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Percutaneous vertebroplasty by two-step fluoroscopy: a treatment for osteoporotic compression fractures of thoracic vertebrae in older adults

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Abstract

Objective This study aimed to evaluate the clinical efficacy of percutaneous vertebroplasty (PVP) performed with a two-step fluoroscopy technique for treating thoracic osteoporotic vertebral compression fractures (OVCFs) in older patients.

Methods A retrospective analysis was conducted on clinical and imaging data from 48 patients diagnosed with thoracic OVCFs, who underwent treatment with percutaneous vertebroplasty(PVP) utilizing a two-step fluoroscopy technique at Yangquan First People's Hospital between January 2019 and January 2022. The study assessed the clinical efficacy of this procedure by analyzing Visual Analog Scale(VAS) scores, Cobb angle values, and vertebral height measurements before surgery and at 2 days, 3 months, 6 months, and 12 months postoperatively.

Results Before treatment, the mean VAS score of patients was 7.5 ± 0.6. Subsequently, at 2 days, 3 months, 6 months, and 12 months after the procedure, these mean scores decreased to 2.3 ± 0.6, 2.2 ± 0.5, 2.2 ± 0.4, and 2.0 ± 0.3, respectively. This decline was statistically significant ($P < 0.05$) compared to the preoperative VAS score. The preoperative Cobb angle was 12.1° ± 0.9°, and the Cobb angle values at the corresponding time points were 12.2° ± 0.8°, 12.3° ± 1.1°, 12.3° ± 1.0°, and 12.2° ± 0.9°. Initially, the mean height of the vertebral body in these patients was 17.38 ± 1.56 mm. Postoperatively, at 2 days, 3 months, 6 months, and 12 months, these values were 19.30 ± 1.81 mm, 19. 12 ± 1.60 mm, 19.00 ± 1.45 mm, and 19.00 ± 1.20 mm, respectively. No significant difference was observed between postoperative and preoperative Cobb angle and vertebral height ($P > 0.05$).

Conclusion Percutaneous vertebroplasty using a two-step fluoroscopy method not only has the therapeutic effect of traditional surgical methods, reducing pain from thoracic vertebral compression fractures in the elderly and enhancing their quality of life and mobility, but also streamlines the intraoperative fluoroscopy procedure. This method stand as an effective approach for managing osteoporotic compression fractures of the thoracic vertebrae in elderly.

Keywords Thoracic Vertebra, Vertebroplasty, Osteoporotic vertebral compression, Fracture

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Introduction

The progressive aging of China's population has led to an increase in osteoporosis- associated thoracic vertebral fractures [1]. Patients with these fractures often experience severe chest and back pain, along with radiating intercostal pain that can extend to the chest. In some cases, patients may even seek respiratory treatment due to the pain. When left untreated, these fractures can lead to complications such as chronic chest and back pain or thoracic kyphosis, significantly impacting the patient's quality of life [2–4]. Percutaneous vertebroplasty has become a widely used treatment for osteoporotic vertebral compression fractures (OVCFs) [5–7]. However, identifying the affected vertebrae in the thoracic region, which consists of 12 vertebrae, can be challenging due to the narrower transverse diameter of the pedicle compared to lumbar vertebrae, as well as the presence of the scapular block [8, 9]. This complexity makes it more difficult to identify affected thoracic vertebrae through lateral X-ray imaging, posing challenges and potential risks during vertebral puncture [10, 11]. The appropriateness of using imaging strategies that expose patients to radiation in this context is uncertain, and there have been relatively few studies focused on this issue [12]. Some scholars have reported using computed tomography (CT) guidance for puncture procedures [13, 14]. However, compared to CT, most operating rooms are equipped with a C-arm machine, which offers simpler programming and more.

convenient operation. To minimize the number of surgical fluoroscopy sessions and shorten the surgery duration, we employed a two-step fluoroscopy method using a C- arm machine for PVP. During the study period from January 2019 to January 2022, a total of 48 patients with OVCFs of the thoracic vertebrae underwent percutaneous vertebroplasty using this technique. This approach resulted in reduced intraoperative fluoroscopy exposure and a shortened duration of surgery, leading to positive outcomes.

Materials and method

Patients

This study retrospectively analyzed clinical and imaging data from 48 patients (32 female, 16 male) with osteoporotic vertebral compression fractures (OVCFs) of the thoracic vertebrae who were treated at Yangquan First People's Hospital from January 2019 to January 2022. The patients' ages ranged from 60 to 86 years (mean: 69.7 ± 6.8 years), and the duration of their illness ranged from 2 to 35 days (mean: 10.2 ± 3.5 days). All patients reported persistent pain in the chest, waist, and back, which limited their daily activities. X-ray, computed tomography (CT), and magnetic resonance imaging (MRI) scans confirmed single-segment OVCFs in all patients, with 2 cases involving upper segment fractures (T1-4), 26 cases involving middle segment fractures (T5-8), and 20 cases involving lower segment fractures (T9-12). Inclusion criteria: (1) Patients with MRI-diagnosed thoracic vertebral compression fractures with pain exhibiting consistent localization to the fracture site detected via plain radiography [15] ;(2) Patients ≥ 60 years of age in good general condition without any serious cardiovascular or cerebrovascular diseases; (3) patients with severe pain but without any nerve compression or injury-related symptoms; and (4) patients capable of laying in a prostrate position for 1–2 h and tolerating the surgical procedure [16, 17]. Exclusion criteria:(1)Vertebral body fractures or dislocation complicated by injuries to the nerves or spinal cord; (2) patients with bone cement allergies or coagulatory dysfunction; (3) patients with severe heart and/or lung diseases who were unable to tolerate surgery; or (4) patients with pain found to be caused by disc herniation and vertebral body or paravertebral tumors [18]. The medical ethics committee of Yangquan First People's Hospital approved this study.All participating patients provided written informed consent and agreed to the publication of these data.

