

Results of Using a Novel Percutaneous Pedicle Screw Technique for Patients with Diffuse Idiopathic Skeletal Hyperostosis—The Single or Double Endplates Penetrating Screw (SEPS/DEPS) Technique

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Abstract:

Introduction: We have developed the single or double endplates penetrating screw (SEPS/DEPS) technique, which is a novel percutaneous pedicle screw (PPS) insertion technique suitable for osteoporotic vertebral body fracture (OVF) patients with diffuse idiopathic skeletal hyperostosis (DISH). This study aims to compare the effectiveness of this SEPS/DEPS technique with the conventional pedicle screw technique.

Methods: The screw is inserted upward from the outer caudal side of the pedicle toward the inner cranial side. Vertebrae affected with DISH were inserted with screws using the SEPS/DEPS technique, whereas non-fused vertebrae were inserted with screws using the conventional PPS technique. Twelve OVF patients with DISH were included in this study; three with SEPS/DEPS technique only and nine with a hybrid of both the DEPS and the conventional PPS techniques. As a control group, 12 OVF patients with DISH treated by conventional PPS. The rates of implant failures and of surgical complications were compared between the SEPS/DEPS group and the control group. The insertion torque was measured and compared between DEPS and conventional PPS in three hybrid patients.

Results: In the SEPS/DEPS group, 70 screws were inserted with the SEPS/DEPS technique and 56 screws were inserted with the conventional PPS technique. In the control group, 116 screws were inserted using the conventional PPS and the PS techniques. The loosening of screws was significantly less in screws inserted with the SEPS/DEPS technique (0/70 screws, 0%) than with screws inserted with the conventional technique (12/116 screws, 10.3%). The average insertion torque of DEPS was 2.25 Nm, which was 134% higher than that of conventional PPS which was 1.64 Nm ($p = 0.04$).

Conclusions: This novel SEPS/DEPS technique has a higher insertion torque compared with the conventional PPS techniques and demonstrated itself to be an effective option for patients with concomitant bone fragility due to DISH.

Keywords:

osteoporotic vertebral body fracture (OVF), diffuse idiopathic skeletal hyperostosis (DISH), percutaneous pedicle screw (PPS), minimally invasive spine stabilization (MIS), single endplate penetrating screw (SEPS) technique, double endplates penetrating screw (DEPS) technique

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Introduction

In patients with diffuse idiopathic skeletal hyperostosis (DISH), vertebral instability caused by pseudoarthrosis after osteoporotic vertebral body fracture (OVF) may be difficult to heal because of the long lever arms at the cranial and

caudal sides of the affected vertebra. Moreover, the complication and mortality rates after spinal fracture in patients with DISH are significantly higher than in patients with a normal spine¹⁾. Therefore, surgical treatment is necessary for these patients. Among various spinal fixation methods, minimally invasive spine stabilization using a percutaneous pedi-

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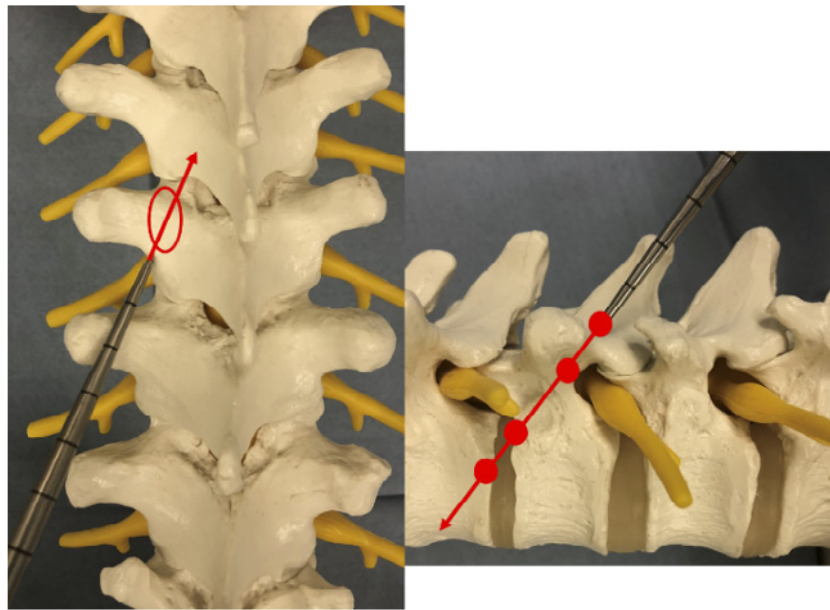


