

Efficacy of percutaneous cement-augmented screw fixation plus percutaneous kyphoplasty in the management of unstable osteoporotic vertebral compression fractures

T.-Z. CHEN¹, M.-H. WEN¹, X.-J. LU², F.-F. MENG², W. ZHANG²,
D.-Z. WU², X. LI², R.-J. QIN¹

¹Lianyungang Clinical College of Nanjing Medical University, The First People's Hospital of Lianyungang, Lianyungang, Jiangsu, China

²The First People's Hospital of Lianyungang, Lianyungang, Jiangsu, China

Abstract. – OBJECTIVE: The present study was performed to compare the efficacy of percutaneous kyphoplasty (PKP) vs. percutaneous cement-augmented screw fixation plus PKP in the management of unstable osteoporotic vertebral compression fractures (OVCF).

PATIENTS AND METHODS: A total of 197 patients with unstable OVCF treated in the Department of Spine Surgery, Lianyungang First People's Hospital from September 2019 to September 2021 were recruited and assigned *via* random number table method 1:1 to receive either PKP (group A, n=106) or PKP plus percutaneous cement-augmented screw fixation (group B, n=91). The outcome measures for the evaluation of different surgical methods included visual analogue scale (VAS), the height of the anterior-posterior border of the injured spine, Cobb angle of the posterior convexity, Oswestry disability index (ODI) scores, and Japanese Orthopaedic Association (JOA) scores.

RESULTS: PKP exhibited shorter operative time and length of hospital stay and less intra-operative blood loss vs. PKP plus percutaneous cement-augmented screw fixation ($p<0.05$). Patients with PKP plus percutaneous cement-augmented screw fixation experienced milder post-operative pain vs. those with PKP alone at 7 days postoperatively, as evidenced by the lower VAS scores ($p<0.05$). PKP plus percutaneous cement-augmented screw fixation provided more restoration of anterior margin height and posterior convexity Cobb angle vs. PKP alone ($p<0.05$). Patients with PKP only showed slightly higher Japanese Orthopaedic Association (JOA) scores than those with combined surgery, while the postoperative clinical signs between the two arms were similar ($p>0.05$).

CONCLUSIONS: Single PKP features the benefits of minimal trauma, simple operation, and rapid postoperative recovery in the treatment of OVCF. PKP plus percutaneous cement-aug-

mented screw fixation for severe OVCF provided distinctly better performance than PKP alone in terms of early pain relief, restoration of vertebral body height, correction of posterior convexity deformity, and firm spinal stability.

Key Words:

Percutaneous cement-augmented screw fixation, Percutaneous kyphoplasty, Osteoporotic vertebral compression fractures.

Introduction

The prevalence of osteoporotic vertebral compression fracture (OVCF) is currently on the rise, with a predominance in the elderly. Elderly people with limited mobility and poor disease awareness usually fail to seek the best medical care after a thoracolumbar fracture, which gradually evolves into a compression fracture and results in kyphosis, hunchback, loss of height of the injured vertebrae, and compression of nerves, seriously compromising the quality of life of patients. Burst fractures of OVCF with vertebral compression exceeding 2/3 of the original height or combined with injury to the middle and posterior columns are considered unstable fractures and are currently challenging for management. Internal fixation with percutaneous pedicle screws is a common surgical option for the treatment of thoracolumbar spine fractures. However, simple bracing of the vertebral body by posterior pedicle screws prevents complete repositioning of the injured vertebra due to cancellous bone compression, resulting in an eggshell-like change anteriorly. In addition, decreased support in the anterior column of the injured spine leads

to screw loosening or even fractures¹. The efficacy of percutaneous vertebroplasty (PVP) and percutaneous kyphoplasty (PKP) for osteoporotic stable vertebral fractures with an intact posterior canal and no neurological symptoms has been widely established worldwide. PKP relies on the injection of bone cement into the injured vertebra to increase the stiffness of the vertebral body, which simply highlights the curing of the injured vertebra at the expense of the overall mechanical balance of the spine. Adjacent segmental refractures are another common occurrence after OVCF internal fixations. The incidence can reach more than 17% within 5 years after surgery². The combination of the spinal stability of percutaneous internal pedicle nailing with the vertebral stability of PKP can effectively compensate for the shortcomings and amplify the merits of both procedures, providing a better solution for OVCF³⁻⁵. To this end, the current research was performed to compare the efficacy of PKP vs. percutaneous cement-augmented screw fixation plus PKP in the management of unstable OVCF.

