and a logistic regression analysis was conducted to uncover the risk factors for UIVF. The group with an ORPS ≥80% and <80% was defined as the H (n=198) and L (n=99) group, respectively.

Results: The mean age of both groups was 69 years. The average ORPS in the L and H groups was 70% and 85%, respectively. The incidence of UIVF was 30% in group L and 15% in group H (P<0.01). Additionally, the 99 patients in group H were subdivided into two groups, according to whether the screws penetrated the anterior wall of the vertebral body: 68 patients had no penetration (group U), while it was present in 31 patients (group B). A total of 10% and 26% of

the patients in the U and B groups, respectively, experienced UIVF (P<0.05). Logistic regression analysis of possible UIVF risk factors revealed an odds ratio of 3.9 for ORPS <80% (P=0.007, 95% confidence interval 1.4-10.5).

Conclusion: To reduce UIVF, screw length should be set with a target ORPS of 80% or higher. If the screw is long enough to penetrate the anterior wall of the vertebral body, the risk of UIVF is greater.

Keywords: Adult spinal deformity, upper instrumented vertebral fracture, proximal junctional kyphosis, proximal junctional failure, occupancy rate of pedicle screw, mechanical complications

INTRODUCTION

Proximal junctional kyphosis (PJK) is a common mechanical complication of surgery for adult spinal deformity (ASD). PJK is a compensatory change in spinal alignment after surgery, whereas proximal junctional failure (PJF) is associated with structural destruction of fractures, ligaments, and discs.[1-4] Furthermore, among PJF, fractures of the upper instrumented vertebra (UIV) are sometimes reported to cause serious neurological complications, such as spinal cord injury and myelopathy.[1,5-7] Oe et al. reported that UIV fractures (UIVF) occurred in 18.2% of ASD surgeries, and 10.3% resulted in spinal cord injury.[5] Preventing UIVF is very important because, although infrequent, it is a serious complication. However, the effective approaches to prevent UIVFs remain unclear. Strengthening bone density is considered an important measure,[8,9] but some reports indicate that bone density and PJF are not related.[5,10,11] Recently, Oe et al. named the ratio of pedicle screw (PS) length to the anterior-posterior diameter of the vertebral body at UIV as occupancy rate of pedicle screw (ORPS) and, using finite element analysis, reported that the stress on the UIV decreased the most when the ORPS was 81.8% or more .[12] However, if the screw is too long, it can penetrate the anterior wall of the UIV. Furthermore, a few reports have shown that bicortical screw fixation is also a risk factor for UIVF.[13,14]

The present study aimed to investigate the incidence of UIVF in ASD patients with ORPS ≥ 80% and in those with ORPS < 80%. In addition, a sub-analysis of the patients with high ORPS compared the incidence of UIVF between patients with and without anterior vertebral wall injury.

MATERIALS AND METHODS

Ethical Considerations

The study protocol was approved by the Institutional Review Board of our university. Informed consent was obtained from all the participants.

Patients

A total of 519 patients who underwent surgery for ASD between March 2010 and August 2020 at our hospital were included in this study. ASD was defined as the presence of at least one of the following: degenerative or idiopathic scoliosis with a Cobb angle ≥20° in the coronal plane, sagittal vertical axis (SVA) ≥50 mm, pelvic tilt (PT) ≥25°, and/or thoracic kyphosis (TK) ≥60° on a standing radiograph of the whole spine. The inclusion criteria were: (1) age ≥40 years, (2) follow-up of at least two years, (3) PS diameter is 5.5 mm at UIV, and (4) informed consent provided by the patient for participation in this study. The exclusion criteria were: (1)

instrumentation other than PS (e.g., transverse process hook or sub-lamina taping) on one side or both sides of the UIV; (2) pathology of deformity as follows: neuromuscular disease, spinal tuberculosis, or congenital or syndromic scoliosis; (3) number of fused levels ≤3; (4) incomplete questionnaire or radiographic data; and (5) screw malposition (cutout to outside) at the UIV level. The patients were divided into a lower ORPS group (ORPS <80%, group L) and a higher ORPS group (ORPS ≥80%, group H). As a sub-analysis, group H was divided into the unicortical group (group U, defined as no penetration of the anterior wall of the vertebral body at UIV) and bicortical group (group B, defined as penetration of the anterior wall of the vertebral body on at least either side). The other sub-analysis were perfored to evaluate the cause of UIVF. The patients with UIVF within 2 years after the surgery were defiened as group UIVF+, those without it were assigned to group UIVF-.

Measurement data

The following patient characteristics were evaluated: age, sex, body mass index (BMI), smoking and alcohol habits, medications for osteoporosis (bisphosphonate, teriparatide, estrogen, and denosumab), American Society of Anesthesiologists performance status (ASA-PS), number of fused segments, presence of pelvic fusion, 3-column osteotomy (grades 3, 4, 5, and 6),[15] operative time, and estimated blood loss. Bone mineral density was measured using dual-energy X-ray

absorptiometry for the total proximal femur and expressed as a T-score. The cut-out and penetration of PS at the UIV were evaluated using postoperative computed tomography (CT).

The radiographic parameters measured were (1) PT, (2) lumbar lordosis (L1-5), (3) pelvic incidence, PI (4) TK (T5-T12), (5) T1 slope, (6) cervical lordosis, (7) C2-7 SVA, (8) proximal junctional angle (PJA), and (9) SVA. Whole-spine radiographs were taken using 36-inch-long cassettes in the standing position. Patient-reported outcome measures (PROMs) were evaluated using the Oswestry Disability Index (ODI) and Scoliosis Research Society-22 (SRS-22) score.

As shown in **Figure 1**, the parameters related to instrument installation at the UIV were evaluated using radiographs obtained during surgery. These parameters were the following: tip-apex distance of the PS (TAD = [a+b+c+d], where a (left side) and b (right side) represent the distance from the tip of the PS to the center line of the UIV in the anteroposterior view, and c and d represent the distance from the tip of the PS to the anterior wall of the vertebral body in the lateral view), anteroposterior diameter of the vertebral body at the UIV (APD), and ORPS in the UIV ([e+f]×100/[2×APD], where e and f represent the distance from the posterior wall of the vertebral body to the tip of the PS). **Figure 2** shows a reference image for each ORPS value. UIVF was defined as a change in shape above grade 2, according to the Genant classification.[16]

Fractures of the cranial side of one vertebra of the UIV (UIV+1F), spinal cord injury or myelopathy due to UIVF, days to UIVF, reoperation due to proximal junctional fracture (PJFr;

UIV or UIV+1F), and days to reoperation were evaluated for up to 2 years postoperatively.