Surgical approach

Surgical instrumentation and reagents

The affected vertebrae were located preoperatively using a C-arm machine, which also monitored the intraoperative puncture process and dynamically tracked the dispersion of bone cement in the vertebral body. The procedure involved using 40 g of polymethyl methacrylate (PMMA) granule powder and 20 mL of water agent for the bone cement [19].

Surgical procedure

Routine radiography and MRI scans were used for the preoperative examination of the thoracic vertebrae. After confirming the injury of the affected vertebral body with MRI, it was observed that the vertebral body exhibited a mild wedge deformation along with diffuse high signal intensity. (Fig. 1), they were marked on the anteroposterior and lateral views on X-ray film. Accurately determining the shape of the injured vertebrae and assessing the presence of osteophyte hyperplasia in adjacent.

vertebrae were crucial for facilitating easier fluoroscopic detection. The patient was positioned in a prone-decubitus position. [20, 21]. A two-step procedure was used for C-arm machine monitoring. First, The endplate of the lower edge of the injured vertebra was flat, with symmetrical bilateral pedicles and a centrally located spinous process. Subsequently,the surface projections of the pedicles were marked bilaterally. After routine disinfection and the placing of aseptic towels, local infiltration

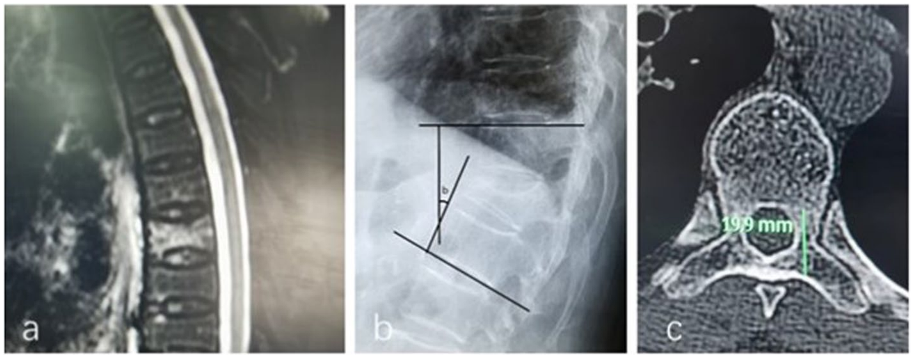

Fig. 1 **a** The MRI reveals a mild wedge deformation of the vertebral body, along with diffuse high signal intensity, indicating a T7 vertebral body fracture in a representative patient. **b** Cobb angle was utilized to evaluate the kyphosis angle of thoracic vertebrae. **c** The distance from the entry point of the pedicle to the posterior edge of the vertebral body was preoperatively measured via CT

anesthesia was administered. The punture needle was placed in the skin about 2–3 cm on both sides of the target vertebra such that the tip of the needle was located in the posterolateral border of the pedicle. If there were deviations in needle positioning, it could then be slightly adjusted, with 2–3 adjustments being typical. Fluoroscopy was then used to determine whether the puncture needle was properly fixed on the lateral edge of the pedicle [22], to assess puncture needle depth, and to confirm the scale (typically 3 cm or less). The needle was then further advanced in a 5- 10° position of mild abduction with anteroposterior fluoroscopic monitoring such that the needle direction of the puncture needle was between the upper and lower edges of the vertebral body. Before surgery, the distance between the entry point of the pedicle and the posterior edge of the vertebral body was measured (generally ~ 2 cm). When the puncture needle reached the medial edge of the pedicle, the entry of the needle into the bone above 2 cm was confirmed. Then, the machine was adjusted to the lateral position to allow clinicians to determine whether the two puncture needles had reached or entered the posterior edge of the vertebral body, after which the puncture needle was advanced into the middle 1/3 of the vertebral body. When the bone cement was prepared to a toothpaste-like consistency, it was injected under fluoroscopic guidance. Intraoperative fluoroscopy monitoring.(a) Needle inserted at the posterior margin of the T7 vertebra;(b) An image of a lateral view of the T7 vertebra with bone cement; (c) An anteroposterior view showing the vertebral body injected with bone cement (Fig. 2).

Bone cement injection

Forty grams of PMMA granule powder were thoroughly mixed with 20 ml of a water agent to form a paste, which was then carefully loaded into a syringe attached to A push rod. Once the bone cement reached a toothpaste-like consistency, it was injected under fluoroscopic guidance. Injection was conducted slowly and continuously, immediately halted if any cement entered a vein or protruded beyond the vertebral body. The needle core was positioned within the needle path to prevent blockage. Following solidification of the bone cement, the needle sheath was rotated to prevent trailing. Upon completion of the procedure, the patient was allowed to reposition themselves in bed independently. After 24 h post-surgery, they were permitted to wear a brace for ground movement.