Figure 1. Trajectory of DEPS technique.

oval; pedicle

filled circle; strong fixation point

arrow; direction of insertion

The screw is inserted upward from the outer caudal side of the pedicle toward the inner cranial side.

cle screw (PPS) is often used because of less surgical invasion and lower complication rates than using conventional open procedures²⁻⁴). However, rigid fixation is not easily accomplished because of concomitant bone fragility. As the mobility of vertebral body diminishes in DISH, its bone mineral density may decrease because of stress shielding, which results in a higher risk of vertebral fracture. We have developed the single or double endplates penetrating screw (SEPS/DEPS) technique, which is a novel PPS insertion technique, and have utilized it for patients with DISH. This study aims to introduce this novel SEPS/DEPS technique and to evaluate its effectiveness for DISH patients by comparing it with the conventional PPS technique.

Material and Methods

SEPS/DEPS technique

The SEPS or DEPS technique is a modification of the penetrating S1 endplate screw (PES) technique reported by Matsukawa et al.⁷. The screw is inserted upward from the outer caudal side of the pedicle toward the inner cranial side (Fig. 1). The skin incision should be made 20 mm caudal to that of the conventional PPS position and should be made vertically to facilitate the adjustment of the sagittal probe angle. The probe is inserted from 7:00 toward 1:00 for the left pedicle and from 5:00 toward 11:00 for the right pedicle. The tip of the probe should reach to the upper endplate in the lateral view before touching the inner edge of the pedicle in the A-P view. The probe should penetrate the up-

per endplate of the vertebral body and the lower endplate of the adjacent cranial vertebral body. As it might be difficult to penetrate double endplates because of the sagittal pedicle angle at lumbar spine level, only a single endplate is penetrated and this is referred to as the single endplate penetrating screw (SEPS) technique. A guidewire is then inserted, followed by a pedicle screw as in the conventional PPS technique (Fig. 2). We often use 50-55 mm-long screws for female patients and 55-60 mm-long screws for male patients, depending on the preoperative measurements based on the reconstructed sagittal CT view.

As the double endplates penetrating screws extend to the adjacent vertebral body, this technique was applied only to vertebral bodies, which had fused due to DISH, whereas the conventional PPS technique was applied to unfused vertebral bodies to maintain mobility.

For patients with DISH in both cranial and caudal vertebrae, the DEPS technique was applied to both sides. However, for patients with DISH in only cranial vertebra, the DEPS technique was applied only to cranial vertebra, and, at the same time, the conventional PPS technique was applied to caudal vertebra (Hybrid technique) (Fig. 3).

Materials

In the first study, we retrospectively evaluated the patients who underwent surgery for DISH-related OVF. DISH was defined as ossification along the anterolateral aspect of at least four contiguous vertebral bodies⁸). Twelve patients with DISH-related OVF who were treated using the SEPS/DEPS technique were included (four males and eight females). The

