Am J Transl Res 2022;14(5):3448-3455
www.ajtr.org /ISSN:1943-8141/AJTR0141551

Original Article

Biomechanics of the unilateral posterosuperior, unipedicular, and bipedicular approaches for treatment by percutaneous vertebroplasty: a comparative study

Chenxi Gu[1], Anquan Huang[1], Yefeng Wang[1], Dongzhu Liang[2], Peidong Sun[2], Zhenfeng Zhang[3], Xiaoqiang Cai[1], Jun Shen[1], Jun Ou-Yang[2], Tianming Zou[1], Xiao Yu[1]

[1]*Department of Orthopedics, The Affiliated Suzhou Hospital of Nanjing Medical University, Suzhou Municipal Hospital, Suzhou, Jiangsu, China;* [2]*Key Laboratory of Medical Biomechanics, Southern Medical University, Guangzhou, Guangdong, China;* [3]*Guangzhou Development District Hospital, Guangzhou, Guangdong, China*

Received January 5, 2022; Accepted April 27, 2022; Epub May 15, 2022; Published May 30, 2022

Abstract: Percutaneous vertebroplasty (PVP) via the unilateral posterosuperior approach has achieved good clinical results for the treatment of osteoporotic vertebral compression fractures. This study compared the biomechanical performance of a single vertebral body after PVP by the unilateral posterosuperior, unipedicular, and bipedicular approaches. Twenty-one vertebral bodies from the osteoporotic spine segments (T11-L1) of seven older female cadavers were randomly assigned to the unipedicular (group A), bipedicular (group B), or unilateral posterosuperior approach group (group C). After constructing the fracture compression model, PVP was performed by the different approaches. CT scans showed symmetrical, evenly distributed bone cement in groups B and C and unilaterally distributed cement in group A. The recovery rates of the anterior vertebral body height in groups B and C were significantly higher than those in group A after PVP ($P<0.05$). The left curvature elastic moduli after PVP were significantly higher in group A than in groups B and C; however, the right curvature moduli in group A were lower than in the other groups ($P<0.05$). The flexion, extension, and vertical compression elastic moduli were lowest in group B ($P<0.05$). After PVP, failure strength and stiffness in groups B and C were comparable ($P>0.05$) and higher than those in group A ($P<0.05$). PVP through the unilateral posterosuperior approach was superior to the unipedicular approach and comparable to the bipedicular approach based on the biomechanical performance of a single vertebral body. Due to its safety, simplicity, and efficacy, the unilateral posterosuperior approach is recommended for clinical application.

Keywords: Percutaneous vertebroplasty, extrapedicle, transpedicle, compression fracture, polymethylmethacrylate

Introduction

Osteoporotic vertebral compression fractures (OVCF) are the most common osteoporotic fractures and result in both substantial pain and poor quality of life [1]. Conservative treatment of OVCF is usually ineffective. Percutaneous vertebroplasty (PVP) can rapidly relieve pain, stabilize the fracture, and allow the patient to resume normal activities through injection of polymethylmethacrylate (PMMA) bone cement into the fractured vertebral body [2]. PVP is currently well-recognized due to its advantages of being safe and simple and resulting in minimal trauma. The puncture approaches for PVP have been thoroughly analyzed, as the optimal approach will ensure the complete distribution of bone cement and reduce relevant risks [3]. The bipedicular approach has traditionally been used for PVP; however, clinical evidence now supports the unipedicular approach due to its therapeutic efficacy, minimal trauma, short surgery time, and low puncture risk and exposure [4]. Nevertheless, PVP through the unipedicular approach may result in stress concentration due to uneven distribution of bone cement. The unilateral posterosuperior approach features the convenience of unilateral puncture, a wide adjustment range of the puncture angle, and symmetrical diffusion of bone cement in the vertebral body. Our previous retrospective study involving 109 OVCF patients (144 vertebral bodies) suggested that the unilateral posterosuperior approach in PVP is highly effective [5].

To further validate the safety and efficacy of the unilateral posterosuperior approach, this study aimed to compare its biomechanical efficacy with the conventional unipedicular/bipedicular approach in fresh human vertebral bodies, thus providing a clinical reference.

