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Original Article

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Application of Transverse Process Hooks at Distal Thoracic Vertebrae in Uppermost Vertebral Instrumentation for Adult Spinal Deformity Surgery: Special Focus on Delayed-Onset Neurologic Deficits

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Objective: We aimed to investigate the incidence of delayed-onset neurological deficits (DONDs), DOND-related reoperation rates following adult spinal deformity (ASD) surgery, and efficacy of transverse process hooks (TPHs) at the uppermost instrumented vertebra (UIV) compared to pedicle screws (PSs).
Methods: We included 90 consecutive patients who underwent instrumented fusion from the sacrum to the distal thoracic spine for ASD, with a minimum follow-up of 24 months. Clinical and radiological outcomes were compared between 33 patients in the TPH group and 57 patients in the PS group, using the Scoliosis Research Society-22 Outcomes questionnaire (SRS-22), Medical Outcomes Study Questionnaire Short-Form 36 (SF-36), and various spinal sagittal parameters.
Results: While absent in the TPH group, myelopathy occurred in 15.8% of the PS group, wherein 15 patients underwent reoperation. The change in the proximal junctional angle, from the pre- to postoperative assessment, was lower in the TPH group than in the PS group (0.2 vs. 6.6, $p=0.002$). Postoperative facet degeneration in the PS group progressed more significantly than in the TPH group (0.5 vs. 0.1, $p=0.002$). Surgical outcomes were comparable for both groups, except for the back visual analogue scale (3.5 vs. 4.1, $p=0.010$) and SRS-22 domains, including pain and satisfaction (3.3 vs. 2.9, $p=0.033$; 3.7 vs. 3.3, $p=0.041$). No intergroup difference was observed in SF-36.
Conclusion: Using TPHs at the UIV level can prevent DOND, and thereby prevent postoperative myelopathy that necessitates reoperation; thus, TPHs is preferable over PSs in ASD surgery.

Keywords: Adult spinal deformity, Transverse process hook, Pedicle screw, Uppermost instrumented vertebra, Proximal junctional kyphosis

INTRODUCTION

Adult spinal deformity (ASD) treatment aims to correct spinal and pelvic misalignment and restore sagittal alignment. This often requires long-segment fixation from the thoracic spine to the pelvis.[1,2] However, such fixation can lead to mechanical complications, such as pseudoarthrosis, implant failure, and proximal junctional problems.[3-7] Notably, proximal junction kyphosis (PJK) and proximal junction failure (PJF) are common after spinal reconstruction and can worsen a patient's neurological function.[8-12] PJK may result from progressive deformity from aging, osteoporosis, bone fracture, instrumentation failure, facet violation, or disruption of the posterior ligament complex.[8,13,14] Preventive techniques for PJK include preservation of the interspinous and supraspinous ligament complex,[14] stabilization of fusion structures using allograft tendon[15] or strap devices,[16] and transverse process hooks (TPHs).[17] Most research on TPHs focuses on the proximal thoracic region, with limited study of the distal thoracic level due to size challenges. This study will assess the feasibility and applicability of TPH insertions at the distal thoracic vertebrae.

Delayed-onset neurological deficit (DOND) is a severe complication following extensive thoracic spine fusion, typically from facet subluxation or spinal canal stenosis due to facet hypertrophy near the upper instrumented vertebra (UIV). Few studies address surgical techniques to prevent these complications. Existing research on TPH and pedicle screws (PSs) primarily focus on preventing PJK or mechanical complications with little on facet degeneration related to DOND. While lumbar facet arthritis is well-studied, thoracic arthritis is not.

This study aims to investigate the incidence of PJK, DOND-related reoperation, and changes in the proximal junctional angle (PJA) after ASD surgery using TPH and PS implants at the UIV. Additionally, we aim to develop a grading system for evaluating thoracic facet degeneration during UIV procedures.

MATERIALS AND METHODS

1. Patient Selection

Before the commencement of this study, this study was approved by the Institutional Review Board of Yongin Severance Hospital, Yonsei University College of Medicine (IRB No. 9-2023-0255). This retrospective study involved identifying and enrolling patients who underwent thoracic instrumentation for ASDs between January 2018 and December 2020 from a single institutional database. PSs as UIV implants were used in the first 57 patients until 2019, and TPHs were used in the next 33 patients from 2020 onward. Bone density tests were performed preoperatively on the spine and femur neck, and patients with osteoporosis were treated preoperatively with 3-month teriparatide injection. The inclusion criteria were (1) patient age >18 years; (2) primary diagnosis of ASD: sagittal imbalance >50 mm, thoracic kyphosis (TK) >60° (T5–12), lumbar lordosis (LL) <30°, thoracolumbar kyphosis (TLK, T10–L2) >20°, or pelvic tilt (PT) >25°; (3) instrumented fusion from the sacrum or ilium to midthoracic vertebrae (T6–9); and (4) a minimum follow-up period of >24 months. Exclusion criteria included acute traumatic, infectious, or neoplastic conditions, as well as ankylosing spondylitis (Fig. 1).