Statistical Analysis

All statistical analyses were performed using SPSS version 25 (IBM Corp., Armonk, NY, USA). Statistical significance was set at $P<0.05$. Continuous variables are presented as the mean ± SD. Categorical variables were evaluated using the chi-squared test or Fisher's exact test. An independent t-test was used to assess the differences between groups L and H ,groups U and B,and groups presence of UIVF (UIVF -) and absence of UIVF (UIVF -). In the comparioon of groups UIVF minus and positive, the adjustment using propensity score matching was performed based on the age, sex, T-score, and level of UIV shown as follows; 1=T1, 2=T2…12=T12, 13=L1, 14=L2…, 18=S1, 19=ilium. The survival rate for UIVF was evaluated using Kaplan–Meier survival plots, and the differences were statistically evaluated using the log-rank test.

RESULTS

A total of 222 patients were excluded for the following reasons: age less than 40 years (84 patients), neuromuscular disease (41 patients), spinal tuberculosis (6 patients), congenital or syndromic scoliosis (4 patients), number of fused levels ≤3 (20 patients), incomplete questionnaire or radiographic data (22 patients), and cutout to outside of PS at the UIV level (45 patients).

Ultimately, 297 patients were included in this study.

Patient characteristics are shown in **Table 1**. There were 198 and 99 patients in groups L and H, respectively. The mean age was 68.8±8.5 years in group L and 68.6±8.1 years in group H (P=0.911). There were significantly more female patients in group H (79.3% in group L and 90.9% in group H, P=0.012). There were no significant differences in BMI, smoking habits, alcohol consumption, use of osteoporosis medicine, ASA-PS, T-score (evaluated in 133 and 63 patients in groups L and H, respectively), number of steroid users, comorbidies (hypertension, diabetes mellitus, cardiovascular disease, respiratory disease, autoimmune disease, and psychogenic disorder), number of fused segments, presence of pelvic fixation using iliac screw, presence of 3-column osteotomy, operative time, and estimated blood loss.

The radiographic parameters and PROMs before and two years after surgery are shown in **Table 2**. There were no significant differences in any radiographic parameters between the two groups, either preoperatively or 2 years postoperatively. There was no significant difference in the ODI between the two groups preoperatively (45.3% in group L vs. 46.3% in group H, P=0.687) or 2 years postoperatively (29.9% in group L vs. 32.2% in group H, P=0.367). Similarly, there was little difference in the SRS-22 total score between the two groups both preoperatively (2.5 in group L vs. 2.5 in group H, P=0.885) and 2 years postoperatively (3.4 in group L vs. 3.4% in group H, P=0.367).

As shown in **Table 3**, the total TAD was 37.1 mm in group L and 22.9 mm in group H, being significantly lower in group H (P=0.000). Similarly, ORPS was significantly higher in the H group (70.2% in the L group and 85.2% in the H group; P=0.000). UIVF was significantly more prevalent in group L (30.3% [60/198 patients] in group L vs. 15.2% [15/99 patients] in group H, P=0.005). Conversely, UIV+1F were frequent in group H, although the difference between the groups was not significant (2.5% in group L vs. 7.1% in group H, P=0.062). The revision rate for PJF was significantly higher in group L than that in group H (9.1% vs. 1.0%, P=0.007). There were no significant differences in the timing of UIVFs between the groups (82.6 days in group L vs. 75.9 days in group H, P=0.812). **Figure 3** shows the Kaplan–Meier plots for UIVF. Survival estimates for UIVF in both groups showed significant differences using the log-rank test (P=0.007).

Comparison between Unicortical and Bicortical groups

In group H, there were 68 patients in group U and 31 in group B (**Table 4**). There were no significant differences in age, sex, BMI, T-score, number of fused segments, or the presence of pelvic fusion. The incidence of UIVF was significantly higher in group B (25.8%, 8/31 patients) than that in group U (10.3%, 7/68 patients) (P=0.048). However, there were no significant differences in other UIV+1F, spinal cord injury (SCI) or myelopathy, revision for PJFr, and days until UIVF.

Comparison between UIVF + and UIVF – groups

There were 222 patients in the UIVF- group and 75 in the UIVF+ group (**Table 5)**. Mean age was significantly higher in the UIVF+ group (67.7 vs. 71.8 years old, P<0.001). However, there were no significant differences in gender, BMI, T-score, fused segment, level of UIV and LIV, presence of bicortical screws in UIV, or number of UIV+1F occurrences. On the other hand, ORPS was significantly higher in the UIVF- group (76.3% vs. 72.1%, P=0.001). In addition, propensity score matching based on age, sex, T-score, and UIV level resulted in 53 evaluable subjects in both groups. After these adjustments, ORPS was still significantly higher in the UIVF- group (76.5% vs 71.8%, P=0.013).

The risk factors of UIV fracture

Significant risk factors for UIVF were assessed using multiple logistic regression analysis. The dependent variable was the presence or absence of UIVF for up to 2 years after surgery. The independent variables were age, ORPS <80%, bicortical screw fixation at the UIV, and T-score. The significant risk factors for UIVF were ORPS <80% (P=0.007, odds ratio 3.900, 95% confidence interval (CI) 1.443–10.542) and age (P=0.004, odds ratio 1.077, 95% CI 1.024–1.132).

Representative cases

Figure 4a showed the case with ORPS less than 80%. She was a 76 year-old female who had spinal kyphoscoliosis deformity. Fusion range was T10 to ilium (**Figure 4a-1**). The calculated ORPS was 51.1% because the APD was 30.9 mm and the length of the screw within the vertebral body was 18.4 mm and 13.2 mm, respectively (**Figure 4a-2**). UIVF occurred one month after surgery (**Figure 4a-3**), and the collpase progressed further one year later(**Figure 4a-4**). Then she underwent revision surgery for extended fixation(**Figure 4a-5**).

On the other hand, **Figure 4b** presented a 79-year-old female in the bicortical fixation group who underwent fusion surgery from T9 to the ilium for spinal kyphoscoliosis deformity (**Figure 4b-1**). ORPS was 94.6% because the APD was 31.5 mm and the screw length was 29.8 mm on both sides (**Figure 4b-2**). CT images showed that the left tip of the screw penetrated the anterior wall of the vertebral body (**Figure 4b-3**). UIVF occurred 14 days postoperatively(**Figure 4b-4**), and marked collapse was observed 1 year after surgery (**Figure 4b-5,6**).

DISCUSSION

Although there have been many studies on the causes of PJK and PJF, they remain unclear and no established prevention methods have been reported. In recent years, some studies have investigated instrumentation placement in UIV, such as the mismatch between the proximal spinal

curve and Rod's contour and the cranially directed UIV screw angles compared to the superior endplate of UIV.[17-20] However, few studies have investigated the relationship between screw length and PJK or PJF. In this study, we investigated the relationship between screw length and UIVF, based on previously reported finite element analysis results that indicated a relationship between them.

As shown in **Table 3**, group H, with significantly higher TAD and ORPS, had significantly lower UIVF and revision for PJFr. These results indicate that it is very important to ensure that the ORPS is 80% or higher using preoperative CT and intraoperative radiographs prior to PS insertion. In addition, we use a feeler to check the touch of the cortical bone, which is the anterior wall of the vertebral body, and measure the depth using a ruler to determine the length of the screw. But still, aiming for ORPS > 80% and avoiding bicortical screw is a very narrow window. Oe et al reported that a 5 mm change in screw length can change ORPS by more than 10%.[12] Therefore, the use of an intraoperative navigation system may be useful to achieve optimal ORPS.