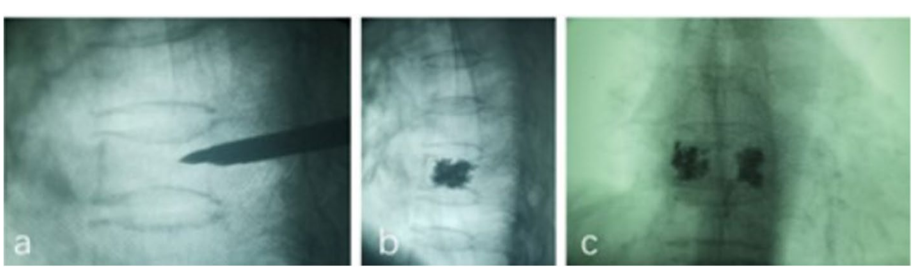

Fig.2 Intraoperative fluoroscopy monitoring. **a** Needle inserted at the posterior margin of the T7 vertebra;**b** An image of a lateral view of the T7 vertebra with bone cement; **c** An anteroposterior view showing the vertebral body injected with bone cement

Analyses of clinical efficacy

Pain levels were evaluated utilizing visual analog scale (VAS) scores, whereas the anterior edge height, posterior edge height, and Cobb angle of kyphosis were measured preoperatively, and at 2 days, 3 months, 6 months, and 12 months post- procedure. The Cobb angle was defined based on a vertical line between the upper edge of the upper vertebral body of the injured vertebrae and the lower edge of the next vertebral body (Fig. 1) [18]. All results were independently measured by three clinicians, with the average value being reported and used for all analyses.

Statistical analyses

SPSS 19.0 was used to analyze the results of this study. Normally distributed data are reported as means ± standard error and were compared via one-way analysis of variance(ANOVA), with data within groups being compared using paired t-tests. $P < 0.05$ served as the cut-off to define statistical significance [23].

Results

In this study 41 patients underwent bilateral puncture treatment while 7 underwent unilateral puncture-based treatment including 5 cases with poor cardiopulmonary function and 2 with more than 2/3 vertebral height loss. All patients reported significant relief from postoperative pain with 6 receiving a local nerve block for additional pain management. The shortest and longest operative durations recorded were 30 and 51 min respectively with a mean duration of 40.0 ± 2.5 min. Hospital stays ranged from 3 to 5 days. Although 9 patients experienced extravertebral leakage, none displayed clinical symptoms or evidence of bone cement overflow into the spinal canal. Paraspinal leakage occurred in 3 cases intervertebral disc leakage in 4 cases and leakage in the anterior vertebral vein in 2 cases. Before treatment the mean VAS score of patients was 7.5 ± 0.6. Subsequently at 2 days, 3 months, 6 months, and 12 months after the procedure, these mean scores decreased to 2.3 ± 0.6, 2.2 ± 0.5, 2.2 ± 0.4, and 2.0 ± 0.3, respectively. This decline was statistically significant ($P < 0.05$) compared to the preoperative VAS score. The preoperative Cobb angle was 12.1° ± 0.9°, and the Cobb angle values at the corresponding time points were 12.2° ± 0.8°, 12.3° ± 1.1°, 12.3° ± 1.0°, and 12.2° ± 0.9°. Initially, the mean height of the vertebral body in these patients was 17.38 ± 1.56 mm. Postoperatively, at 2 days, 3 months, 6 months, and 12 months, these values were 19.30 ± 1.81 mm, 19. 12 ± 1.60 mm, 19.00 ± 1.45 mm, and 19.00 ± 1.20 mm, respectively. No significant difference was observed between postoperative and preoperative Cobb angle and vertebral height ($P > 0.05$) (Fig. 3).

Discussion

Due to the smaller dimensions of the pedicle in thoracic vertebrae compared to lumbar vertebrae [9] with a forward and downward inclination and their connection to the ribs on both sides with the scapula above, fluoroscopic interference is a common issue. In certain studies, researchers have utilized CT scans to monitor these vertebrae effectively [13, 14]. In the present study, the utilization of a C-arm machine offers straightforward implementation [24], presenting several key advantages for performing the PVP procedure.(1) In most primary hospital operating rooms, a C-arm machine is readily available, offering convenient access to appropriate rescue and anesthesia equipment. This setup contrasts with a CT room, thereby ensuring greater patient safety.(2) CT scans necessitate repeated scanning and movement of the operating bed, thereby heightening the risk of contamination; (3) Additionally, CT scans may not comprehensively reveal the puncture path and lack the intuitive real-time guidance provided by a C-arm machine.In an effort to reduce radiation-related harm to patients, a two-step approach was herein employed to simplify the C-arm machine-related procedures.Prior to surgery, the distance between the pedicle entry point and the posterior edge of the vertebral body (~ 2 cm) was measured via CT. In the initial stage of fluoroscopic assessment, the inferior margin of the affected vertebra aligns flush under anteroposterior fluoroscopy, with the spinous process positioned centrally within the vertebral body. The puncture needle's depth from the lateral edge of the pedicle to the medial edge (the inner wall of the spinal canal) should measure at least 2 cm, with the puncture needle extending to the posterior edge of the vertebral body according to preoperative CT imaging.During the second stage of fluoroscopic assessment, under lateral observation, the puncture needle tip was positioned at the posterior edge of the vertebral body before being advanced into the center of the vertebral body. This method offers the advantage of utilizing preoperative CT results to measure the distance from the puncture point to the posterior edge of the vertebral body. Moreover, it requires only two rotational positions for the C-arm machine, thereby minimizing the need for repetitive adjustments.

