Short Fixation Using Upward/Downward Penetrating Endplate Screws and Percutaneous Vertebral Augmentation for Unstable Osteoporotic Vertebral Fractures

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Abstract:

Introduction: Percutaneous vertebral augmentation techniques, such as balloon kyphoplasty (BKP) and vertebral body stenting (VBS), are commonly used for surgical intervention in osteoporotic vertebral fractures (OVFs). However, markedly unstable OVF cases require additional fixation procedures, prompting the exploration of combined percutaneous vertebral augmentation and posterior fixation. A novel surgical approach involving percutaneous vertebral augmentation with upward penetrating endplate screws (PES) and downward PES, complemented by a short fusion of one above one below, was developed. This study aimed to introduce and report the preliminary outcomes of this technique based on a retrospective analysis of 20 consecutive cases in the short and medium term.

Methods: Surgical indications are a vertebral wedge angle difference of 10° or more, vertebral pedicle fractures, posterior wall fractures, and diffuse low-signal changes exceeding 50% on T1-weighted magnetic resonance imaging. The procedure is reserved for highly unstable cases following a comprehensive health assessment. The surgical technique involves prone positioning, fluoroscopy-guided percutaneous vertebral augmentation, and the use of downward PES in the cranial vertebral body and upward PES for the caudal vertebral body by percutaneous technique. The fixation range is one above and one below.

Results: The case series of 20 patients, with an average follow-up period of 146.9 days, demonstrates a mean surgical time of 57 min and minimal complications. The advantages of the technique are as follows: ease of performance, minimal fixation range, and time efficiency. Risks, such as potential screw loosening and the need for prolonged follow-up, are acknowledged.

Discussion: The technique represents a promising surgical approach that balances the requirements of minimally invasive intervention and relatively robust initial fixation for elderly osteoporotic patients with unstable OVFs. While short- and medium-term results are favorable, long-term observations are needed to further assess its efficacy. This novel technique has a potential to be a valuable surgical option for unstable OVFs.

Keywords:

osteoporotic vertebral fracture, percutaneous pedicle screw, penetrating endplate screw, short fixation

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Introduction

Percutaneous vertebral augmentation techniques, such as balloon kyphoplasty (BKP) and vertebral body stenting (VBS), are commonly used for surgical intervention in osteoporotic vertebral fractures (OVFs)[1-4]. However, markedly unstable OVF cases require additional fixation procedures. Simultaneous posterior fixation during percutaneous vertebral augmentation was not approved for medical use in Japan in the past; however, recent approvals have led to an increasing number of cases considering the combined use of percutaneous vertebral augmentation and posterior fixation for highly unstable OVFs[5-8]. Considering the need for a surgical plan accounting for the bone fragility in OVF patients, concerns regarding the insufficient stability of the one above one below posterior fixation have arisen, necessitating the

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Figure 1. Preoperative plain radiographs of the thoracolumbar spine. (A) Anteroposterior radiograph. (B) Lateral cross-table radiograph. (C) Seated lateral radiograph. The vertebral wedge angle difference in lateral cross-table (B) and seated lateral images (C) was 12 degrees.

extension of the fixation range to two above two below in many cases. Alternative techniques, such as lateral lumbar interbody fusion (LLIF) or anterior cage insertion (via anterior or posterior approaches), have been contemplated; however, they are associated with considerable surgical invasiveness and potential risks, including adjacent junctional fractures with prolonged fixation ranges[9]. Due to these considerations, a surgical approach involving percutaneous vertebral augmentation with upward penetrating endplate screws (PES) and downward PES, complemented by a short fusion of one above one below, was developed[10-16]. This study aims to introduce and report the initial outcomes of this technique based on a retrospective analysis of 20 consecutive cases in the short and medium term.

Materials and Methods

Surgical indications

The indications for this technique encompassed cases meeting multiple criteria, such as a vertebral wedge angle difference of 10° or more in simple X-ray dynamic imaging (load/supine cross-table imaging), vertebral pedicle fractures, posterior wall fractures, and diffuse low-signal changes exceeding 50% of the vertebral body on T1-weighted magnetic resonance imaging (MRI). The procedure was reserved for cases that were considered highly unstable, with the ability to endure approximately 1 h of general anesthesia in a prone position for the surgery, following a comprehensive assessment of the overall health status.

