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Original Article

Efficacy of percutaneous kyphoplasty in treating stage III Kümmell disease without neurological injury

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Abstract: Purpose: To evaluate the safety and efficacy of percutaneous kyphoplasty (PKP) for Kümmell's disease with vertebral posterior wall defects but no neurological symptoms. Methods: This retrospective study analyzed 79 patients with Kümmell disease, who were divided into an experimental group (with vertebral posterior wall rupture, n = 46) and a control group (with vertebral posterior wall intact, n = 33) based on imaging findings. Their vertebral height recovery, kyphosis correction, cement leakage rate, VAS scores, and postoperative changes were compared. Results: After 10-26 months (avg. 18.9 months) of follow-up, both groups improved in vertebral height and Cobb angle post-operation. The control group had better postoperative vertebral height and Cobb angle recovery. At the last follow-up, the experimental group had more height and Cobb angle loss. VAS scores improved in both groups with no difference between them. There were 5 cement leakage cases in the experimental group and 3 in the control group, with no neurological symptoms (all $P < 0.05$). Conclusion: PKP is safe and effective for stage III Kümmell's disease with or without posterior wall integrity. However, having intact posterior walls is better for maintaining vertebral height in long-term.

Keywords: Kümmell disease, posterior wall of vertebral body, bone cement, percutaneous kyphoplasty

Introduction

As the aging population continues to grow, the incidence of osteoporotic vertebral compression fractures is increasing annually, making it one of the common diseases threatening the health of the elderly [1]. Some patients experience progressive vertebral collapse, kyphotic deformity, and even neurological symptoms after an asymptomatic period lasting from several weeks to months [2]. This condition was first described by the German surgeon Hermann Kümmell in 1891 and is therefore also known as Kümmell's disease [3]. Due to its mild early symptoms, it is often overlooked by patients, leading to delayed treatment. Its typical imaging feature is the "intravertebral vacuum cleft sign" [4], which frequently causes severe and persistent low back pain. In severe cases, it may lead to spinal cord compression and corresponding neurological symptoms, significantly impairing the quality of life of elderly patients and increasing the burden on their families [5].

In terms of treatment, conservative management often yields unsatisfactory results for Kümmell's disease, and thus surgical intervention is usually required [6]. For mid to advanced-stage Kümmell's disease, the main surgical options include simple bone cement augmentation, additional internal fixation, and vertebral corpectomy with reconstruction. However, there remains controversy regarding which surgical approach is more advantageous for elderly patients [7, 8]. Specifically, simple bone cement augmentation techniques such as percutaneous kyphoplasty (PKP) offer advantages such as minimal invasiveness and rapid recovery, making them suitable for cases with intact or mildly defective posterior walls. However, in patients with vertebral posterior wall fractures, there is a higher risk of bone cement leakage. Surgical procedures with additional internal fixation provide better spinal stability and facilitate the correction of kyphotic deformity, but they involve increased surgical trauma and place higher demands on the tolerance of elderly patients with multiple comorbidities. Vertebral

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corpectomy and reconstruction, while enabling thorough decompression and effective restoration of vertebral height, is an open surgery associated with significant trauma and blood loss, and is only suitable for patients with severe nerve compression or spinal deformity.

In recent years, there have been a growing number of reports on the use of PKP for the treatment of mild to advanced-stage Kümmell's disease [9-12]. Our previous studies have also confirmed the effectiveness of PKP in treating Kümmell's disease [13]. However, its efficacy in patients with posterior wall defects warrants further investigation. Hence, this study aims to evaluate the clinical efficacy and safety of PKP in treating Kümmell's disease with posterior wall rupture but without spinal cord compression, and to compare it with a group of patients with an intact posterior wall, thereby providing more reliable evidence for surgical decision-making in such cases.

Material and methods

Study design

This retrospective study analyzed 79 patients with Kümmell disease, who were divided into an experimental group (with vertebral posterior wall rupture, n = 46) and a control group (with vertebral posterior wall intact, n = 33) based on imaging findings. All patients in both groups received standard anti-osteoporosis medication (e.g., bisphosphonates or denosumab) during the treatment period. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board/Ethics Committee of The First Affiliated Hospital of Soochow University (Approval No. 2025032). The requirement for informed consent was waived due to the retrospective nature of the study.

Inclusion criteria comprised all of the following: (1) Diagnosis of Stage III Kümmell's disease according to Li's radiological staging system, confirmed by the presence of a clear "intravertebral vacuum cleft sign" on lateral X-ray; (2) Vertebral posterior wall integrity or defect confirmed by computed tomography (CT) and/or magnetic resonance imaging (MRI); (3) Age ≥ 50 years with chronic, persistent low back pain refractory to conservative treatment for a minimum duration of 3 months; (4) Medical fitness to undergo percutaneous kyphoplasty under general anesthesia; (5) Complete clinical data.