However, the UIV+1F tended to be higher in the H group, although the difference was not significant. This indicates that a high ORPS does not prevent UIV+1F. However, since UIVF is the cause of most of the serious complications of PJF, such as spinal cord injury and myelopathy, ORPS must be high to prevent these complications.[1,5-7]

Figure 3 shows the Kaplan–Meier plot for UIVF. At 3 months postoperatively, 80% (48/60

patients) of patients in the L group and 73.3% (11/15 patients) of patients in the H group had UIVF, which is consistent with previous reports.[1-3,21,22] Nonetheless, even at one month postoperatively, UIVF occurred in 36.7% (22/60 patients) in group L and 53.3% (8/15 patients) in group H. Therefore, preventing UIVF should be a concern immediately after surgery. In contrast, UIVF rarely occurred 200 days postoperatively in both groups. At 200 days postoperatively, the risk of new UIVF development was minimal.

The higher the ORPS for UIVF prevention, the more likely it was for the PS to penetrate the anterior wall of the vertebral body. As shown in **Table 4**, the incidence of UIVF in Group B was 25.8%, which was comparable to that in Group L (30.3 %). It is important to avoid bicortical screw fixation. As shown in **Figure 5a**, the damage around the screw was minimal immediately after bicortical screw fixation. However, in cases with weak bone quality, penetration of the screw tip can destroy the anterior wall when the screw is loosened owing to the initiation of ambulation (**Figure 5b**). In the case of unicortical screw fixation, the screw itself is unlikely to damage the anterior wall, but in bicortical screw fixation, the destruction of the anterior wall can be a cause of UIVF. Park et al. reported a similar hypothesis.[13]

Table 5 also examined the differences by presence of UIVF, before propensity score matching, age was significantly higher in the UIVF+ group in addition to ORPS. Although propensity score matching was based on sex, T-score, and level of UIV, which are considered risk factors for PJF

in addition to age, ORPS was still significantly lower in the UIVF+ group, suggesting that a greater ORPS is important for preventing the occurrence of UIVF. In fact, multiple logistic regression analysis also showed that ORPS < 80% was the risk with the highest odds ratio.

This study has several limitations. First, this was a single-center study, which means that the number of cases was relatively small. Second, there was a significant difference in sex between the two groups. The possibility that this result may have induced statistical bias cannot be ruled out. Third, although no significant difference in T-score was found, the fact that 34% of the total patients were not evaluated is also an issue to be addressed in future studies. Fourth, although there was no significant difference in the range of screw fixation in this study, it was not strictly standardized. However, since the level of the UIV may be a risk factor for UIVF, it is necessary to uniformly evaluate the level of the UIV in the future.

In conclusion, an ORPS <80% was a significant risk factor for UIVF, with an odds ratio of 3.9-fold. UIVF often occurs within 1 month postoperatively and at the latest within 3 months. Furthermore, the occurrence of UIVF after 200 days postoperatively is rare. In addition, destruction of the anterior vertebral wall by bicortical screw fixation in an attempt to increase the ORPS is also a risk factor for UIVF and should be treated with caution.

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Table 1. Characteristics of Patients			
Group	L (ORPS < 80%)	H (ORPS ≥ 80%)	P value
No. of patients	198	99	
Age	68.8±8.5	68.6±8.1	0.911
Female	157 (79.3%)	90 (90.9%)	0.012**
BMI	23.2±3.6	23.0±4.0	0.694
Smoking	28 (14.1%)	9 (9.1%)	0.214
Alcohol	38 (19.2%)	18 (18.2%)	0.834
Osteoporosis medications (none, BP, PTH, EST, DEN)	(121, 36, 31, 7, 3)	(59, 15, 20, 3, 2)	0.314
ASA-PS	2.0±0.4	1.9±0.4	0.456
T-Score (L:H=133: 63 patients)	-1.5±1.2	-1.7±1.0	0.221
Steroid user	14 (7.1%)	4 (4.0%)	0.302
Hypertension	84 (42.4%)	42 (42.4%)	1.000
Diabetes mellitus	22 (11.1%)	13 (13.1%)	0.611
Cardiovascular disease	18 (9.1%)	5 (5.1%)	0.219
Respiratory disease	26 (13.1%)	6 (6.1%)	0.064
Autoimmune disease	13 (6.6%)	7 (7.1%)	0.870
Psychogenic disease	5 (2.5%)	1 (1.0%)	0.349
Fused segment	8.8±2.1	8.4±2.1	0.132
Pelvic fusion	166 (83.8%)	78 (78.8%)	0.284
3-column osteotomy	66 (33.3%)	30 (30.3%)	0.599
Operative time (min)	426.4±89.2	410.6±96.4	0.163
EBL (ml)	1350.9±896.1	1345.3±986.1	0.961
*,P < 0.05; **,P < 0.01; ***,P < 0.001, ORPS; occupancy rate of pedicle screw, BP; bisphosphonate, PTH; teriparatide, EST; estrogen, DEN; denosumab, ASA; American Society of Anesthesiologists physical status EBL; estimated blood loss			

Table 2. The radiographic parameters and PROMs before and two year after the surgery				
Group		L (198)	H (99)	P (ANOVA)
PT	Before surgery	33.4±11.6	34.9±11.6	0.193
	Two years after surgery	25.6±9.5	27.2±11.3	0.236
LL	Before surgery	13.8±20.8	13.2±25.0	0.838
	Two years after surgery	40.3±15.7	37.8±17.8	0.255
PI	Before surgery	51.5±11.5	53.3±11.3	0.193
	Two years after surgery	52.4±10.4	53.5±13.1	0.494
PI-LL	Before surgery	38.4±19.7	40.9±23.7	0.372
	Two years after surgery	12.1±16.3	14.7±18.7	0.257
TK	Before surgery	25.6±19.4	22.1±20.2	0.139
	Two years after surgery	41.9±16.5	38.7±14.9	0.126
TS	Before surgery	33.2±14.6	31.2±14.9	0.277
	Two years after surgery	30.7±11.5	31.1±13.2	0.813
CL	Before surgery	19.8±17.1	20.2±16.7	0.844
	Two years after surgery	17.9±15.2	18.5±15.1	0.791
C2-7 SVA	Before surgery	20.0±21.9	18.5±17.4	0.572
	Two years after surgery	19.3±14.7	20.6±16.8	0.514
PJA	Before surgery	4.9±8.1	4.6±8.2	0.785
	Two years after surgery	17.6±10.6	16.5±12.2	0.469
SVA	Before surgery	115.2±74.9	112.5±78.7	0.777
	Two years after surgery	56.2±53.8	66.9±58.9	0.140
ODI	Before surgery	45.3±18.4	46.3±17.1	0.687
	Two years after surgery	29.9±19.1	32.2±20.3	0.367
SRS-22	Before surgery	2.5±0.6	2.5±0.6	0.885
	Two years after surgery	3.4±0.7	3.4±0.8	0.781