Cases with fractures within diffuse idiopathic skeletal hyperostosis (DISH) or adjacent vertebral fractures related to DISH and cases presenting late-onset paralysis were excluded.

Representative case presentation

A 94-year-old man, presenting with difficulty in ambulation after a fall at home, was urgently transported to the hospital. His pre-injury ambulatory capacity was unassisted. There were no neurological abnormalities in the lower limbs. A diagnosis of L1 vertebral fracture was confirmed through plain radiographs of the thoracolumbar spine. The patient had a transitional vertebra (lumbarization). The vertebral wedge angle difference in lateral cross-table and seated lateral images was 12 degrees (Fig. 1). A computed tomography (CT) scan revealed posterior wall and bilateral pedicle damage to the L1 vertebral body (Fig. 2). MRI demonstrated diffuse low-signal changes in approximately 60% of the mid-sagittal section of the L1 vertebral body on T1-weighted images (Fig. 3A). There were high-signal changes in the cleavage formation on T2-weighted sagittal images (Fig. 3B). On the 10^{th} postinjury day, posterior fixation by percutaneous PES/downward PES from T12 to L2 with BKP to L1 vertebrae was performed (Fig. 4). A Jewett brace was prescribed for 3 months postoperatively. Ambulation training started on the day after surgery. Three weeks postoperatively, the patient regained ambulatory ability at the level of walking with a T-cane without residual back pain and was transferred to a rehabilitation hospital.

Surgical technique

Under prone positioning, fluoroscopy was used to obtain anteroposterior and lateral images for each vertebra. KYPHON® BKP (Medtronic Sofamor Danek USA, Inc., Mineapolis, MN, USA) was commonly used in many cases for percutaneous vertebral augmentation. In cases where there were concerns about marked vertebral height correction, vertebral body stenting (VBS™ - Vertebral Body Stent - DePuy Synthes Spine, Inc., Raynham, MA, USA) was

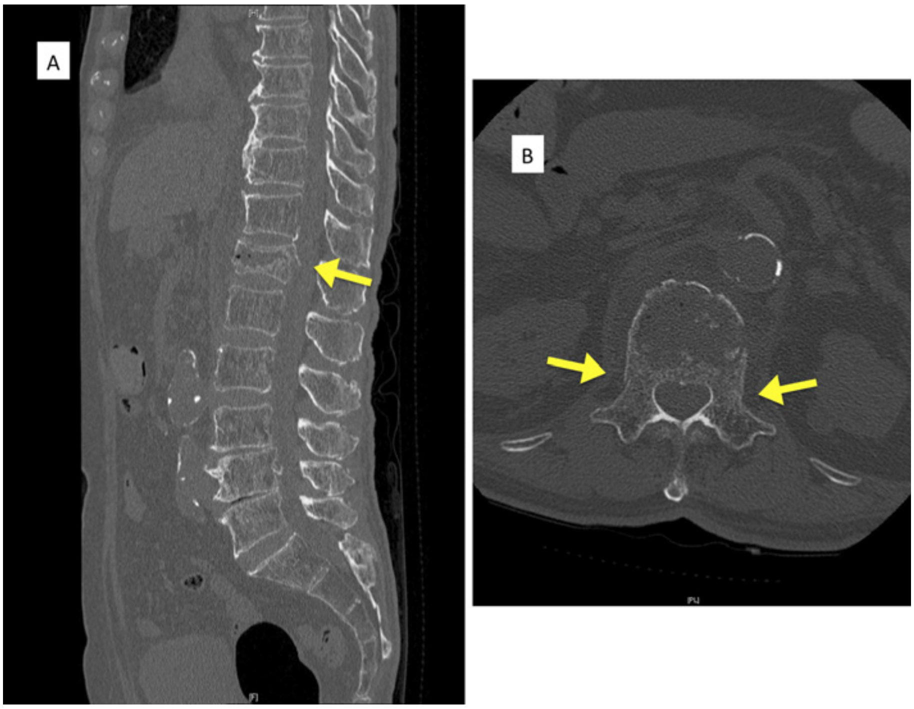

Figure 2. A computed tomography (CT) scan of thoracic to lumbar spine. (A) A mid-sagittal slice and (B) an axial slice. Posterior wall (arrow) and bilateral pedicle damage to the L1 vertebral body (arrows) were revealed. The patient had a transitional vertebra (lumbarization).

used[17]. Following percutaneous vertebral augmentation, a downward PES, penetrating the caudal endplate, was inserted using the groove entry method for the cranial vertebral body. Similarly, a percutaneous technique was used to insert a upward PES penetrating the cranial endplate for the caudal vertebral body. A guidewire was inserted into the affected vertebra before cement solidification, and then short percutaneous pedicle screws were inserted. Finally, a titanium alloy rod, bent in an arc to create posterior convexity, was inserted and fixed in a one above one below configuration. Although rod bending was primarily in situ, attention was paid to a slightly posteriorly inclined bending to anticipate the force direction of forward flexion (bending) when the patient rises and bears weight after surgery, considering the potential impact on the fractured area.

