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Original Article

Efficacy of pedicle screw fixation and vertebroplasty treatment of severe osteoporotic thoracolumbar vertebral compression fractures in senior patients

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Abstract: Objective: Osteoporotic thoracolumbar compression fractures have become an important public health problem due to population aging. This study aimed to assess the efficacy of percutaneous pedicle screw fixation combined with vertebroplasty for severe osteoporotic thoracolumbar compression fractures in senior patients. Methods: Twenty-seven patients who had been diagnosed with osteoporotic thoracolumbar compression fractures without neurological deficits underwent percutaneous pedicle screw fixation combined with vertebroplasty. Polymethylmethacrylate bone cement was used. Visual analogue scale (VAS) scores, Cobb angles, and anterior column height were assessed before and after the operation. The patients returned for clinical evaluations 1, 3, 6, 12, and 24 months after surgery. Results: The mean follow-up period was 24.11 ± 1.23 months. The mean VAS score decreased significantly, from 6.98 ± 1.31 preoperatively to 2.52 ± 1.64 postoperatively to 0.72 ± 1.66 at the two-year follow-up ($P < 0.001$). The mean Cobb angle was 41.38° ± 4.18° before surgery, 25.41° ± 2.67° after the operation, and 27.98° ± 2.76° ($P < 0.001$) at the two-year follow-up. The average increase in vertebral body height was 8.14 mm anteriorly. No complications, such as infections or neurological impairments, were observed, and there was no bone cement leakage. Conclusions: Percutaneous pedicle screw fixation combined with vertebroplasty provides a safe and effective option for the treatment of severe osteoporotic thoracolumbar compression fractures in senior patients.

Keywords: Osteoporosis, thoracolumbar compression fractures, percutaneous pedicle screw fixation, vertebroplasty

Introduction

Due to population aging, osteoporotic thoracolumbar compression fractures have become a significant public health problem. Osteoporosis causes bones to become fragile, increasing the risk of fracture [1]. One of the major complications is osteoporotic vertebral compression fractures (VCFs), which represents a major health issue worldwide [2, 3]. Typically, osteoporotic VCFs in the spine occur where the lowest thoracic vertebra connects to the first lumbar vertebra. This accounts for approximately 15% of all vertebral injuries [4, 5].

Traditionally, osteoporotic VCFs have been treated with analgesics, bed rest, physical therapy, and antiresorptive medications. However, these methods have certain limitations. Conservative management cannot reverse kyphotic deformities that lead to an increased incidence of adjacent vertebral fractures caused by biomechanical changes in the spinal segments [5]. Because of low bone density, classic open surgery with the insertion of metal implants often fails, contributing to persistent back pain, neurological symptoms, and functional limitations. Moreover, open procedures are limited by neurological deficits and spinal sequence instability. They are also associated with significant perioperative complications, including blood loss, infections, and long hospital stays [6].

Minimally invasive percutaneous pedicle screw (MIPS) fixation was recently introduced as an alternative approach to treating thoracolumbar fractures. The aim is to minimize soft tissue injury and perioperative morbidity [7-10].