Confirming the identity of the affected vertebrae is essential prior to treatment. Some patients with lower thoracic vertebral fractures only exhibit lower back pain without associated tenderness, and these patients generally exhibit no clear radiographic features such that MRI-based diagnosis is often required. Preoperative MRI

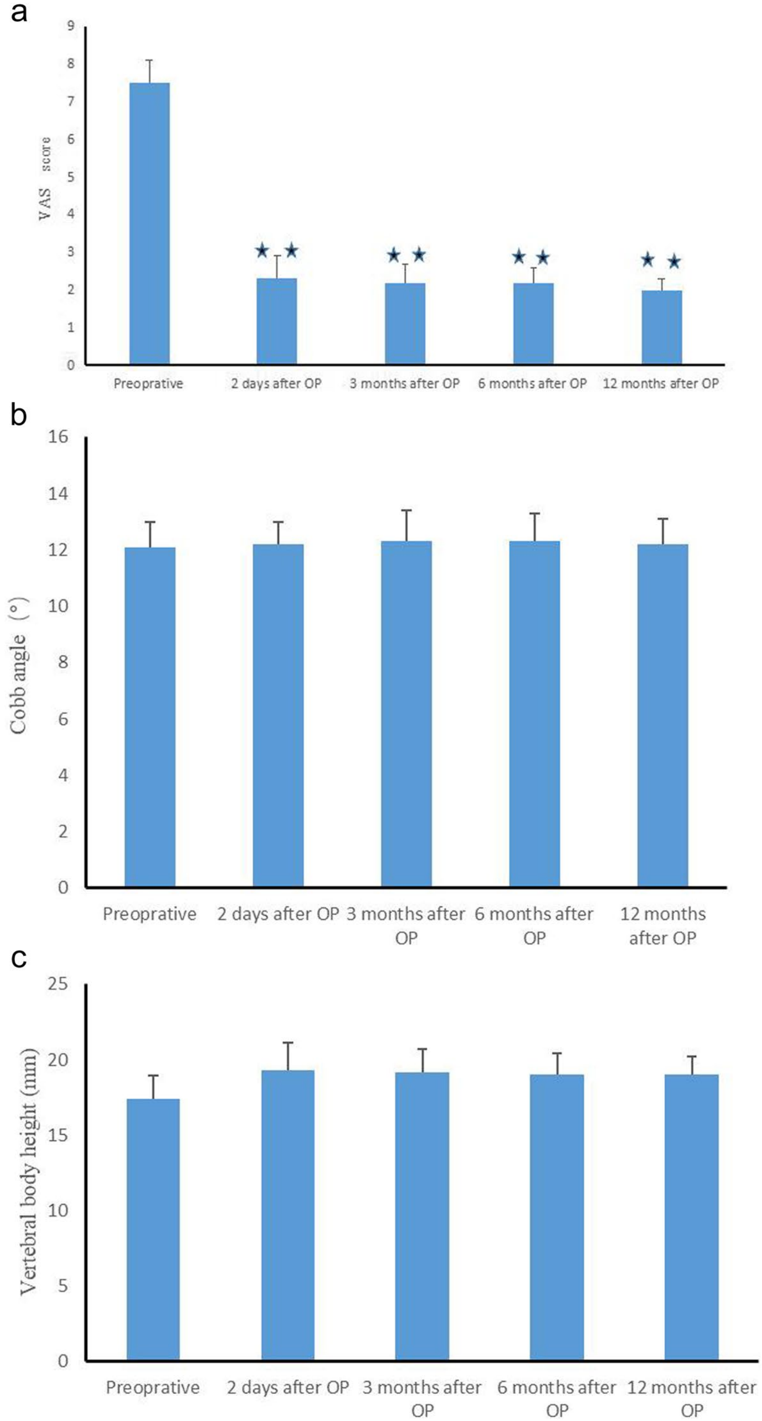

Fig. 3 Changes in various indices between preoperative and postoperative values. **a** VAS scores. **b** Cobb angle values. **c** Vertebral body height. Data are reported as x ± s. ***P* < 0.01 vs preoperative group. OP: operation, VAS: visual analog scale

is thus necessary before the PVP procedure in order to accurately identify the affected vertebrae. Moreover, given that there are many thoracic vertebrae, it can be difficult to determine the locations of the middle thoracic vertebrae, and MRI scans can enable the direct observation of the shape and characteristics of the affected vertebrae including whether wedge degeneration or anterior osteophytes were present. In certain scenarios, the 'relay method' becomes necessary for identification.This method involves positioning a Kirschner needle between the T12 and the affected vertebra to confirm the vertebral body where the needle is located.Subsequently, the Kirschner needle and the affected vertebra are placed in a fluoroscopic image to facilitate identification.In general, a transpedicular approach is utilized; however, in cases where the pedicle width is narrow, a thin thoracic puncture needle may be employed for puncture via the parapedicular approach.