Patients and Methods

Baseline Patient Profiles

A total of 197 patients with unstable OVCF treated in the Department of Spine Surgery, Li-anyungang First People's Hospital from September 2019 to September 2021 were recruited and assigned *via* random number table method 1:1 to receive either PKP (group A) or PKP plus percutaneous cement-augmented screw fixation (group B). There were 106 cases in group A, 47 males and 59 females, aged 55-79 years, with passage of 16-56 days from fracture to treatment; 12 cases had fractured segments in T11, 44 cases in T12, 23 cases in L1, 18 cases in L2, and 9 cases in L3. There were 91 cases in group B, 34 males and 57 females, aged 53-72 years, with passage of 23-64 days from fracture to treatment; 16 cases had fractured segments in T11, 39 cases in T12, 21 cases in L1, 13 cases in L2, and 2 cases in L3.

Inclusion Criteria

(1) Examination confirmed the diagnosis of OVCF of the thoracolumbar spine, and preoperative X-ray, CT, and MRI showed that the degree of wedge compression of the injured vertebral body was greater than 50%, with varying degrees of posterior convexity deformity and posterior convexity Cobb angle greater than 20 degrees. (2) The patient met WHO diagnostic criteria for osteopo-

rosis, with a thoracolumbar vertebral bone density *t* value less than -2.5 SD; (3) old and unstable vertebral fractures, with passage of >2 weeks from fracture to surgery; (4) a VAS score of >7.

Exclusion Criteria

(1) Imaging suggested multi-segmental thoracolumbar fractures or symptoms not compatible with physical examinations. (3) Stable thoracolumbar fractures or compression of the upper thoracic spine exceeding 50% and the lumbar spine exceeding 75%, preventing PKP. (4) Other factors affecting surgery and follow-up.

Dropout Cases

One patient died of natural causes, and 13 patients refused to be followed up for personal and family reasons, so they were excluded due to data loss.

Treatment Methods

PKP

Patients in group A received PKP. The patient was placed in a prone position with the abdomen suspended, and C-arm fluoroscopy system [OEC 9900 Elite (GE Healthcare, Chicago, IL, USA)] was used to confirm the projection of the injured vertebral arch on the body surface and to mark the puncture site. The puncture site was anesthetized with local infiltration of 2% lidocaine (Baxter Healthcare Corporation, Deerfield, IL, USA), a 0.5 cm incision was made, and the puncture was performed after determining the angle of the puncture needle. A successful puncture is indicated by fluoroscopy, demonstrating that the needle tip has reached or surpassed the midline of the vertebral body in the orthogonal position and has reached the anterior, middle third of the vertebral body in the lateral position. The puncture needle core was withdrawn, followed by the placement of the guide needle and the expansion cannula to establish a working channel. A balloon was placed through the channel, the contrast agent was slowly injected into the balloon to observe the raising of the upper vertebral plate and the recovery of vertebral body height in the injured spine, and the balloon was removed after a satisfactory operation. The liquid-solid phase bone cement was injected, followed by close monitoring for leakage, and the channel was removed by rotation after a satisfactory injection. Sterile dressings were applied to the incision.

PKP Plus Percutaneous Cement-Augmented Screw Fixation

The procedure was performed with an L2 vertebral compression fracture as an example. The patient was placed in a prone position with the abdomen suspended, and the midpoint of the lumbar 1-lumbar 3 arch was located under C-arm fluoroscopy and marked on the corresponding body surface, followed by sterilization and draping. A 1.5-cm longitudinal incision was made at the entry point, and the lumbar 1 and 3 pedicle entry points were revealed in sequence with the aid of a small hook, and the localization needle was used for puncture. A long-tailed titanium screw was inserted under C-arm fluoroscopy, and the puncture needle was inserted laterally from the middle of the pedicle under frontal fluoroscopy and parallel to the upper endplate under lateral fluoroscopy. The puncture needle was inserted into the vertebral body about 2-3 mm under lateral fluoroscopy, followed by the hollowing of the puncture needle and placement of the guide needle. The soft tissue expansion tube of level 1, level 2, and level 3 was placed along the guide needle, and the level 1 expansion tube was removed and tapped along the guide needle. The level 2 expansion tube was removed, and a long-tailed titanium alloy screw was placed. The level 3 expansion tube was removed, and the bone cement was injected into the screw. Fluoroscopy showed good height recovery of the injured vertebra, uniform distribution of bone cement in the vertebral body, and good po-

sition and length of the screw. After determining the distance of the vertebral arch, both sides of the titanium rod were passed sequentially through the tail of the screw *via* the subcutaneous soft tissue and fixed sequentially using the mounting nut. The C-arm X-ray machine fluoroscopically guided the puncture to enter the lumbar 2 vertebral body *via* the pedicle, with the puncture needle being inserted from the lateral pedicle and the needle pointing to the anterior inferior edge of the vertebral body under lateral fluoroscopy. Under lateral fluoroscopy, the puncture needle was inserted about 2-3 mm into the vertebral body, the needle core was removed, the 4.5 mm diameter working cannula was used, and the bone drill was slowly placed to drill to the anterior middle third of the vertebral body. The prepared barium-containing bone cement was instilled into the injured spine through the working cannula. After fluoroscopic confirmation of bone cement filling, the working channel was withdrawn, the caudal part of the long caudal screw was detached, and the incision was sutured and covered with a sterile dressing (Figure 1).