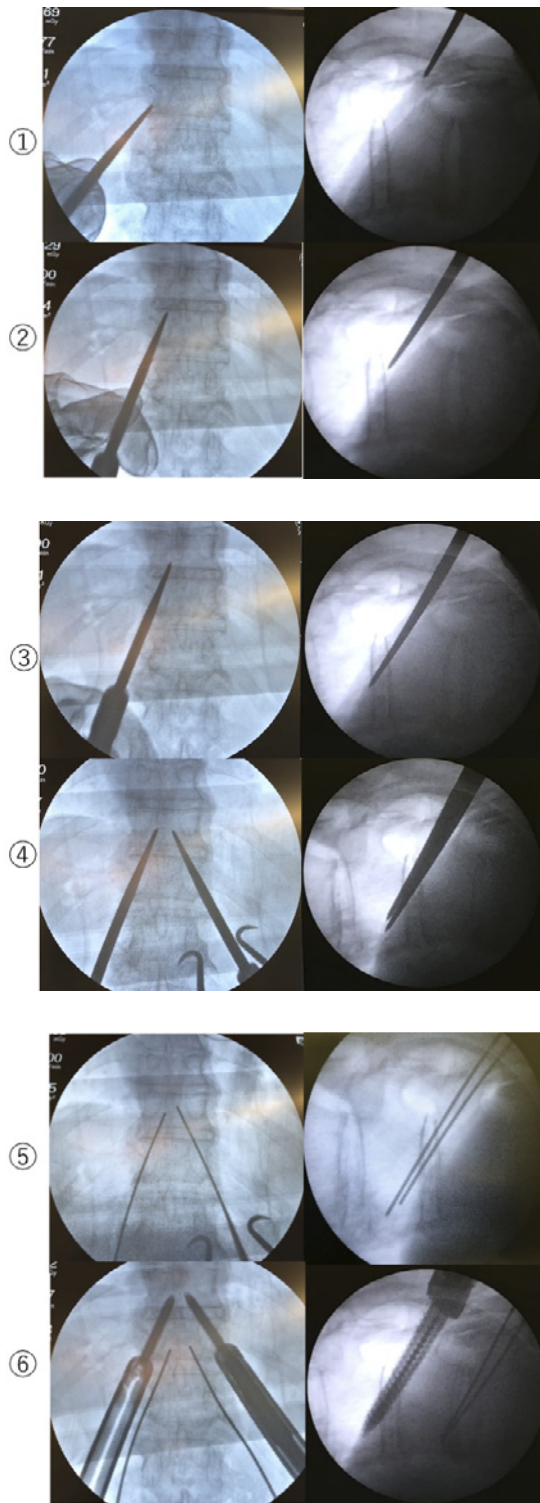


Figure 2. Intraoperative fluoroscopy. A-P view (Left), Lateral view (Right).
 1; Left pedicle; insert the probe; 7:00 → 1:00 direction
 Right pedicle; insert the probe; 5:00 → 11:00 direction
 2; The tip of probe should reach to the upper endplate in the lateral view before touching the inner edge of the pedicle in the A-P view.
 3, 4; Penetrate the lower endplate of the cranial adjacent vertebral body.
 5; Insert the guidewire.
 6; Insert the pedicle screw in the same way as in conventional PPS.

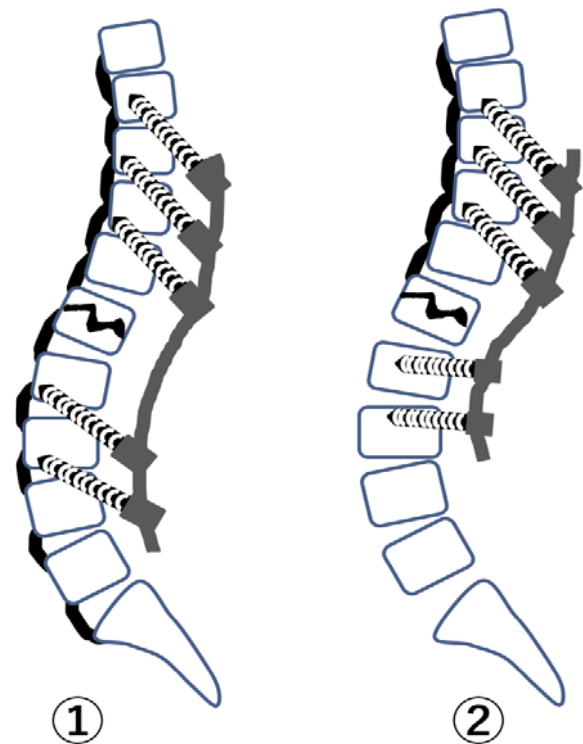


Figure 3. Our treatment strategy of vertebral fracture.
 1; Patients with DISH at both cranial and caudal vertebrae; SEPS or DEPS technique to cranial and caudal vertebrae (all SEPS or DEPS technique).
 2; Patients with DISH at only cranial vertebrae; DEPS technique to cranial vertebrae and conventional PPS to caudal vertebrae (Hybrid technique).

