Retrospective Study

Comparison of the Clinical Efficacy and Bone Cement Distribution Difference Between Kummell's Disease and Osteoporotic Vertebral Compression Fracture After Percutaneous Kyphoplasty

Yuzhi Ning, Ziyu Li, Jiahu Huang, MD, Shuang Xu, PhD, Qing Wang, MD, Jiyuan Yan, MD, and Song Wang, PhD

From: Department of Orthopaedics, The Affiliated Hospital of Southwest Medical University, Sichuan Province, China

Address Correspondence:
Song Wang, PhD
Department of Orthopaedics
The Affiliated Hospital of Southwest Medical University
No. 25 Taiping Street, Luzhou
Sichuan Province 646000, China
E-mail:
jasewangspine@swmu.edu.cn

Disclaimer: Y Ning and Z Li contributed equally to this work. This research was funded by Strategic Cooperation Project of Sichuan University and Luzhou Municipal People's Government (No. 2020CDLZ-5), Sichuan Science and Technology Program (No. 2022-YFS0628), Natural Science Foundation of Sichuan (No. 2023NSFSC0333), and Investigator-Initiated Trials of The Affiliated Hospital of Southwest Medical University (No. HR21008).

Conflict of interest: Each author certifies that he or she, or a member of his or her immediate family, has no commercial association (i.e., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted manuscript.

Manuscript received: 05-30-2023
Revised manuscript received: 09-19-2023
Accepted for publication: 10-10-2023

Free full manuscript: www.painphysicianjournal.com

Background: Kummell's disease (KD) and osteoporotic vertebral compression fracture (OVCF) are commonly found in patients with osteoporosis. Several studies have been conducted on bone cement distribution in OVCF or KD; a comparison between the 2 diseases is rarely reported.

Objectives: To compare the clinical efficacy and bone cement distribution difference between KD and OVCFs after percutaneous kyphoplasty (PKP).

Study Design: This was a retrospective, nonrandomized controlled study.

Setting: Department of Orthopedics from an affiliated hospital.

Methods: From January 2018 to December 2020, 61 patients who underwent PKP surgery for single KD or OVCF and met the inclusion criteria were retrospectively reviewed. All patients were assigned to 2 groups: the KD group and the OVCF group. Clinical and radiologic characteristics, including the bone cement volume, leakage, bone cement dispersion scale, anterior vertebral height (AVH), median vertebral height (MVH), posterior vertebral height (PVH), Cobb angle and Visual Analog Scale (VAS) were analyzed and compared using Mimics three-dimensional (3D) reconstruction images and 3D reconstruction computed tomography, preoperatively, postoperatively, and 2 years after the operation, respectively. The correlations between the bone cement dispersion scale and the VH improvement rate (VHIR), VH change rate (VHCR), VAS improvement rate (VASIR), and follow-up VAS improvement rate (f-VASIR) were also evaluated.

Results: The mean follow-up time was 24.0 months. Postoperative VH, Cobb angle, vertebra volume, and VAS score were significantly improved in the 2 groups ($P < 0.05$). There was no statistical difference in postoperative parameters between the 2 groups. While a strong positive correlation between VHIR and bone cement dispersion scale was observed in the OVCF group ($P < 0.01$), no significant correlation between VHIR and bone cement dispersion scale was found in the KD group. There was no correlation between VASIR and bone cement dispersion scale in both groups. Compared with postoperation, VH was lower in both groups in later follow-up, and the difference between the 2 groups was statistically significant ($P < 0.05$). VH, VAS, f-VASIR, and VHCR had a worse manifestation in the KD group than in the OVCF group. However, no significant correlation was found between VHCR, f-VASIR, and bone cement dispersion scale in the 2 groups.

Limitations: This study was limited by the non-randomized design, small sample size, and lack of a comprehensive follow-up period.

Conclusions: Although there was no significant difference in the bone cement distribution and early clinical efficacy between KD and OVCF patients under the same surgical plan and surgeon, OVCF patients exhibited better long-term radiologic and clinical outcomes.

Key words: Kummell's disease, osteoporotic vertebral compression fractures, percutaneous kyphoplasty, bone cement distribution

Pain Physician 2024: 27:E327-E336

Kummell's disease (KD) was first named in 1895 by German surgeon Herman Kümmell. It has been described as delayed post-traumatic collapse of the vertebra occurring in patients weeks to months following minor trauma, with the essential pathology consisting of multiple, minute traumas of the osseous and ligamentous structures of the spine causing small interruptions in bony continuity and blood supply (1-3).

KD and osteoporotic vertebral compression fracture (OVCF) are commonly found in patients with osteoporosis. The rate of both diseases is soaring with an aging population and increasing prevalence of osteoporosis (4,5). Both OVCF and KD are characterized by persistent pain, kyphosis, neurological deficits, and decreased quality of life (6,7). Compared with OVCF, KD patients had an early asymptomatic period after mild trauma, and typical imaging manifestations were intervertebral cleft (IVC) and double-line sign (8). Percutaneous kyphoplasty (PKP) is a safe and effective minimally invasive surgical treatment for vertebral compression fracture (VCF) (9,10). It can reduce pain and significantly improve the quality of life of patients compared with non-surgical treatment.

In PKP surgery, the bone cement distribution has a very important impact on the surgical effect. It is generally believed that the more dispersed the bone cement distribution after PKP surgery, the better the surgical efficacy (11). Although several studies have been conducted on bone cement distribution in OVCF or KD, a comparison between the 2 diseases is rarely reported.

Computed tomography (CT) imaging can accurately measure vertebral height (VH). Besides, Materialise's Interactive Medical Image Control System (Mimics 21.0, Materials Software, Belgium), which can convert two-dimensional (2D) image data into 3D image data, is widely used in the field of digital medicine, enabling doctors to visualize the converted 3D model more intuitively and accurately (12). Therefore, we used 3D CT images imported into Mimics 21.0 software to assess the bone cement dispersion scale, bone cement volume, and vertebral body volume. This study aimed to compare the clinical efficacy, bone cement distribution difference, and radiographic and digital parameters of KD and OVCF patients after PKP operation to provide a reference for clinical practice.