Postoperative Management

Postoperatively, the patient was given 20% mannitol intravenously for 3 days, and antibiotics were applied as appropriate. After 3 days, the patient was allowed to perform off-bed activities with a back protector. Postoperatively, the patients were given active calcium (Nature's Boun-

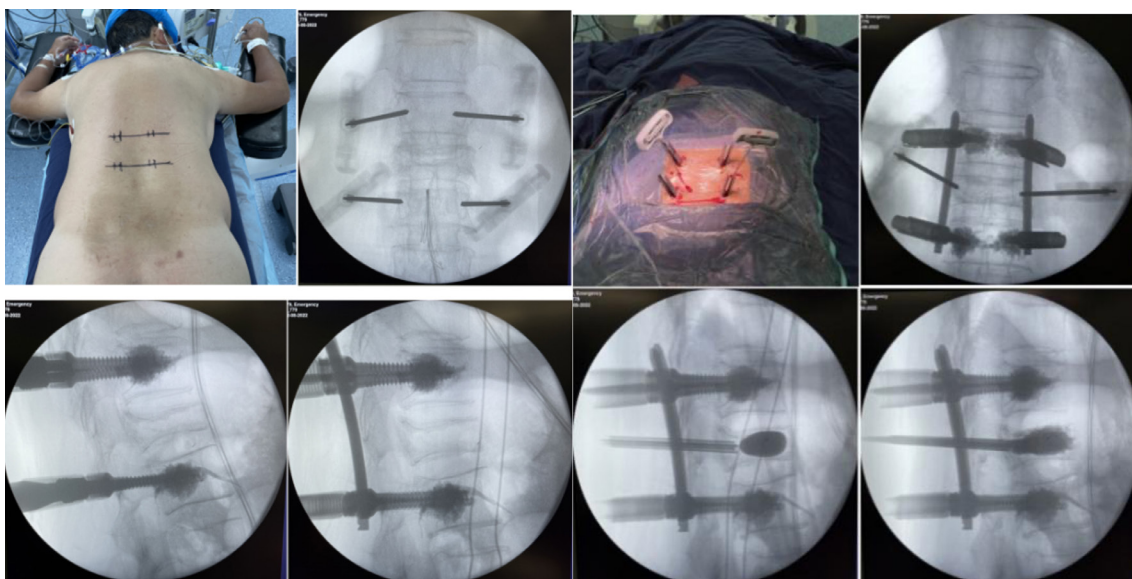


Figure 1. Intraoperative operations and fluoroscopic images.

ty, Ronkonkoma, NY, USA) and alendronate sodium (Merck & Co., Inc., Kenilworth, NJ, USA) and other drugs for anti-osteoporosis. 3 days after surgery, the lumbar frontal and lateral X-rays (Siemens Healthineers, Erlangen, Germany) and CT (GE Healthcare, Chicago, IL, USA) were reviewed to determine the position of the internal fixation and the distribution of bone cement. Positive and lateral x-ray images of the lumbar spine were obtained 6 or 12 months after surgery to observe the condition of the pedicle screws and to assess the recovery of lumbar spine function.

Outcome Measures

The outcome measures for the evaluation of different surgical methods included visual analogue scale (VAS), the height of the anterior-posterior border of the injured spine, Cobb angle of the posterior convexity, Oswestry disability index (ODI) scores, and Japanese Orthopaedic Association (JOA) scores. Positive and lateral X-ray images of the lumbar spine were obtained 3 days after surgery and at the last follow-up visit to observe whether there was any collapse of the screw rod and bone cement in the injured spine.

Statistical Analysis

SPSS 26.0 (IBM Corp., Armonk, NY, USA) was used for data analyses. Measurement data were expressed as mean±standard deviation; an independent sample *t*-test was performed for inter-group comparison at the same period, and the LSD method was used for intra-group comparison. Count data were examined using the Chi-square test. Statistical significance was indicated at *p*<0.05.

Results

Perioperative-Related Indicators

All patients were followed up for 6-13 months. PKP exhibited shorter operative time and length of hospital stay and less intraoperative blood loss vs. PKP plus percutaneous cement-augmented

screw fixation (*p*<0.05). This suggests that PKP features merits of small surgical wounds, simple surgical operations, and rapid recovery (Table I).