average age was 83.3 years (61 to 94 years old), and the average follow-up period was 22.3 months (9 to 30 months) (Table 1). For the control group, 12 patients with DISH-related OVf treated by conventional PPS (seven patients) and pedicle screw (PS) (five patients) were used (eight males and four females). The average age was 78.0 years (75 to 92 years old), and the average follow-up period was 27.8 months (8 to 72 months) (Table 2). Radiological parameters including the level of affected vertebral body, the range of DISH, the number of instrumented segments, the grade of SEPS/DEPS perforation, and the implant failure rate were evaluated. Screw perforation was graded using Raley's grade, Grade 0: screw within the cortex of the pedicle; Grade 1: perforation ≤ 2 mm; Grade 2: perforation > 2 mm, complication (-); and Grade 3: perforation > 2 mm, complication (+)⁹. The rate of implant failure was compared between the SEPS/DEPS technique group and the control group using the χ^2 test.

In the second study, we prospectively measured the insertion torque in three patients to whom the Hybrid technique had been applied, and it was compared between that of the DEPS technique and that of the conventional PPS technique using the Mann-Whitney U test (Table 3).

The insertion torque was measured with a screwdriver connected with a torque meter (HTG2-5N, Imada) during

Table 1. Patients Demographics in SEPS/DEPS Technique Group.

Case	Sex Age (years)	Affected vertebrae	DISH range	Hybrid or All S/DEPS	Number of instrumented segments	Instrumented vertebrae	Applied S/DEPS technique	Applied Conventional PPS technique	S/DEPS screw perforation	Implant failure/revision surgery	Follow up Period (months)
1	M 92	L1	T8-L1	Hybrid	5	T10-L3	T12 DEPS	T10 11 L1 2 3	Grade0	none	30
2	F 81	T11	C6-L1	Hybrid	6	T8-L2	L1 DEPS	T8 9 10 12 L2	Grade0	none	29
3	F 94	T12	T8-T12	Hybrid	4	T10-L2	T10 11 DEPS	T12 L1 2	Grade0	none	26
4	F 61	L1	T3-L1	Hybrid	5	T10-L3	T11 12 DEPS	T10 L2 3	Grade0	L2 3 loosening removal	27
5	F 89	L1	T3-L1	Hybrid	5	T11-L3	T11 12 DEPS	L1 2 3	Grade1×1	none	24
6	F 81	T11	T7-11	Hybrid	4	T9-L1	T9 10 DEPS	T11 12 L1	Grade0	none	23
7	F 91	L1	T3-S1	All S/DEPS	6	T10-L4	T10 11 12 DEPS L2 3 4 SEPS	none	Grade0	none	23
8	M 90	T12	T2-12	Hybrid	4	T10-L2	T10 11 DEPS	T12 L1 2	Grade0	L2 back out removal	17
9	F 69	L1	T5-L4	Hybrid	6	T10-L4	T10 11 12 DEPS L3 4 SEPS	L2	Grade0	none	22
10	M 81	L1	T5-S1	All S/DEPS	5	T11-L3	T11 12 DEPS L2 3 SEPS	none	Grade1×2	none	15
11	M 85	L1	T4-T12	Hybrid	5	T11-L3	T11 12 DEPS	L2 3	Grade0	none	9
12	F 85	T12	T5-L4	All S/DEPS	6	T9-L3	T9 10 11 DEPS L1 2 3 SEPS	none	Grade1×1	none	12
average	83.3				5.1						22.3

screw insertion. All screws showed a steady increase in torque toward the end of the insertion, and the maximum insertion torque was measured in the last phase⁷.

Results

In the first study, the affected vertebral bodies in the SEPS/DEPS technique group were at T11 in two patients, T12 in three patients, and L1 in seven patients. DISH was extended from the cervical spine to the lumbar spine in all the patients. The number of instrumented segments was 5.1 (4-6) in the SEPS/DEPS technique group (Table 1). In the control group, the affected vertebral bodies were at T11 in four patients, T12 in four patients, L1 in one patient, both T7 and T8 in one patient, both T11 and T12 in one patient, and T11, L1, and L2 in one patient. DISH was extended from the thoracic spine to the lumbar spine in all the patients. The number of instrumented segments was 4.7 (3-7) (Table 2).