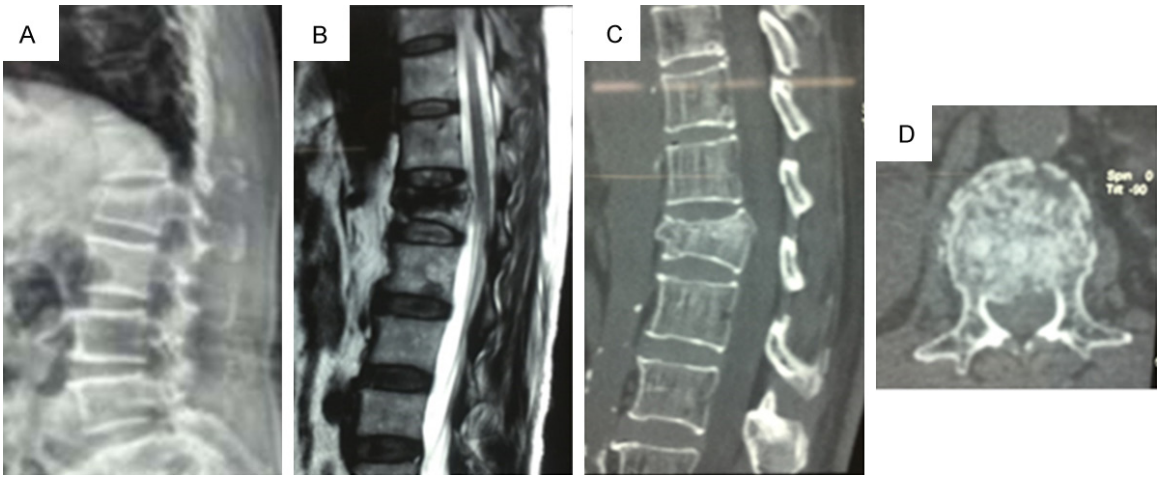

Figure 1. Representative images of a 66-year-old male patient with an L1 thoracolumbar fracture. (A) Lateral radiographs, (B) magnetic resonance imaging, and (C) computed tomography images showing the L1 facture. (D) Preoperative axial computed tomography image showing no neurological compression.

Because of the advantages of a minimally invasive technique, MIPS fixation may represent a useful strategy for treating osteoporotic thoracolumbar fractures [11-14]. However, the long-term outcomes of percutaneous pedicle screw fixation for osteoporotic thoracolumbar fractures have not been well established. Consequently, there is little evidence regarding the efficacy of this technique. This study therefore aimed to assess the efficacy of MIPS fixation combined with vertebroplasty for severe osteoporotic thoracolumbar fractures in senior patients.

Material and methods

Patients

This study was conducted with approval from the Ethics Committee of Rizhao Traditional Chinese Medicine Hospital and included 27 patients diagnosed with a single osteoporotic thoracolumbar fracture (**Figure 1**) who underwent MIPS fixation combined with percutaneous vertebroplasty (PVP) with the use of polymethylmethacrylate (PMMA) between October 2014 and October 2017 in the Department of Orthopedic Surgery, Rizhao Traditional Chinese Medicine Hospital (Rizhao, Shandong, China). The patients' mean age was 67 years (range: 62-75 years). Patients who exhibited neurological impairment, were under 60 years old, or had undergone previous vertebroplasty were excluded from the study.

Surgical procedure

Each patient was placed in the prone position after general anesthesia. The use of pelvic and chest wall cushions allowed the abdomen to hang to avoid compression. Special metal mesh body positioning and a C-arm X-ray were used to mark the position of the vertebral pedicle and the adjacent upper and lower segments (**Figure 2A**). Four small incisions, approximately 1.5 cm long were made at the upper and lower vertebral body surface markers (**Figure 2B**). The superior articular processes and the transverse roots of the vertebral body were exposed through the multi-fissure muscle space, and two pairs of pedicle screws were inserted under the guidance of lateral fluoroscopy (**Figure 2C**). The diameter of the screws was 6.5 mm. Connecting rods of an appropriate length were selected. After prebending, the double-sided connecting rods were installed percutaneously, the reset was opened, and the nuts were tightened (**Figure 2D**). Next, a puncture needle was placed at a specific abduction angle (between the 2 and 3 o'clock positions) on the body surface of the injured vertebrae, avoiding the connecting rod (**Figure 3A**). The puncture tube cannula was pulled out of the tube core, and PMMA cement was injected slowly under fluoroscopic guidance (**Figure 3B**) with close observation of the dispersion of the bone cement in the vertebral body. Approximately 5 ml of PMMA was injected in total. The bone cement was filled completely, with no leakage inside the spinal