Methods

Selection of Patients and Groupings

All patients with KD or OVCF who underwent PKP and 3D CT from June 2019 to December 2020 were enrolled. A total of 61 patients were enrolled in our study with a female-to-male ratio of 45:16. Patients were divided into 2 groups: the KD group (n = 35) and the OVCF group (n = 26) based on extra criteria of KD. The inclusion criteria were as follows: 1) history of severe low back pain, 2) radiographic examination suggested an acute or subacute VCF, 3) patients with single vertebral collapse, 4) bone mineral density (BMD) examination suggested osteoporosis, 5) 3D CT was performed preoperatively, postoperatively, and 2 years after operation, 6) KD patients had an extra criterion: CT showed IVC in the collapsed vertebra or magnetic resonance imaging (MRI) showed a low signal on the T2 image and a clear high signal area on the fat-saturated image. The exclusion criteria were as follows: patients with 1) dural sac or nerve tissue compression symptoms, 2) serious diseases, 3) clinical or radiographic diagnosis of infection or vertebral malignancy, 4) multiple vertebral fractures.

Surgical Procedures

All PKP procedures were performed by one senior surgeon with over 10 years of experience in PKP surgery. Patients were maintained in a prone position under local anesthesia using 1% lidocaine. The injured vertebra was located by fluoroscopy visualization. An appropriate puncture method (transpedicular puncture in the lumbar or extrapedicular puncture in the thoracic) was performed unilaterally. The bone entry point was located at the transverse process, 4-5 mm outside the lateral edge of the pedicle projection. The puncture needle reached the medial margin of the pedicle protrusion. Then, the needle was slowly inserted. In lateral imaging, the target point of the puncture needle was the midpoint of the first third of the vertebral body. Then, the bone needle was replaced with a working cannula. Based on the cannula, a balloon was inserted into the fractured vertebral body and then filled with a radiopaque medium to restore the damaged vertebral body until adequate height restoration and kyphotic correction were achieved. Afterward, the inflated balloon was deflated and withdrawn, and the resultant intravertebral cavity was filled with polymethylmethacrylate cement. All patients were discharged 3 days postoperatively and instructed to use a brace to avoid physical strain for one month. No contralateral cement injections were administered to any of the patients in this study.

Outcome Measures

Clinical Parameters

The baseline information of patients included age, gender, duration, BMD, operative time, and fluoroscopy times. The Visual Analog Scale (VAS) scores were assessed preoperatively, postoperatively, and 2 years after operation. The VAS score was used to evaluate pain intensity and efficacy. VAS improvement rate (VASIR) was calculated as follows: VASIR = (postoperative VAS score - preoperative VAS score)/(0 - preoperative VAS score) * 100%. The follow-up VAS improvement rate (f-VASIR) was calculated as follows: f-VASIR = (follow-up VAS score - preoperative VAS score)/(0 - preoperative VAS score) * 100%.

Radiographic Parameters

All patients underwent CT scanning before operation, one day after operation, and 2 years after operation, under the following scanning conditions: 120 kV and 250 mA. The collapsed vertebra was scanned as the center, and the layer thickness was set at 0.625 mm. The anterior vertebral height (AVH), middle vertebral height (MVH), posterior vertebral height (PVH), and Cobb angle were measured at the sagittal position of the CT image workstation (iMedPacs Dicom Viewer) preoperatively, postoperatively, and 2 years after the operation, respectively (Fig. 1). Then, the 3D CT data were exported in the DICOM file format.

The following were compared between the 2 groups: vertebral height (VH) = (AVH + MVH + PVH)/3; the vertebral height improvement rate (VHIR) = (preoperative VH – postoperative VH)/(0 - preoperative VH) * 100%; the vertebral height change rate (VHCR) = (follow-up VH – postoperative VH)/(0 - postoperative VH) *100%.

Digital Parameters

The 3D CT DICOM data were imported into Mimics 21.0 software. The bone tissue and bone cement were separated, respectively. (The threshold of the bone tissue was 226-3071 Hounsfield units (HU), and that of the bone cement was 1500-3071 HU). The bone cement and vertebral body of the target segment were selected, respectively. The 3D model of the bone cement and vertebral body was reconstructed using the 3D mask reconstruction function. The 3D model was recorded with an accuracy of 0.01 cm^3 (Fig. 2). In the coronal plane, sagittal plane, and cross-plane, the vertebral model was bisecting anteroposterior, left-right, and upper-lower. The vertebral body was divided into 8 quadrants. The bone cement and vertebral volume in the quadrants were calculated, respectively. The calculation quadrants with a bone cement volume more than or equal to one-third of the vertebral body volume were denoted as score 1, from which the bone cement dispersion scale (0-8 score) for each vertebral body was measured as an indicator of the degree of bone cement dispersion (Fig. 3).

Statistical Analysis

SPSS version 25.0 (Chicago, IL, USA) was used for all data analyses. The normality of quantitative data was assessed using the Kolmogorov-Smirnov method. Normally distributed data of subgroup populations were analyzed using t tests, and non-normally distributed data were analyzed with the Mann-Whitney test. Spearman correlation analysis was used to analyze the

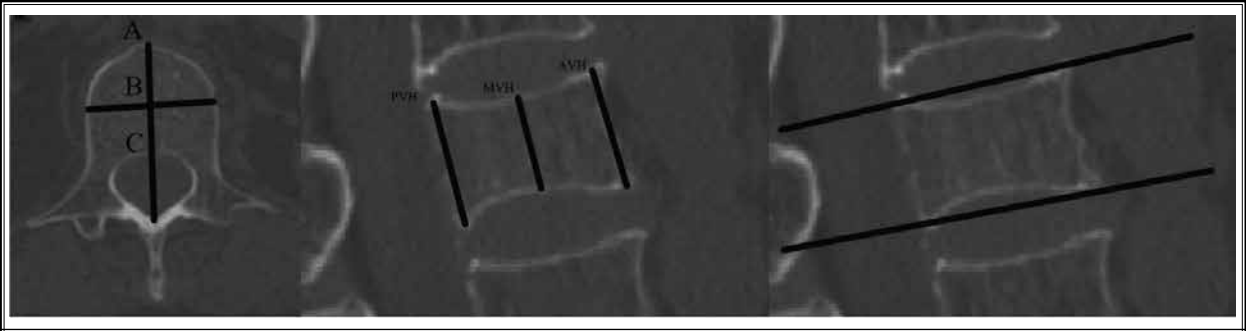

Fig. 1. *Measurement of VH on 3D CT scans. Two bisectors were drawn on the axial vertebral body view, and AVH, MVH, PVH, and Cobb angle were measured to determine the improvement ratio and kyphotic deformity. VH was equal to (a + b + c)/3.*
VH, vertebral height; AVH, anterior vertebral height; MVH, median vertebral height; PVH, posterior vertebral height.