Materials and methods

Reagents and instruments

This study used the following equipment: ElectroForce® 3510 Test Instrument (Bose Wintest, United States); ATES6010 Microcomputer Controlled Electronic Tensile Testing Machine (Okyiqi, Guangzhou, China); BG9000 Mobile High Frequency C-arm X-ray Machine (Pioway Medical Lab Equipment Co., Ltd, Shanghai, China); Akdx-09W-I Dual Energy X-ray Absorption Bone Densitometer (Shenzhen Xray Electric Co., Ltd, Shenzhen, China); Access CT 16 (Phillips, Holland); High-precision digital display vernier caliper (Deli Group, China); Mendec® Spine Bone Cement (TECRES, China); and a spinal vertebroplasty tool system (WEGO ORTHO, Shandong, China).

Methods

Sample collection: A total of 21 vertebral bodies were collected from the osteoporotic spine segments (T11-L1) of cadavers from seven volunteer older women after natural death, which were provided by the Department of Anatomy, Southern Medical University. None of the cadavers had obvious spinal deformity or a history of surgery or spinal tumors. The paravertebral muscles, ligaments, and periosteum and intervertebral discs connecting the vertebral bodies were removed. The superior and inferior endplate cartilages of the vertebral body were scraped for a single complete sample of the vertebral body. The upper and lower articular processes and the tips of the spinous processes were trimmed for the following experiments. Bone density of the vertebral body was measured using the dual-energy X-ray absorption bone densitometer. Vertebral bodies were labeled and randomly assigned to the unipedicular approach group (group A, n=7), bipedicular approach group (group B, n=7), or unilateral posterosuperior approach group (group C, n=7). The fixed position of the anterior superior endplate of the vertebral body was marked, and the vertebral body height (H1) was measured using a vernier caliper with 0.01-mm accuracy. The mean H1 was calculated from three independent measurements. Each vertebral body was wrapped with saline gauze and placed in a sealed bag for later use. This study was approved by the Ethic Committee of Suzhou Municipal Hospital (KL901131).

Measurement of elastic modulus: The vertebral body sample was placed on the platform of the ElectroForce® 3510 Test Instrument, which was loaded at the anterior third of the superior endplate of the vertebral body with a maximum tensile force of 500 N. A stress-strain curve was obtained to calculate the elastic modulus of flexion. The elastic moduli at extension, left curvature, right curvature, and vertical compression were measured as the loading at the posterior third, medial third, lateral third, and central area of the superior endplate, respectively (**Figure 1**) [6].

Compression fracture model: The compression fracture model was generated following a previously reported procedure [7]. Briefly, the vertebral body sample was placed on the ATES6010 Microcomputer Controlled Electronic Tensile Testing Machine, and the compression-molded denture base resins were placed on the top of the vertebral body to fit the machine. A 100-N preload at 1 mm/min eliminated the potential influence of the relaxation or creep of the sample. Subsequently, vertical compression with load and displacement accuracies of 0.01 N and 0.01 mm, respectively, was performed at 5 mm/min and was terminated at the maximum load. The stress-strain curve was dynamically recorded. During the preparation of the compression fracture model in an environment with constant temperature, normal saline was sprayed on the vertebral body to keep it moist. The anterior vertebral body height after compression fracture modeling (H2) was recorded (**Figure 2**).

PVP procedure: PVP was performed under the guidance of the C-arm X-ray. Briefly, bone cement-prepared by mixing powders and liquids at 24°C-was injected into the fractured vertebral body during its pasty polymerization phase through a 12.5-cm percutaneous access needle (Φ 3.4 mm).

In group A, the needle punctured the upper outer quadrant of the left pedicle to the anteri-