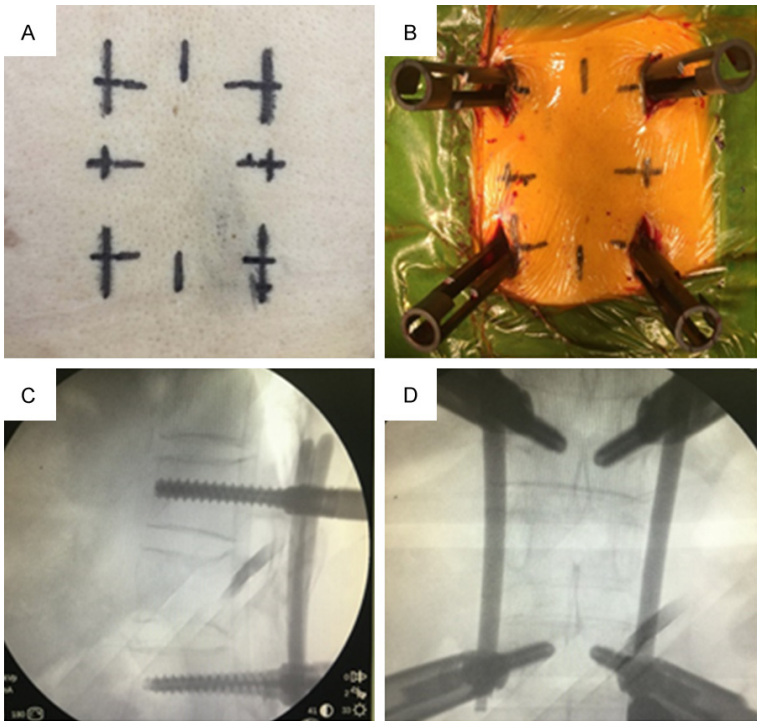

Figure 2. A. Under lateral fluoroscopic guidance, the skin was marked before the start of the surgical procedure. B. Placement of the pedicle screws into the adjacent vertebrae. C. Fluoroscopic image showing the placement of the pedicle screws. D. The pedicle screws were systematically inserted under anteroposterior and lateral fluoroscopic guidance.

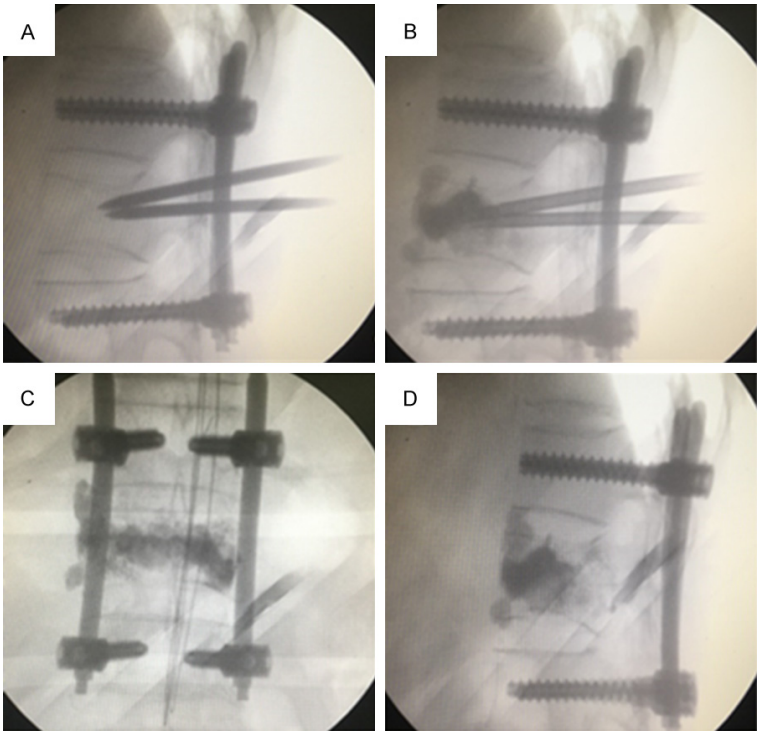

Figure 3. A. Insertion of the needle into the fractured vertebrae under fluoroscopic guidance. B. Injection of cement after the reduction. C. Anterior fluoroscopic image showing the finished bone cement injection. D. Lateral fluoroscopic image of the finished bone cement injection.

canal (**Figure 3C**, **3D**). After the bone cement solidified, the previously placed needles were pulled out with approximately 5 ml of bleeding. Most patients did not need to wear a lumbar brace after surgery (**Figure 4A**, **4B**). Also, most were given a spine surgery guide to recovery.

Follow-up

A minimum follow-up of 24 months, which corresponds to the natural duration of bone consolidation after a spinal fracture, was applied in each case. Anteroposterior and lateral spinal radiographs were obtained at 3, 6, and 12 months postoperatively and annually thereafter.

Clinical evaluation

Preoperative and postoperative pain was assessed with the visual analogue scale (VAS). The Cobb angles were calculated on lateral X-ray images preoperatively and postoperatively. The preoperative and postoperative anterior vertebral body height was also measured. The evaluation of the clinical outcomes also included data on patient demographics, length of stay, preoperative and postoperative pain medications, and potential complications.