Exclusion criteria were defined as follows: (1) Acute osteoporotic vertebral compression fractures with an onset of less than 3 months; (2) Presence of any neurological symptoms or signs indicative of spinal cord compression; (3) Involvement of two or more vertebral levels by Kümmell's disease; (4) Any contraindication to surgery or general anesthesia; (5) Coexisting spinal pathologies that could confound pain assessment, such as severe spinal stenosis, spondylolisthesis, tumor, or infection.

Preoperative preparation

A comprehensive assessment of the patient's general condition was conducted. Standard vertebral anteroposterior and lateral views, dynamic X-ray films, computed tomography (CT) imaging (including sagittal and coronal reconstruction), and magnetic resonance imaging (MRI) were used to assess the deficiency of the vertebral wall, especially the posterior wall. Besides the deficiency of the vertebral wall, especially the posterior wall, the stability of the fractured vertebral segment was evaluated using a combination of imaging and clinical methods. CT imaging was used to assess the integrity of the vertebral structure, including the degree of vertebral body fragmentation and the involvement of the posterior column. MRI was used to evaluate the condition of the spinal cord and soft tissues around the fracture site. Clinically, the patient's symptoms, such as the presence of pain during movement and the degree of spinal deformity, were also considered. Additionally, the range of motion of the affected spinal segment was measured to further assess its stability. This study used dynamic X-rays to measure the sagittal plane mobility of the segment containing the injured vertebra. During postoperative follow-up, lateral X-rays were taken of the patient's lumbar spine in maximum flexion and extension positions. The angle between the functional segment centered on the operated vertebra (the operated vertebra and its superior vertebra) in flexion and extension was measured. The mobility of this segment was the absolute value of the difference between the extension angle and the flexion angle. This measurement of segmental sagittal mobility using dynamic radiographs was performed cautiously to avoid any aggravation of vertebral injury or patient pain, and no such adverse events were observed.

Surgical methods

General anesthesia was selected to ensure patient cooperation during the prolonged, complex PKP procedure, facilitating accurate pedicle puncture and balloon expansion [14]. While neuroleptic analgesia is commonly used for spinal surgeries, general anesthesia is preferred for our elderly patients with multiple comorbidities, as it ensures hemodynamic stability, optimizes airway control, and minimizes intraoperative complication risks [15].

Following anesthesia, patients were positioned prone. The fractured vertebra was localized via C-arm fluoroscopy, followed by bilateral pedicle puncture and balloon insertion into the vertebral body. Balloons were inflated to restore vertebral height and correct kyphosis, and then removed prior to injection of PMMA cement. Fluoroscopy was used to monitor cement distribution and prevent leakage.

Postoperative management

Vital signs were monitored postoperatively, and patients were maintained in a supine position for 2 hours. Early functional exercises were encouraged according to the patient's general status, with routine anti-osteoporosis therapy administered postoperatively.

The stability of the treated vertebral segment was re-evaluated via postoperative X-rays to assess bone cement position and vertebral height restoration. CT scans were performed if indicated to rule out bone cement leakage or new fractures. Additionally, patients' ability to perform daily activities and exercise-induced pain were monitored to further evaluate segmental stability.

Evaluation indicators

X-rays were obtained preoperatively, 1 month postoperatively, and at the final follow-up to measure the average height of fractured vertebrae and Cobb angle (Cobb method), as well as to assess bone cement leakage. The visual analog scale (VAS) was used to evaluate back pain (0 = no pain; 10 = worst imaginable pain). Functional disability was assessed using the Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire. The DASH questionnaire is a 30-item self-reported tool designed to measure physical function and symptoms in patients with musculoskeletal disorders of the upper limb. Scores range from 0 (no disability) to 100 (most severe disability), with higher scores indicating greater functional limitation. In this study, the DASH score was employed as a supplemental measure to broadly assess the impact of spinal pathology and surgery on patients' overall physical capacity and daily activities involving the trunk and proximal girdle. DASH scores were collected preoperatively, at one week, and three months postoperatively. All X-ray measurements were performed by two independent physicians in a double-blind manner.

Fasting venous blood samples were collected upon admission using standard vacuum tubes. Approximately 5-10 mL of venous blood was drawn, with specific volumes allocated for different tests: 2 mL in an EDTA anticoagulant tube for complete blood count, and the remaining volume in a serum separator tube for subsequent biochemical and immunological assays (IL-6, CRP, liver and kidney function, etc.).