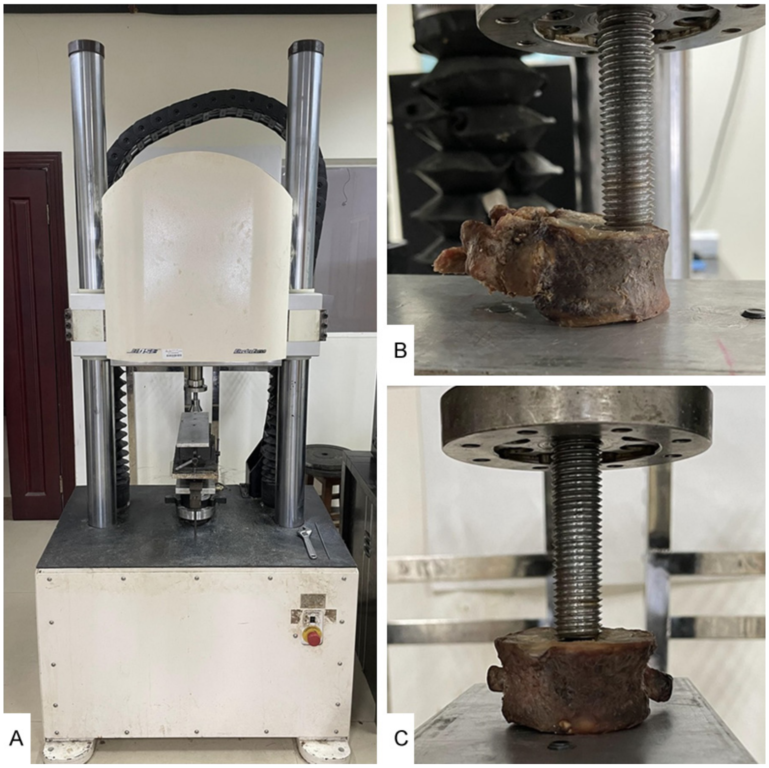

Figure 1. Elastic modulus of the vertebral body under different states of motion. (A) System for experimental determination of complex biomaterial. The stress-strain relationship on the (B) lateral view and (C) posteroanterior view.

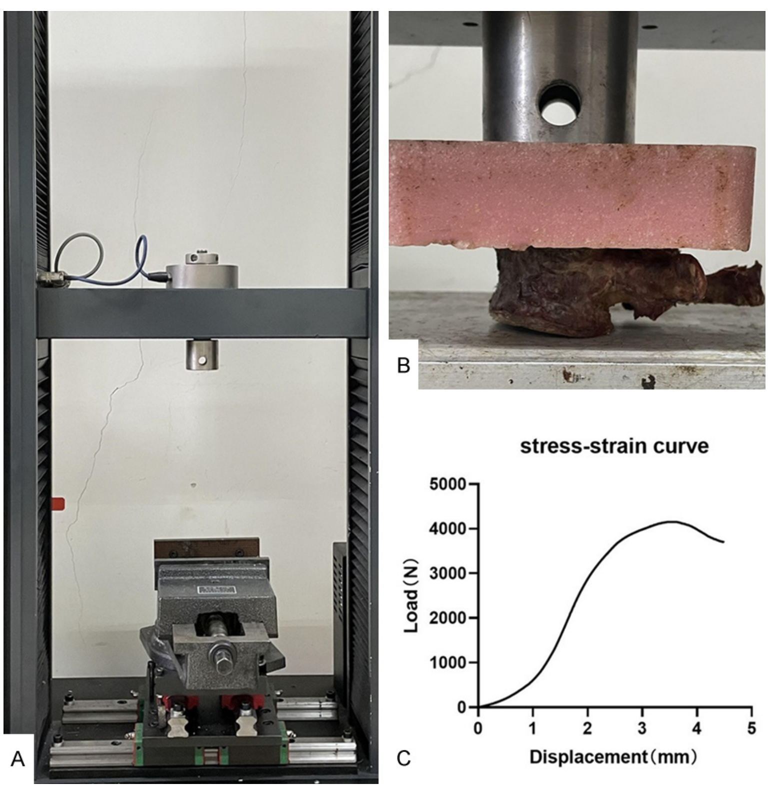

Figure 2. Compression fracture model in the vertebral body. A. Microcomputer Controlled Electronic Tensile Testing Machine. B. Preparation of vertebral body with compression fracture. C. Stress-strain curve under compression.

or third of the vertebral body on the lateral view, approaching or reaching the midline of the vertebral body on the posteroanterior view [8].

In group B, the needle similarly punctured the upper outer quadrant of the bilateral pedicles to the midline of the vertebral body on the posteroanterior view, located at the anterior third of the vertebral body on the lateral view.

In group C, the needle punctured the posterosuperior area of the left vertebral body at 30° abduction and a 15° tilt angle. The angle and depth of puncture allowed the needle to reach the anterior third of the vertebral body on the lateral view and the midline of the vertebral body on the posteroanterior view.