*; P<0.05, **; P<0.01, ***;P<0.001, PROMs; patients reported outcome measures, PT; Pelvic tilt, LL; Lumbar lordosis, PI; Pelvic incidence, TK; Thoracic kyphosis, TS; T1 slope, CL; Cervical lordosis, SVA; Sagittal vertical axis, PJA; proximal junctional angle, ODI; Oswestry disability index, SRS-22; Scoliosis Research Society-22

Table 3. TAD, ORPS and Post-operative outcome			
Group	L (198)	H (99)	P value
TAD ;a (mm)	7.1±4.6	5.2±4.2	0.001**
TAD ;b (mm)	8.3±4.0	7.2±11.5	0.221
TAD ;c (mm)	10.7±3.3	5.1±2.5	0.000***
TAD ;d (mm)	11.1±3.3	5.4±2.1	0.000***
Total TAD ;a+b+c+d (mm)	37.1±8.4	22.9±13.6	0.000***
ORPS (%)	70.2±7.0	85.2±4.7	0.000***
UIVF	60 (30.3%)	15 (15.2%)	0.005**
UIV+1F	5 (2.5%)	7 (7.1%)	0.062
SCI or myelopathy	7 (3.5%)	1 (1.0%)	0.191
Revision for PJFr	18 (9.1%)	1 (1.0%)	0.007**
The day of UIVF	82.6±121.1	75.9±91.1	0.812
The day of revision	487.8±476.6	685	-

*;P < 0.05; **;P < 0.01; ***;P < 0.001, TAD; Tip-apex distance

ORPS; Occupancy rate of Pedicle screw in upper instrumented vertebral body

UIVF; Upper instrumented vertebra fracture, UIV+1F; Upper instrumented vertebra +1 fracture,

SCI; spinal cord injury, PJFr; proximal junctional fracture

Table 4. The comparison based on the presence or absence of penetration with pedicle screw at anterior wall UIV among high ORPS group			
Group	U (68)	B (31)	P value
Age	68.4±8.6	69.3±7.2	0.611
Female	61 (89.7%)	29 (93.5%)	0.716
BMI	22.9±0.764	23.2±3.1	0.764
T-Score (U:B=45: 18 patients)	-1.7±0.9	-1.8±1.1	0.865
Fused segment	8.3±2.0	8.7±2.4	0.332
Pelvic fusion	56 (82.4%)	22 (71.0%)	0.288
ORPS (%)	83.7±3.1	88.5±6.0	0.000***
UIVF	7 (10.3%)	8 (25.8 %)	0.048*
UIV+1F	5 (7.4%)	2 (6.5%)	0.619
SCI or myelopathy	0 (0%)	1 (3.2%)	0.313
Revision for PJFr	0 (0%)	1 (3.2%)	0.313
The day of UIV fracture	67.0±60.4	86.6±121.1	0.627
The day of revision	487.8±476.6	685	-

*;P < 0.05; **;P < 0.01; ***;P < 0.001, UIV; Upper instrumented vertebra
ORPS; Occupancy rate of Pedicle screw in upper instrumented vertebral body
U; Unicortical group, B; Bicortical group, UIVF; Upper instrumented vertebra fracture,
UIV+1F; Upper instrumented vertebra +1 fracture,
SCI; spinal cord injury, PJFr; proximal junctional fracture

Table 5. The comparison based on the presence or absence of UIVF						
	Before propensity score matching			After propensity score matching		
Group	UIVF - (222)	UIVF + (75)	P value	UIVF - (53)	UIVF + (53)	P value
Age	67.7±8.7	71.8±6.5	0.000***	71.1±7.7	71.2±6.0	0.933
Female	186 (83.8%)	60 (80.0%)	0.246	45 (84.9%)	46 (86.8%)	0.780
BMI	23.0±3.6	23.5±3.9	0.306	22.6±3.7	23.3±3.6	0.281
T-Score	-1.5±1.1 (144 pt.)	-1.8±1.2 (53 pt.)	0.141	-1.8±1.1 (53 pt.)	-1.8±1.2 (53 pt.)	0.754
Fused segment	8.7±2.1	8.8±2.1	0.584	9.2±2.2	9.2±2.4	0.966
UIV	9.1±2.0	9.0±2.0	0.840	8.7±2.2	8.6±2.2	0.724
LIV	18.4±1.3	18.7±1.2	0.181	18.6±1.2	18.6±1.4	0.942
ORPS (%)	76.3±9.1	72.1±10.0	0.001**	76.5±8.5	71.8±10.5	0.013*
Bicortical screw	23 (10.4%)	10 (13.3%)	0.526	5 (9.4%)	7 (13.2%)	0.750
UIV+1F	11 (5.0%)	1 (1.3%)	0.140	2 (3.8%)	1 (1.9%)	0.500

*,P < 0.05; **,P < 0.01; ***,P < 0.001, UIVF; Upper instrumented vertebral fracture,
UIV; Upper instrumented vertebra, LIV; Lower instrumented vertebra,
ORPS; Occupancy rate of Pedicle screw, UIV+1F; Upper instrumented vertebra +1 fracture

Figure legends

Figure 1 TAD and ORPS

TAD is the sum of the distances (a+b+c+d) from the tip of the PS. The distances a (left side) and b (right side) represent the distances from the tip of the PS to the centerline of the UIV in the anteroposterior view and the distance between c and d represents the distance from the tip of the PS to the anterior wall of the vertebral body in lateral view. The distances e and f represent the distance from the tip of the PS to the posterior wall of the vertebral body. ORPS was defined as follows: ORPS=(e+f)×100/(2×APD). APD: anteroposterior diameter of the vertebral body at the UIV; ORPS: occupancy rate of pedicle screw; TAD: tip-apex distance; UIV: upper instrumented vertebra; PS: pedicle screw.

Figure 2 The reference image of each ORPS value. ORPS: occupancy rate of pedicle screw.

Figure 3 Kaplan–Meier plots for UIVF

The survival estimated for UIVF was significantly lower in the low ORPS group (ORPS<80%) using the log tank test (P=0.007). UIVF: upper instrumented vertebra fracture; ORPS: occupancy rate of pedicle screw.

Figure 4

Figure 4a. The case with ORPS less than 80%. She was a 76-year-old female who had spinal kyphoscoliosis deformity.

Figure 4a-1 The radiograps just after correction surgery.

Figure 4a-2 The calculated ORPS was 51.1% because the APD was 30.9 mm and the length of the screw within the vertebral body was 18.4 mm and 13.2 mm, respectively.

Figure 4a-3 UIVF occurred one month after surgery.

Figure 4a-4 and 5 The collapse of UIVF progressed further one year later. Then she underwent revision surgery for extended fixation.

Figure 4b The case with bicortical fixation. She was a 79-year old female with spinal kyphoscoliosis.

Figure 4b-1 The radiograps just after correction surgery.

Figure 4a-2 ORPS was 94.6% because the APD was 31.5 mm and the screw length was 29.8 mm on both sides.