A complete blood count was performed using a fully automated hematology analyzer (Sysmex XN-9000) to determine the white blood cell (WBC) count. Serum interleukin-6 (IL-6) levels were quantified via chemiluminescent immunoassay (Roche Cobas e801), and C-reactive protein (CRP) via immunoturbidimetry (Beckman Coulter AU5800).

Liver and kidney function were assessed using a biochemical analyzer (Roche Cobas c702), including alanine aminotransferase (ALT) and aspartate aminotransferase (AST) for liver function, and creatinine (SCr) and blood urea nitrogen (BUN) for kidney function. All tests were performed strictly following the standard operating procedures provided by the reagents' manufacturers.

Statistical analysis

Statistical analysis was performed using SPSS software (version 18.0; IBM Corp.). Normally distributed quantitative data are presented as mean ± standard deviation. Comparisons among multiple groups were conducted using one-way analysis of variance (ANOVA). Upon identifying a significant overall difference ($P < 0.05$), post hoc pairwise comparisons were performed using the Tukey's honestly significant differ-

Table 1. Comparison of preoperative general characteristics between the experimental and control groups

	Experimental Group	Control Group	*P*-values
Gender (Male:Female)	16:30	11:22	0.762
Age (Years)	71.8±5.3	74.3±4.8	0.286
Duration of LBP (Months)	2.8±0.7	3.2±1.1	0.611
Bone Density	-3.5±0.7	-2.9±0.6	0.429
Comorbidities (Diabetes:Hypertension)	14:27	9:17	0.255

Note: Data are presented as mean ± standard deviation or number of patients. LBP: low back pain; Bone density was measured by T-score from dual-energy X-ray absorptiometry (DEXA).

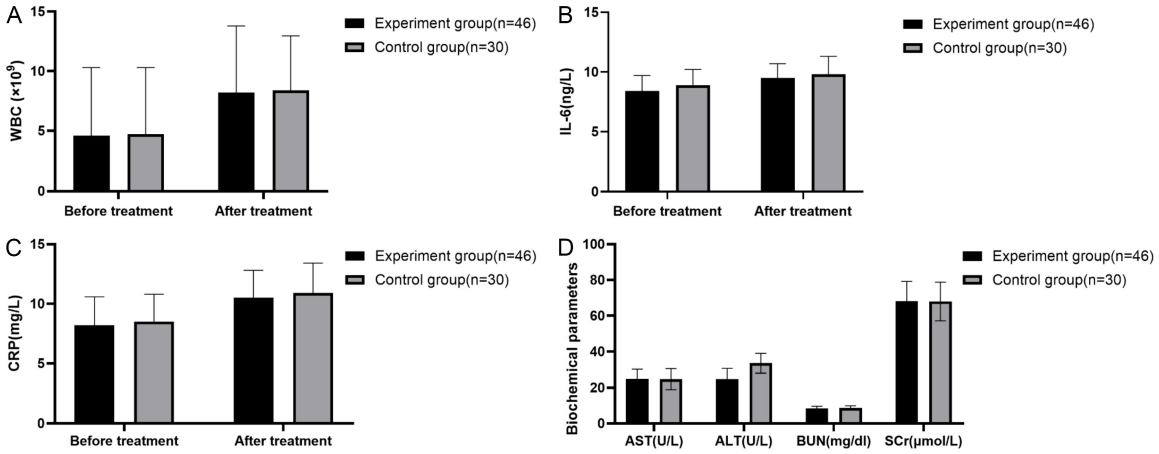

Figure 1. Comparison of peripheral blood inflammatory markers between the experimental and control groups. White blood cell (WBC) count (A), interleukin-6 (IL-6) (B), and C-reactive protein (CRP) (C) levels were measured preoperatively and postoperatively. Comparison of liver and kidney function indicators, serum albumin, and total protein levels between the experimental and control groups. Alanine aminotransferase (ALT), aspartate aminotransferase (AST), serum creatinine (Scr), blood urea nitrogen (BUN), serum albumin (ALB), and total protein (TP) levels were assessed preoperatively and postoperatively (D). Data are presented as mean ± standard deviation.

ence (HSD) test, which controls the family-wise error rate. Direct comparisons between two independent groups were made using the independent samples t-test. Categorical data, presented as rates or proportions, were compared using the chi-square test (or Fisher's exact test when expected cell counts were less than 5). A two-tailed *P*-value of less than 0.05 was considered statistically significant. $P < 0.05$ was considered statistically significant.

Results

Baseline characteristics and surgical tolerance

No statistically significant differences were observed in preoperative baseline data between the two groups ($P > 0.05$). All patients tolerated the procedure well without adverse events.

Surgical duration, volume of bone cement injected, and length of hospital stay were slightly greater in the posterior wall rupture group compared to the intact wall group (all $P < 0.05$); however, intergroup differences in operative time and hospital stay were not statistically significant ($P > 0.05$, **Table 1**).