Bone cement was injected into each side of the vertebral body until leakage or overpressure occurred. The volume of injected bone cement was recorded. Each vertebral body injected with bone cement was wrapped with saline gauze and placed in a sealed bag at room temperature for 24 h. The distribution of bone cement was analyzed by computed tomography (CT) (**Figure 3**). Four regions of the vertebral body were classified based on the vertical line of the central vertebral body and those of the inner edge of the bilateral pedicles; the regions

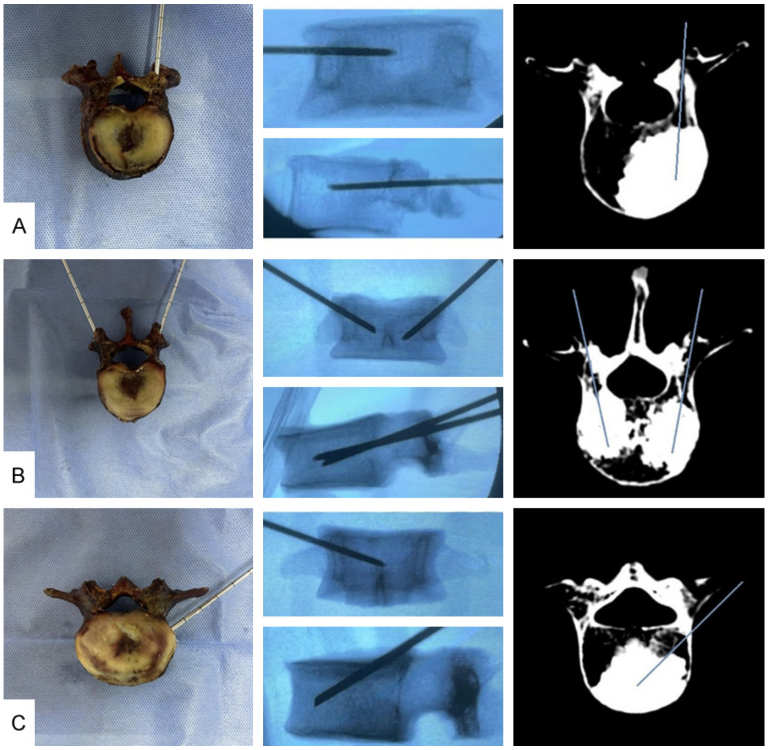

Figure 3. Representative images of the vertebral body sample (left column), C-arm X-rays on the posteroanterior view during puncture (middle column), and CT scans after percutaneous vertebroplasty (right column) in groups A, B, and C.

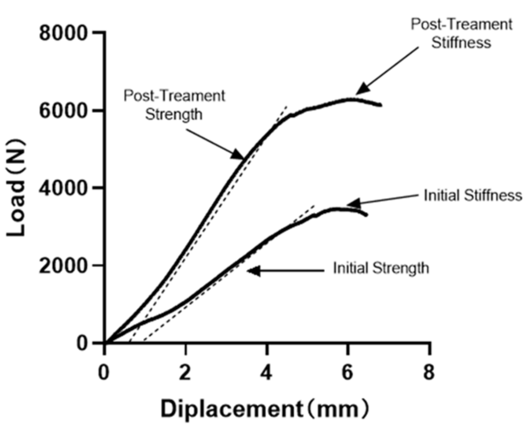

Figure 4. Stress-displacement curves before and after percutaneous vertebroplasty.

were numbered 1-4 from left to right. Each vertebral body was then assigned to a type (I-V) depending on the bone cement distribution among the regions: type I, regions 1-4; type II, regions 2 and 3; type III, regions 1 and 4; type IV, regions 1 and 2 or 3 and 4; type V, region 1 or 4 [9]. The bone cement distribution of types I, II, and III was bilateral, whereas that of types IV and V was unilateral. The bone cement distribution classification was recorded (**Figure 3**), and the anterior vertebral body height was re-measured (H3). The recovery rate (%) of the anterior vertebral body height was calculated as (H3-H2)/(H1-H2) ×100%.

Biomechanical testing: The flexion, extension, left curvature, right curvature, and vertical compression elastic moduli of the vertebral body after PVP were re-measured following the aforementioned procedure, and a stress-displacement curve was plotted by GraphPad Prism 8 to calculate the failure strength, stiffness, and failure displacement (**Figure 4**).