Statistical analysis

The collected data was analyzed using the Statistical Product and Service Solutions (SPSS) 19.0 software (IBM Corp., Armonk, NY, USA). The measurement data were expressed as the mean ± standard deviation (mean ± sd). The measurement data between the preoperative and postoperative values for all

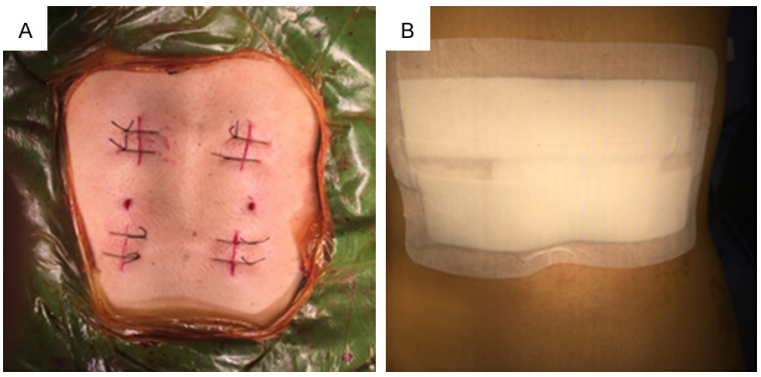

Figure 4. A. Photograph of the skin surface resulting from the percutaneous pedicle screw fixation and percutaneous vertebroplasty. B. Without a lumbar brace.

Table 1. Summary of the patients' clinical data (n = 27)

Age (years)	67 ± 2.61
Gender (Female/Male)	20/7
Body mass index (kg/m^2)	21.92 ± 1.81
Bone mineral density (T-score)	-2.6 ± 0.21
Duration of operation (minutes)	61 ± 11
Bone cement injected (ml)	5.11 ± 0.49
Blood loss (ml)	34.09 ± 5.16
Hospital stay (days)	10.12 ± 2.16
Follow-up period (months)	24.11 ± 1.23

parameters were compared by independent sample t test. The significance level was set at $P < 0.05$.

Results

The patients' clinical data are presented in **Table 1**. The fracture occurred at T11 in 3 of the 27 cases, at T12 in 7 cases, at L1 in 13 cases, and at L2 in 4 cases. The mean procedure duration was 61 ± 11 minutes. No implant failures or pullouts were noted during the screw and rod insertions. The mean blood loss was 34.09 ± 5.16 ml. The mean length of hospital stay was 10.12 ± 2.16 days. The patients were followed up for a mean duration of 24.11 ± 1.23 months. The mean preoperative VAS score was 6.97 ± 1.31. It decreased to 2.52 ± 1.64 immediately after the operation, and to 1.11 ± 1.55 at the 6-month follow-up, it was 0.75 ± 1.42 at the 12-month follow-up, and 0.72 ± 1.66 at the 24-month follow-up (**Table 2**). The mean Cobb angle was 41.38° ± 4.18° before the operation and 25.41° ± 2.67° immediately afterwards. The anterior vertebral body height increased from 14.98 ± 2.16 mm before the operation to 23.12 ± 2.06 mm immediately afterwards, it was 22.45 ± 1.75 mm at the 6-month follow-up, 22.16 ± 1.67 mm at the 12-month follow-up, and 22.13 ± 1.11 mm at the 24-month follow-up (**Table 2**). During the follow-up period, no instrumentation failures were noted, and no revision surgeries were required (**Figure 5**). No complications, such as infections or neurological impairments, were observed, and there was no bone cement leakage.

Discussion

Osteoporosis is a prevalent disease characterized by reduced bone mass and architectural deterioration that leads to structurally weakened bones and an increased risk of fragility fractures. VCFs are the most common osteoporotic fractures [15, 16], and several classification systems have been devised to describe them. In the simplest terms, a VCF is a fracture in which the vertebral body has partially collapsed [17, 18].

Osteoporosis is a major cause of VCFs and disability in elderly populations. To date, the management of osteoporotic thoracolumbar fractures has not been well defined. The treatments are conservative or surgical and involve either posterior or anterior approaches [19-21]. Surgical treatment seems to reduce pain and promote mobilization, thereby leading to shorter hospital stays. It provides immediate pain relief, eliminates donor site pain, reduces blood loss, shortens the operative time, and contributes to early mobilization. It also prevents postoperative complications such as bone fragment displacement that could cause neurological deterioration or cauda equina syndrome [16]. When conservative treatment is not possible and open posterior fusion could represent overtreatment, a minimally invasive percutaneous approach is a good alternative [10, 22, 23].