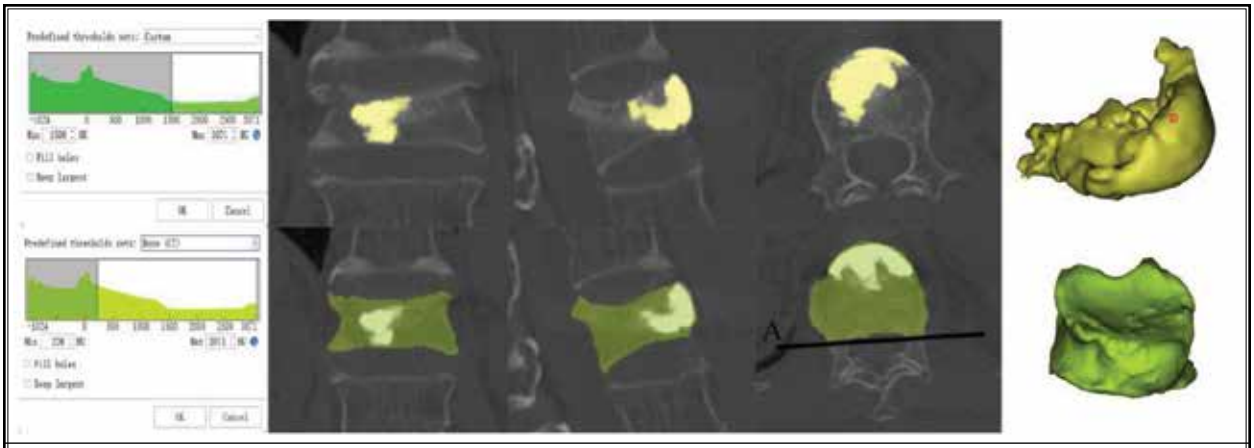

Fig. 2. *Model of bone cement and vertebra. Choose a constant grayscale value threshold (bone cement >1500, vertebra >226) and split the mask to obtain the bone cement and the vertebral profile. Use the Region Grow to remove irrelevant parts, and then use Smart Fill to fill the gap in the mold and to obtain the corresponding bone cement and vertebral body model. Search for the posterior tangent line A corresponding to the largest area in the transverse section of the vertebral body for molding.*

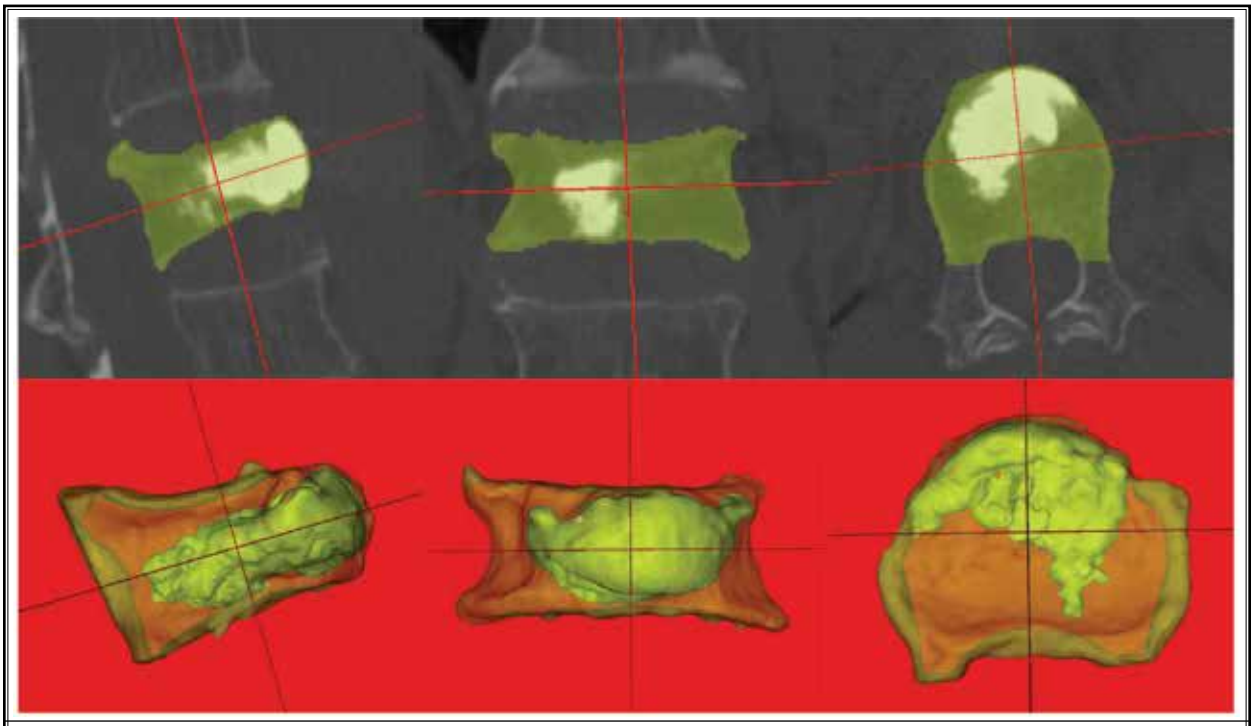

Fig. 3. *Diagrams of bone cement dispersion scale. At the midpoint of the upper and lower endplates of the vertebral body in coronal and sagittal positions, the vertebral body was sectioned left-right, anteroposterior; at the midpoint of the anterior and posterior edges and left and right edges of the vertebral body in coronal and sagittal positions, the vertebral body was sectioned up and down, and the vertebral body was divided into 8 quadrants. The vertebral volume and cement volume were calculated separately for each quadrant.*

correlation between bone cement and clinical outcomes. Intergroup differences were analyzed using the Bonferroni method. The chi-squared test was used for qualitative data. Non-normally distributed data were presented as medians (interquartile range, IQR), while normally distributed data were expressed as means ± standard deviation (x ± s). $P < 0.05$ was considered statistically significant.