PVP represents a revolutionary approach to treating vertebral fractures [25]. Recently, an increasing number of reports have documented the utilization of this procedure as a treatment method for thoracic vertebral fractures, emphasizing its therapeutic efficacy [26–29]. Ballon kyphoplasty was developed as an alternative to PVP to reduce chances of cement leakage and improve the vertebral height. Meta analytic studies have shown that PVP and kyphoplasty reduce pain comparably, and patient functional outcomes have been similar in most series [30, 31]. But Ballon kyphoplasty is 10–20 times more expensive than a PVP procedure [32]. However, conflicting conclusions seem to arise in the literature regarding whether balloon kyphoplasty is more effective than PVP in preventing collapse of augmented vertebrae. Sahinturk et al. [33] reported on a study involving 351 patients who underwent both balloon kyphoplasty and PVP. They concluded that balloon kyphoplasty did not prevent the loss of height in augmented vertebral bodies over mid- and long-term follow-up periods compared to PVP. Cerny et al. conducted a study involving 280 patients who underwent both treatments as well. Their findings suggest that kyphoplasty procedures are more effective in preventing further collapse of vertebral bodies compared to PVP. However,they noted that for precise accuracy in measuring vertebral compression ratio, regular postoperative CT scans would have been necessary [34].

In this study, patients showed significant improvements in VAS scores for both back and chest pain compared to preoperative values ($P<0.05$), However,there were no significant corresponding improvements in vertebral height or Cobb angle values. These results suggest that PVP has the potential to effectively alleviate pain associated with OVCFs in older adults.Several factors refer to the following aspects. For one, the use of bone cement filler enabled the restoration of vertebral body stability and prevented further movement of the fracture, thus preventing additional vertebral body compression [35]. This also led to a reduction in the stimulation of the nerve endings in the vertebral body. Bone cement injection results in a transient exothermic reaction that can destroy the surrounding tissue and nerve endings [18]. Chiras J et al. reported that among a cohort of 274 patients who underwent vertebroplasty, the complication rate was 1.3% for those with osteoporotic vertebral fractures and as high as 10% for those with metastatic fractures [36]. In general, the procedure is relatively safe, and complications from either procedure appear to be primarily caused by improper needle placement or inattention to fluoroscopic patterns of cement flow during the injection process.Leakage of cement into the epidural or paravertebral areas has been reported in 30% to 70% of vertebroplasties, but usually it has been minor and has not resulted in adverse events [37]. In the present study, the most prevalent complication observed is cement leakage [16]. Among the patients in the present cohort, nine experienced slight bone cement leakage in the anterior,superior, inferior, and lateral aspects of the vertebral body. However, none of them encountered bone cement infiltration into the spinal canal. To prevent this complication, it is essential to position the leading end of the bone cement push rod at the junction of the anterior and middle thirds of the vertebral body. This positioning prevents the backward leakage of bone cement. The bone cement should be injected when it reaches a toothpaste-like consistency [15], which helps prevent its entry into the vertebral venous sinus or nearby blood vessels thereby minimizing the risk of migration. Additionally, monitoring the bone cement injection through lateral fluoroscopy of the vertebral body is essential. This ensures the proper directionality of bone cement filling and helps prevent any leakage into the spinal canal [38].

The selection of unilateral or bilateral bone cement injection approaches was primarily dependent on the physical condition of the patient and the distribution of the bone cement in the target vertebra following unilateral injection [23, 39, 40]. In this study, the bilateral pedicle approach was commonly utilized for bone cement injection. The unilateral approach was only used when patients were in poor overall.

condition and could not tolerate longer surgeries. To ensure uniform distribution of the bone cement within the affected vertebra, during unilateral injections, the puncture needle was inserted through the midline of the vertebra to reach the contralateral side whenever possible. Wang et al. [41]. Previously reported a higher incidence of nerve root stimulation following unilateral PVP procedures compared to bilateral punctures. However, this was not observed in the present study cohort.

Cost-effectiveness analysis of percutaneous vertebroplasty (PVP) compared to conservative treatment and open surgery is an important consideration. Compared to conservative treatment, PVP may have higher direct medical costs in the short term because it involves surgery and the use of specialized equipment. However, PVP typically provides faster pain relief and functional improvement [42], potentially reducing patients' long-term medical costs such as prolonged use of pain medications and rehabilitation therapy. Compared to open surgery, PVP generally incurs lower direct medical costs due to its minimally invasive nature, which avoids extensive incisions in the skin and soft tissues, leading to shorter surgery times and faster patient discharge. However, operative intervention is necessary in a very small subset of patients with vertebral compression fractures in whom a progressive neurologic deficit or intractable pain develops from the fracture deformity. These operations are extensive, involving prolonged duration of anesthesia, blood transfusion, and associated complications [37]. Therefore, PVP may also shorten patients' recovery time and hospital stay, consequently decreasing indirect costs for both patients and the healthcare system.

There are several limitations to this study. Firstly, the current sample size may not be adequate to draw definitive conclusions. Larger and more diverse samples are necessary for future studies to validate the findings and improve generalizability. Secondly, this study involved a small patient cohort with a short follow-up duration, making it challenging to rule out the potential for an increased risk of new vertebral body fractures at later time points after PVP. Therefore, further research is necessary to explore long-term outcomes and optimal patient selection strategies for PVP. Thirdly, PVP was not associated with any pronounced Cobb angle improvements such that this procedure was not beneficial to patients with severe vertebral compression and associated kyphosis. Lastly, the study lacked a control group undergoing conservative treatment for comparison.