Screws were inserted into two or three vertebral bodies both at the cranial and caudal sides using either method because the affected vertebra was severely unstable due to long lever arm associated with DISH. Seventy screws were inserted using the SEPS/DEPS technique, and 116 screws were inserted using the conventional PPS and PS techniques

in the control group. There were four screws with Grade1 perforation in the SEPS/DEPS technique group (Table 1). No perioperative complications related to the surgery were observed in either group.

No screw loosening was observed in the SEPS/DEPS technique group (0%), whereas 12 screws loosened in the control group (10.3%), which showed a statistically significant difference ($p = 0.005$) (Table 4). Revision surgery was required because of screw loosening in three patients: two patients with conventional PPS in the SEPS/DEPS technique group (Hybrid technique) and one patient in the control group. No revision surgery was required in the SEPS/DEPS technique group. Two patients required removal of a part of PPS, and the other patient required removal of all PPS and had Balloon Kyphoplasty performed to the distal adjacent segmental fracture (Table 1, 2).

In the second study, the insertion torque was measured in 28 screws: 18 screws with the DEPS technique and 10 screws with the conventional PPS technique (Table 4). The diameter of PSs in DEPS was 5.5 mm in six screws and 6.5 mm in 12 screws, whereas the diameter was 7.5 mm in all screws using the PPS technique. The average insertion torque of the DEPS technique was 2.25 Nm, and that of the conventional PPS technique was 1.64 Nm ($p = 0.04$). Therefore, the DEPS technique achieved a 134% higher average

Table 2. Patients Demographics in Control Group.

Case	Sex Age (years)	Affected vertebrae	DISH range	Number of instrumented segments	Instrumented vertebrae	PPS/open technique	Implant failure/revision surgery	Follow up Period (months)
1	F 76	T12	T5-L2	3	Th10-L1	PPS	L1 back out	52
2	F 81	T11	T5-11	3	Th9-12	PPS	none	24
3	M 77	T12	T8-L2	4	Th10-L2	PPS	none	30
4	M 75	T11 12	T5-L5	7	Th8-L3	PPS	none	31
5	M 78	T11	T3-L5	6	T8-L2	open	none	9
6	M 65	T7 8	T6-L1	5	T5-10	open	none	24
7	F 84	T11	T3-L3	6	T8-L2	PPS	none	8
8	M 92	T11 L1 2	T5-T12	6	T9-L3	PPS	T9 10 11 loosening removal	11
9	M 75	L1	T8-L1	4	T11-L3	PPS	none	12
10	M 75	T12	T7-T12	4	T10-L2	open	L2 loosening	12
11	M 75	T12	T7-T12	4	T10-L2	open	L2 loosening	48
12	F 83	T11	T5-L4	4	T9-L1	open	none	72
average	78			4.7				27.8

Table 3. Demographics of Hybrid Technique Patients with the Insertion Torque Measurement.

Case	Sex Age (years)	Diagnosis	Affected vertebrae	DISH range	Instrumented vertebrae	Applied DEPS technique	Applied Conventional PPS technique
1	M 90	osteoporotic vertebral body fracture	T12	T2-12	T10-L2	T10 11	T12 L1 2
2	F 69	osteoporotic vertebral body fracture	L1	T5-L4	T10-L4	T10 11 12 L3 4	L2
3	M 75	pyogenic spondylitis	L1 2	T4-L1	T11-L4	T11 12	L3 4

insertion torque than using the conventional PPS technique (Fig. 4).

Illustrative case (case 15)

An 85 year-old female was admitted to our hospital because of severe back pain and lower extremity paralysis after the failure of conservative treatment at a nearby hospital. Radiography showed a compression fracture at T12 and an ankylosed spine from the upper thoracic spine to L4. CT and MRI revealed that the fracture at T12 was a reverse Chance-type fracture. Posterior fusion was performed using the DEPS technique at T9, T10, and T11 and using the SEPS technique at L1, L2, and L3. She was able to sit up a few days afterward, and bony union was verified 3 months

after the surgery (Fig. 5).

Discussion

DISH is a non-inflammatory disease whereby the spinal longitudinal ligaments and entheses become ossified over time resulting in the decreased mobility of the affected segment¹⁰. The diagnosis can be made when flowing ossification of the anterior longitudinal ligament is present on spine radiographs over at least four consecutive levels⁸. This condition is associated with osteoporosis as a result of chronic inflammation and disuse atrophy¹¹. In DISH patients, minor trauma can cause serious spinal fractures that carry a high risk of delayed and surgical complications. As with fracture

Table 4. Comparison of Implant Failure Rate between SEPS/DEPS Group and Control Group.