Results

Patient Baseline Characteristics

No difference was found between the 2 groups in terms of age, gender, disease course, BMD, and other baseline features ($P > 0.05$). All operations were performed without spinal cord injury or mortality. The KD group follow-up was 22.5 months (IQR, 15.25-30.50 months), and the OVCF group follow-up was 25.5 months (IQR, 15-41 months). Nine patients were lost to follow-up, of which 5 cases were due to loss of follow-up, 2 cases were due to invalid phone numbers, and 2 cases were due to death caused by other diseases. All baseline characteristics of patients are presented in Table 1. Typical case presented in Figs. 4 and 5.

Clinical Outcomes

The operative time was 32.71 ± 11.20 and 31.35 ± 10.82 minutes, and the number of fluoroscopy times was 19.03 ± 5.91 and 20.88 ± 9.856 for KD and OVCF groups, respectively; there was no statistically significant difference between the 2 groups (Table 2).

The median VAS score in the KD group was significantly reduced from a preoperative score of 7.0 (6.0-7.0) to a postoperative score of 3.0 (2.0-3.0), and the follow-up score was 3.0 (2.0-3.0). The median VAS score in the OVCF group was significantly reduced from a preoperative score of 7.0 (6.0-7.0) to a postoperative score of 2.0 (2.0-3.0), and the follow-up score was 2.0 (1.0-2.0) (Table 3). Compared with preoperative scores, postoperative VAS scores were significantly reduced in both groups, but with no significant difference. There was no correlation between the VASIR and the bone cement dispersion scale (Fig. 6).

However, the follow-up VAS score of the OVCF group was much better than that of the KD group. There was a striking difference in f-VASIR between the 2 groups. The f-VASIR for KD and OVCF groups was 56.78 ± 14.51% and 74.30 ± 9.60%, respectively. The improvement rate of the KD group was much lower than that of the OVCF group (Table 2). The VAS score in patients with KD was much closer to the preoperative VAS score than compared with the 2-year postoperative score in patients with OVCF. Until the last follow-up, 7 (20%) patients in the KD group and 3 (11%) patients in the OVCF group had other vertebral fractures and underwent PKP surgery. No correlation was found between the f-VASIR and the bone cement dispersion scale (Fig. 6).

Radiographic and Digital Outcomes

AVH, MVH, PVH, Cobb angle, and vertebra volume were significantly improved postoperatively than preoperatively in all patients ($P < 0.05$) (Table 3). However, there was no significant difference between the KD group and the OVCF group in postoperative outcomes ($P > 0.05$). Moreover, no significant differences were found between the 2 groups in terms of bone cement volume (4.36 ± 0.35 mL vs 4.52 ± 0.94 mL, $P >$

Table 1. *Comparison of patient baseline data between KD group and OVCF group.*

Characteristics	KD group	OVCF group	*P*-value
Age (years)	76.26 ± 7.36	75.46 ± 8.09	0.691[a]
Gender			0.284[b]
Women	24	21	
Men	11	5	
Follow-up time (months)	22.5 (15.25-30.50)	25.5 (15-41)	0.43[c]
BMD (T-score)	-3.05 ± 1.15	-3.26 ± 0.92	0.453[a]
Disease course (day)	15 (5.75-22.50)	10 (4-60)	0.655[c]
Damaged segments			0.154[a]
T7-T10	7	7	
T11-L2	23	14	
L3-L5	5	5	
Trauma history			0.53[b]
Yes	19	12	
No	16	14	

Note: KD group, Kummell's disease group; OVCF group, osteoporotic vertebral compression fractures group; BMD, bone mineral density. [a]Data were analyzed by t tests. [b]Data were analyzed by Chi-square test. [c]Data were analyzed by Mann-Whitney tests and data were expressed as medians (IQR).

Table 2. *Comparison of patient clinical parameters between KD group and OVCF group.*

Parameter	KD group	OVCF group	*P*-value
Operative time (min)	32.71 ± 11.20	31.35 ± 10.82	0.634[a]
Fluoroscopy times	19.03 ± 5.91	20.88 ± 9.856	0.364[a]
Pre-VAS (score)	7.0 (6.0-7.0)	7.0 (6.0-7.0)	0.767[c]
Post-VAS (score)	3.0 (2.0-3.0)	2.0 (2.0-3.0)	0.148[c]
f-VAS (score)	3.0 (2.0-3.0)	2.0 (1.0-2.0)	< 0.001[c]
VASIR (%)	62.70 ± 10.43	65.15 ± 14.65	0.448[a]
f-VASIR (%)	56.78 ± 14.51	74.30 ± 9.60	< 0.001[a]

Note: KD group, Kummell's disease group; OVCF group, osteoporotic vertebral compression fractures group; Pre-VAS, preoperative VAS score; Post-VAS, postoperative VAS score; f-VAS, follow-up VAS score; VASIR, VAS improvement rate; f-VASIR, follow-up VAS improvement rate. [a] Data were analyzed by t tests. [c] Data were analyzed by Mann–Whitney tests and data were expressed as medians (IQR).

Table 3. *Comparison of AVH, MVH, PVH, Cobb Angle and vertebra volume of the vertebral body preoperatively, postoperative and 2 years after operation between KD group and OVCF group.*

	KD group				OVCF group			
Parameter	**Preoperation**	**Postoperation**	**Follow-up**	**t, *P*-value (pre- vs post-)**	**t, *P*-value (post- vs follow-up)**	**Preoperation**	**Postoperation**	**Follow-up**	**t, *P*-value (pre- vs post-)**	**t, *P*-value (post- vs follow-up)**
AVH (cm)	1.62 ± 0.49	1.85 ± 0.43	1.63 ± 0.42	-7.682, < 0.001	8.086, < 0.001	1.85 ± 0.45	2.00 ± 0.43	1.98 ± 0.38	-2.794, 0.010	5.705, <0.001
MVH (cm)	1.24 ± 0.43	1.52 ± 0.33	1.36 ± 0.31	-7.665, < 0.001	6.129, < 0.001	1.43 ± 0.34	1.66 ± 0.36	1.54 ± 0.28	-6.093, < 0.001	3.314, 0.004
PVH (cm)	2.12 ± 0.35	2.18 ± 0.33	2.13 ± 0.32	-2.862, 0.007	4.663, < 0.001	2.09 ± 0.32	2.20 ± 0.38	2.13 ± 0.34	-2.92, 0.007	2.165, 0.046
Cobb (°)	9.65 ± 6.64	6.28 ± 5.31	9.04 ± 7.18	6.237, <0.001	-2.833, 0.011	6.44 ± 6.32	3.73 ± 4.72	5.07 ± 5.20	4.437, < 0.001	-1.753, 0.099
vertebra volume (mL)	22.09 ± 6.48	24.86 ± 6.46	22.01 ± 8.69	-10.249, < 0.001	4.663, 0.002	22.87 ± 9.28	24.67 ± 9.15	24.24 ± 5.00	-6.999, < 0.001	2.259, 0.038