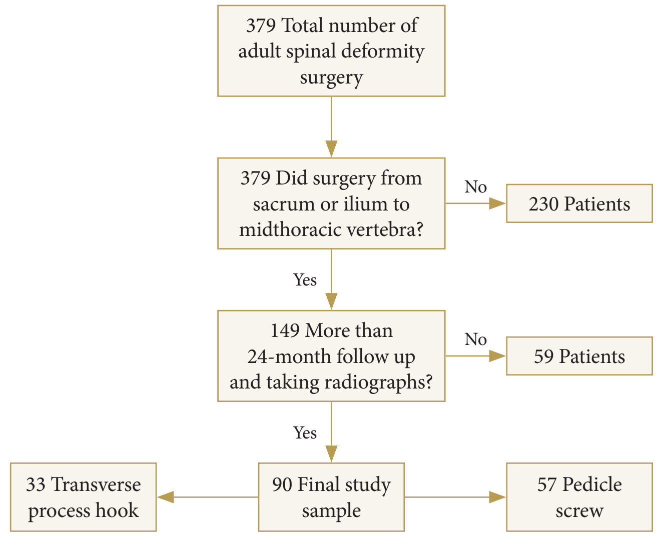

Fig. 1. A flowchart depicting the selection of patients for inclusion in this study.

Radiographic monitoring included assessments at preoperative, immediate postoperative (within 2 weeks of surgery), and final follow-up visit or preceding any reoperation. Clinical and demographic information was retrieved from electronic medical records, and surgical information was acquired from operation reports.

2. Surgical Procedure

Posterior spinal instrumented fixation was performed using a Jackson table. PSs constructs consisted of 5.5- or 6.5-mm titanium alloy rod-based segmental Cotrel-Dubousset Horizon instrumentation (CDH Solera spinal system; Medtronic Sofamor-Danek, Memphis, TN, USA). Polyaxial screws were used to allow greater flexibility in screw alignment, which is particularly important in long-segment fusions to reduce stress at the UIV. All PSs were inserted using the O-arm navigation system. The

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diameter of PSs was determined intraoperatively by evaluating the size of the pedicle using O-arm navigation and preparing the pedicle channel. In all patients, pelvis fixation was performed at least to the sacrum, and iliac fixation was determined according to the level of fusion and degree of correction.

The hook constructs consisted of 5.5-mm titanium rod-based segmental CD instrumentation (Medtronic Sofamor-Danek). TPHs were prepared using a periosteal elevator to prepare the superior edge of the transverse process at the UIV location, after which the hook was inserted in a close fit to the transverse process.[18]

All patients underwent lumbar facetectomy and osteotomy to correct the lordotic angle. Additionally, the rod was initially fixed in the caudal area and then gradually fixed in the cranial hook direction using a multiscrew simultaneous reduction device (SmartLink System; Medtronic Sofamor-Danek) to correct the deformity. During the surgery, all patients underwent intraoperative posterior bone grafting, using a mixture of allograft and autologous bone from the patient's lamina, spinous process, or iliac crest, that was implemented between the rib head, around the instruments, and the decorticated lamina.

Fig. 2. Immediate postoperative EOS image. UIV TPHs at T9 (A) and UIV pedicle screw at T9 (B). UIV, uppermost instrumented vertebra; TPH, transverse process hook.

3. Radiological Measurements

Both anteroposterior and lateral standing whole-body radiographs generated by the EOS machine (EOS Imaging, Paris, France) (Fig. 2), as well as computed tomography (CT) scans, were evaluated at various stages: preoperatively, immediate postoperatively, and at the final outpatient follow-up visit. Radiographic measurements were manually extracted by 2 investigators who were not directly involved in the operative care of the patients. The following parameters were evaluated: C7 sagittal vertical axis (SVA); pelvic parameters, including pelvic incidence (PI), PT, and sacral slope (SS); LL (LL; Cobb angle between L1 upper endplate and S1 upper endplate); TLK (Cobb angle between T10 upper endplate and L2 lower endplate); TK (Cobb angle between T5 upper endplate and T10 lower endplate); T2–5 segmental angle; and PJA (caudal endplate of the UIV to the cephalad endplate of the UIV+2 vertebrae).[19] As previously described,[20] criteria were employed to evaluate the patients using lateral whole-spine radiographs immediately after surgery and at the final follow-up: PJA $<10°$ and PJA progression of $<10°$ at the final follow-up. PJK was defined as PJA change $>10°$.[21,22] PJF was defined as a progression of PJK that required revision surgery.[2] Criteria for PJF included a postoperative increase in PJA of more than 15°, vertebral fracture at the UIV or UIV+1, failure of UIV fixation, or other causes leading to neurological compromise and disability, necessitating surgical intervention.[10]

Additionally, we analyzed the facet joints of the UIV. Although criteria for grading facet joint arthritis in the lumbar vertebrae have been previously established,[23] there is no known criteria for thoracic arthritis. Therefore, we developed new criteria for diagnosing thoracic facet degeneration in this study, as follows:

Grade 0: Normal facet joint space (female >1-mm width, male >1.25-mm width).