VAS Score, ODI Score, Height Percentage of the Anterior Margin of the Injured Vertebra, and Posterior Convexity Cobb Angle

Patients with PKP plus percutaneous cement-augmented screw fixation experienced milder postoperative pain vs. those with PKP alone at 7 days postoperatively, as evidenced by the lower VAS scores (*p*<0.05). This is because PKP alone provides limited restoration of injured spine height and vertebral stability, and the increased weight-bearing of the injured spine during early postoperative off-bed activities can induce or aggravate postoperative pain⁶. PKP plus percutaneous cement-augmented screw fixation provided more restoration of anterior margin height and posterior convexity Cobb angle vs. PKP alone (*p*<0.05). It is suggested that PKP combined with percutaneous cement-augmented screw fixation is superior to conventional PKP in terms of orthopedic recovery and long-term stability support, and its stability is mainly derived from the adhesive fixation effect of bone cement. PKP alone fails to significantly restore the height of the anterior and middle posterior columns, with low cement volume and low cement dispersion, which leads to reduced stability and postoperative collapse. Thus, PKP combined with percutaneous cement-augmented screw fixation realizes multi-dimensional orthosis and fixation and therefore allows for better height restoration and stability of the vertebral body⁷⁻⁹ (Tables II-III).

JOA Scores

Patients with PKP only showed slightly higher JOA scores than those with combined surgery, while the postoperative clinical signs between the two arms were similar (*p*>0.05). This indicates similar safety and recovery of postoperative limb mobility between PKP with and without percutaneous cement-augmented screw fixation (Table IV).

Table I. Perioperative-related indicators.

Groups	n	Operative time (min)	Intraoperative blood loss (ml)	Length of hospital stay (days)
Group A	106	45.1±5.3	29.9±4.1	3.3±0.7
Group B	91	94±7.2 ^a	78.3±5.6 ^a	6.8±0.8 ^a

^aindicates *p*<0.05 when compared with group A.

Table II. Height percentage of the anterior margin of the injured vertebra, and posterior convexity Cobb angle ($\chi \pm s$).

Groups	n	Height percentage of the anterior margin of the injured vertebra (%)		Cobb angles	
		Preoperatively	Postoperatively	Preoperatively	Postoperatively
Group A	106	44.6 \pm 2.6	67.9 \pm 3.4 ^b	22.3 \pm 2.3	16.8 \pm 1.6 ^b
Group B	91	45.4 \pm 2.5	92.2 \pm 3.9 ^{ab}	21.8 \pm 2.0	11.9 \pm 0.7 ^{ab}

^aindicates $p < 0.05$ when compared with group A; ^bindicates $p < 0.05$ when compared with preoperatively.

Table III. VAS scores and ODI scores ($\chi \pm s$).

Groups	n	VAS scores			ODI scores		
		Preoperatively	7 days postoperatively	Last follow-up visits	Preoperatively	7 days postoperatively	Last follow-up visits
Group A	106	7.5 \pm 0.2	4.7 \pm 0.5 ^b	1.5 \pm 0.2 ^b	47.9 \pm 4.5	38.5 \pm 3.1 ^b	19.2 \pm 1.9 ^b
Group B	91	7.6 \pm 0.3	3.3 \pm 0.3 ^{ab}	1.2 \pm 0.2 ^b	48.8 \pm 5.6	39.5 \pm 3.0 ^b	18.6 \pm 2.1 ^b

^aindicates $p < 0.05$ when compared with group A; ^bindicates $p < 0.05$ when compared with preoperatively.

Table IV. JOA scores.

Indices	7 days postoperatively		t	p	Last follow-up		t	p
	Group A	Group B			Group A	Group B		
Leg elevation	8.6 \pm 1.5	8.1 \pm 1.1	2.878	0.004	9.5 \pm 0.8	8.4 \pm 0.7	11.419	0.001
Sensory impairment	5.9 \pm 1.2	6.2 \pm 0.9	-1.811	0.072	9.2 \pm 0.4	9.3 \pm 0.6	1.598	0.112
Motor impairment	3.8 \pm 0.7	4.6 \pm 0.6	-8.457	0.001	0.5 \pm 0.2	0.7 \pm 0.2	-7.510	0.000
Daily activities	0.5 \pm 0.1	0.4 \pm 0.2	2.953	0.004	3.2 \pm 0.4	2.4 \pm 0.4	13.209	0.000
Bladder function	7.1 \pm 0.9	6.7 \pm 1.0	3.406	0.001	10.0 \pm 0.8	9.8 \pm 0.9	9.926	0.000
Total scores	25.9 \pm 2.1	26.0 \pm 1.8	1.009	0.993	32.8 \pm 1.4	29.6 \pm 1.3	16.163	0.000

JOA: Japanese Orthopaedic Association.

Typical Cases

Case one

The patient was an elderly female, 67 years old, with severe osteoporosis, and reported 3 weeks of lumbar pain, which caused the inability to straighten the back and worsened severely with standing and weight bearing (Figure 2).