Note: KD group, Kummell's disease group; OVCF group, osteoporotic vertebral compression fractures group; AVH, anterior vertebral height; MVH, median vertebral height; PVH, posterior vertebral height.

0.05), dispersion scale (5.54 ± 1.35 vs 5.46 ± 1.14, $P > 0.05$) and VHIR (12.00 ± 10.06% vs 8.30 ± 6.91%, $P > 0.05$) after the operation (Table 4). Additionally, although no significant correlation was found between bone cement dispersion scale and VHIR in the KD group ($R^2 = 0.122$, $P = 0.485$), there was a strong positive correlation in the OVCF group ($R^2 = 0.522$, $P < 0.01$) (Fig. 7).

Compared with postoperative outcomes, 3D CT measurements showed that AVH, MVH, PVH, and vertebral volume were decreased at follow-up in all patients, with a statistical difference ($P < 0.05$) (Table 3). A comparison between the 2 groups showed that the AVH was lower in the KD group than in the OVCF group at follow-up. There was no significant difference in PVH, MVH, and Cobb angle between the 2 groups at follow-up. VHCR was higher in the KD group than in the OVCF group, with VHCR higher than 10% observed in 10 patients in the KD group and none in the OVCF group. However, no significant correlation was found between the bone cement dispersion scale and VHCR in the KD and OVCF groups (Fig. 7).

Discussion

PKP is an extensive and effective surgical treatment for VCF that both corrects vertebral kyphosis and relieves the pain caused by VCF (13). The present study found that there was a statistically significant difference between KD and OVCF after PKP surgery, both in preoperative and postoperative VH restoration or kyphotic correction. However, it was found that this recovery was not significantly different between the 2 diseases in the short term. PKP can rapidly restore the normal life of patients with KD or OVCF. Adamska et al (14) reported similar findings, in which PKP had a good effect on KD. Huang et al (15) also reached the same conclusion in OVCF.

It has been previously demonstrated that bone cement distribution has an important effect on VH restoration in patients undergoing vertebral augmentation operations. Studies have suggested that the more widely dispersed the bone cement, the more satisfactory the VH restoration of patients (16,17). Zhang et al (18) found that the percentage of bone cement in the vertebral volume was significantly positively correlated with VHIR. Lin et al (19) reached similar conclusions, in which the distribution of bone cement was positively correlated with VH repair. We found a similar correlation to these findings in the OVCF group but not in the KD group. Assuming that there are no significant differences in the bone cement diffusion between the

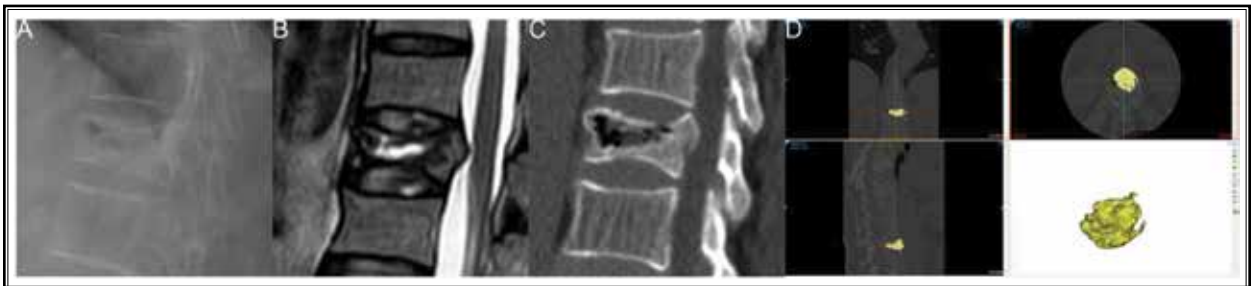

Fig. 4. *A 69-year-old woman with T12 Kummell's disease. A) Sagittal x-ray of the injured vertebra; B) sagittal MRI of the injured vertebra; C) sagittal CT of the injured vertebra; D) model of the bone cement.*

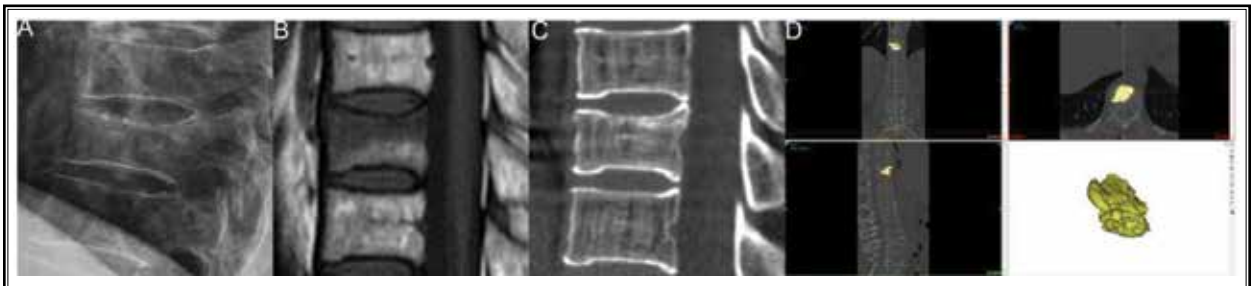

Fig. 5. *A 63-year-old man with T11 OVCF. A) Sagittal x-ray of the injured vertebra; B) sagittal MRI of the injured vertebra; C) sagittal CT of the injured vertebra; D) model of the bone cement.*

2 groups, the difference in correlation may be caused by the IVC of the fractured vertebra in KD patients, i.e., the area of different densities (liquid, gas, etc.) in the vertebra. Meanwhile, Liu et al (20) proposed in their study that differences in vertebral body density may lead to differences in bone cement distribution. Therefore, we believe that the presence of IVC may lead to uneven bone cement distribution in KD patients during bone cement injection, thus affecting the performance of VH restoration.