Figure 4a-3 CT images. The left tip of the screw penetrated the anterior wall of the vertebral body.

Figure 4a-4 UIVF occurred 14 days postoperatively.

Figure 4b-5 and 6 The severe collapsed vertebra was observed 1 year after surgery.

Figure 5 Model of penetration of the anterior vertebral wall in the UIV by bicortical screw fixation. UIV: upper instrumented vertebra.

Figure 5a No damage around the screw was observed right after the surgery.

Figure 5b The destruction of the anterior wall of the vertebral body around the screw spreads with the body movements of ambulation after the surgery, increasing the risk of vertebral fracture.

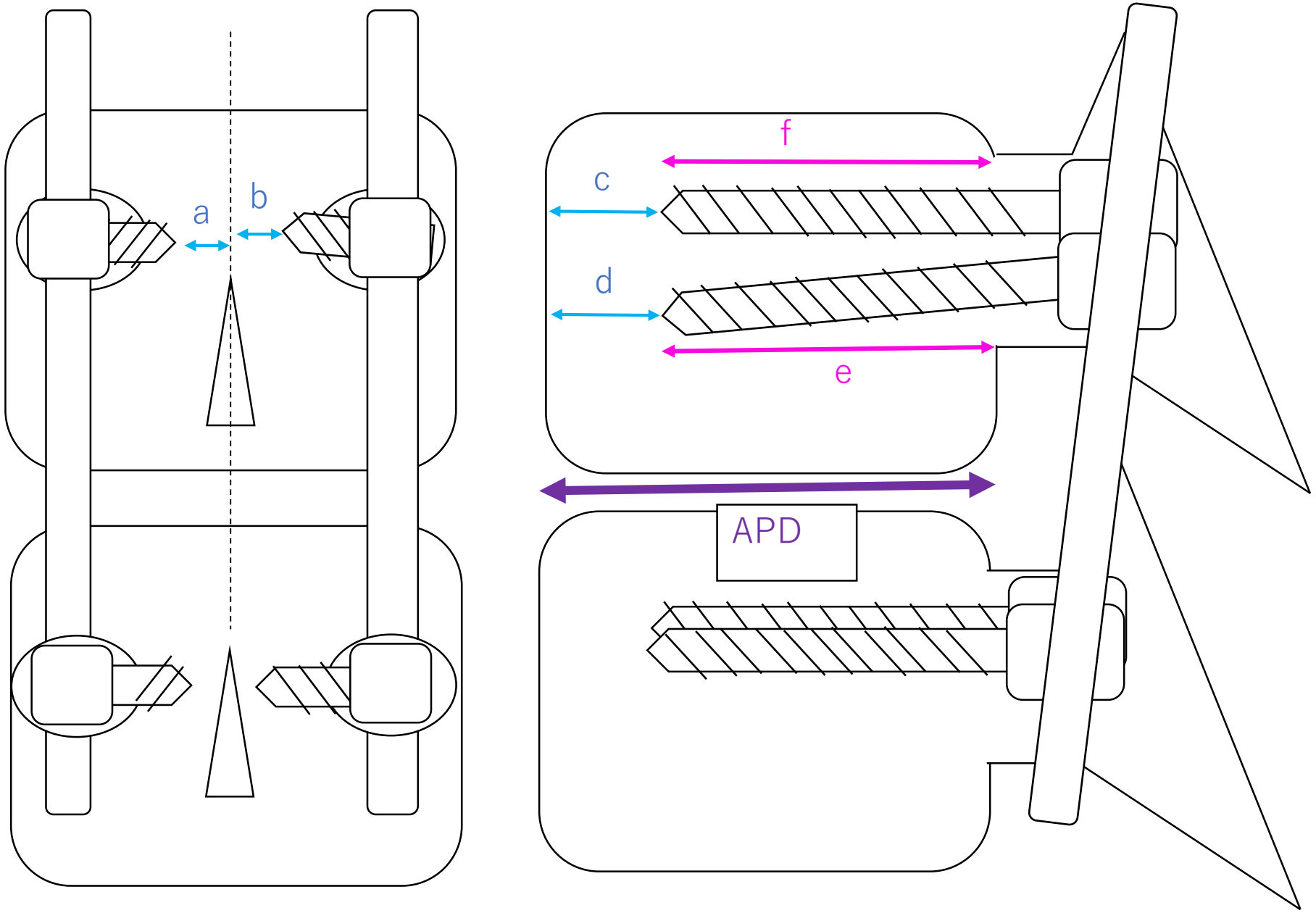


Figure 1

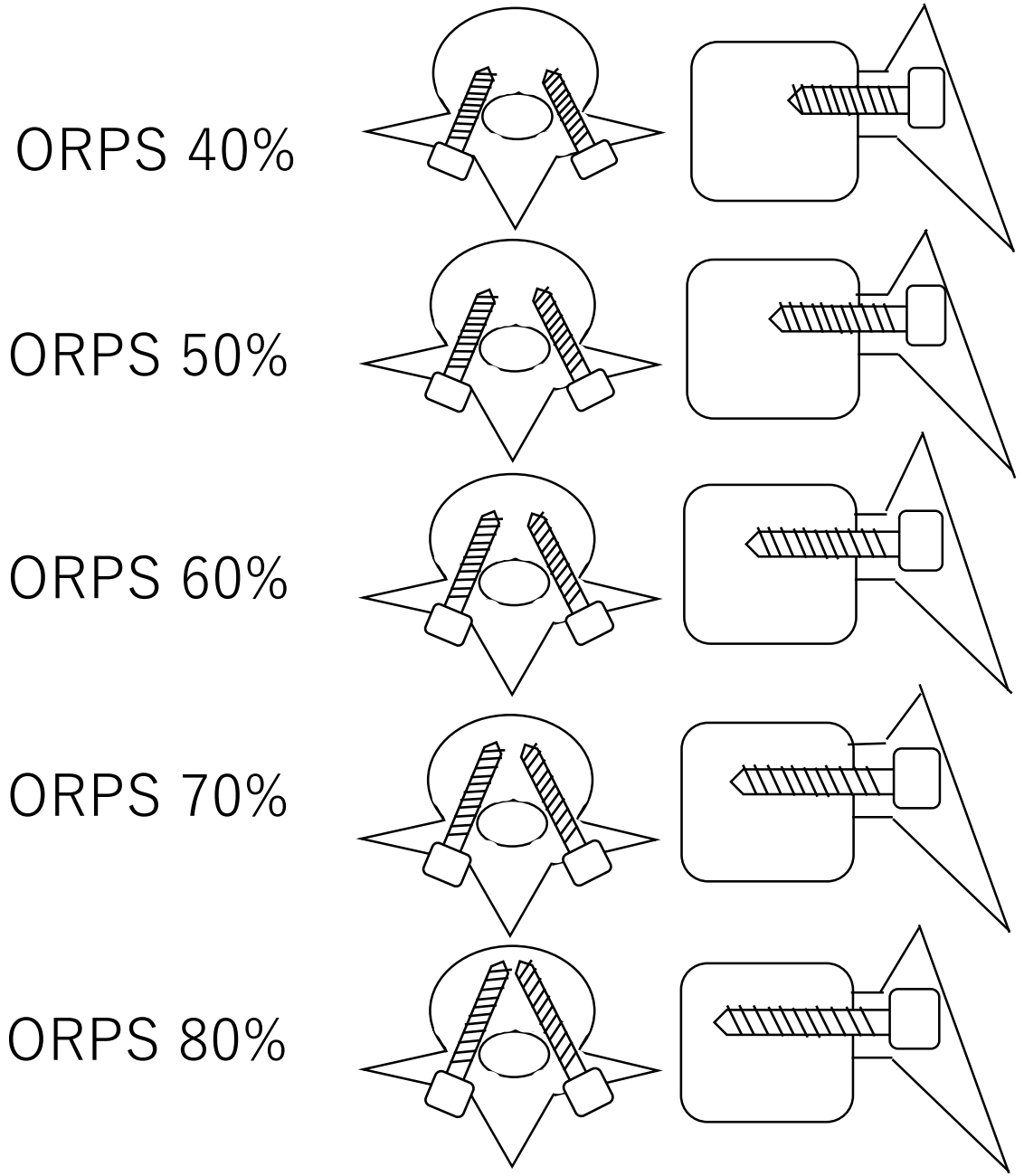
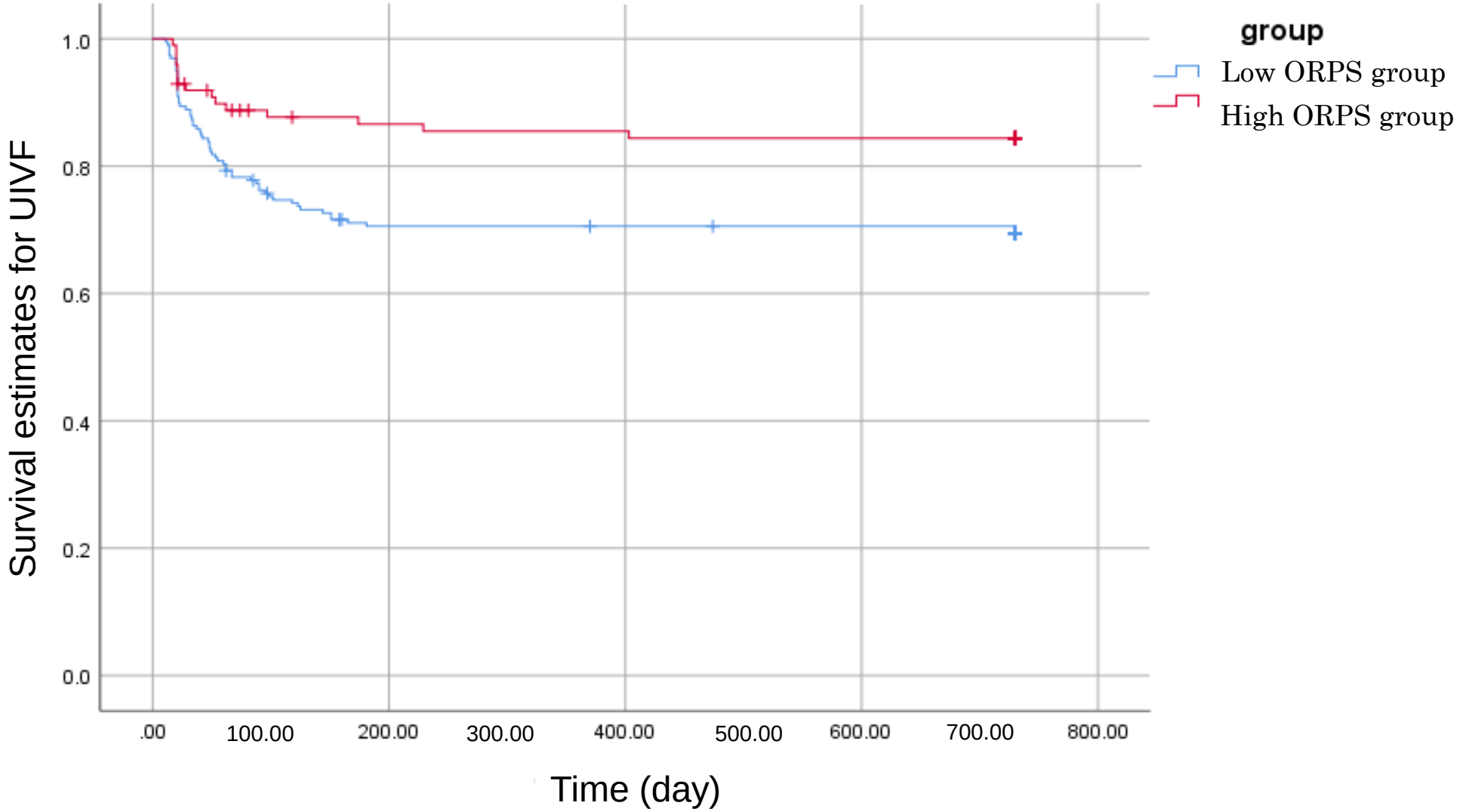