Postoperative pain relief and vertebral restoration

Both groups demonstrated significant postoperative reductions in VAS scores and significant improvements in anterior vertebral body height and Cobb angle compared to preoperative values (all $P < 0.05$). The further reduction in VAS score at the final follow-up compared to the immediate postoperative period was not significant in either group ($P > 0.05$).

Table 2. Comparison of surgical time, hospital stay, VAS score improvement, vertebral height recovery, Cobb angle correction, bone cement leakage rate, and loss of vertebral height and Cobb angle between the experimental and control groups

	Experimental Group	Control Group	*P*-value
Surgical Time (minutes)	48.5±23.1	43.8±27.1	0.082
Hospital Stay (days)	3.3±2.0	2.7±1.6	0.177
VAS Score Improvement (points)	4.8±1.4	4.9±1.7	0.883
Vertebral Height Recovery (mm)	5.1±2.7	6.0±3.1	0.562
Cobb Angle Correction (degrees)	7.2±3.1	6.2±2.7	0.562
Bone Cement Leakage Rate (%)	15.15	6.52	0.021
Vertebral Height Loss (mm)	2.4±0.8	1.5±0.7	0.037
Cobb Angle Loss (degrees)	2.2±0.5	0.9±0.5	0.022

Note: VAS: Visual Analog Scale; Surgical time is presented in minutes; hospital stay in days; VAS pain score improvement in points; vertebral height recovery and loss in millimeters (mm); Cobb angle correction and loss in degrees (°); bone cement leakage rate expressed as a percentage (%).

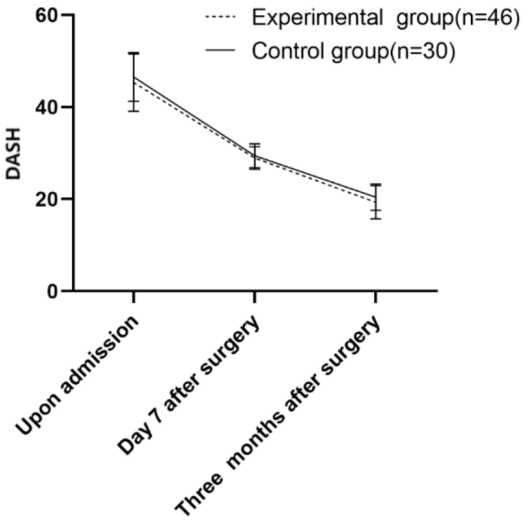

Figure 2. Comparison of Disability of the Arm, Shoulder and Hand (DASH) scores between the experimental and control groups. DASH scores were assessed preoperatively, at one week, and three months postoperatively. Data are presented as mean ± standard deviation.

Correlation analysis revealed no significant association between the degree of pain relief (ΔVAS) and the restoration of vertebral height or correction of the Cobb angle in either group (all P > 0.05).

Regarding safety, the incidence of bone cement leakage was significantly higher in the posterior wall rupture group (P = 0.021). However, no neurological symptoms resulted from any leakage case. No significant loss of the restored vertebral height or Cobb angle correction was observed in either group at the final follow-up (P > 0.05).

Laboratory markers

No statistically significant intergroup differences were detected in preoperative or postoperative levels of peripheral inflammatory markers (e.g., IL-6, CRP), liver and renal function indices, or nutritional parameters (all P > 0.05) (**Figure 1**).

Outcomes

Intergroup comparisons showed no significant differences in operative time, hospital stay, or the extent of pain relief (all P > 0.05). However, the posterior wall intact group achieved significantly better restoration of vertebral height and correction of the Cobb angle immediately after surgery, with significantly less loss of both correction parameters at the final follow-up (all P < 0.05) (**Table 2**).

Postoperative joint function and excellent-good rates

No statistically significant differences were observed in preoperative DASH scores between the groups (P > 0.05). Post-treatment, DASH scores at one week and three months postoperatively showed no significant difference between the groups (both P > 0.05). Follow-up periods also revealed no significant difference in excellent-good joint function rates (experimental 86.96%, control 86.67%; P = 0.971) (**Figure 2**; **Table 3**).

Table 3. Excellent-good rates between the two groups

Group	Excellent	Good	Poor	Excellent-Good Rate
Experimental (n = 46)	40	3	3	40/46 (86.96%)
Control (n = 30)	26	3	1	26/30 (86.67%)
X^2				0.001
P value				0.971

Note: The excellent-good rate (%) indicates the proportion of patients rated as excellent or good. X^2: chi-square test statistic.