	SEPS and DEPS technique group	Control group
Implant failure (+)	0	12
Implant failure (-)	70	104

in long bone, the long lever arm formed by the ossified spine increases the mechanical stress at the fracture^{15,6}. Paxisons et al. reported that bone quality is an important factor that influences the stability of posterior thoracic implant and that fixation strength in osteoporotic patients was only one-fourth of the value measured in vertebrae with good bone quality¹². Caron et al. evaluated the surgical results of spine fracture in patients with ankylosing spinal disorders and suggested that posterior segmental fixation extending a minimum of three levels above and below the injured vertebra resulted in reliable fracture healing¹³. These studies suggest that it is difficult to obtain rigid fixation to osteoporotic bone and to determine the appropriate fixation method in DISH patients.

To resolve these issues, we have developed the SEPS/DEPS technique, which is a novel PPS insertion technique suitable for patients with DISH.

The DEPS technique is a modification of the PES technique reported by Matsukawa et al. The PES technique was demonstrated to have a 141% higher average insertion torque than the traditional technique and the endplate offered the best screw fixation, which was confirmed by the higher insertion torque despite the shorter screw length⁷.

The screw used in the DEPS technique is a type of transvertebral screw that was first reported by Abdu et al. for high-grade spondylolisthesis in adults¹⁴. Minamide et al. reported the biomechanical results of transdiscal L5-S1 screws for the fixation of isthmic spondylolisthesis. They reported that transdiscal L5-S1 fixation produced a 1.6-1.8 times stiffer construct than traditional PS fixation in a cadaveric model of simulated L5-S1 spondylolisthesis¹⁵. Several other studies have reported on screws that penetrate the adjacent vertebra. Nottmeier et al. reported on the transvertebral PS placement in the thoracic spine with the aid of 3-D image guidance¹⁶. Rodriguez-Martinez et al. reported the biomechanical results of transvertebral screw fixation for thoracic spine. They reported that transvertebral screw fixation had good fixation force similar to the traditional PS fixation, and it can be a viable therapeutic option for fixation in a salvage procedure, if PS insertion is not possible¹⁷. Sandquist et al. reported on the multilevel stabilization screw technique for decreasing the incidence of proximal junctional failure in long segmental instrumented fusions for adult degenerative scoliosis¹⁸. These reports suggested that transvertebral screws are a useful device to obtain favorable surgical outcomes. As a result, we have developed this unique SEPS/DEPS technique designed particularly for DISH patients.

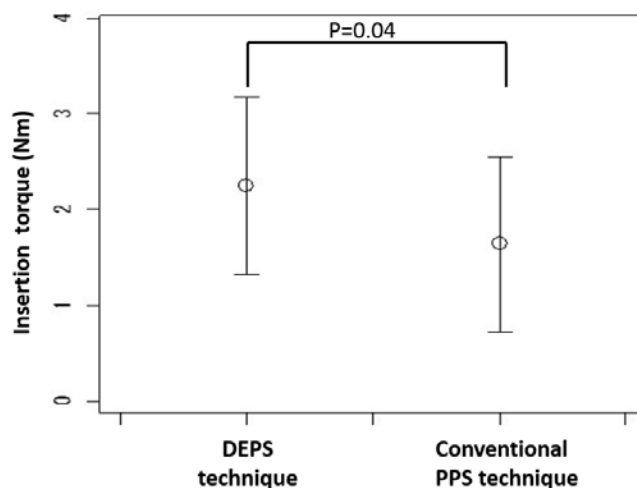


Figure 4. Comparison of insertion torque (DEPS technique vs. Conventional PPS technique).

The DEPS technique had a 134% higher average insertion torque than the conventional PPS technique (p=0.04).