Figure 2



Number at risk

Low ORPS	198	146	135	135	134	133	133	133
High ORPS	99	81	79	78	78	77	77	77

Figure 3

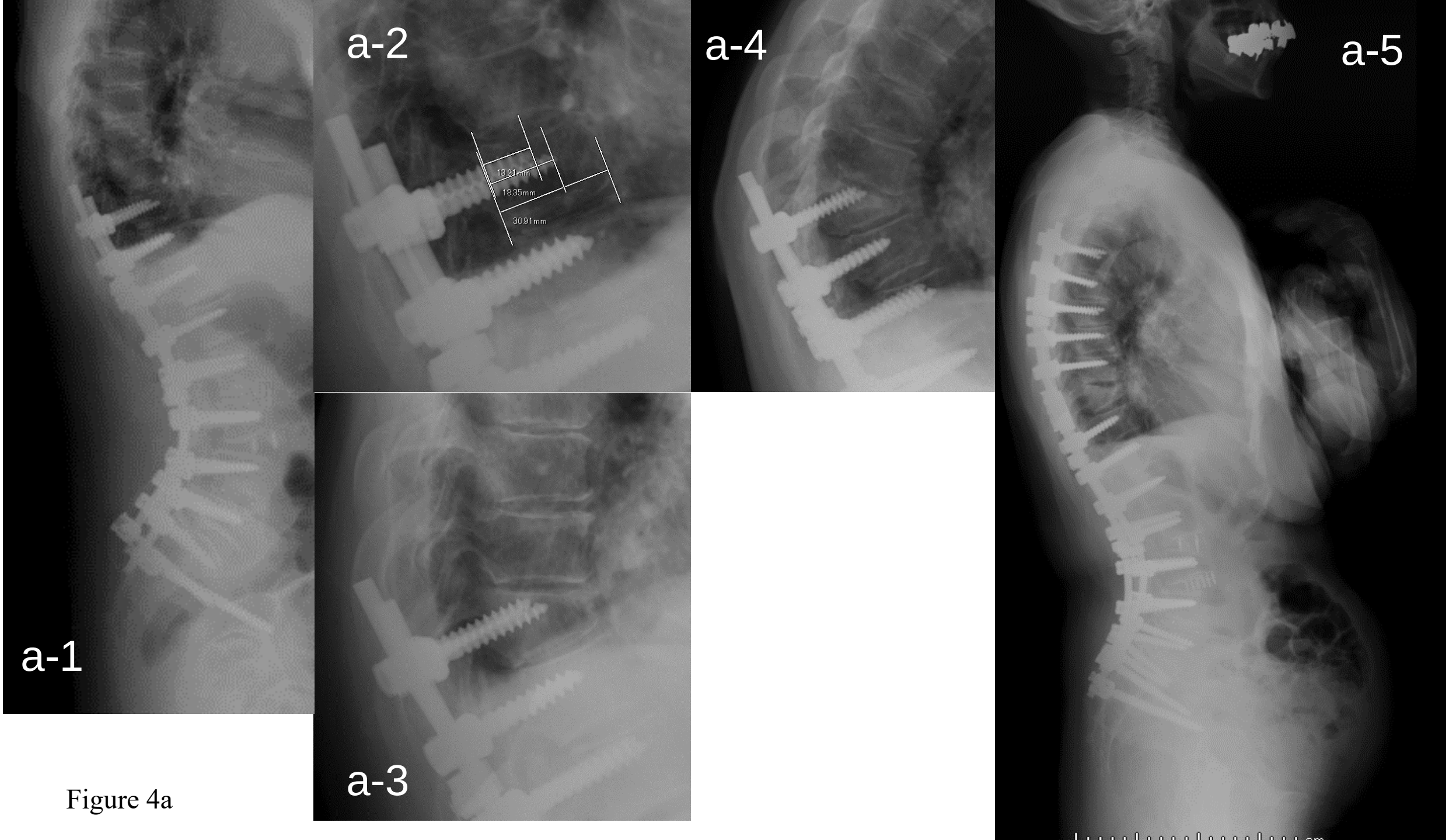


Figure 4a