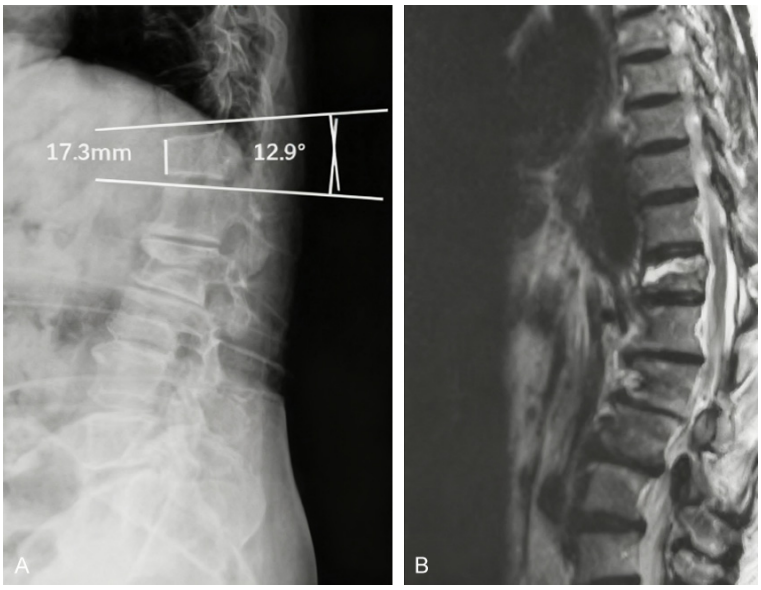

Figure 3. Radiographic and magnetic resonance imaging images at the time of injury. A. The initial lateral X-ray shows a fresh T12 vertebral fracture, with the anterior vertebral height measured at 17.3 mm and the Cobb angle at 12.9°. B. The sagittal MRI confirms the diagnosis of a fresh T12 vertebral fracture.

Typical case presentation

A 65-year-old female patient with lower back pain and limited mobility from a fall was diagnosed with a fresh T12 vertebral fracture. Initial X-ray and MRI showed a Cobb angle of 12.9° and anterior vertebral height of 17.3 mm (**Figure 3**). Four months later, pain worsened and imaging revealed vertebral collapse with kyphotic deformity and a clear "vertebral cleft sign", measuring Cobb angle 25.1° and anterior vertebral height 7.8 mm (**Figure 4**). CT confirmed posterior vertebral wall rupture, and Stage III Kümmell disease was diagnosed. She underwent percutaneous kyphoplasty. One month postoperatively, Cobb angle improved to 21.9° and vertebral height to 15.6 mm (**Figure 5A**). At two-year follow-up, Cobb angle was 24.4° and height 11.8 mm (**Figure 5B**).

Discussion

Kümmell disease remains a clinically challenging condition, with unresolved issues regarding its pathogenesis, diagnosis, and optimal treatment. Current understanding of its pathophysiology centers on two competing hypotheses: intravertebral pseudarthrosis formation following osteoporotic vertebral compression fractures, and primary avascular necrosis of the vertebral body. The latter positing that impaired vertebral blood supply induces trabecular necrosis and subsequent non-union, has gained wider acceptance among researchers [4, 11]. Our clinical observations support this ischemic necrosis hypothesis, as the characteristic intravertebral vacuum cleft observed in advanced stages likely represents a mechanical sequela of this avascular process.

The treatment paradigm for Kümmell disease has evolved substantially, with percutaneous kyphoplasty (PKP) emerging as the preferred minimally invasive intervention for Li stage I and II patients due to its favorable efficacy and safety profile [16, 17]. However, the management of stage III disease, characterized by posterior vertebral wall deficiency, remains controversial [18-21]. In our clinical practice, we observed that posterior wall integrity, rather than the underlying etiology, serves as the primary determinant of bone cement leakage risk. This finding is consistent with the existing literature [6] and was corroborated in our study, where patients with posterior wall defects exhibited a significantly higher leakage rate.

Notably, our clinical experience indicates that PKP can be safely performed in stage III cases with meticulous preoperative planning and technical modifications. We attribute our successful outcomes without neurological complications to three key technical considerations:

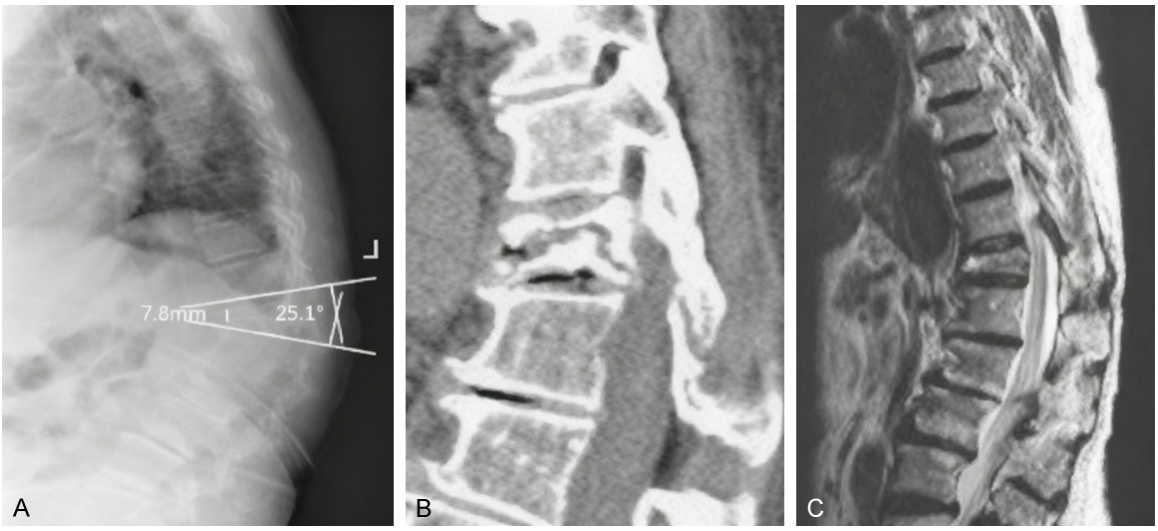

Figure 4. Imaging data four months post-injury. A. Lateral X-ray showing significant vertebral collapse and kyphotic deformity, with the anterior vertebral height decreased to 7.8 mm and the Cobb angle increased to 25.1°. B. Sagittal CT scan confirming the presence of a clear 'intravertebral vacuum cleft sign' and demonstrating the rupture of the posterior vertebral wall. C. Sagittal MRI showing vertebral collapse and confirming no spinal cord compression.

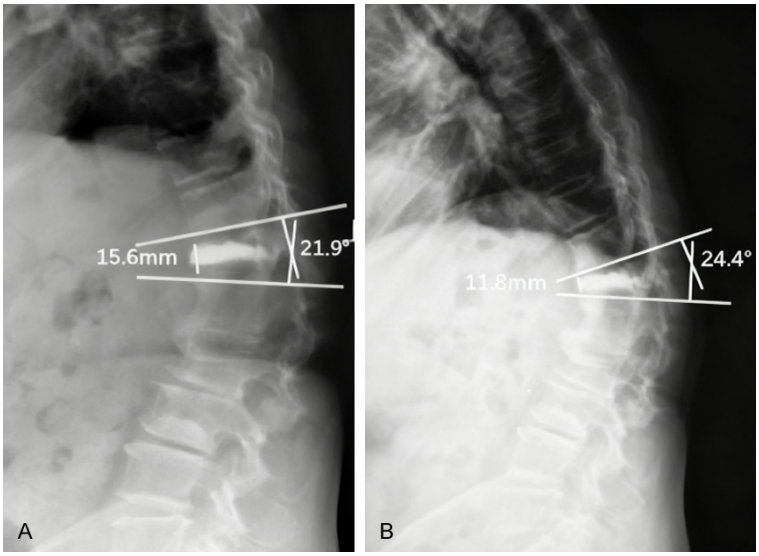

Figure 5. X-ray images at one month post-surgery (A) and last follow-up (B).

first, high-resolution CT imaging enables precise preoperative assessment of posterior wall defect morphology; second, real-time fluoroscopic guidance during cement injection ensures controlled distribution; and third, optimization of injection parameters (including volume, pressure, and staged delivery) substantially mitigates leakage risk. We propose that these technical refinements, rather than abandoning PKP entirely for stage III patients, represent a more nuanced approach to managing this complex subgroup.

The pain pathophysiology of Kümmell disease is multifactorial, with micromotion at the fracture site identified as a primary contributor [1, 22, 23]. While cement augmentation effectively addresses this mechanical instability, we hypothesize that the marked pain relief observed in our cohort may also stem from the dual mechanism of chemical neurolysis and thermal denervation induced by PMMA [24, 25], particularly in cases with established intravertebral pseudarthrosis.

A major concern in Kümmell disease management is the risk of late cement displacement due to inadequate bone-cement integration. In contrast to prior studies reporting an 18.20% displacement rate [26], our study observed no such complications. We attribute this favorable outcome to strict patient selection (excluding cases with preoperatively severe vertebral instability) and technical emphasis on achieving optimal cement interdigitation with trabecular bone, even in the challenging sclerotic bone environment of Kümmell lesions. Furthermore, we acknowledge that select cases with severe instability might benefit from

supplementary fixation; however, this falls beyond the scope of the current investigation.