Case two

The patient was an elderly male, 65 years old, and complained of more than 2 months of low back pain that prevented straightening his back and worsened recently, with no significant mitigation after bed rest (Figure 3).

Discussion

The efficacy of PVP and PKP minimally invasive surgery for OVCF is well-established worldwide¹⁰. However, sole use of PVP is associated with limited restoration of sagittal balance in patients with severe vertebral body collapse. In this regard, some scholars¹¹ classified patients with a vertebral compression ratio of more than 75% as a contraindication to PVP. Besides, research⁵ has shown a significant decrease in spinal stability after PKP alone, which is detrimental to the patient's limb movement and thus compromises postoperative rehabilitation. Patients treated with percutaneous cement-augmented screw fixation, especially those



Figure 2. X-rays and CT images of case one. **A**, Preoperative radiograph showed a compression fracture of the L1 vertebral body with loss of vertebral stability, significant narrowing of the upper and lower vertebral space heights, and a significant increase in the Cobb angle of the injured vertebra. **B**, Preoperative CT showed L1 vertebral body fracture with more than 50% compression and hollowing within the bony structures. **C**, Postoperative X-ray 3 days after surgery showed a recovery of the postoperative injured spine height to more than 75%, good recovery of the upper and lower intervertebral space height, and a significant reduction in the Cobb angle of the injured spine compared with that before surgery. **D**, Six months postoperative CT of the lumbar spine showed good metal internal fixation in place without displacement or fracture, clear bone cement shadow, and no significant leakage.



Figure 3. X-rays and CT images of case two. **a**, Preoperative radiograph showed a compression fracture of the L1 vertebral body with loss of vertebral stability, significant narrowing of the upper and lower vertebral space heights, and a significant increase in the Cobb angle of the injured vertebra. **b**, Preoperative CT showed 50% compression of the L1 vertebral fracture. **c**, 3 days after surgery, the X-ray showed that the height of the injured spine basically recovered after surgery, and the Cobb angle of the injured spine was significantly reduced compared with that before surgery. **d**, The postoperative 6-month review X-ray showed no displacement or fracture of the screw, clear cement shadow, and no new fracture.

over 60 years of age with underlying disease, are less tolerant of the procedure and suffer from poor support, poor reduction, and complications after placement of the pedicle screw¹². Moreover, additional fixation segments have also been demonstrated to be ineffective in significantly improving fracture repositioning, and the overall efficacy of treatment is compromised by the increase in medically induced trauma¹³.

Advantages of PKP Combined with Percutaneous Cement-Augmented Screw Fixation in the Treatment of OVCF with Kyphosis

This combined therapy features the following characteristics:

(1) Percutaneous pedicle screw fixation can effectively avoid damage to the paravertebral muscles, intervertebral ligaments, and supraspi-

nal ligaments caused by open surgery, which is conducive to maintaining the stability of the spine and avoiding delayed low back pain caused by postoperative muscle atrophy and stiffness¹⁴.

(2) PKP for the injured spine can significantly restore the height of the vertebral body, rapidly correct the kyphosis deformity caused by compression fracture, and effectively relieve pain symptoms.

(3) The use of cement-reinforced percutaneous pedicle screws and subsequent injection can help prevent “eggshell” changes after spinal injury surgery, reducing the risk of vertebral body re-collapse^{15,16}. Also, the adjacent cement-reinforced percutaneous pedicle screws can share the forces on the injured vertebra, avoiding further loss of height of the injured vertebra, failure of correction of posterior convexity deformity, and re-fracture⁷. The cement-injected pedicle screws can provide good anchorage to the vertebral bone, and the bone cement injected into the bone provides reinforcement to the lax bony structures. Both of these effects provide immediate and firm stabilization of the pedicle screw and avoid complications such as screw loosening or fracture due to excessive local stress concentration^{6,17,18}.

Indications for PKP Combined with Percutaneous Cement-Augmented Screw Fixation for OVCF with Kyphosis

PKP combined with percutaneous cement-augmented screw fixation has the advantages of good stability and strong support. Its indications include:

(1) The patient had a comorbid thoracolumbar fracture with a posterior convexity deformity and an AO staging of type A3. Given the instability of such fractures, the application of PKP plus percutaneous cement-augmented screw fixation plays an important role in long-term stabilization support.

(2) In patients with thoracolumbar fractures with osteoporosis, PKP with percutaneous cement-augmented screw fixation may provide support to the bony structures. In contrast, the application of PKP or percutaneous internal arch fixation for the treatment of thoracolumbar fractures with neurological symptoms has been marginally explored, and there is insufficient evidence of specific efficacy. Thus, the efficacy of PKP combined with percutaneous cement-augmented screw fixation in patients with thoracolumbar fractures with neurological symptoms requiring spinal canal decompression needs further verification¹⁹.