There are no strict guidelines or consensus regarding the appropriate treatment for os-

Table 2. Changes in the clinical parameters of the 27 patients from the preoperative evaluation to the last follow-up*

	Anterior vertebral body height (mm)	Cobb angle (°)	VAS score
Preoperative	14.98 ± 2.16	41.38 ± 4.18	6.98 ± 1.31
Postoperative day 1	23.12 ± 2.06	25.41 ± 2.67	2.52 ± 1.64
1 month	22.92 ± 2.34	25.91 ± 2.74	2.07 ± 1.19
3 months	22.67 ± 2.19	26.32 ± 3.18	1.39 ± 1.28
6 months	22.45 ± 1.75	27.66 ± 3.39	1.11 ± 1.55
12 months	22.16 ± 1.68	27.83 ± 3.41	0.75 ± 1.42
24 months	22.13 ± 1.11	27.98 ± 2.76	0.72 ± 1.66

*The difference between the preoperative and postoperative values for all parameters: $P < 0.001$; the difference between the postoperative values and those at the 24-month follow-up: $P > 0.05$. VAS: Visual analogue scale.

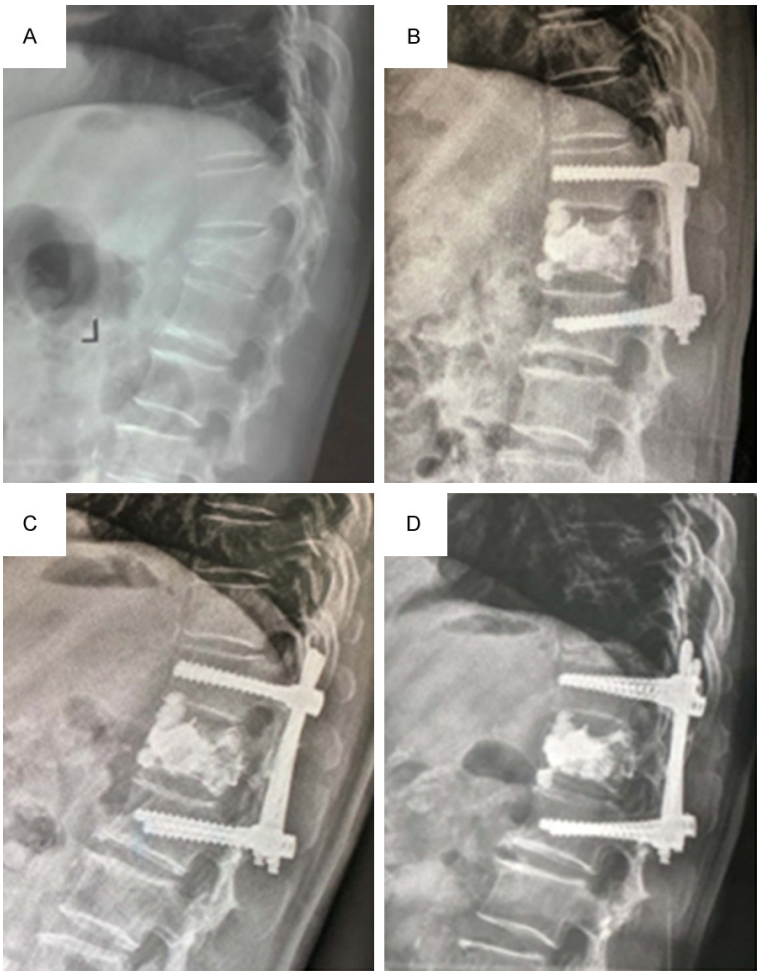

Figure 5. A 66-year-old male patient undergoing percutaneous pedicle screw fixation and vertebroplasty. (A) Preoperative lateral X-ray image of an L1 fracture. (B) Postoperative lateral X-ray image. (C) Evolution at the one-year follow-up and (D) evolution at the two-year follow-up showing no significant differences.

teoporosis thoracolumbar fractures. However, the injury pattern, spinal stability, neurological status, patient age, associated comorbid injuries, and available anatomical approaches should be considered in the treatment decision-making process. In this series, all the participants were neurologically intact elderly patients with osteoporosis. Thus, MIPS fixation combined with PVP was chosen. The results indicate that MIPS fixation combined with PVP can prevent the occurrence of secondary VCFs that have been observed after the application of PVP only.