Radiological evaluation

Regarding bone union definition, we defined union as the following conditions: (1) obvious bridging bone formation to the fracture gap and no vertebral instability in lateral dynamic radiographs with a loaded (standing or sitting) and nonloaded position (supine position) and (2) bridging bone formation to the fracture gap observed in CT scan multiplanar reconstruction slices.

Results

Twenty cases (11 men, 9 women, age range: 68-94 years, mean age: 83.0 years) underwent this procedure from March 2022 to September 2023. Table 1 shows patient characteristics. The average duration until discharge postoperatively was 15.3 days, with an average follow-up period of 146.9 days (range: 13-366 days). The distribution of treated vertebrae was as follows: T12 (five cases), L1 (eight cases), L2 (three cases), L3 (two cases), and L4 (two cases). The mean surgical time was 57 min (range: 44-85 minutes), and the mean blood loss was 6.1 mL (range: 0-30 mL). Perioperative complications included nerve root injury due to inappropriate screw insertion and deep surgical site infection (SSI) in one case each. All cases, except for one (developing hyponatremia), regained ambulatory ability beyond using a walking aid upon discharge.

Of 20 cases, 11 could be followed up for more than 6 months, and the clinical results are shown in Table 2. In 10 of the 11 cases, we have confirmed the union using CT scans or dynamic X-rays. Furthermore, there were three cases with postoperative radiographical findings with radio lucent zones (RLZ) around the screws, two of the three cases finally achieved union, and one case was diagnosed as non-union. In that case, the patient's complaint is only back pain without any neurologic symptoms and gait disturbance; therefore, we are continuing careful follow-up at the outpatient clinic. There was one case with early postoperative adjacent vertebral fracture (AVF), and luckily the bone union was confirmed in 111 postoperative days.

Figure 3. Magnetic resonance images. (A) T1-weighted mid-sagittal image. Diffuse low-signal changes in approximately 60% of the L1 vertebral body were revealed. (B) T2-weighted mid-sagittal image. High-signal changes in the cleavage formation were observed. The patient had a transitional vertebra (lumbarization).