Grade 1: Narrowing of the facet joint space (female <1-mm width, male <1.25-mm width) and/or small osteophytes and/or mild hypertrophy of the articular process.

Grade 2: Narrowing of the facet joint space and/or moderate osteophytes and/or moderate hypertrophy of the articular process and/or mild subarticular bone erosions.

Grade 3: Narrowing of the facet joint space and/or large osteophytes and/or severe hypertrophy of the articular process and/or severe subarticular bone erosions and/or subchondral cysts.

4. Functional Evaluation

Clinical assessments were performed using various measures, including the back and leg visual analogue scale (VAS), Oswestry Disability Index (ODI), Scoliosis Research Society-22 Outcomes questionnaire (SRS-22), and Medical Outcomes Study

Table 1. Demographic and baseline data

Characteristic	Total (n = 90)	TPH (n = 33)	PS (n = 57)	p-value
Sex				
Female	81 (90)	30 (90)	51 (89.5)	
Male	9 (10)	3 (10)	6 (10.5)	
Age at surgery (yr)	68.8 ± 8.1	69.6 ± 10.5	68.3 ± 6.3	0.477†
Body mass index (kg/m²)	25.1 ± 3.8	25.3 ± 4.0	24.9 ± 3.7	0.605†
Bone mineral density (g/cm²)	-2.0 ± 1.0	-1.9 ± 1.1	-2.1 ± 0.9	0.521†
Osteoporosis	29 (32.2)	11 (33.3)	18 (31.6)	0.433‡
Follow-up period (mo)	24.5 ± 6.5	25.4 ± 4.8	24.0 ± 7.2	0.304†
Diagnosis				
Lumbar degenerative kyphosis	43 (47.8)	14 (42.4)	29 (50.9)	
Degenerative lumbar scoliosis	20 (22.2)	8 (24.2)	12 (21.1)	
Iatrogenic flat back	12 (13.3)	4 (12.1)	8 (14.0)	
Adjacent segment disease	4 (4.4)	1 (3.0)	3 (5.3)	
Mechanical complications	11 (12.2)	6 (18.2)	5 (8.8)	
Comorbid conditions				
Smoking status	3 (3.3)	2 (6.1)	1 (1.8)	
Hypertension	54 (60.0)	20 (60.6)	34 (59.6)	
Diabetes mellitus	18 (20.0)	7 (21.2)	11 (19.3)	
Rheumatoid arthritis	6 (6.7)	5 (15.2)	1 (1.8)	
Parkinson's disease	5 (5.6)	3 (9.1)	2 (3.5)	
Upper instrumented vertebra				
T6	5 (5.6)	3 (9.1)	2 (3.5)	
T7	4 (4.4)	1 (3)	3 (5.3)	
T8	12 (13.3)	4 (12.1)	8 (14)	
T9	40 (44.4)	16 (48.5)	24 (42.1)	
T10	23 (25.6)	7 (21.2)	16 (28.1)	
T11	6 (6.7)	2 (6.1)	4 (7)	
Osteotomy grade				
Grade 1	21 (23.3)	9 (27.3)	12 (21.1)	
Grade 2	47 (52.2)	13 (39.4)	34 (59.6)	
Grade 3	3 (3.3)	1 (3)	2 (3.5)	
Grade 4 (PSO)	19 (21.1)	10 (30.3)	9 (15.8)	
Fusion level (n)	-	10.8 ± 1.6	10.9 ± 1.1	0.275†
Iliac fixation	-	21 (63.6)	30 (52.6)	0.158‡
Previous surgery	-	16 (48.5)	32 (56.1)	0.483‡
GAP score	-	11.2 ± 1.6	11.5 ± 1.6	0.178†
Occurrence of myelopathy	-	0 (0)	9 (15.8)	0.016*,‡
Revision surgery	-	3 (9.1)	15 (26.3)	0.050‡

Values are presented as number (%) or mean ± standard deviation.
TPH, transverse process hook; PS, pedicle screw; PSO, pedicle subtraction osteotomy; GAP score, global alignment and proportion score.
*$p < 0.05$, statistically significant differences. †Student t-test. ‡Chi-square test.

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Questionnaire Short-Form 36 (SF-36) to evaluate patients before and 2 years after surgery.