Another advantage of this innovative technique in comparison with previous conventional techniques is that SEPS/DEPS is a percutaneous method and utilizes fluoroscopy, not 3-D image guidance. Therefore, this technique is less invasive and can be performed at medium-sized hospitals that do not have 3-D image guidance. Our comparative study between the SEPS/DEPS technique group and the control group demonstrated a more successful radiological outcome with a lower implant failure rate in the SEPS/DEPS technique group. Okada et al. have reported on screw loosening in conventional PPS for vertebral fractures associated with DISH. Although no screw loosening was observed postoperatively, there was 12.5% of screw loosening intraoperatively³. In our study, no screw loosening intraoperatively and postoperatively was observed using the SEPS/DEPS technique. Furthermore, the safety of this method was confirmed by the absence of critical screw perforation or complications related to SEPS/DEPS insertion. Revision surgery was required in two patients in the SEPS/DEPS technique group, but these were due to screws inserted using the conventional PPS method in the Hybrid technique, and none was required in the SEPS/DEPS technique group.

To obtain more accurate comparisons, we measured and evaluated the insertional torque of two different methods applied to three patients who had been treated with both DEPS and conventional PPS (Hybrid technique). The DEPS technique showed a 134% higher average insertion torque in spite of the smaller diameter of the screw than with the conventional PPS technique. There are several potential reasons for the higher insertion torque in DEPS. Firstly, based on the idea that the PES technique was demonstrated to have a 141% higher average insertion torque than the traditional technique, the screws used in the DEPS technique penetrated double endplates in a similar way as in the PES technique⁷. Secondly, the trajectory of DEPS technique screws passes the caudal half of the pedicle, which has the highest