Our analysis revealed an important long-term observation: patients with posterior wall defects experienced significantly greater vertebral height loss and Cobb angle progression at final follow-up. We interpret this finding as evidence that posterior wall integrity is crucial for maintaining mechanical stability under cyclic spinal loading. While this radiographic deterioration was not associated with worse clinical outcomes in our series, it underscores the need for diligent postoperative monitoring in this subgroup.

The relationship between kyphotic deformity and pain severity remains debated. While some authors report a correlation between deformity magnitude and symptom intensity [27, 28], our data support the alternative view that pain improvement following PKP is not significantly associated with radiographic parameters (i.e., vertebral height restoration or Cobb angle correction) [25, 29, 30]. This dissociation between radiographic and clinical outcomes leads us to conclude that the primary mechanisms of pain relief in Kümmell disease are likely fracture stabilization and PMMA-induced neurolysis, rather than mechanical correction of spinal alignment.

Conclusion

This study provides valuable insights into the clinical outcomes of PKP for Kümmell disease, particularly in patients with posterior vertebral wall defects but no neurological deficits. Our findings demonstrate that PKP is a safe and effective treatment option for both patients with intact and compromised posterior vertebral walls, yielding significant short-term pain reduction, vertebral height restoration, and kyphotic deformity correction.

However, the long-term maintenance of vertebral height and deformity correction was superior in patients with intact posterior walls. This suggests that while PKP achieves immediate symptomatic relief and anatomical restoration, posterior wall structural integrity plays a crucial role in sustaining these benefits over time. Consistent with the known risk profile of vertebral augmentation in the setting of posterior wall defects, the experimental group exhibited a higher cement leakage rate, though no neurological complications were observed. This highlights the importance of careful patient selection and refined surgical technique to minimize procedural risks.

Despite the inherent limitations of a retrospective design, including the absence of randomization and variable follow-up durations, our results contribute to the growing body of evidence supporting PKP as a viable treatment for Kümmell disease. Future prospective studies with larger sample sizes and standardized long-term follow-up are warranted to further clarify long-term outcomes and refine patient selection criteria.

Disclosure of conflict of interest

None.

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References

[1] Li HK, Hao DJ, Yang JS, Huang DG, Yu CC, Zhang JN, Gao L, Li H and Qian B. Percutaneous kyphoplasty versus posterior spinal fixation with vertebroplasty for treatment of Kummell disease: a case-control study with minimal 2-year follow-up. Medicine (Baltimore) 2017; 96: e9287.

[2] Zhang B, Chen G, Yang X, Fan T and Chen Z. Percutaneous kyphoplasty versus percutaneous vertebroplasty for neurologically intact osteoporotic Kümmell's disease: a systematic review and meta-analysis. Global Spine J 2022; 12: 308-322.

[3] Brower AC and Downey EF Jr. Kümmell disease: report of a case with serial radiographs. Radiology 1981; 141: 363-364.

[4] He D, Yu W, Chen Z, Li L, Zhu K and Fan S. Pathogenesis of the intravertebral vacuum of Kümmell's disease. Exp Ther Med 2016; 12: 879-882.

[5] Li KC, Li AF, Hsieh CH, Liao TH and Chen CH. Another option to treat Kümmell's disease with cord compression. Eur Spine J 2007; 16: 1479-1487.

[6] Zhang TY, Zhang PX, Xue F, Zhang DY and Jiang BG. Risk factors for cement leakage and nomogram for predicting the intradiscal cement