5. Statistical Analysis

Data analysis was performed using IBM SPSS Statistics ver. 27.0 (IBM Co., Armonk, NY, USA). Statistical significance was set at $p < 0.05$. All continuous data are presented as mean ± standard deviation and were tested for normal distribution using the Kolmogorov-Smirnov test. Differences in baseline data and radiologic parameters were analyzed using analysis of variance with the Student t-test or Mann-Whitney U-test for continuous variables and the chi-square test or Fisher exact test for categorical variables.

RESULTS

1. Patients Demographics

The initial database included 379 patients. Of these, 149 underwent surgery from the sacrum or ilium to the midthoracic vertebrae. We excluded 59 patients who lacked pre- or postoperative whole-body radiographs or had a follow-up period of less than 24 months. Finally, 90 patients were included in this study, consisting of 81 women and 9 men with a mean age of 68.8 years (SD, 8.1 years) at the time of surgery. The mean follow-up duration was 24.5 months (SD, 6.5 months). There were 11 patients with osteoporosis in the TPH group and 18 in the PS group, and there was no difference between the 2 groups. There was also no difference in global alignment and proportion (GAP) scores between the 2 groups.

Postoperative myelopathy did not occur in any patient in the TPH group, whereas it developed in 9 patients in the PS group ($p = 0.016$). Notably, 3 patients in the TPH group and 15 in the PS group underwent reoperation linked to surgery ($p = 0.050$) (Table 1).

2. Comparison of Perioperative Radiological Parameters Between the TPH and PS Groups

There were no significant differences in pelvic parameters, including C7-SVA, LL, PI, PT, and SS. However, TLK was significantly smaller in the TPH group compared to the PS group immediately postoperative state ($p = 0.015$). The final follow-up period was shorter in the TPH group ($p = 0.009$). While there was no difference in PJA between the 2 groups before surgery, significant differences were observed immediately after surgery ($p < 0.001$) and at the last follow-up ($p < 0.001$). The degree of change in postoperative PJA, which correlated with PJK was

Table 2. Radiographic data comparison between patients TPH and PS

Radiologic parameter	TPH	PS	p-value
C7 sagittal vertical axis			
Preoperative	111.9 ± 54.8	100.4 ± 59.8	0.370
Immediate postoperative	36.3 ± 36.7	28.6 ± 38.7	0.357
Last follow-up	44.6 ± 45.0	59.6 ± 48.3	0.164
Lumbar lordosis (°)			
Preoperative	8.6 ± 24.6	13.2 ± 17.3	0.308
Immediate postoperative	41.9 ± 16.0	40.4 ± 10.1	0.593
Last follow-up	41.8 ± 16.7	36.3 ± 12.3	0.080
Pelvic incidence (°)			
Preoperative	55.5 ± 9.0	55.8 ± 11.0	0.876
Immediate postoperative	52.1 ± 8.5	52.5 ± 11.3	0.855
Last follow-up	56.2 ± 9.8	55.8 ± 11.1	0.884
Pelvic tilt (°)			
Preoperative	32.8 ± 13.3	35.1 ± 11.3	0.393
Immediate postoperative	21.3 ± 9.4	23.6 ± 10.4	0.298
Last follow-up	28.0 ± 9.1	28.7 ± 10.6	0.756
Sacral slope (°)			
Preoperative	22.7 ± 13.8	20.6 ± 10.3	0.425
Immediate postoperative	30.6 ± 10.5	29.1 ± 8.6	0.462
Last follow-up	27.7 ± 10.2	27.2 ± 8.6	0.835
Thoracolumbar kyphosis			
Preoperative	1.6 ± 21.7	9.0 ± 18.4	0.088
Immediate postoperative	-1.7 ± 10.8	5.7 ± 15.1	0.015*
Last follow-up	-0.9 ± 12.9	9.0 ± 19.2	0.009*
Thoracic kyphosis			
Preoperative	11.3 ± 20.4	15.2 ± 14.0	0.295
Immediate postoperative	18.9 ± 20.7	24.7 ± 10.3	0.099
Last follow-up	33.6 ± 17.8	30.0 ± 13.2	0.285
T2–5 segmental angle			
Preoperative	2.4 ± 8.1	-0.1 ± 5.6	0.126
Immediate postoperative	1.4 ± 8.0	-2.0 ± 7.2	0.080
Last follow-up	1.1 ± 9.0	-2.3 ± 7.7	0.066
Proximal junctional angle			
Preoperative	1.1 ± 8.3	0.4 ± 8.0	0.417
Immediate postoperative	3.3 ± 8.8	6.8 ± 8.5	< 0.001*
Last follow-up	3.1 ± 11.6	13.7 ± 10.5	< 0.001*
Change in PJA	0.2 ± 6.7	6.6 ± 10.0	0.002*

Values are presented as mean ± standard deviation.
TPH, transverse process hook; PS, pedicle screw; PJA, proximal junctional angle.
All radiologic parameters analyzed by Student t-test.
*$p < 0.05$, statistically significant differences.