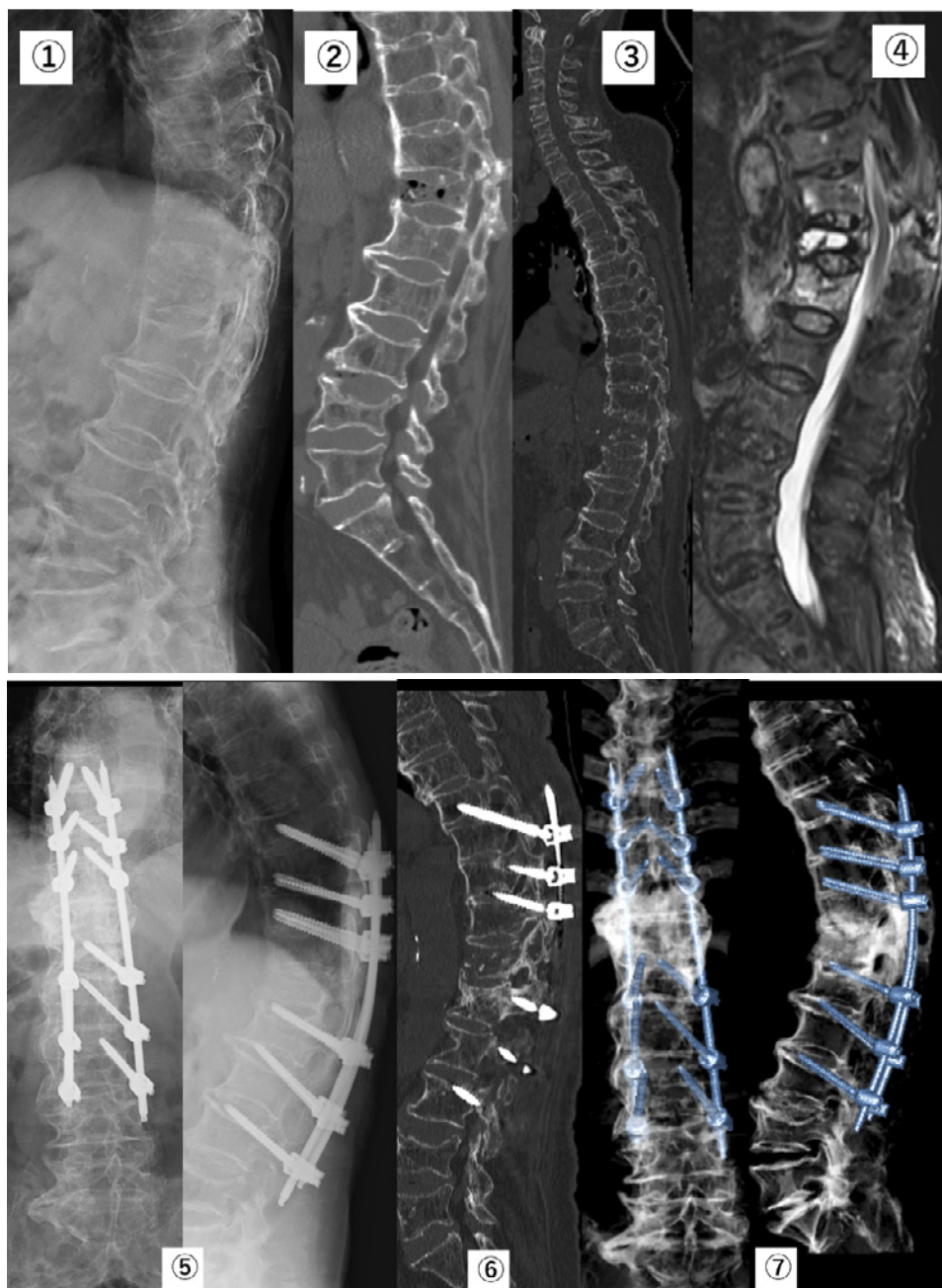


Figure 5.

- ① ; Lateral radiograph of the spine showing the T12 fracture and ankylosed spine.
 ② , ③ ; Sagittal view of CT imaging showing the ankylosed spine from the upper thoracic spine to L4 and reverse Chance-type fracture at T12.
 ④ ; Sagittal view of MRI (T2) showing the diffuse high signal intensity area in T12, L1 vertebral body and posterior element of T12.
 ⑤ ; Coronal and lateral radiograph after the surgery. DEPS technique was applied to T9, T10, T11, and SEPS technique was applied to L1, L2, and L3.
 ⑥ , ⑦ ; Sagittal and 3-D reconstructed CT imaging after the surgery.

bone density in the pedicle and has a 44% higher load to failure during PS compression testing¹⁹⁾ (Fig. 1). We believe that these reasons for the higher insertion torque explain the lower implant failure rate using the DEPS technique compared with using conventional PPS.

One of the limitations of DEPS is that this technique might be slightly difficult to apply at lumbar spine level.

The sagittal pedicle angle (measured between the superior endplate of the vertebral body and a line extending down the axis of the pedicle) is greater in the thoracic spine than in the lumbar spine²⁰⁾. Accordingly, in DEPS, the thoracic spine has a greater chance of being able to engage the superior endplate. In contrast, the sagittal pedicle angle is nearly zero in the mid lumbar spine and can be negative in the

lower lumbar spine²⁰⁾, which makes it more difficult to engage the superior endplate in the lumbar spine using the DEPS technique. Even if the screw could penetrate only a single endplate (SEPS technique), we consider that it could obtain a stronger fixation than using the conventional PPS technique and is comparable with using the PES technique.

It should be noted that there are some other limitations in this study. Firstly, the level of affected vertebra varied among the patients who underwent the SEPS/DEPS technique. Secondly, the control group included patients who had been treated not only with the conventional PPS technique but also with the open PS technique, and, therefore, it may be difficult to draw a precise direct comparison between the two techniques. Lastly, as the insertion torque was measured in only three patients, it may not be sufficient to draw definite conclusions. However, torque measurement was seen as a useful tool in assessing the stability of screw insertion.

Conclusion

We have demonstrated that this novel technique has a stronger insertion torque and fixation compared with the conventional PPS and PS techniques. The number of OVF patients with DISH will likely increase in the future and that combined Hybrid and SEPS/DEPS technique treatment will also become more accepted, and this study has demonstrated the efficacy and viability of this innovative approach. Further studies focusing on the biomechanical aspect of our SEPS/DEPS technique are required to validate our clinical results.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

Author Contributions: Study conception and design; Takumi Takeuchi, Keitaro Matsukawa, Naobumi Hosogane
Acquisition of data; Takumi Takeuchi, Kenichiro Yamagishi

Analysis and interpretation of data; Takumi Takeuchi

Drafting of manuscript; Takumi Takeuchi

Critical revision; Naobumi Hosogane, Kazuhiko Satomi, Shoichi Ichimura

Informed Consent: Informed consent was obtained from all participants in this study.

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