leakage after the vertebra augmented surgery. BMC Musculoskelet Disord 2020; 21: 792.
[7] Henrich D, Seebach C, Nau C, Basan S, Relja B, Wilhelm K, Schaible A, Frank J, Barker J and Marzi I. Establishment and characterization of the Masquelet induced membrane technique in a rat femur critical-sized defect model. J Tissue Eng Regen Med 2016; 10: 382-396.
[8] Yang H, Pan J and Wang G. A review of osteoporotic vertebral fracture nonunion management. Spine (Phila Pa 1976) 2014; 39: B4-B6.
[9] Jindal V, Binyala S and Kohli SS. Balloon kyphoplasty versus percutaneous vertebroplasty for osteoporotic vertebral body compression fractures: clinical and radiological outcomes. Spine J 2023; 23: 579-584.
[10] Adamska O, Modzelewski K, Stolarczyk A and 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.
[11] Jiang J, Gu FL, Li ZW and Zhou Y. The clinical efficacy and experience of bipedicular percutaneous vertebroplasty combined with postural reduction in the treatment of Kümmell's disease. BMC Musculoskelet Disord 2020; 21: 82.
[12] Chang JZ, Bei MJ, Shu DP, Sun CJ, Chen JB and Xiao YP. Comparison of the clinical outcomes of percutaneous vertebroplasty vs. kyphoplasty for the treatment of osteoporotic Kümmell's disease: a prospective cohort study. BMC Musculoskelet Disord 2020; 21: 238.
[13] Chen L, Dong R, Gu Y and 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.
[14] Ge C, Wu X, Gao Z, Xu Z, Hao D and Dong L. Comparison of different anesthesia modalities during percutaneous kyphoplasty of osteoporotic vertebral compression fractures. Sci Rep 2021; 11: 11102.
[15] Bao LS, Wu W, Wang X, Zhong XH, Wang LX and Wang H. Clinical observation of intraosseous anesthesia in percutaneous kyphoplasty. J Healthc Eng 2021; 2021: 5528073.
[16] Lu W, Wang L, Xie C, Teng Z, Han G, Shi R, Liang J and Lu S. Analysis of percutaneous kyphoplasty or short-segmental fixation combined with vertebroplasty in the treatment of Kummell disease. J Orthop Surg Res 2019; 14: 311.
[17] Huang YS, Hao DJ, Feng H, Zhang HP, He SM, Ge CY and Li R. Comparison of percutaneous kyphoplasty and bone cement-augmented short-segment pedicle screw fixation for management of Kümmell disease. Med Sci Monit 2018; 24: 1072-1079.
[18] Li R, Ma Y, Zhang Y, Zhang M and Sun D. Potential of rhBMP-2 and dexamethasone-loaded Zein/PLLA scaffolds for enhanced in vitro osteogenesis of mesenchymal stem cells. Colloids Surf B Biointerfaces 2018; 169: 384-394.
[19] Heydari Z, Mohebbi-Kalhori D and Afarani MS. Engineered electrospun polycaprolactone (PCL)/octacalcium phosphate (OCP) scaffold for bone tissue engineering. Mater Sci Eng C Mater Biol Appl 2017; 81: 127-132.
[20] Endres S and Badura A. Shield kyphoplasty through a unipedicular approach compared to vertebroplasty and balloon kyphoplasty in osteoporotic thoracolumbar fracture: a prospective randomized study. Orthop Traumatol Surg Res 2012; 98: 334-340.
[21] Friedrich HC, Friedrich HJ, Kneisel P, Drumm J and Pitzen T. Balloon kyphoplasty improves back pain but does not result in a permanent realignment of the thoracolumbar spine. Cent Eur Neurosurg 2011; 72: 176-180.
[22] Yan Y, Chen H, Zhang H, Guo C, Yang K, Chen K, Cheng R, Qian N, Sandler N, Zhang YS, Shen H, Qi J, Cui W and Deng L. Vascularized 3D printed scaffolds for promoting bone regeneration. Biomaterials 2019; 190-191: 97-110.
[23] Wang G, Yang H, Meng B, Zhu X, Zou J, Gan M, Mei X, Chen K and Tang T. Post-traumatic osteoporotic vertebral osteonecrosis treated using balloon kyphoplasty. J Clin Neurosci 2011; 18: 664-668.
[24] Shah RV. Sacral kyphoplasty for the treatment of painful sacral insufficiency fractures and metastases. Spine J 2012; 12: 113-120.
[25] Chen C, Chen L, Gu Y, Xu Y, Liu Y, Bai X, Zhu X and Yang H. Kyphoplasty for chronic painful osteoporotic vertebral compression fractures via unipedicular versus bipedicular approachment: a comparative study in early stage. Injury 2010; 41: 356-359.
[26] Gao X, Du J, Zhang Y, Gong Y, Zhang B, Qu Z, Hao D, He B and Yan L. Predictive factors for bone cement displacement following percutaneous vertebral augmentation in Kümmell's disease. J Clin Med 2022; 11: 7479.
[27] Liu W, Bi W, Sun Y, Wang L, Yu X, Cheng R, Yu Y and Cui WG. Biomimetic organic-inorganic hybrid hydrogel electrospinning periosteum for accelerating bone regeneration. Mater Sci Eng C Mater Biol Appl 2020; 110: 110670.
[28] Xin T, Gu Y, Cheng R, Tang J, Sun Z, Cui W and Chen L. Inorganic strengthened hydrogel mem-

brane as regenerative periosteum. ACS Appl Mater Interfaces 2017; 9: 41168-41180.
[29] Wang F, Wang D, Tan B, Dong J, Feng R, Yuan Z and Wang N. Comparative study of modified posterior operation to treat Kummell's disease. Medicine (Baltimore) 2015; 94: e1595.
[30] Hoffman MD and Benoit DSW. Emulating native periosteum cell population and subsequent paracrine factor production to promote tissue engineered periosteum-mediated allograft healing. Biomaterials 2015; 52: 426-440.