Table 3. Facet degeneration grade and facet widths comparison between patients TPH and PS

Parameter	TPH	PS	p-value
Facet degeneration grade			
Preoperative	0.29 ± 0.53	0.39 ± 0.54	0.446
Immediate postoperative	0.36 ± 0.56	0.55 ± 0.60	0.182
2 Years after surgery	0.50 ± 0.70	1.24 ± 0.76	< 0.001*
Facet width			
Preoperative	1.47 ± 0.21	1.59 ± 0.34	0.079
Immediate postoperative	1.37 ± 0.26	1.53 ± 0.36	0.057
2 Years after surgery	1.33 ± 0.33	1.31 ± 0.26	0.848
Change in facet degeneration grade	0.12 ± 0.33	0.51 ± 0.66	0.002*
Change in facet width	-0.04 ± 0.12	-0.15 ± 0.26	0.015*

Values are presented as mean ± standard deviation.
TPH, transverse process hook; PS, pedicle screw.
*p < 0.05, statistically significant differences.

Table 4. Surgical outcomes for the TPH and PS groups: VAS and ODI

Parameter	TPH	PS	p-value
Back VAS score			
Preoperation	6.4 ± 2.7	7.5 ± 2.3	0.048
Postoperation	3.5 ± 2.3	4.1 ± 2.3	0.010*
Δ Back VAS score	2.8 ± 3.0	2.9 ± 2.5	0.880
Leg VAS score			
Preoperation	5.6 ± 3.0	6.9 ± 2.9	0.061
Postoperation	4.9 ± 2.4	5.7 ± 7.0	0.219
Δ Leg VAS score	1.4 ± 3.0	1.1 ± 8.2	0.840
ODI			
Preoperation	58.1 ± 17.3	65.0 ± 18.6	0.106
Postoperation	57.9 ± 24.8	62.1 ± 20.1	0.412
Δ ODI score	-0.6 ± 23.5	-0.8 ± 20.5	0.979

Values are presented as mean ± standard deviation.
TPH, transverse process hook; PS, pedicle screw; VAS, visual analogue scale; ODI, Oswestry Disability Index.
*p < 0.05, statistically significant differences.

substantially lower in the TPH group than in the PS group (p = 0.002) (Table 2).

3. Comparison of Perioperative Facet Degeneration Between the TPH and PS Groups

The facet degeneration grade did not differ between the 2 groups before and immediately after surgery. However, as shown in the CT scan performed 2 years later, degeneration progressed significantly more in the PS group compared to the TPH group (p < 0.001). There was no difference in facet width between the 2 groups before and after surgery. However, the degree of facet degeneration increased in both groups before and after surgery, and this increase was significantly greater in the PS group (p = 0.002). Additionally, the PS group showed a significant decrease in facet widths (p = 0.015) (Table 3).

4. Comparison of Clinical Outcomes Between the TPH and PS Groups

The clinical outcomes showed improvement before and after surgery in both groups. The preoperative back and leg VAS scores were higher in the PS group. Furthermore, the postoperative back VAS score was significantly lower in the TPH group (p = 0.010). However, there was no significant intergroup difference in the VAS and ODI before and after surgery (Table 4).

The mean total SRS-22 score showed no significant intergroup difference between the PS and TPH groups both before and after surgery. Both groups showed significant improvements before and after surgery, with no significant difference between them. Regarding the SRS-22 domains, there was no significant difference in change in functionality/activity, self-image, or mental health between both groups before and after surgery. Notably, before surgery, there was no discernible difference in the pain domain between the 2 groups; however, the TPH group exhibited a statistically significant increase in scores after surgery (p = 0.033). Additionally, the satisfaction domain score was significantly higher in the TPH group (p = 0.041). All SF-36 domains significantly improved before and after surgery in both groups, and there was no difference between the 2 groups (Table 5).

5. Complications

In this study, a total of 18 patients underwent reoperation: 3 in the TPH group and 15 in the PS group. The average time to reoperation in each group was 14 months after surgery in the TPH group and 23.5 months in the PS group. Reoperation in the TPH group was not associated with myelopathy resulting from adjacent segment degeneration or stenosis progression. One TPH patient had a UIV level of T6, and a hook dislodgement at the UIV level was detected 12 months after surgery, which was addressed through reoperation without significant deterioration in clinical outcomes. Another patient underwent sacroplasty for a sacral fracture around the right S1 pedicle, which occurred 7 months after surgery. The last patient had a rod change due to a bilateral distal rod fracture.