Operation Highlights of PKP Combined with Percutaneous Cement-Augmented Screw Fixation

(1) Screws of reasonable length were selected for fixation according to the condition of the injured vertebra. Screws with insufficient length are insufficiently anchored and prone to loss of support, displacement, or even fracture. Excessive screw length may penetrate the anterior edge of the vertebral body and damage surrounding tissues, blood vessels, and nerves. (2) Prior to performing percutaneous kyphoplasty (PKP), the percutaneous screw should be positioned at an appropriate angle under fluoroscopic guidance. This helps avoid cement leakage and screw breakage due to excessive stress caused by an overly acute bracing angle, while also correcting the posterior convex Cobb angle. (3) Depending on the degree of fracture compression or orthopedic recovery, the optimal PKP working channel is selected, i.e., the working cannula is inserted from the medial or lateral side of the titanium rod. In most cases, the working cannula is inserted from the lateral side of the titanium rod through the injured vertebral arch, or if the vertebral arch is blocked by the titanium rod, the titanium rod is then installed on one side, and then the working cannula is inserted from the injured vertebral arch.

Limitations

The mechanical analysis of the implant was not performed in this study, and the reasonability of the screw rod angle and bone cement injection volume should be determined in conjunction with mechanical studies, which can be incorporated with finite element analysis or 3D printing technology in future studies. Adjacent segment re-fracture is a common complication after OVCF, with an incidence of up to 17% of adjacent segment re-fractures within 5 years^{2,20,21}. Although none of the follow-up subjects in this study experienced any re-fracture of the prevertebral spine during the follow-up time, the short follow-up time in this study precluded judgment of the long-term effects on orthopedic and maintenance outcomes as the course of osteoporotic disease progressed¹⁷.

Conclusions

Two Level I evidence publications^{22,23} indicated that vertebral augmentation, particularly PVP, did not demonstrate superior efficacy compared to conservative treatment in the management of OVCFs. Subsequently, both articles have been frequently

cited. Based on these two articles and other level II evidence publications^{24,25}, the American Academy of Orthopaedic Surgeons (AAOS) strongly advises against using PVP to treat OVCFs that are diagnosed through imaging with corresponding clinical signs²⁶. However, PKP is recommended with less certainty for patients who have similar diagnoses.

Despite the AAOS recommendation, vertebral augmentation is still commonly used in clinical practice and has proven highly beneficial for many patients, particularly elderly ones. To address its drawbacks, numerous new technologies have been developed to replace traditional bone cement, and various alternative surgical methods have been explored. Although vertebral augmentation procedures are generally safe and provide quick pain relief and improved physical function, there is still a chance of postoperative complications such as bone cement leakage, embolism, implantation syndrome, infection, thermal damage to surrounding tissue, and adjacent vertebral fractures²⁷⁻²⁹.

Incorporation of percutaneous pedicle screw fixation with PKP can effectively compensate for the disadvantages and amplify the advantages of both procedures, providing a better solution for osteoporotic spinal compression fractures^{30,31}. Percutaneous injectable bone cement screws improve pedicle screw stability, and the bone cement effectively fills the cavity formed after repositioning the injured spine, reconstructs the collapsed anterior and middle columns, and distributes the stress load on the pedicle screws, thus avoiding re-collapse and internal fixation failure³²⁻³⁴. Since cement-reinforced percutaneous pedicle screw repositioning restores vertebral height and indirect decompression of the spinal canal creates the conditions for vertebroplasty of the injured spine, PKP can be performed to maximize stress dispersion and height restoration of the injured spine, allowing the coexistence of spinal stability and vertebroplasty. Single PKP features the benefits of minimal trauma, simple operation, and rapid postoperative recovery in the treatment of OVCF. PKP plus percutaneous cement-augmented screw fixation for severe OVCF provided distinctly better performance than PKP alone in terms of early pain relief, restoration of vertebral body height, correction of posterior convexity deformity, and firm spinal stability.

Ethics Approval

The protocol was approved by the Ethics Committee of The First People's Hospital of Lianyungang, with No.: LW-20230529003-01. Clinical Trial Registration Number: ChiCTR2300074077

Informed Consent

Written informed consent was obtained from all the patients involved in the study.

Availability of Data and Materials

All data generated or analyzed during this study are included in this published article.

Conflict of Interest

The authors declare that they have no competing interests.

Funding

No funding was received for this study.