Statistical analysis: SPSS 26.0 was used for statistical analysis. Data were expressed as mean ± standard deviation. Bone density and H1 before fracture were compared among the groups by one-way ANOVA. The elastic moduli, failure strength, stiffness, failure displacement, and H2 at compression fractures were likewise compared among the groups by one-way ANOVA. The bone cement volume, H3, recovery rate, elastic moduli, failure strength, stiffness, and failure displacement after compression fractures were compared by one-way ANOVA, followed by the least significant difference test for pairwise comparison. The elastic moduli, failure strength, stiffness, and failure displacement before and after compression fractures were compared by the Student's *t*-test. *P*-values <0.05 were considered significant.

Results

Vertebral compression fracture model

The bone densities of groups A, B, and C were comparable at 0.535±0.07 g/cm^2, 0.557±0.09 g/cm^2, and 0.5335±0.07 g/cm^2, respectively (P>0.05). No significant difference was noted in the anterior vertebral body height among the groups before fracture (P>0.05), but this height

Table 1. Anterior vertebral body height

	Group A (n=7)	Group B (n=7)	Group C (n=7)	F value	*P*-value
Before fracture (H1, mm)	25.063±2.67	26.78±2.80	28.07±1.73	2.665	0.097
After fracture (H2, mm)	21.14±1.52	22.14±2.51	22.98±1.56	1.600	0.229
After PVP (H3, mm)	22.08±1.88	23.63±2.72	25.01±1.15	3.669	0.046
Recovery rate (%)	22.98±3.95	33.42±12.73*	39.15±12.79*	4.137	0.033

PVP, percutaneous vertebroplasty; Recovery rate (%) = (H3-H2)/(H1-H2) ×100%; *P<0.05 vs. group A.

Table 2. Bone cement distribution in vertebral bodies

	Bone cement distribution				
	Type I	Type II	Type III	Type IV	Type V
Group A (n, %)	0	4 (57.1%)	0	3 (42.9%)	0
Group B (n, %)	6 (85.7%)	0	1 (14.3%)	0	0
Group C (n, %)	5 (71.4%)	2 (28.6%)	0	0	0

The vertebral body was classified into four regions (1-4 from left to right) based on the vertical line of the central vertebral body and those of the inner edge of bilateral pedicles. Type I, regions 1-4; Type II, regions 2 and 3; Type III, regions 1 and 4; Type IV, regions 1 and 2 or 3 and 4; Type V, region 1 or 4.

was significantly reduced after the compression fracture (P<0.05). There was no significant difference in the anterior vertebral body height after fracture among the three groups (P> 0.05). We detected a significant difference in the anterior vertebral body height after PVP among the groups (P<0.05). In particular, the recovery rate of the anterior vertebral body height after PVP was significantly higher in groups B (33.42±12.73%) and C (39.15± 12.79%) than in group A (22.98±3.95%). No significant difference was detected between groups B and C (P>0.05) (**Table 1**).

Biomechanical tests

Bone cement distribution: The bone cement volumes in groups A, B, and C were 5.9±0.13 ml, 6.1±0.19 ml, and 6.0±0.13 ml, respectively. Bone cement leakage was not reported in any group. According to the bone cement distribution classification, there were 4 (57.1%) type II and 3 (42.9%) type IV vertebral bodies in group A; 6 (85.7%) type I and 1 (14.3%) type III in group B; and 5 (71.4%) type I and 2 (28.6%) type II in group C (**Table 2**).

Failure strength, stiffness, and failure displacement of the vertebral body under different states of motion: There were no significant differences in the failure strength, stiffness, and failure displacement before fracture among the three groups (all P>0.05). The failure strength and stiffness after PVP were significantly greater than those before fracture in each group (P<0.05). These increases were comparable in groups B and C, and those in group C were significantly greater than those in group A. No significant difference in failure displacement was detected among the three groups (P>0.05, **Table 3**).