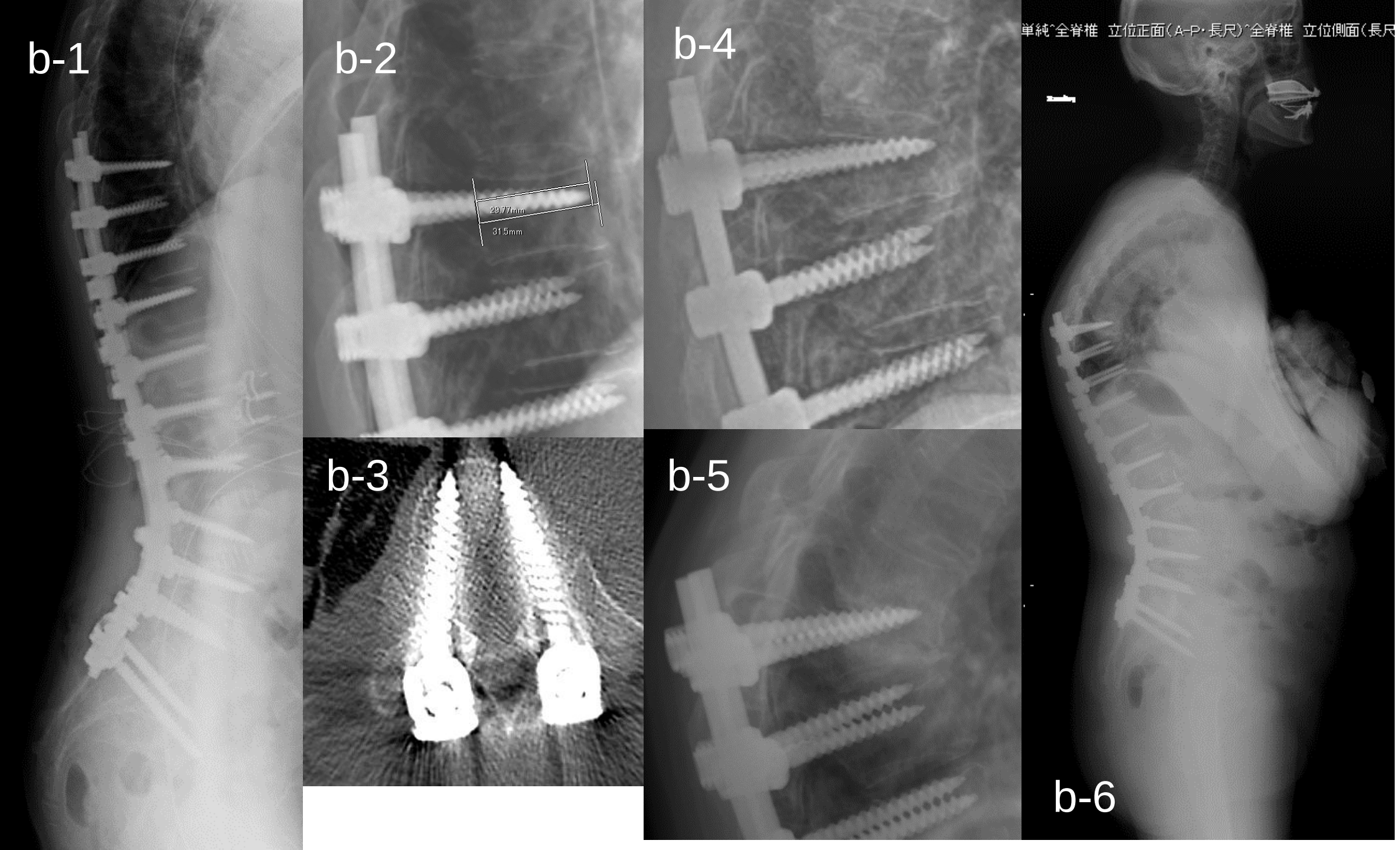


Figure 4b

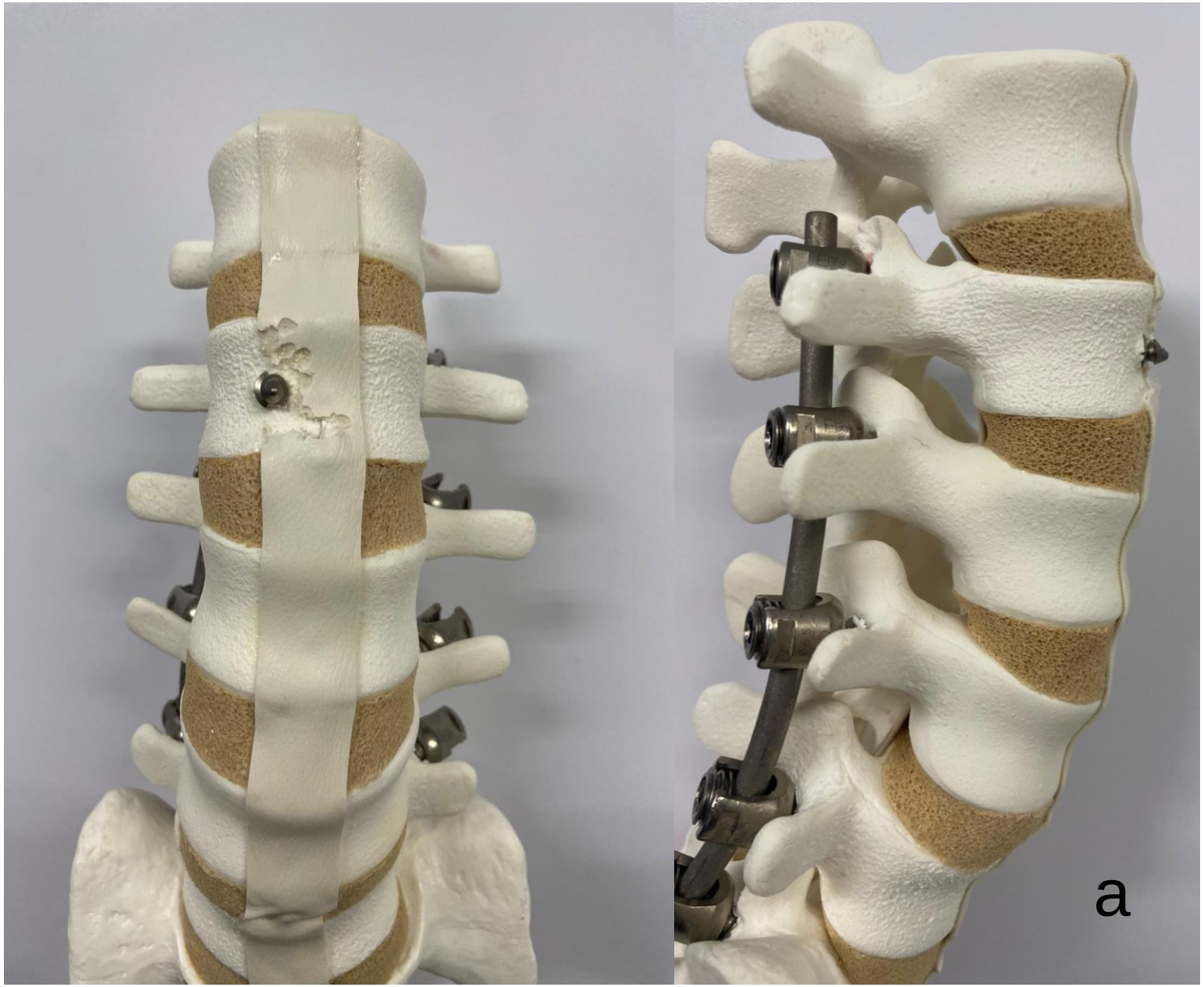


Figure 5a

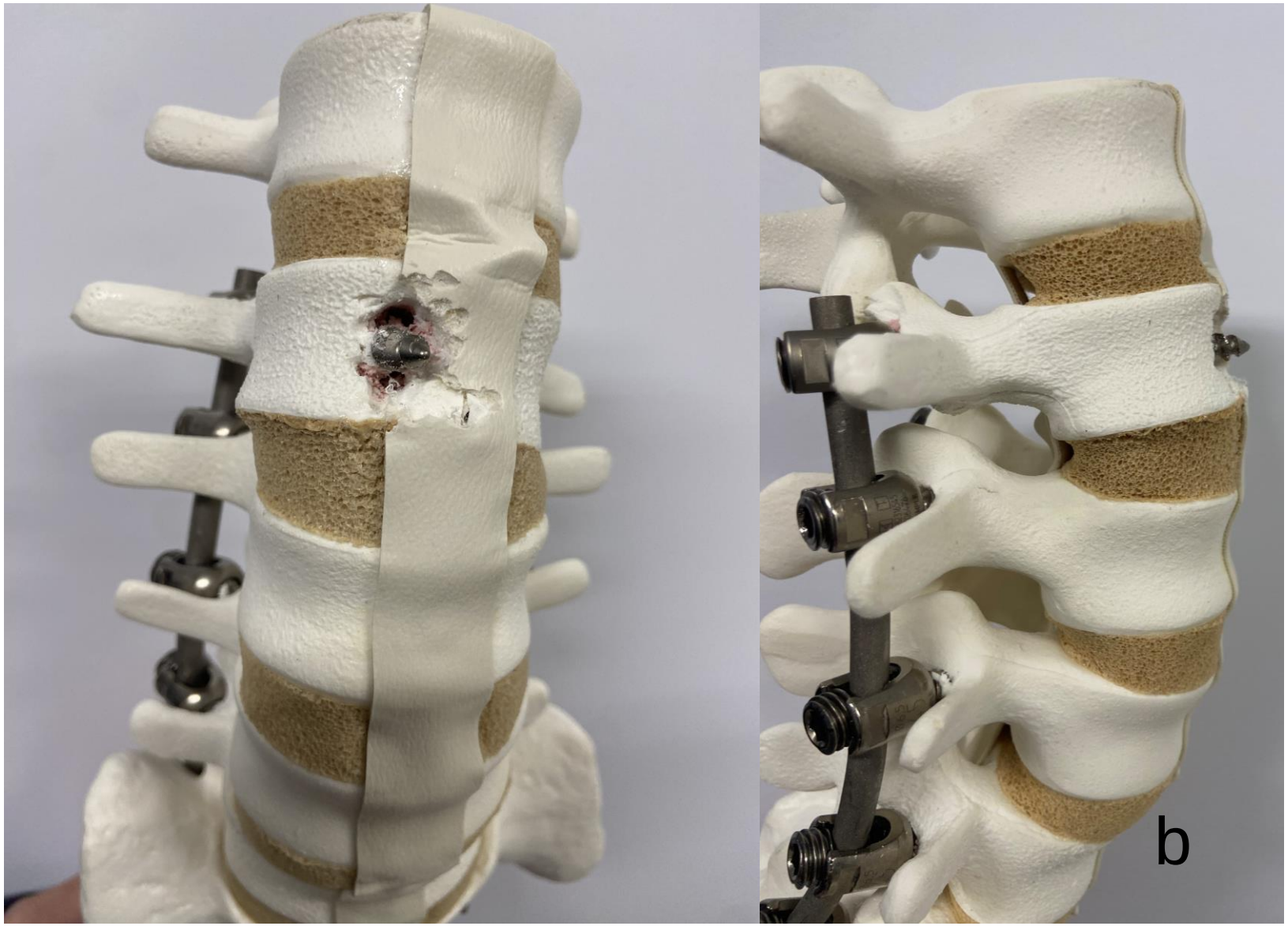


Figure 5b