Conclusion

Percutaneous vertebroplasty by two-step fluoroscopy not only alleviates pain associated with thoracic vertebral osteoporotic compression fractures (OVCFs) in elderly individuals, but also promotes corresponding improvements in motor ability and quality of life. Furthermore it reduces intraoprative fluoroscopy exposure and shortens the duration of surgery. This technique holds considerable reference value for treating thoracic OVCF in elderly individuals. However, due to the larger number of thoracic vertebrae and the smaller diameter of the pedicles, along with interference from the scapula during fluoroscopy, this surgical method presents a learning curve in terms of positioning and puncture. Integrating navigation or robotics in the future may further reduce the surgical duration and shorten the learning curve [43, 44]. Additionally, due to the limited number of patients and short follow-up duration in this study, it is necessary to conduct multi-center, large-sample, long-term follow-up studies in the future to obtain more accurate results.

Abbreviations

OVCT	Osteoporotic vertebral compression fracture
PVP	Percutaneous vertebroplasty
VAS	Visual analog scale
PMMA	Polymethyl methacrylate
ANOVA	Analysis of variance

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Authors' contributions

J.G and K.C contributed to the study design and conducted the statistical analysis. J.G,P.X, Z.Z, K.W,T.Z,X.D，K.Z and Y.G conducted the study and gathered important background information.J.G and Y.G drafted the manuscript, while K.C and F.C reviewed and revised it. All authors have read and approved the final manuscript.

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Data availability

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This retrospective review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and Helsinki Declaration. The study was reviewed and approved by the Ethics Review Committee of Yangquan first People's Hospital affliated to Shanxi medical university. Informed consent was obtained from each patient's guardian.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Hu KZ, Chen SC, Xu L. Comparison of percutaneous balloon dilation kyphoplasty and percutaneous vertebroplasty in treatment for thoracolumbar vertebral compression fractures. Eur Rev Med Pharmacol Sci. 2018;22(1 Suppl):96–102. https://doi.org/10.26355/eurrev_201807_15370.
2. Jindal V, Binyala S, Kohli SS. Balloon kyphoplasty versus percutaneous vertebroplasty for osteoporotic vertebral body compression fractures: clinical and radiological outcomes. Spine J. 2023;23(4):579–84. https://doi.org/10.1016/j.spinee.2022.11.015.
3. Oh Y, Lee B, Lee S, Kim J, Park J. Percutaneous Vertebroplasty versus Conservative Treatment Using a Transdermal Fentanyl Patch for

Osteoporotic Vertebral Compression Fractures. Korean Neurosurg Soc J. 2019;62(5):594–602. https://doi.org/10.3340/jkns.2019.0086.