Elastic modulus of the vertebral body under different states of motion: There were no significant differences in the elastic moduli of flexion, extension, left curvature, right curvature, and vertical compression before fracture among the three groups (all P>0.05), which were comparable in each group before fracture as well (all P>0.05). After PVP for the treatment of fracture, the elastic moduli of flexion in group B were significantly lower than those of group C (P<0.05). The elastic moduli of extension in groups B and C were significantly lower than those of group A (both P<0.05). In addition, the elastic moduli of the left curvature in groups B and C were significantly lower than those of group A, whereas those of the right curvature in groups B and C were significantly higher than those of group A (P<0.05). Under the vertical compression, the elastic moduli of extension in group B were significantly smaller than those in group C (P<0.05, **Table 4**).

Discussion

PVP is preferred for Osteoporotic vertebral compression fracture (OVCF) patients, and the bipedicular approach is the classic puncture approach [10, 11], though it has certain limitations: i.e., its complexity, long surgery time and exposure, high risk of complications, and increased medical costs due to the 2-puncture system. More importantly, the bipedicular app-

Table 3. The failure strength, stiffness, and failure displacement of vertebral bodies

	Group A (n=7)	Group B (n=7)	Group C (n=7)	F value	*P*-value
Failure strength (N)					
Before fracture	4294.43±713.39	4617.86±697.62	4119.43±693.27	0.0.910	0.420
After PVP	6338.29±1263.89#	7544.14±443.02*	7464.71±666.36*	4.269	0.030
t-value	-3.806	-11.077	-12.072	-	-
P-value	0.009	0.000	0.000	-	-
Stiffness (N/mm)					
Before fracture	820.43±187.39	923.73±409.44	911.09±340.26	0.209	0.813
After PVP	1172.91±259.45#	1613.16±210.82*	1570.81±108.06*	10.036	0.001
t-value	-2.651	-5.254	-4.583	-	-
P-value	0.038	0.002	0.004	-	-
Failure displacement (mm)					
Before fracture	5.23±1.00	5.88±1.89	5.24±1.41	0.446	0.647
After PVP	6.81±2.02	7.28±0.61	7.98±1.18	1.230	0.316
t-value	-1.614	-2.160	-3.661	-	-
P-value	0.158	0.074	0.011	-	-

PVP, percutaneous vertebroplasty; **P*<0.05 vs. group A; #*P*<0.05 vs. group B.

Table 4. Elastic modulus of vertebral bodies under different states of motion

	Group A (n=7)	Group B (n=7)	Group C (n=7)	F value	*P*-value
Elastic modulus before fracture (N/mm)					
Flexion	533.45±125.55	535.73±127.15	637.26±157.70	1.395	0.272
Extension	414.71±189.38	364.39±127.83	471.43±184.31	0.741	0.490
Left curvature	568.11±251.40	500.71±147.65	593.48±175.44	0.440	0.650
Right curvature	604.87±199.05	524.69±197.37	581.62±182.28	0.323	0.728
Vertical compression	560.40±168.58	497.39±150.38	611.14±235.55	0.661	0.528
Elastic modulus after PVP (N/mm)					
Flexion	343.22±109.99	245.55±63.15	343.65±88.46#	2.872	0.081
Extension	316.51±87.41#	182.76±49.17*	297.41±111.62#	4.779	0.021
Left curvature	498.47±153.97#	268.72±87.44*	306.36±137.32*	6.384	0.008
Right curvature	150.95±33.48#	333.22±85.12*	269.05±86.28*	11.141	0.001
Vertical compression	394.29±76.68	318.57±81.69	470.93±144.93#	3.709	0.044

PVP, percutaneous vertebroplasty; **P*<0.05 vs. group A; #*P*<0.05 vs. group B.

roach is limited by the anatomical structure of the pedicle, which narrows below the thoracic spine. As a result, a bipedicular puncture may penetrate the inner wall of the pedicle, leading to hematoma and even spinal cord damage. However, the unipedicular approach is not ideal for the diffusion of bone cement and sometimes affects the therapeutic efficacy, leading to the possibility of refracture due to uneven stress [12].

Based on the Kambin Triangle theory for percutaneous transforaminal endoscopic discectomy, we proposed a novel unilateral posterosuperior approach in PVP for the treatment of OVCF. Unrestricted by pedicle puncture, it avoids spinal nerve roots and the segmental medullary artery, thus providing a larger operation area and wider adjustment angle [13]. It is a unilateral approach that shortens the surgery and exposure times and reduces perioperative risk. The puncture points for this extrapedicular approach are located in the unilateral posterosuperior region of the vertebral body.