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Table 5. Surgical outcomes for the TPH and PS groups: Scoliosis Research Society-22 (SRS-22) outcomes questionnaire and health-related quality of life outcomes measured with the medical outcomes study

Variable	Functional/activity	Pain	Self-image	Mental health	Total score	Satisfaction	PF	RP	BP	GH	VT	SF	RE	MH	PCS	MCS
Preoperative																
TPH groups	2.4	2.4	2.1	2.6	2.4	-	19.0	18.8	24.7	34	33.2	31.7	19.7	48	25.8	36.5
PS groups	2.2	2.1	1.9	2.4	2.2	-	17.8	12.9	14.9	33.7	30.1	32.4	25.7	40	19.9	31.9
p-value	0.336	0.142	0.225	0.375	0.124	-	0.788	0.295	0.067	0.941	0.536	0.910	0.415	0.170	0.140	0.367
2 years after surgery																
TPH groups	2.7	3.3	2.7	2.8	2.9	3.7	34.8	31.3	47.4	31.7	35.2	43.1	38.8	48.9	36.3	41.5
PS groups	2.7	2.9	2.5	2.6	2.7	3.3	27.4	25.1	41.1	30.3	33.5	41.8	27.4	43.7	31	36.6
p-value	0.99	0.033*	0.327	0.303	0.302	0.041*	0.158	0.386	0.287	0.761	0.741	0.822	0.199	0.299	0.210	0.332
Changes in SRS-22																
TPH groups	0.3	0.8	0.6	0.3	0.5	-	16.6	13.2	22.7	0.7	4.1	12.5	20.8	1.6	11.5	1.6
PS groups	0.4	0.7	0.6	0.2	0.5	-	9.5	13.3	27.1	-3.8	3.8	5.7	1	2.4	11.4	2.4
p-value	0.506	0.578	0.984	0.726	0.859	-	0.259	0.990	0.557	0.427	0.969	0.424	0.085	0.901	0.987	0.613

TPH, transverse process hook; PS, pedicle screw; PF, physical function; RP, role-physical; BP, bodily pain; GH, general health; VT, vitality; SF, social functioning; RE, role-emotional; MH, mental health; PCS, physical component summary; MCS, mental component summary.

*$p < 0.05$, statistically significant differences.

In the PS group, a total of 15 patients underwent reoperation, of which 5 had PJK and 6 had PJF. In addition, 4 patients underwent reoperation due to implant-related complications such as rod fracture. A total of 9 patients had myelopathy, which occurred in patient who underwent reoperation. The cause of myelopathy was PJK in 4 patients and PJF in 5 patients. PJF included UIV fracture in 2 patients, UIV-1 level fracture in 2 patients, and adjacent segment disease in 1 patient. The average time to onset of DOND was 27.44 months

DISCUSSION

PJK commonly occurs after ASD surgery, especially in long-instrumented spinal fusions. Typically defined as a change of > 10° in PJA,[24] some studies suggest these changes may not affect clinical outcomes. Yagi et al.[21,22] classified PJK into 3 types: bone failure, disc and ligament failure, and implant/bone interface failure.

Preventing PJK in ASD surgery is crucial for successful corrective surgery as it can impact postoperative quality of life and the results of subsequent reoperation.[25] Despite various preventive measures, a definite solution remains elusive. Strategies include teriparatide treatment,[26] cement augmentation at UIV,[27] percutaneous screws,[28] transitional rods,[14,29] thoughtful UIV selection,[9,27] preservation of the posterior ligamentous complex,[10] and UIV anchors.[19,30,31]

We investigated the types of anchors used at the UIV. Matsumura et al.[31] reported a 17.6% incidence of PJK in TPHs at UIV and 27.3% in PSs at UIV. Hassanzadeh et al.[17] found no PJK in the hook group but 29.6% in the screw group. Kim et al.[19] found the highest PJK rate (35.1%) in PSs-only constructs, 24.1% in hook-only constructs, and 29.1% in hybrid constructs (proximal hooks with distal PSs).

PJK might compensate for decreased TK, restoring global sagittal balance. This was evident in our patient cohort, with a more substantial postoperative reduction in TK in the PS group than in the TPH group. These results align with the theory that elevated PJA compensates for diminished TK and subsequent negative sagittal balance. Importantly, our study showed a lower incidence of PJK in patients using TPH as a UIV anchor.

In proximal junctional problems, LL distribution also plays an important role. Roussouly classified the distribution of LL using the SS and the shape of LL (Roussouly study). In this study, the distribution of Roussouly types was analyzed in both the TPH and PS groups. In the TPH group, there was 1 patient classified as type 1, 4 patients as type 2, 19 patients as type 3, and 9 patients as type 4. In the PS group, the distribution was 3 patients classified as type 1, 5 patients as type 2, 34 patients as type 3, and 15 patients as type 4. There was no statistical difference in Roussouly type between the 2 groups. Proximal junctional problems occurred in 7 type 3 patients and 4 type 4 patients. As in other studies, proximal junctional problems occurred more in types 3 and 4. However, in the TPH group, there were patients with types 3 and 4, but no problems occurred.