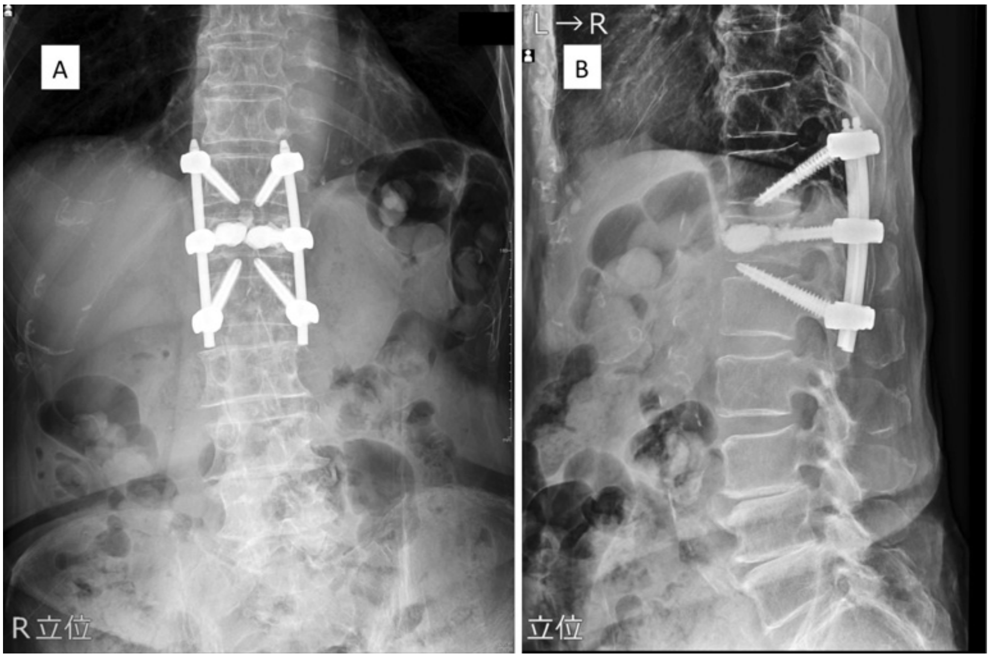

Figure 4. Postoperative plain radiographs of the thoracolumbar spine. (A) Anteroposterior radiograph. (B) Lateral radiograph. Posterior fixation by percutaneous pedicle screws from T12 to L2 with L1 balloon kyphoplasty (BKP) was performed. The patient had a transitional vertebra (lumbarization).

Table 1. Patient Demographics of the Case Series.

Case No.	Sex	Age	Affected vertebrae	Postoperative duration until discharge (days)	Follow-up period (days)	Surgical time (minutes)	Estimated blood loss (mL)	Perioperative complication	Ambulatory status upon discharge
1	Male	94	L1	15	15	60	5		Walker
2	Male	87	T12	21	21	59	20		Walker
3	Female	73	L3	10	365	72	0		Walker
4	Male	89	L1	16	16	72	0		Walker
5	Male	85	L3	14	365	50	5		T-cane
6	Female	88	L1	14	503	63	0		Walker
7	Male	86	L2	13	13	60	0		Walker
8	Female	84	L1	10	363	44	0		Walker
9	Male	83	L4	16	16	49	0	Deep surgical site infection	T-cane
10	Male	83	T12	14	14	49	0		Walker
11	Female	87	L4	35	35	48	0	L4 nerve root injury during surgery (malposition of probe: fully recovered upon discharge)	T-cane
12	Female	70	L1	10	366	45	0		Walk without support
13	Female	92	L1	13	13	45	20		Walker
14	Female	78	T12	13	465	85	30		Walker
15	Male	79	T12	15	374	45	0		T-cane
16	Female	87	L2	36	364	62	18		Walker
17	Male	81	L2	13	234	50	5		Walk without support
18	Male	68	L1	11	181	50	67		Walk without support
19	Male	77	L1	13	188	57	19		Walker
20	Male	89	T12	15	30	60	15		Walk without support

Table 2. Bone Union Evaluation for Patients Followed Up for More than 180 Days.

Case No.	Sex	Age	Affected vertebrae	Follow-up period (days)	Radiolucent zone (RLZ) around the screws/adjacent vertebral fracture (AVF) during follow-up	Bone union	Time (days) from the surgery to bone union	Used modality to confirm bone union
3	Female	73	L3	365		Union	92	CT
5	Male	85	L3	365		Union	90	CT
6	Female	88	L1	503		Union	272	CT
8	Female	84	L1	363		Union	363	X-ray
12	Female	70	L1	366	AVF	Union	364	X-ray
14	Female	78	T12	465	RLZ	Union	370	X-ray
15	Male	79	T12	374		Union	213	CT
16	Female	87	L2	364		Union	364	X-ray
17	Male	81	L2	234	RLZ	Non-union/ screw loosening		X-ray
18	Male	68	L1	181	RLZ	Union	111	X-ray
19	Male	77	L1	188		Union	87	X-ray

Discussion

To the best of our knowledge, this study represents the initial report of a short fixation combined percutaneous vertebral augmentation technique employing upward and downward PES. There is no universally accepted standard for the treatment strategy of OVF with instability, resulting in the exploration of various surgical techniques[2,4,18,19]. Biomechanical studies recommend fixation in the two above two below or greater range for posterior fixation in OVFs[20]. In addition, efforts to enhance the stability of posterior fixation and prevent implant failure, such as the use of laminar hooks, sublaminar braiding ultrahigh-molecular polyethylene tape, cortical bone trajectory screws, and fenestrated screws, have been reported[8,21-23]. For cases inadequately addressed by posterior fixation alone, more invasive procedures, such as LLIF with percutaneous pedicle screws (PPS), anterior corpectomy with expandable cage insertion with PPS, and vertebral column resection with PPS, may be required[2,18,19]. Among these options, fenestrated screws have demonstrated superior fixation strength and utility but are associated with the risk of cement leakage, as reported in recent studies[24-26]. Furthermore, the integration of screws and cement poses challenges in potential future screw removal. Techniques such as laminar hooks, sublaminar braiding ultrahigh-molecular polyethylene tape, LLIF, and anterior corpectomy require more invasive procedures beyond percutaneous techniques, presenting challenges[9].