In the present study, no significant difference in bone cement volume was detected among groups A, B, and C. Classified by the bone cement distribution, there were 4 (57.1%) type II and 3 (42.9%) type IV vertebral bodies in group A; 6 (85.7%) type I and 1 (14.3%) type III in group B; and 5 (71.4%) type I and 2 (28.6%) type II in group C. The bone cement distribution in groups B and C was similar, and both were superior to that of group A, which is consistent with our previous findings [5]. Owing to the sufficient abduction angle, the unilateral posterosuperior approach was able to achieve bilateral diffusion of bone cement. Moreover, the puncture site of the unilateral posterosuperior approach was more lateral than that of the pedicular approach. The bone cement injected in the unilateral posterosuperior approach was generally located at the anterior and middle regions of the vertebral body, resulting in less stress on the posterior wall and a reduced leakage rate [14].

The distribution of bone cement determines the biomechanical recovery of the compressed fractured vertebral body [15]. In our study, failure strength and stiffness were enhanced in all three groups after PVP but were more pronounced in groups B and C ($P<0.05$), suggesting a direct correlation with the symmetrical distribution of bone cement. The recovery rate of the anterior vertebral body height after PVP was significantly higher in group C than in groups A and B. The height recovery rate relies on the distribution of bone cement, but clinical experience suggests that the fact that the unilateral posterosuperior approach was not limited by the cross-sectional area may have also played a role. Therefore, a wider range of adjusted puncture angles into the fractured vertebral body helped to reach the fracture site [16, 17].

We further assessed the elastic modulus of fractured vertebral bodies under different states of motion. The elastic moduli in the left curvature in group A were much larger than those in groups B and C as well as those of the right curvature. The concentrated stress at the left curvature in the unipedicular approach in PVP may be attributed to the small inclination angle and the subsequent uneven distribution of bone cement to the other side. Significant differences were detected between the elastic moduli of flexion, extension, and vertical compression in group B and those of groups A and C, which may be due to the incomplete connection of vertebral bodies with the bone cement injected through the bipedicular approach. The concentrated stress and differences of the elastic moduli can lead to adjacent vertebral fractures or refractures of the injured vertebrae [18, 19]. Due to the unilateral punctureof the unilateral posterosuperior approach, the symmetrical diffusion of bone cement remarkably reduced the concentrated stress and differences of elastic moduli in different regions of the vertebral body.

Some limitations of the present study should be noted. First, the small sample size may influence the reliability of our results. Second, the study lacked an appropriate imaging assessment and ideal biomechanical modeling of the fractured vertebral bodies, which may result in potential bias. Altogether, our study demonstrated that the biomechanical performance of a single vertebral body after the treatment of PVP through the unilateral posterosuperior approach was superior to that of the unipedicular approach and comparable to that of the bipedicular approach. The wider adjustment of the puncture angle contributed to bone cement diffusion and the recovery of vertebral body height, and blocky symmetrical distribution resulted in decreased elastic moduli.

Conclusion

Biomechanical indices measured in the present study were found to be closely linked with clinical outcomes of PVP, further supporting the clinical advantages of the unilateral posterosuperior approach. We recommend that this approach be applied in clinical practice.

Acknowledgements

This study was financially supported by Key Disease Diagnosis and Treatment Technology Special Project of Suzhou, China (LCZX2019-10).

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Xiao Yu and Tianming Zou, Department of Orthopedics, The Affiliated Suzhou Hospital of Nanjing Medical University, No. 26 Daoqian Street, Suzhou 215000, Jiangsu, China. Tel: +86-15851446261; E-mail: yuxiao-szmh@foxmail.com (XY); Tel: +86-130638-92207; E-mail: zoutianming0@163.com (TMZ)

References

[1] Kendler DL, Bauer DC, Davison KS, Dian L, Hanley DA, Harris ST, McClung MR, Miller PD, Schousboe JT, Yuen CK and Lewiecki EM. Vertebral fractures: clinical importance and management. Am J Med 2016; 129: 221.

[2] Luthman S, Widén J and Borgström F. Appropriateness criteria for treatment of osteoporotic vertebral compression fractures. Osteoporos Int 2018; 29: 793-804.