Furthermore, our results revealed that DOND did not develop when a TPHs was used at the UIV level. We observed that the absence of facet hypertrophy and disc degeneration are causes of DOND. For facet degeneration, we developed a grading system using values from the lumbar facet arthritis grade classification.[23,32] Grades 0 and 1 were based on normal thoracic facet width, and grades 2 and 3 focused on bony arthropathy and arthritis of the thoracic facet. Before surgery, there was no noticeable difference in facet degeneration grades between TPH and PS groups. However, at 2 years after surgery, the grade was 0.5 in the TPH group and 1.24 in the PS group, which demonstrated a significant difference. This suggests that facet degeneration progressed more rapidly in 15.8% of PS group, potentially leading to thoracic canal stenosis and thoracic myelopathy. These results highlight factors linked to patient reoperation and clinical outcomes.

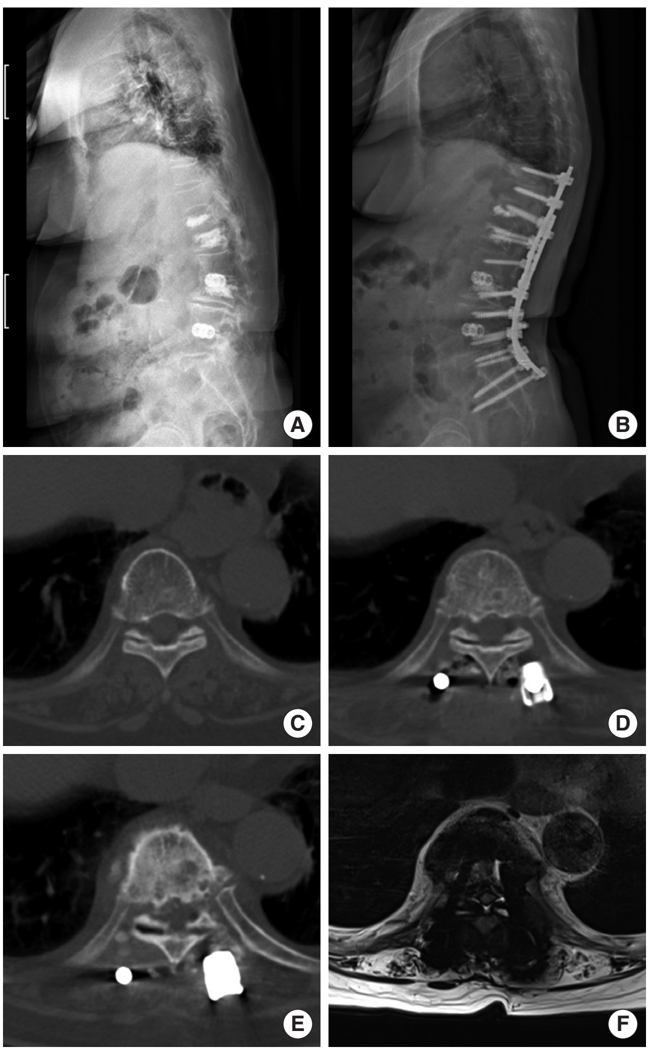

Fig. 3. Occurrence of DOND at 2 years after surgery. (A) Preoperative radiographs. (B) Two years after surgery. (C) Preoperative computed tomography (CT) image. (D) Immediate postoperative CT image. (E) CT image show facet degeneration and hypertrophy. (F) Magnetic resonance imaging shows facet hypertrophy and cord compression. DOND, delayed-onset neurological deficit.

TPHs at the proximal thoracic level is common in ASD or scoliosis surgery,[17,19,33] but challenging at the distal thoracic level due to shorter transverse processes. Singh et al.[34] reported that transverse process at T10, T11, and T12 are shorter than those at T2 to T7, likely due to muscular attachments and rib size. Upper thoracic transverse processes have more muscular attachments than lower ones, explaining this variation.[35] Consequently, hook dislodgement occurred in one TPHs patient in this study. However, 2-year follow-up radiographs showed no facet degeneration in patients with well-placed TPH. In contrast, in the patient who used PSs at the UIV level, facet degeneration progressed 2 years after surgery (Fig. 3). Additional decompression and fixation of the upper joint were performed due to signal changes in the cord and myelopathy from facet hypertrophy. Fig. 4 shows that the facet joint of the UIV was preserved in both the preoperative and postoperative CT scans of patients with TPHs.