PVP offers significant benefits. It can quickly achieve the goals of pain relief, fracture stabilization, and restoration of the mechanical strength of the injured vertebrae. The patient can thus resume normal activities sooner because things like being bed-ridden for a prolonged peroid of time, pneumonia, urinary tract infections, hemorrhoids, atrophy in the lower limb muscles, and complications such as deep venous thrombosis of the lower extremities are avoided [24]. However, PVP also has clear deficiencies, and there is a high incidence of bone cement leakage and vertebral collapse caused by postoperative fractures. The thoracolumbar vertebral body is involved in intense activity and is situated in a relatively complex biomechanical environment. Changes in stress distribution can easily lead to refracture. To prevent refracturing of the injured vertebrae after PVP in patients with osteoporosis, this study used MIPS in combination with PVP for patients with severe osteoporotic thoracolumbar fractures. The results demonstrate that the percutaneous pedicle screw is more conducive to maintaining height and preventing the collapse

of the injured vertebrae. This suggests that this clinical strategy is effective.

To ensure effective pain relief, joint surgery is performed to manage the collapse of the injured vertebrae. The MIPS technique has recently been applied to thoracolumbar fractures. Because it is minimally invasive, percutaneous fixation can preserve the integrity of the posterior longitudinal ligament complex, compensate for the deficiencies of traditional open surgery, and effectively avoid facet joint denervation caused by tissue dissection. Postoperative low back pain, spinal instability, and accelerated degeneration greatly reduce intraoperative blood loss and infection and accelerate postoperative recovery [24, 25]. During MIPS fixation, the vertebral body height can be partially restored with a distractor to achieve a good kyphosis correction effect, a surgical reduction effect that cannot be achieved by PVP alone. The inserted nail rod system greatly improves spinal stability. It is firmly affixed, and it can reduce the occurrence of postoperative complications. The annulus is tough and strong, and it adheres to the edge of the vertebral endplate. The pedicle screw is pulled longitudinally through the annulus. The vertebral body and its height are restored. At the same time, the pedicle screw is stretched to make the anterior and posterior longitudinal ligaments tense. The centripetal compression of the fracture block also has a very reliable fixation effect.

It is still a challenge for spine physicians to manage the severe osteoporotic thoracolumbar fractures in senior patients. In the treatment of patients with thoracolumbar disease, the method for injecting bone cement must be considered. When the vertebral body is strengthened during surgery, bilateral or unilateral pedicle injection is generally adopted. The conventional use of the bilateral pedicle approach can simultaneously improve the stiffness of and maintain the biomechanical balance between both sides of the vertebral body [26]. Unilateral injection can shorten the operation time, reduce the radiation dose, and simplify the surgical procedure. However, the clinical procedure is difficult. The assessment of the safety of excessive introversion puncture is difficult, and damage to the inner wall of the pedicle, with the resulting serious complications, can easily occur [27]. Because of its advantages for height recovery, bilateral injection of bone cement was adopted in this study to strengthen the vertebral body.

Several studies have found that calcium phosphate bone cement overcomes the possible side effects of PMMA [28, 29]. In 2004, the United States Food and Drug Administration formally approved PMMA bone cement for treating vertebral fractures resulting from osteoporosis and tumors. Its advantages, such as bioinertness, ease of handling, considerable mechanical strength, and cost-effectiveness, make it an ideal choice [30]. In this series, most patients were over 65 years old; therefore, the use of PMMA cement was appropriate. The amount of bone cement injected is one of the critical factors for treatment success. The strengthening of the bone cement can increase the strength and stiffness of an injured vertebra, thereby increasing biomechanical stability. If inadequate bone cement is used, the strength and rigidity of the injured vertebra cannot be restored, which makes it prone to re-collapse after surgery. On the other hand, injection of excessive bone cement can cause leakage. The amount should therefore be strictly controlled under the guidance of fluoroscopy, and the injection should be administered slowly.