Authors' Contributions

Tianzuo Chen and Xiangjun Lu designed the research study. Dongze Wu and Feifan Meng performed the research. Wei Zhang, Mohan Wen, Xu Li, and Rujie Qin conducted the experiments and analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ORCID ID

T.-Z. Chen: 0000-0003-4612-1572

R.-J. Qin: 0000-0002-7036-3267

References

- 1) Zhao Q, Zhang H, Hao D, Guo H, Wang B, He B. Complications of percutaneous pedicle screw fixation in treating thoracolumbar and lumbar fracture. *Medicine (Baltimore)* 2018; 97: e11560.
- 2) Yasuda T, Kawaguchi Y, Suzuki K, Nakano M, Seki S, Watabnabe K, Kanamori M, Kimura T. Five-year follow up results of posterior decompression and fixation surgery for delayed neural disorder associated with osteoporotic vertebral fracture. *Medicine (Baltimore)* 2017; 96: e9395.
- 3) Kim HS, Ju CL. Spinal Instability Predictive Scoring System for Subsequent Fractures after Bone cement augmentation in Patients with Osteoporotic Vertebral Compression Fractures. *World Neurosurg* 2017; 106: 736-745.
- 4) Guo D, Cai J, Zhang SF, Zhang L, Feng XM. Treating osteoporotic vertebral compression fractures with intrasosseous vacuum phenomena using high - viscosity bone cement versus bilateral percutaneous vertebroplasty. *Medicine* 2017; 96: 6549.
- 5) Chang X, Lv YF, Chen B, Li HY, Han XB, Yang K, Zhang W, Zhou Y, Li CQ. Vertebroplasty versus kyphoplasty in osteoporotic vertebral compression fracture: a meta-analysis of prospective comparative studies. *Int Orthop* 2015; 39: 491-500.

- 6) Wardlaw D, Van Meirhaeghe J, Ranstam J, Bastian L, Boonen S. Balloon kyphoplasty in patients with osteoporotic vertebral compression fractures. *Expert Rev Med Devices* 2012; 9: 423-436.
- 7) Hu CH, Li QP, Wang C, Liu QP, Long HG. [Analysis of clinical effects of three operative methods for osteoporotic vertebral compression fracture]. *Zhongguo Gu Shang* 2016; 29: 619-624.
- 8) Korovessis P, Mpountogianni E, Syrimpeis V. Percutaneous pedicle screw fixation plus kyphoplasty for thoracolumbar fractures A2, A3 and B2. *Eur Spine J* 2017; 26: 1492-1498.
- 9) Builjat G, Perovie D. Treatment of osteoporotic fractures of the spine. *Arh Hig Rada Toksikol* 2007; 58: 49-54.
- 10) Schupfner R, Stoevelaar HJ, Blattert T, Fagan D, Fransen P, Marcia S, Schils F, Siddiqi MA, Anselmetti GC. Treatment of Osteoporotic Vertebral Compression Fractures: Applicability of Appropriateness Criteria in Clinical Practice. *Pain Physician* 2016; 19: 113.
- 11) Zhang L, Liu Z, Wang J, Feng X, Yang J, Tao Y, Zhang S. Unipedicular versus bipedicular percutaneous vertebroplasty for osteoporotic vertebral compression fractures: a prospective randomized study. *BMC Musculoskelet Disord* 2015; 16: 145-159.
- 12) Wang CH, Ma JZ, Zhang CC, Nie L. Comparison of high-viscosity cement vertebroplasty and balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures. *Pain Physician* 2015; 18: 187-194.
- 13) Liu T, Li Z, Su Q, Hai Y. Cement leakage in osteoporotic vertebral compression fractures with cortical defect using high-viscosity bone cement during unilateral percutaneous kyphoplasty surgery. *Medicine* 2017; 96: 7216.
- 14) Gong Y, Fu G, Li B, Li Y, Yang X. Comparison of the effects of minimally invasive percutaneous pedicle screws osteosynthesis and open surgery on repairing the pain, inflammation and recovery of thoracolumbar vertebra fracture. *Exp Ther Med* 2017; 14: 4091-4096.
- 15) Liang L, Chen X, Jiang W, Li X, Chen J, Wu L, Zhu Y. Balloon kyphoplasty or percutaneous vertebroplasty for osteoporotic vertebral compression fracture? An updated systematic review and meta-analysis. *Ann Saudi Med* 2016; 36: 165-174.
- 16) Li C, Pan J, Gu Y, 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.
- 17) Elmasry S, Asfour S, Travascio F. Effectiveness of pedicle screw inclusion at the fracture level in short-segment fixation constructs for the treatment of thoracolumbar burst fractures: a computational biomechanics analysis. *Comput Methods Biomech Biomed Engin* 2017; 20: 1412-1420.
- 18) Özbek Z, Özkara E, Öner H, BaŞ G, Erman İC, Özen H, Entok E, Arslantaş A. Treatment of Unstable Thoracolumbar Fractures: Does Fracture-Level Fixation Accelerate the Bone Healing? *World Neurosurg* 2017; 107: 362-370.
- 19) Wang H, Zhou Y, Li C, Liu J, Xiang L. Comparison of Open Versus Percutaneous Pedicle Screw Fixation Using the Sextant System in the Treatment of Traumatic Thoracolumbar Fractures. *Clin Spine Surg* 2017; 30: E239-E246.
- 20) Graham J, Ahn C, Hai N, Buch BD. Effect of bone density on vertebral strength and stiffness after percutaneous vertebroplasty. *Spine* 2007; 32: E505-E511.
- 21) Park JW, Park JH, Jeon HJ, Lee JY, Cho BM, Park S-H. Kümmell's disease treated with percutaneous Vertebroplasty: minimum 1 year follow-up. *Korean J Neurotrauma* 2017; 13: 119-123.
- 22) Kallmes DF, Comstock BA, Heagerty PJ, Turner JA, Wilson DJ, Diamond TH, Edwards R, Gray LA, Stout L, Owen S, Hollingworth W, Ghdoke B, Annesley-Williams DJ, Ralston SH, Jarvik JG. A randomized trial of vertebroplasty for osteoporotic spinal fractures. *N Engl J Med* 2009; 361: 569-579.
- 23) Buchbinder R, Osborne RH, Ebeling PR, Wark JD, Mitchell P, Wriedt C, Graves S, Staples MP, Murphy B. A randomized trial of vertebroplasty for painful osteoporotic vertebral fractures. *N Engl J Med* 2009; 361: 557-568.
- 24) Rousing R, Andersen MO, Jespersen SM, Thomsen K, Lauritsen J. Percutaneous vertebroplasty compared to conservative treatment in patients with painful acute or subacute osteoporotic vertebral fractures: three-months follow-up in a clinical randomized study. *Spine (Phila Pa 1976)* 2009; 34: 1349-1354.
- 25) Voormolen MH, Mali WP, Lohle PN, Fransen H, Lampmann LE, van der Graaf Y, Juttmann JR, Janssens X, Verhaar HJ. Percutaneous vertebroplasty compared with optimal pain medication treatment: short-term clinical outcome of patients with subacute or chronic painful osteoporotic vertebral compression fractures. The VERTOS study. *AJNR Am J Neuroradiol* 2007; 28: 555-560.
- 26) McGuire R. AAOS clinical practice guideline: the treatment of symptomatic osteoporotic spinal compression fractures. *J Am Acad Orthop Surg* 2011; 19: 183-184.
- 27) Buchbinder R, Golmohammadi K, Johnston RV, Owen RJ, Homik J, Jones A, Dhillon SS, Kallmes DF, Lambert RG. Percutaneous vertebroplasty for osteoporotic vertebral compression fracture. *Cochrane Database Syst Rev* 2018; 4: Cd006349.
- 28) Rousing R, Andersen MO, Jespersen SM, Thomsen K, Lauritsen J. Percutaneous vertebroplasty compared to conservative treatment in patients with painful acute or subacute osteoporotic vertebral fractures: three-months follow-up in a clinical randomized study. *Spine* 2009; 34: 1349-1354.
- 29) Gao X, Du J, Gao L, Hao D, Hui H, He B, Yan L. Risk factors for bone cement displacement af-