The lower incidence of DOND and PJK associated with TPHs can be attributed to several factors. First, TPHs is less proximally invasive than with PS, reducing the risk of encroaching on the facet joint proximal to the UIV. This preserves the integrity

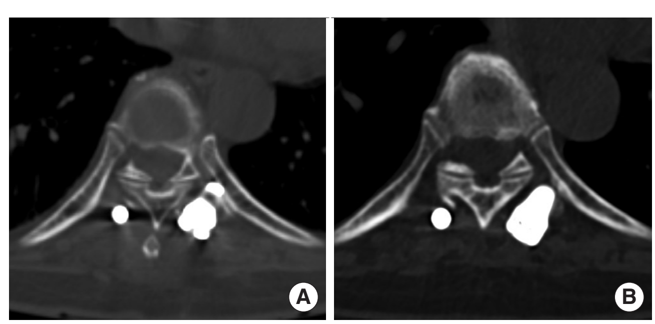

Fig. 4. Computed tomography axial image of a patient using TPHs at UIV level before (A) and 2 years after surgery (B). Facet preserved even after surgery. TPH, transverse process hooks; UIV, uppermost instrumented vertebra.

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of the ligament complex and adjacent facet joint capsule.[17] Conversely, PS directly affects the posterior. As indicated by Anderson et al.,[36] preservation of the supraspinous and interspinous ligament complexes during UIV anchor preparation is critical for mitigating PJK, which is straightforward with PSs. Secondly, TPHs offers a gentler load distribution, causing less mechanical stress in the segment above. Rhee et al.[37] have postulated that the posterior compression forces from proximal constructs may contribute to PJK, making TPHs advantageous compared to PSs. Additionally, TPHs does not breach the vertebral body, and this prevents compression fractures of the UIV.

The biomechanical advantage of a soft landing on the TPHs of a UIV is that it reduces mechanical stress and force on the UIV. Consequently, using a TPHs at the UIV helps mitigate the risk of adjacent segment disease, which includes complications such as UIV body fracture, hypertrophy of the ligament flavum, and disc degeneration. In our study, ligament flavum hypertrophy was observed exclusively in the PS group, affecting 6 patients during follow-up. Five of these patients required reoperation due to proximal junctional problems. No cases of ligament flavum hypertrophy were observed in the TPH group, suggesting that the use of TPHs may help reduce the risk of adjacent segment degeneration and ligamentous changes.

Furthermore, this approach can serve as a prophylactic measure against postoperative thoracic myelopathy, often caused by adjacent segment disease. Our findings revealed that postoperative myelopathy occurred in 45.6% of patients who received PSs at UIV, whereas those who utilized TPHs did not develop myelopathy.

Thoracic myelopathy from adjacent segment disease, such as canal stenosis due to facet hypertrophy, can cause complications such as impaired lower extremity weakness, severe pain, and difficulty walking after adult deformity corrective surgery, especially in the thoracic area. Consequently, further surgical intervention may be required, as myelopathy is associated with poor clinical outcomes. In this study, the pain and satisfaction domains at the last follow-up SRS-22 score were significantly lower in those in the TPH group. While a clinical outcome evaluation may not show all the patient's conditions, the patient's pain and satisfaction can be used to measure postoperative symptoms, indicating that myelopathy negatively impacts clinical outcomes.

This study had some limitations. First, being a retrospective study that analyzed patient records of angle changes and functional outcomes pre- and postoperatively, the statistical power is limited. Second, this study was conducted at a single center with heterogeneous surgical indications, which may affect the generalizability of our findings. Third, the significantly shorter follow-up period in the TPH group compared to the PS group may have influenced the assessment of long-term complications such as PJK and DOND. While the shorter follow-up in the TPH group is a limitation, the study still demonstrated significant findings regarding the lower incidence of PJK and myelopathy in the TPH group during the available follow-up period. Extended follow-up would be beneficial to further validate these results.

Despite these limitations, this study has notable strengths. Firstly, we observed a significant difference in PJK and myelopathy associated with postoperative development of DOND between patients who received TPHs and those who received PSs at the UIV level. Secondly, this is a novel study of DOND associated with thoracic facet degeneration in ASD surgery, providing new evidence for the importance of preserving facet joint health. Lastly, our relatively large sample size strengthens the reliability of our findings compared to similar studies, contributing valuable data to the ongoing discussion about the optimal UIV anchoring technique in ASD surgery.

CONCLUSION

Our findings demonstrate that employing TPHs as an implant for UIV in ASD surgery effectively prevented the advancement of DOND-related reoperation, alleviated pain and PJK, and enhanced postoperative patient satisfaction. Particularly, a TPHs at the UIV level not only helps reduce the risk of reoperation but also prevents postoperative myelopathy, ultimately improving the health-related quality of life of patients with ASD treated with surgery. Consequently, the TPHs should be considered at the UIV level during ASD surgery.

NOTES

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