Previous studies have shown that an injection of 2 ml of bone cement into the vertebral body can restore its strength. However, stiffness recovery requires an injection of 4 ml into the thoracolumbar segment and 6 ml into the lumbar segment [31, 32]. In this study, the mean amount of PMMA cement injected was approximately 5 ml. The volume of bone cement injected through the unilateral pedicle did not exceed 3 ml, the bilateral side pedicle injection did not exceed 6 ml, and 0.5 ml per unilateral bolus was administered. To avoid leakage, once the bone cement is found to reach the edge of the vertebral body, it is imperative to stop the bolus immediately. In this study, no loose screws, broken nails, broken rods, or other complications were observed during the follow-up period. Although the patients had osteoporosis, the bone cement used in the PVP provided better support for the injured anterior and middle columns after perfusion. PMMA cement can reduce the stress of the upper and lower pedicle screws and greatly enhance the combined treatment of the thoracolumbar segments.

Conclusions

This study demonstrates that MIPS fixation combined with PVP provides a reliable strategy for the treatment of osteoporotic thoracolumbar fractures in senior patients. The procedure can therefore make a positive contribution to long-term quality of life.

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Disclosure of conflict of interest

None.

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References

[1] Musbahi O, Ali AM, Hassany H and Mobasheri R. Vertebral compression fractures. Br J Hosp Med (Lond) 2018; 79: 36-40.

[2] Muratore M, Ferrera A, Masse A and Bistolfi A. Osteoporotic vertebral fractures: predictive factors for conservative treatment failure. A systematic review. Eur Spine J 2018; 27: 2565-2576.

[3] Joestl J, Lang N, Bukaty A, Tiefenboeck TM and Platzer P. Osteoporosis associated vertebral fractures-health economic implications. PLoS One 2017; 12: e0178209.

[4] Wood KB, Li W, Lebl DR and Ploumis A. Management of thoracolumbar spine fractures. Spine J 2014; 14: 145-164.

[5] Heary RF and Kumar S. Decision-making in burst fractures of the thoracolumbar and lumbar spine. Indian J Orthop 2007; 41: 268-276.

[6] Sun H and Li C. Comparison of unilateral and bilateral percutaneous vertebroplasty for osteoporotic vertebralcompression fractures: a systematic review and meta-analysis. J Orthop Surg Res 2016; 11: 156.

[7] Laghmouche N, Prost S, Farah K, Graillon T, Blondel B and Fuentes S. Minimally invasive treatment of thoracolumbar flexion-distraction fracture. Orthop Traumatol Surg Res 2019; 105: 347-350.

[8] Scheer JK, Bakhsheshian J, Fakurnejad S, Oh T, Dahdaleh NS and Smith ZA. Evidence-based medicine of traumatic thoracolumbar burst fractures: a systematic review of operative management across 20 years. Global Spine J 2015; 5: 73-82.

[9] Oh T, Scheer JK, Fakurnejad S, Dahdaleh NS and Smith ZA. Minimally invasive spinal surgery for the treatment of traumatic thoracolumbar burst fractures. J Clin Neurosci 2015; 22: 42-47.

[10] Vanni D, Pantalone A, Guelfi M and Salini V. Osteoporotic vertebral fractures and minimally invasive percutaneous approach. Int J Physiatry 2016, 2: 005.

[11] Li C, Pan J, Gu Y and Dong J. Minimally invasive pedicle screw fixation combined with percutaneous vertebroplasty for the treatment of thoracolumbar burst fracture. Int J Surg 2016; 36: 255-260.

[12] Gu YT, Zhu DH, Liu HF, Zhang F and McGuire R. Minimally invasive pedicle screw fixation combined with percutaneous vertebroplasty for preventing secondary fracture after vertebroplasty. J Orthop Surg Res 2015; 10: 31.

[13] Kaye ID and Passias P. Minimally invasive surgery (MIS) approaches to thoracolumbar trauma. Bull Hosp Jt Dis 2018; 76: 71-79.

[14] Mobbs RJ, Sivabalan P and Li J. Minimally invasive surgery compared to open spinal fusion for the treatment of degenerative lumbar spine pathologies. J Clin Neurosci 2012; 19: 829-835.

[15] Pesenti S, Blondel B, Peltier E, Adetchessi T, Dufour H and Fuentes S. Percutaneous cement-augmented screws fixation in the fractures of the aging spine: is it the solution? Biomed Res Int 2014; 2014: 610675.