4. Kawanishi M, Tanaka H, Ito Y, Yamada M, et al. Treatment for Osteoporotic Vertebral Fracture - A Short Review of Orthosis and Percutaneous Vertebroplasty and Balloon Kyphoplasty. Neurospine. 2023;20(4):1124–31. https://doi.org/10.14245/ns.2346936.468.
5. Kyriakou C, Molloy S, Vrionis F, et al. The role of cement augmentation with percutaneous vertebroplasty and balloon kyphoplasty for the treatment of vertebral compression fractures in multiple myeloma:a consensus statement from the International Myeloma Working Group (IMWG). Blood Cancer J. 2019;9(3):27. https://doi.org/10.1038/s41408-019-0187-7.
6. Diamond T, Clark W, Bird P, Gonski P. Percutaneous Vertebroplasty for Acute Painful Osteoporotic Vertebral Fractures-Benefits Shown in VAPOUR Trial Masked When Pooled With Other Clinical Trials. J Bone Miner Res. 2019;34(6):1182–4. https://doi.org/10.1002/jbmr.3725.
7. Kobayashi N, Noguchi T, Kobayashi D, Saito H, Shimoyama K, et al. Safety and Efficacy of Percutaneous Vertebroplasty for Osteoporotic Vertebral Compression Fractures:A Multicenter Retrospective Study in Japan. Interv Radiol(Higashimatsuyama).2021;6(2):21–28. https://https://doi.org/10.22575/interventionalradiology. 2020–0032.
8. Wojdyn M, Pierzak O, Zapałowicz K, Radek M. Use of O-arm with neuronavigation in percutaneous vertebroplasty reduces the surgeon's exposure to intraoperative radiation. Arch Med Sci J. 2019;17(1):113–9. https://doi.org/10.5114/aoms.2019.84269.
9. Ding Z, Du X. Clinical Anatomy of Spinal Surgery[M], Shandong Science and Technology Press, 2008, First Edition,Jinan, China.249–277.
10. Chen L, Lu Q, Wang X, Zhu Y, Zhang D. Ultrasound-assisted Percutaneous Vertebroplasty in Upper and Mid-thoracic Osteoporotic Fracture. J Coll Physicians Surg Pak. 2021;31(3):330–3. https://doi.org/10.29271/jcpsp.2021.03.330.
11. Hao S, Yu X, Li L, et al. Case report: Shock after percutaneous vertebroplasty of the 5th thoracic vertebra. Front Surg. 2023;10:1120346. https://doi.org/10.3389/fsurg.2023.1120346.
12. Prod'homme M, Grasset D, Akiki A, et al. Significant Reduction of Radiation Exposure Using Specific Settings of the O-Arm for Percutaneous Cementoplasty in Accordance With the ALARA Principle. Int J Spine Surg. 2023;17(4):534–541.https://doi.org/10.14444/8477.
13. Greffier J, Hamard A, Berny L, et al. A retrospective comparison of organ dose and effective dose in percutaneous vertebroplasty performed under CT guidance or using a fixed C-arm with a flat-panel detector. Phys Med. 2021;88:235–41. https://doi.org/10.1016/j.ejmp.2021.07.002.
14. Pavan LJ, Dalili D, Ranc C, et al. CT-Guided Percutaneous Vertebroplasty for Vertebral Non-union Following Posterior Fixation: A Preliminary Retrospective Study [published correction appears in Cardiovasc Intervent Radiol. Cardiovasc Intervent Radiol. 2022;45(5):687–95. https://doi.org/10.1007/s00270-021-03037-3.
15. Dwivedi MK, Bhende V, Panchbhaiyye DN, Bayaskar MV. Percutaneous Vertebroplasty: Efficacy of Unipedicular Vertebroplasty as Compared to Bipedicular Vertebroplasty. Indian J Radiol Imaging. 2022;31(4):867–72. https://doi.org/10.1055/s-0041-1739375IF:0.6.
16. Cavka M, Delimar D, Rezan R, Zigman T, Duric KS, Cimic M, Dumic-Cule I, Prutki M. Complications of Percutaneous Vertebroplasty: A Pictorial Review. Medicina (Kaunas). 2023;59(9):1536. https://doi.org/10.3390/medicina59091536.
17. Xu L, Huang X, Lou Y, Xie W, et al. Prognostic analysis of percutaneous-vertebroplasty (PVP) combined with 125I implantation on lumbosacral vertebral osteoblastic metastases. World J Surg Oncol. 2023;21(1):391. https://doi.org/10.1186/s12957-023-03268-3.
18. Zhao P, Guo A, Tan Z, et al. The evaluation of the treatment for old osteoporotic vertebral compression fracture pain by percutaneous vertebroplasty. Medicine (Baltimore). 2020;99(27):e20479. https://doi.org/10.1097/MD.0000000000020479.
19. Hammed A, Mahfoud M, Mohamad O. Effectiveness of unilateral percutaneous vertebroplasty for acute traumatic non-osteoporotic compression vertebral fractures. Medicine (Baltimore). 2023;102(37):e35177. https://doi.org/10.1097/MD.0000000000035177.
20. Nurmukhametov R, Enelis B, Bernard E, Ramirez MJE, Dosanov M, Castro JS, Peralta I, Matos Cuevas Y,Shirshov I, Barrientos Castillo RE 2nd. Thoracic Percutaneous Vertebroplasty for the Treatment of Vertebral Hemangioma in a Patient With Forestier's Disease: A Case Report. Cureus. 2022;14(12):e32466. https://doi.org/10.7759/cureus.32466.
21. Zhou C, Huang S, Liao Y, Zhang F, et al. Feasibility Analysis of the BoneCement-Gelatine Sponge Composite Intravertebral Prefilling Technique for Reducing Bone Cement Leakage in Stage I and II Kümmell's Disease: A Prospective Randomized Controlled Trial. Orthop Surg. 2023;15(7):1763–71. https://doi.org/10.1111/os.13764.
22. Zhang Y, Chen X, Ji J, et al. Comparison of Unilateral and Bilateral Percutaneous Kyphoplasty for Bone Cement Distribution and Clinical Efficacy: An Analysis Using Three-Dimensional Computed Tomography Images. Pain Physician. 2022;25(6):E805–13.
23. Ahsan MK, Pandit OP, Khan MSI. Percutaneous vertebroplasty for symptomatic osteoporotic compression fractures: A single-center prospective study. Surg Neurol Int. 2021;12:176. https://doi.org/10.25259/SNI_212_2021.
24. Noguchi T, Yamashita K, Shida Y, et al. Accuracy of vertebral puncture in percutaneous vertebroplasty. Jpn J Radiol. 2022;40(4):419–29. https://doi.org/10.1007/s11604-021-01216-3.
25. Kushchayev SV, Wiener PC, Teytelboym OM, Arrington JA, Khan M, Preul MC. Percutaneous Vertebroplasty: A History of Procedure, Technology, Culture, Specialty, and Economics. Neuroimaging Clin N Am. 2019;29(4):481–94. https://doi.org/10.1016/j.nic.2019.07.011.
26. Dai C, Liang G, Zhang Y, Dong Y, Zhou X. Risk factors of vertebral re-fractureafter PVP or PKP for osteoporotic vertebral compression fractures, especially in Eastern Asia: a systematic review and meta-analysis. J Orthop Surg Res. 2022;17(1):161. https://doi.org/10.11186/s13018-022-03038-z.
27. Wang F, Wang LF, Miao DC, Dong Z, Shen Y. Which one is more effective for the treatment of very severe osteoporotic vertebral compression fractures: PVP or PKP? J Pain Res. 2018;11:2625–31. https://doi.org/10.2147/JPR.S179022.
28. Láinez Ramos-Bossini AJ,López Zúñiga D, Ruiz Santiago F. Percutaneous vertebroplasty versus conservative treatment and placebo in osteoporotic vertebral fractures: meta-analysis and critical review of the literature. Eur Radiol.2021;31(11):8542–8553. https://doi.org/10.1007/s00330-021-08018-1
29. Mao W, Dong F, Huang G, et al. Risk factors for secondary fractures to percutaneous vertebroplasty for osteoporotic vertebral compression fractures: a systematic review. J Orthop Surg Res. 2021;16(1):644. https://doi.org/10.1186/s13018-021-02722-w.
30. Kim KH, Kuh SU, Chin DK, et al. Kyphoplasty versus vertebroplasty: restoration of vertebral body height and correction of kyphotic deformity with special attention to the shape of the fractured vertebrae. J Spinal Disord Tech. 2012;25:338–44. https://doi.org/10.1097/BSD.0b013e318224a6e6.
31. Kim SB, Jeon TS, Lee WS, et al. Comparison of kyphoplasty and lordoplasty in the treatment of osteoporotic vertebral compression fracture. Asian Spine J. 2010;4(2):102–8. https://doi.org/10.4184/asj.2010.4.2.102.
32. Mathis JM. Percutaneous vertebroplasty or kyphoplasty: which one do I choose? Skeletal Radiol. 2006;35(9):629–31. https://doi.org/10.1007/s00256-006-0145-x.
33. Sahinturk F, Sonmez E, Ayhan S, Gulsen S, Yilmaz C. The Influence of Percutaneous Vertebral Augmentation Techniques on Recompression in Patients with Osteoporotic Vertebral Compression Fractures. Percutaneous Vertebroplasty versus Balloon Kyphoplasty. World Neurosurg. 2023;176: e447-e455 https://doi.org/10.1016/j.wneu.2023.05.081
34. Cerny J, Soukup J, Petrosian K, Loukotova L, Novotny T. Efficacy and Complication Rates of Percutaneous Vertebroplasty and Kyphoplasty in the Treatment of Vertebral Compression Fractures: A Retrospective Analysis of 280 Patients. J Clin Med. 2024;13(5):1495. https://doi.org/10.3390/jcm13051495.
35. Litin Y, Rastogi S, Agarwal A, Misra S, Agrawal P, Malviya D. A prospective evaluation of percutaneous vertebroplasty in osteoporotic vertebral compression fracture patients. Cureus. 2023;15(6):e40255. https://doi.org/10.7759/cureus.40255.
36. Chiras J, Depriester C, Weill A, Sola-Martinez MT, Deramond H. Percutaneous vertebral surgery.Technics and indications. J Neuroradiol. 1997;24(1):45–59 (French. PMID: 9303944).
37. Rao RD, Singrakhia MD. Painful osteoporotic vertebral fracture. Pathogenesis, evaluation, and roles of vertebroplasty and kyphoplasty in its management. J Bone Joint Surg Am. 2003;85(10):2010–22 (PMID: 14563813).
38. Dang SJ, Wei WB, Wei L, Xu J. Vertebroplasty combined with facet joint blockvs. vertebroplasty alone in relieving acute pain of osteoporotic vertebral compression fracture: a randomized controlled clinical trial. BMC MusculoskeletDisord. 2022;23(1):807. 10. 1186/s12891–022–05753–4.