To address the aforementioned issues in existing techniques, we devised this technique to fulfill conditions such as obtaining sufficient fixation strength, being minimally invasive, carrying a low risk of complications, and being easy to perform. The PES method was originally developed as a robust fixation technique for spinal disorders associated with DISH. Moreover, it has been reported that the PES method possesses excellent pullout strength and insertion torque[10-15]. Shiraishi et al. reported that downward PES is identical to the technique we have used[16]. Moreover, groove entry method and hooking screws have previously been reported as similar trajectories for pedicle screw insertion[12,27,28]. Downward PES achieves double cortical purchase by penetrating the caudal endplate, providing more robust fixation.

The advantages of this technique are as follows:

(1) The procedure is easy to perform, requiring no specialized equipment like navigation or intraoperative three-dimensional CT. As long as anteroposterior and lateral images can be obtained intraoperatively using fluoroscopy, the surgery can be conducted.

(2) The fixation range is minimal, involving one above one below, providing potential medical economic benefits.

(3) All surgical steps can be performed using percutaneous techniques. The surgery is time-efficient, with minimal intraoperative bleeding in most cases. Particularly for older individuals susceptible to OVF, less invasive surgery is desirable, and the reduction in surgery time and blood loss is crucial. Regarding surgery time, the use of the probe for upper and lower vertebral bodies while waiting for cement solidification shortens the surgery time. Cases requiring more than 1 h of surgery in this case series included instances of reinsertion due to misplaced screws and cases involving the use of VBS, which, compared to BKP, involves more procedural steps and longer surgery time.

(4) Inserting a rod bent in an arc with posterior convexity results in the rod ends and screw heads being inserted relatively deep into the skin. Therefore, the risk of skin damage related to screw heads postoperatively is low. This is particularly relevant in older individuals, where OVF often occurs near the apex of spinal kyphosis and posterior fixation implants are susceptible to compression in the supine position, making it a critical point.

The risks and challenges of this technique are as follows:

(1) Fixation of the affected and adjacent vertebrae in the posterior direction may theoretically lead to screw loosening if bridging fusion between upper and lower vertebrae in the anterior direction is not achieved in the mid to long term, as autogenous bone grafting is not performed. If screw loosening occurs after successful fusion of the affected vertebra, prompt hardware removal is considered desirable.

(2) The risk of AVF necessitates prolonged follow-up for extended periods.

(3) The violation of the disc space by PES may have additional damage to the tissue, and the additional damage to the disc may influence the risk of infection. In our experienced SSI case, the patient had suffered from pancreatic cancer, recurrent postoperative pancreatitis, portal vein thrombosis, esophageal varices, diabetes mellitus, chronic renal dysfunction, malnutrition, and anemia at the preoperative systemic evaluation, and we consider that these risk factors had a stronger influence on the onset of deep SSI than the disc space violation by PES.

(4) Percutaneous screw fixation technique without posterior bone grafting is a limitation of this technique. Posterior fixation with PES insertion into a vertebra without DISH theoretically requires open posterior surgery with posterior bone grafting instead of percutaneous posterior fixation technique. However, considering the patients' old age, we chose a less invasive surgical technique.

(5) This study specifically focused on surgical indications by referencing past research on the risk of non-union in OVF[29-32]. Criteria for selecting cases suitable for this technique, such as whether this technique is applicable to cases with exceptionally strong instability, will require further consideration in the future.

In conclusion, this technique represents a surgical approach that balances the requirements of minimally invasive intervention and relatively robust initial fixation for elderly osteoporotic patients. The short- and medium-term results have been favorable. Since this technique is considered one of the surgical options for OVF with instability, its use is promising. Long-term observations are necessary in order to further assess its efficacy.

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

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Author Contributions: K.F., Y.S., and K.O. designed the study. S.L. and M.Y. supervised the study. K.F. wrote the draft. T.F. critically revised the manuscript. All authors have read and approved the final manuscript.

Ethical Approval: This study was approved by the Ethics Committee of Showa General Hospital (approval code: REC-357).

Informed Consent: Informed consent for publication was obtained by all participants in this study.

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