[3] Tsoumakidou G, Too CW, Koch G, Caudrelier J, Cazzato RL, Garnon J and Gangi A. CIRSE guidelines on percutaneous vertebral augmentation. Cardiovasc Intervent Radiol 2017; 40: 331-342.

[4] Wang W, Duan K, Ma M, Jiang Y, Liu T, Liu J and Hao D. Can an unipedicular approach replace bipedicular percutaneous vertebroplasty for osteoporotic vertebral compression fracture. J Back Musculoskelet Rehabil 2019; 32: 261-267.

[5] Wang YF, Shen J, Li SY, Yu X and Zou TM. Kambin triangle approach in percutaneous vertebroplasty for the treatment of osteoporotic vertebral compression fractures. Medicine (Baltimore) 2019; 98: e17857.

[6] Kraxenberger M, Schröder C, Geith T, Büttner A, von Schulze-Pellengahr C, Birkenmaier C, Müller PE, Jansson V and Wegener B. Fracture generation in human vertebrae under compression loading: the influence of pedicle preservation and bone mineral density on in vitro fracture behavior. Technol Health Care 2018; 26: 155-163.

[7] Belkoff SM, Mathis JM, Jasper LE and Deramond H. The biomechanics of vertebroplasty. The effect of cement volume on mechanical behavior. Spine (Phila Pa 1976) 2001; 26: 1537-41.

[8] Lu Q, Liu C, Wang D, Liu H, Yang H and Yang L. Biomechanical evaluation of calcium phosphate-based nanocomposite versus polymethylmethacrylate cement for percutaneous kyphoplasty. Spine J 2019; 19: 1871-1884.

[9] Zhang D, Mao K, Qiang XJ, Wang Z, Zhao Y, Yang G and Wang P. Clinical study and clinical significance of cement distribution after vertebral augmentation. Chin J Trauma 2018; 34: 130-137.

[10] Tang J, Guo WC, Hu JF and Yu L. Unilateral and bilateral percutaneous kyphoplasty for thoracolumbar osteoporotic compression fractures. J Coll Physicians Surg Pak 2019; 29: 946-950.

[11] Yang S, Chen C, Wang H, Wu Z and Liu L. A systematic review of unilateral versus bilateral percutaneous vertebroplasty/percutaneous kyphoplasty for osteoporotic vertebral compression fractures. Acta Orthop Traumatol Turc 2017; 51: 290-297.

[12] Zhang L, Wang Q, Wang L, Shen J, Zhang Q and Sun C. Bone cement distribution in the vertebral body affects chances of recompression after percutaneous vertebroplasty treatment in elderly patients with osteoporotic vertebral compression fractures. Clin Interv Aging 2017; 12: 431-436.

[13] Hoshide R, Feldman E and Taylor W. Cadaveric analysis of the Kambin's triangle. Cureus 2016; 8: e475.

[14] Hou Y, Yao Q, Zhang G, Ding L and Huang H. Polymethylmethacrylate distribution is associated with recompression after vertebroplasty or kyphoplasty for osteoporotic vertebral compression fractures: a retrospective study. PLoS One 2018; 13: e0198407.

[15] Molloy S, Mathis JM and Belkoff SM. The effect of vertebral body percentage fill on mechanical behavior during percutaneous vertebroplasty. Spine (Phila Pa 1976) 2003; 28: 1549-54.

[16] Wang YF, Gu CX, Huang AQ, Shen J, Cai XQ and Zou TM. Percutaneous vertebroplasty via the unilateral posterolateral approach for the treatment of osteoporotic vertebral compression fractures. Int J Orthop 2021; 42: 247-251.

[17] Ryu KS, Park CK, Kim MK and Kim DH. Single balloon kyphoplasty using far-lateral extrapedicular approach: technical note and preliminary results. J Spinal Disord Tech 2007; 20: 392-8.

[18] Tang B, Cui L, Chen X and Liu Y. Risk factors for cement leakage in percutaneous vertebroplasty for osteoporotic vertebral compression fractures: an analysis of 1456 vertebrae augmented by low-viscosity bone cement. Spine (Phila Pa 1976) 2021; 46: 216-222.

[19] Kwon HM, Lee SP, Baek JW and Kim SH. Appropriate cement volume in vertebroplasty: a multivariate analysis with short-term follow-up. Korean J Neurotrauma 2016; 12: 128-134.