39. Ding X, Zhang Q, Zhao Y, Wang J. Location and Effect of Bone Cement in Percutaneous Vertebroplasty for Osteoporotic Vertebral Compression Fractures.Biomed Res Int.2022;2022:6127620.Published 2022 Jun 26.https://https://doi.org/10.1155/2022/6127620.
40. He Y, Yu Z, Yin J, Wang H, Xu N, Nong L, Jiang Y. Percutaneous curved vertebroplasty and bilateral-pedicle-approach percutaneous vertebroplasty inthe treatment of osteoporotic vertebral compression fracture: a meta-analysis. Geriatr Orthop Surg Rehabil. 2023;14:21514593231182532. https://doi.org/10.1177/21514593231182533.
41. Wang W, Duan K, Ma M, et al. Can an unipedicular approach replace bipedicular percutaneous vertebroplasty for osteoporotic vertebral compression fracture? J Back Musculoskelet Rehabil. 2019;32(2):261–7. https://doi.org/10.3233/BMR-170870.
42. Yang EZ, Xu JG, Huang GZ, et al. Percutaneous vertebroplasty versus conservative treatment in aged patients with acute osteoporotic vertebral compression fractures: a prospective randomized controlled clinical study. Spine (Phila Pa 1976). 2016;41(8):653–660 https://doi.org/10.1097/BRS.0000000000001298
43. Noguchi T, Yamashita K, Kamei R, Maehara J. Current status and challenges of percutaneous vertebroplasty (PVP). Jpn J Radiol. 2023;41(1):1–13. https://doi.org/10.1007/s11604-022-01322-w.
44. Li W, Wang J, Liu W, Xu C, Li W, Zhang K, et al. Machine learning applications for the prediction of bone cement leakage in percutaneous vertebroplasty. Front Public Health. 2021;9:812023. https://doi.org/10.3389/fpubh.2021.812023.

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