[16] Sözen T, Özışık L and Başaran NÇ. An overview and management of osteoporosis. Eur J Rheumatol 2017; 4: 46-56.

[17] Pisani P, Renna MD, Conversano F, Casciaro E, Paola MD, Quarta E, Muratore M and Casciaro S. Major osteoporotic fragility fractures: risk factor updates and societal impact. World J Orthop 2016; 7: 171-181.

[18] Schnake KJ, Bula P, Spiegl UJ, Müller M, Hartmann F, Ullrich BW and Blattert TR. Thoracolumbar spinal fractures in the elderly: classification and treatment. Unfallchirurg 2017; 120: 1071-1085.

[19] Rajasekaran S, Kanna RM, Schnake KJ, Vaccaro AR, Schroeder GD, Sadiqi S and Oner C. Osteoporotic thoracolumbar fractures-how are they different? - Classification and treatment algorithm. J Orthop Trauma 2017; 31 Suppl 4: S49-S56.

[20] Wood KB, Li W, Lebl DR and Ploumis A. Management of thoracolumbar spine fractures. Spine J 2014; 14: 145-164.

[21] Barbagallo GMV, Raudino G, Visocchi M, Alobaid AA, Al-Mutair AA, Naveen T and Certo F.

Restoration of thoracolumbar spine stability and alignment in elderly patients using minimally invasive spine surgery (MISS). A Safe and feasible option in degenerative and traumatic spine diseases. Acta Neurochir Suppl 2017; 124: 69-74.

[22] Kim HS and Heo DH. Percutaneous pedicle screw fixation with polymethylmethacrylate augmentation for the treatment of thoracolumbar intravertebral pseudoarthrosis associated with kummell's osteonecrosis. Biomed Res Int 2016: 3878063.

[23] Lamy O, Uebelhart B and Aubry-Rozier B. Risks and benefits of percutaneous vertebroplasty or kyphoplasty in the management of osteoporotic vertebral fractures. Osteoporos Int 2014; 25: 807-819.

[24] Kim HS and Ju CI. Spinal instability predictive scoring system for subsequent fracture after bone cement augmentation in patients with osteoporotic vertebral compression fracture. World Neurosurg 2017; 106: 736-745.

[25] Li HM, Zhang RJ, Gao H, Jia CY, Zhang JX, Dong FL and Shen CL. New vertebral fractures after osteoporotic vertebral compression fracture between balloon kyphoplasty and nonsurgical treatment PRISMA. Medicine (Baltimore) 2018; 97: e12666.

[26] Chen B, Li Y, Xie D, Yang X and Zheng Z. Comparison of unipedicular and bipedicular kyphoplasty on the stiffness and biomechanical balance of compression fractured vertebrae. Eur Spine J 2011; 20: 1272-1280.

[27] Cheng X, Long HQ, Xu JH, Huang YL and Li FB. Comparison of unilateral versus bilateral percutaneous kyphoplasty for the treatment of patients with osteoporosis vertebral compression fracture (OVCF): a systematic review and meta-analysis. Eur Spine J 2016; 25: 3439-3449.

[28] He S, Zhang Y, Lv N, Wang S, Wang Y, Wu S, He F, Chen A, Qian Z and Chen J. The effect of bone cement distribution on clinical efficacy after percutaneous kyphoplasty for osteoporotic vertebral compression fractures. Medicine (Baltimore) 2019; 98: e18217.

[29] Tang S, Fu W, Zhang H, Zhang H and Liang B. Efficacy and safety of high-viscosity bone cement vertebroplasty in treatment of osteoporotic vertebral compression fractures with intravertebral cleft. World Neurosurg 2019; 132: e739-e745.

[30] He Z, Zhai Q, Hu M, Cao C, Wang J, Yang H and Li B. Bone cements for percutaneous vertebroplasty and balloon kyphoplasty: current status and future developments. J Orthop Translat 2014; 3: 1-11.

[31] Boehm AV, Meininger S, Tesch A, Gbureck U and Müller FA. The mechanical properties of biocompatible apatite bone cement reinforced with chemically activated carbon fibers. Materials (Basel) 2018; 11: 192.

[32] Zderic I, Steinmetz P, Windolf M, Richards RG, Boger A and Gueorguiev B. Bone cement flow analysis by stepwise injection through medical cannulas. Med Eng Phys 2016; 38: 1434-1438.