- ter percutaneous vertebral augmentation for osteoporotic vertebral compression fractures. *Front Surg* 2022; 9: 947212.
- 30) Zhang HT, Sun ZY, Zhu XY, Chen KW, Qian ZL, Yang HL. Kyphoplasty for the treatment of very severe osteoporotic vertebral compression fracture. *J Int Med Res* 2012; 40: 2394-2400.
- 31) Caruso G, Lombardi E, Andreotti M, Lorusso V, Gildone A, Padovani S, Massari L. Minimally invasive fixation techniques for thoracolumbar fractures: comparison between percutaneous pedicle screw with intermediate screw (PPSIS) and percutaneous pedicle screw with kyphoplasty (PPSK). *Eur J Orthop Surg Traumatol* 2018; 28: 849-858.
- 32) Zuo XH, Zhu XP, Bao HG, Xu CJ, Chen H, Gao XZ, Zhang QX. Network meta-analysis of percutaneous vertebroplasty, percutaneous kyphoplasty, nerve block, and conservative treatment for nonsurgery options of acute/subacute and chronic osteoporotic vertebral compression fractures (OVCFs) in short-term and long-term effects. *Medicine (Baltimore)* 2018; 97: e11544.
- 33) Li Y, Qian Y, Shen G, Tang C, Zhong X, He S. Safety and efficacy studies of kyphoplasty, mesh-container-plasty, and pedicle screw fixation plus vertebroplasty for thoracolumbar osteoporotic vertebral burst fractures. *J Orthop Surg Res* 2021; 16: 434.
- 34) Girardo M, Cinnella P, Gargiulo G, Viglierchio P, Rava A, Aleotti S. Surgical treatment of osteoporotic thoraco-lumbar compressive fractures: the use of pedicle screw with augmentation PMMA. *Eur Spine J* 2017; 26: 546-551.