Liu et al (21) believed that the bone cement dispersion scale was an effective index to measure the bone cement distribution, which could reasonably reflect the bone cement distribution in

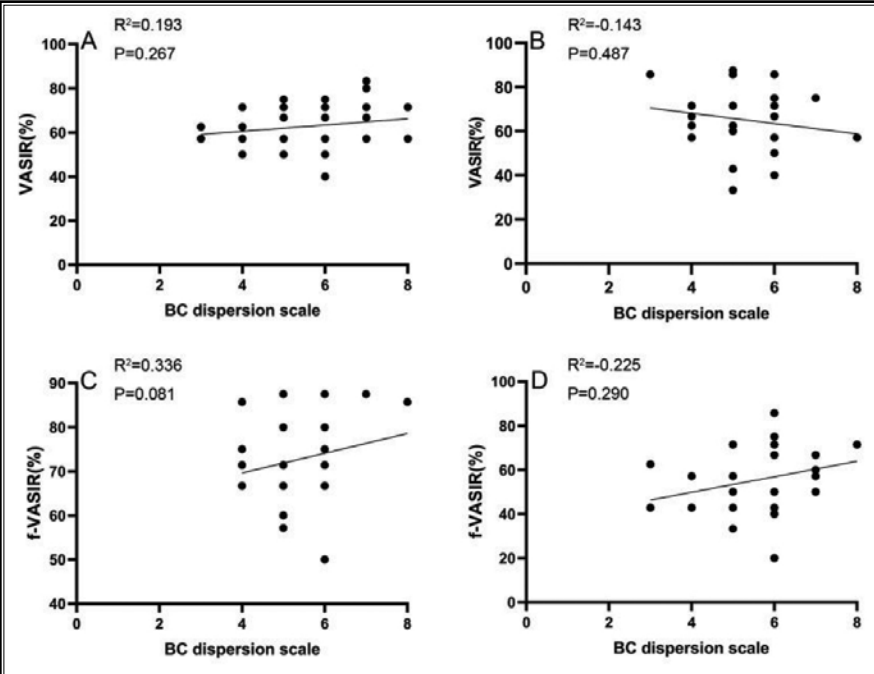

Fig. 6. *Charts of correlation between the BC dispersion scale and VASIR. A) Correlation between the BC dispersion scale and VASIR in the KD group. B) Correlation between the BC dispersion scale and VASIR in the OVCF group. C) Correlation between the BC dispersion scale and f-VASIR in the KD group. D) Correlation between the BC dispersion scale and f-VASIR in the OVCF group.*
BC, bone cement; VASIR, VAS improvement rate; f-VASIR, follow-up VAS improvement rate.

Table 4. *Comparison of postoperative BC volume, BC dispersion scale, VHIR, AVH, MVH, PVH, and Cobb angle between the KD group and OVCF group.*

Parameter	KD group	OVCF group	t	*P* value
BC volume (mL)	4.36 ± 0.35	4.52 ± 0.94	-0.558	0.579
BC dispersion scale (score)	5.54 ± 1.35	5.46 ± 1.14	0.247	0.686
VHIR (%)	12.00±10.06	8.30 ± 6.91	1.653	0.104
AVH (cm)	1.85 ± 0.43	2 ± 0.43	-1.388	0.170
MVH (cm)	1.52 ± 0.33	1.66 ± 0.36	-1.556	0.125
PVH (cm)	2.18 ± 0.33	2.20 ± 0.28	-0.017	0.834
Cobb (°)	6.28 ± 5.31	3.73 ± 4.72	1.942	0.057
Follow-up AVH (cm)	1.63 ± 0.09	1.98 ± 0.09	-2.635	0.012
Follow-up MVH (cm)	1.36 ± 0.07	1.54 ± 0.07	-1.762	0.087
Follow-up PVH (cm)	2.13 ± 0.07	2.13 ± 0.08	0.06	0.952
Follow-up Cobb (°)	9.05 ± 7.18	5.07 ± 5.20	1.896	0.066
VHCR (%)	8.60 ± 0.75	3.05 ± 0.71	5.287	<0.001

Note: KD group, Kummell's disease group; OVCF group, osteoporotic vertebral compression fractures group; VHIR, vertebral height improvement rate; BC, bone cement; VHCR, vertebral height change rate.

the vertebra. The tudies of Liu et al (21) and Tanigawa et al (22) also indicated that the greater the bone cement dispersion, the lower the possibility of fractured vertebral recollapse after the operation. Chen et al (23) suggested that compared with the blocky cement distribution pattern, the treatment of KD in the spongy distribution pattern showed better long-term radiological and clinical effects in KD patients. Meanwhile, Lin et al (19) also reported a similar result in OVCF; they noted that in long-term efficacy, whether in KD or OVCF patients, the more dispersed the bone cement distribution in the vertebra of the operation, the stronger the ability to prevent recollapse. Dong et al (24) defined the recollapse based on whether sagittal AVH lost more than 10% compared with postoperative radiographs during follow-up (VHCR > 10%). In our study, there were 10 KD patients with VHCR > 10% and 0 OVCF patients, and there was no significant correlation between the bone cement dispersion scale and VHCR. The VHCR in the KD group was significantly higher than that in the OVCF group. Therefore, it is speculated that the difference in the follow-up efficacy between KD and OVCF patients in terms of VH may not be related to the bone cement distribution but to the different pathologies of the 2 diseases. Besides, Dong et al (24) and Dai et al (25) pointed out that low preoperative BMD T-scores, the presence of IVC, and separated cement distribution increase the possibility of vertebral recollapse during follow-up. This is to some extent consistent with our results. On the premise that there is no significant difference in bone cement distribution and preoperative BMD examination results, we believe that the presence of IVC in the fractured vertebrae in the KD group may explain why VH maintenance in the KD group was inferior to that in the OVCF group (the VHCR in the KD group was higher than that in the OVCF group)

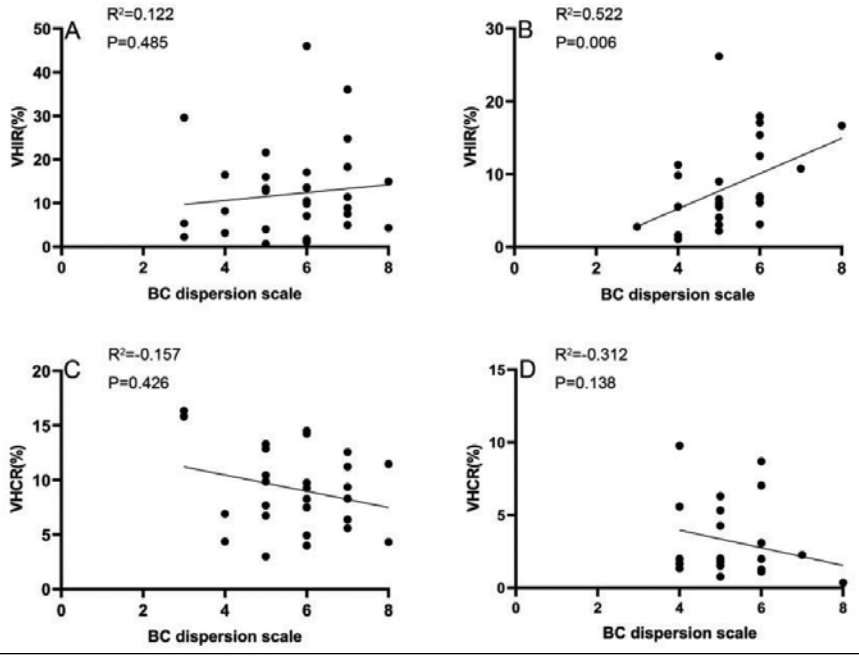

Fig. 7. *Charts of correlation between the BC dispersion scale and VHIR/VHCR. A) Correlation between the BC dispersion scale and VHIR in the KD group. B) Correlation between the BC dispersion scale and VHIR in the OVCF group. C) Correlation between the BC dispersion scale and VHCR in the KD group. D) Correlation between the BC dispersion scale and VHCR in the OVCF group.*
BC, bone cement; VHIR, vertebral height improvement rate; VHCR, vertebral height change rate.

during follow-up, which is similar to the conclusion of Yu et al (26,27). Furthermore, it has been pointed out in the literature that BMD is an independent factor affecting postoperative VH (28), which warrants further investigation.

McKiernan et al (29) pointed out that height restoration and kyphotic correction were correlated with pain relief in patients to a certain extent but higher restoration beyond the threshold did not lead to additional pain relief. Lv et al (30) also showed that there was no significant correlation between the reduction of the VAS score and the restoration of VH. Therefore, the VAS score was used as an independent indicator to evaluate the surgical efficacy; however, it was not completely accurate in the evaluation of postoperative pain relief (31). Zhang et al (18) used VASIR to predict and evaluate the effect of PKP surgery on pain. In our study, VAS scores were decreased in all patients after surgery, and VASIR showed no significant difference between KD and OVCF groups and was not significantly correlated with the bone cement dispersion scale, indicating that PKP surgery can achieve satisfactory short-term results in both KD and OVCF patients, and is independent of bone cement distribution. However, during follow-up, f-VASIR was significantly lower in the KD group than in the OVCF group, and the improvement rate of patients in both groups was not correlated with the distribution of the bone cement, indicating that the pain relief effect was significantly worse in the KD group than in the OVCF group in long-term efficacy. We hypothesized that this condition was caused by the vertebral instability caused by the recollapse in the KD group.

In addition to the differences in the VAS score and VH during the follow-up, 7 (20%) patients in the KD group had other adjacent vertebral fractures during the follow-up, compared with only 3 (11%) patients in the OVCF group. Li et al (32) found that the probability of adjacent vertebral fracture after vertebral augmentation ranged from 12% to 52%. Rho et al (33) found that about 18% of people had a second fracture of the adjacent vertebrae after surgery, which was similar to our results.

Nonetheless, this study has some limitations. First, this study was a retrospective study with a small sample size and a lack of follow-up of BMD, which may have a potential impact on the study results. Second, long-term clinical manifestations and VH of patients with KD and OVCF were inconsistent, and whether this was related to rapid osteoporosis in KD patients than in OVCF patients remains elusive. Finally, multicenter prospective randomized controlled trials are needed to further reveal the differences between KD and OVCF.

Conclusion

In summary, PKP surgery can effectively relieve pain, restore VH, and correct kyphotic deformity from VCF, whether it is caused by KD or OVCF. However, there were no differences between KD and OVCF in the postoperation time. OVCF had a better manifestation in long-term efficiency during follow-up, which may, perhaps, depend on the difference between the 2 diseases rather than the surgical protocol.

Data Availability

The raw data required to reproduce these findings cannot be shared at this time as the data also forms part of an ongoing study but are available from the corresponding author on reasonable request.

Author Contributions

Among the authors in the list, S.W. conceived and designed the study and gave final approval to the article. Y.Z.N. co-designed the study, analyzed the data, and drafted the manuscript. Z.Y.L. made critical reviews and revisions to the manuscript for important intellectual content. Y.Z.N. and Z.Y.L. share the first authorship, due to equal contributions. Y.Z.N. and Z.Y.L. collected the data. Y.Z.N. drew the images and analyzed the data. All the authors gave permission to publish this article.

References

1. Steel HH. Kümmell's disease. *Am. J. Surg* 1951; 81:161-167.
2. Brower AC, Downey EF Jr. Kümmell disease: report of a case with serial radiographs. *Radiology* 1981; 141:363-364.
3. Chen L, Dong R, Gu Y, Feng Y. Comparison between balloon kyphoplasty and short segmental fixation combined with vertebroplasty in the treatment of Kümmell's disease. *Pain Physician* 2015; 18:373-381.
4. Cooper C, Melton LJ. Epidemiology of osteoporosis. *Trends Endocrinol Metab* 1992; 3:224-229.
5. Riggs BL, Melton LJ. The worldwide problem of osteoporosis: Insights afforded by epidemiology. *Bone* 1995; 17(5 Suppl); 505S-511S.
6. Lu J, Ren Z, Liu X, Xu YJ, Liu Q. Osteoporotic fracture guidelines and medical education related to the clinical practices: A nationwide survey in China. *Orthop Surg* 2019; 11:569-577.
7. Libicher M, Appelt A, Berger I, et al.

The intravertebral vacuum phenomen as specific sign of osteonecrosis in vertebral compression fractures: results from a radiological and histological study. *Eur Radiol* 2007; 17:2248-2252.

8. Wu AM, Lin ZK, Ni WF, et al. The existence of intravertebral cleft impact on outcomes of nonacute osteoporotic vertebral compression fractures patients treated by percutaneous kyphoplasty: A comparative study. *J Spinal Disord Tech* 2014; 27:E88-E93.
9. Chen GD, Lu Q, Wang GL, et al. Percutaneous kyphoplasty for Kummell disease with severe spinal canal stenosis. Pain Physician 2015; 18:E1021-1028.
10. Bhalla S, Reinus WR. The linear intravertebral vacuum: a sign of benign vertebral collapse. *AJR Am J Roentgenol* 1998; 170:1563-1569.
11. Skripitz R, Aspenberg P. Attachment of PMMA cement to bone: force measurements in rats. *Biomaterials* 1999; 20:351-356.
12. Zhou C, Liao Y, Chen H, Wang Y. Analysis of optimal volume fraction percentage and influencing factors of bone cement distribution in vertebroplasty using digital techniques. *J Orthop Surg Res* 2023; 18:235.
13. Wardlaw D, Cummings SR, Van Meirhaeghe J, et al. Efficacy and safety of balloon kyphoplasty compared with non-surgical care for vertebral compression fracture (FREE): a randomised controlled trial. *Lancet* 2009; 373:1016-1024.
14. Adamska O, Modzelewski K, Stolarczyk A, Kseniuk J. Is Kummell's disease a misdiagnosed and/or an underreported complication of osteoporotic vertebral compression fractures? A pattern of the condition and available treatment modalities. *J Clin Med* 2021; 10:2584.
15. Huang J, Yang J, Chen L, Xu Y, Wang S. A novel puncture approach via point "O" for percutaneous kyphoplasty in patients with L4 or L5 osteoporotic vertebral compression fracture. *Sci Rep* 2022; 12:18868.
16. Yu W, Xiao X, Zhang J, et al. Cement distribution patterns in osteoporotic vertebral compression fractures with intravertebral cleft: Effect on therapeutic efficacy. *World Neurosurg* 2019; 123:e408-e415.
17. Lv NN, Hou MZ, Zhou ZZ, et al. Does the relationship between bone cement and the intravertebral cleft of Kummell disease affect the efficacy of PKP? *World Neurosurg* 2022; 160:e430-e435.
18. 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:E805-E813.
19. Lin J, Qian L, Jiang C, Chen X, Feng F, Lao L. Bone cement distribution is a potential predictor to the reconstructive effects of unilateral percutaneous kyphoplasty in OVCFs: a retrospective study. *J Orthop Surg Res* 2018; 13:140.
20. Liu J, Liu Z, Luo J, et al. Influence of vertebral bone mineral density on total dispersion volume of bone cement in vertebroplasty. *Medicine (Baltimore)* 2019; 98:e14941.
21. Liu J, Tang J, Liu H, Gu Z, Zhang Y, Yu S. A novel and convenient method to evaluate bone cement distribution following percutaneous vertebral augmentation. *Sci Rep* 2020; 10:16320.
22. Tanigawa N, Komemushi A, Kariya S, et al. Relationship between cement distribution pattern and new compression fracture after percutaneous vertebroplasty. *Am J Roentgenol* 2007; 189:W348-W352.
23. Chen JB, Xiao YP, Chen D, Chang JZ, Li T. Clinical observation of two bone cement distribution modes of percutaneous vertebroplasty in the treatment of thoracolumbar Kümmell's disease. *J Orthop Surg Res* 2020; 15:250.
24. Dong ST, Zhu J, Yang H, Huang G, Zhao C, Yuan B. Development and internal validation of supervised machine learning algorithm for predicting the risk of recollapse following minimally invasive kyphoplasty in osteoporotic vertebral compression fractures. *Front Public Health* 2022; 10:874672.
25. Dai, C., Liang, G., Zhang, Y., Dong, Y. & Zhou, X. Risk factors of vertebral re-fracture after PVP or PKP for osteoporotic vertebral compression fractures, especially in Eastern Asia: a systematic review and meta-analysis. *J Orthop Surg Res* 2022; 17:161.
26. Yu W, Jiang X, Liang D, et al. Intravertebral vacuum cleft and its varied locations within osteoporotic vertebral compression fractures: Effect on therapeutic efficacy. *Pain Physician* 2017; 20:E979-E986.
27. Yu W, Liang D, Yao Z, Qiu T, Ye L, Jiang X. The therapeutic effect of intravertebral vacuum cleft with osteoporotic vertebral compression fractures: A systematic review and meta-analysis. *Int J Surg* 2017; 40:17-23.
28. Kayanja MM, Schlenk R, Togawa D, Ferrara L, Lieberman I. The biomechanics of 1, 2, and 3 levels of vertebral augmentation with polymethylmethacrylate in multilevel spinal segments. *Spine (Phila Pa 1976)* 2006; 31:769-774.
29. McKiernan F, Faciszewski T, Jensen R. Does vertebral height restoration achieved at vertebroplasty matter? *J Vasc Interv Radiol* 2005; 16:973-979.
30. Lv B, Ji P, Fan X, et al. Clinical efficacy of different bone cement distribution patterns in percutaneous kyphoplasty: A retrospective study. *Pain Physician* 2020; 23:E409-E416.
31. Huskisson EC. Measurement of pain. *Lancet* 1974; 2:1127-1131.
32. Li YA, Lin CL, Chang MC, Liu CL, Chen TH, Lai SC. Subsequent vertebral fracture after vertebroplasty: incidence and analysis of risk factors. *Spine (Phila Pa 1976)* 2012; 37:179-183.
33. Rho YJ, Choe WJ, Chun YI. Risk factors predicting the new symptomatic vertebral compression fractures after percutaneous vertebroplasty or kyphoplasty. *Eur Spine J* 2012; 21:905-911.