Research Square

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Efficacy and Safety of Vertebroplasty with Cement Anchoring Technique for Stage II Kümmell's Disease: A Retrospective Cohort Study

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Research Article

Keywords: Kümmell's disease, Vertebral compression fractures, Vertebroplasty, Cement anchoring technique

Posted Date: April 1st, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9129857/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

In Kummell's Disease (KD), stage II patients frequently present with vertebral pseudarthrosis. The associated sclerotic changes at the margins of the pseudarthrosis can hinder the restoration of vertebral height and adversely affect cement distribution and therapeutic outcomes. To evaluate the efficacy of the cement anchoring technique (CAT) in the treatment of stage II KD.

Methods

A total of 71 patients (CAT group: 33 cases, PVP group: 38 cases) were enrolled between January 2020 and June 2024. The following parameters were compared between two groups: gender, age, BMI, lumbar BMD, duration of disease, fracture type, compression ratio, operative time, volume of cement injected, incidence of cement leakage, cement distribution and pattern, VAS, anterior vertebral height (AVH), middle vertebral height (MVH), posterior vertebral height (PVH), Cobb angle preoperatively and at 1 month and 1 year postoperatively, and ODI preoperatively and at 3 months and 1 year postoperatively.

Results

All procedures were completed successfully without serious complications. CAT group had more cement injected (5.73 ± 1.32ml / 4.92 ± 0.91ml, $P < 0.05$) and lower cement leakage (27.27% / 52.63%, $P < 0.05$) than PVP group. The spongy distribution pattern (63.63% / 28.95%, $P < 0.05$) and satisfactory cement distribution (57.57% / 36.84%, $P < 0.05$) was higher in the CAT group. Postoperative VAS and ODI scores improved significantly in two groups. Nevertheless, the postoperative improvement in CAT group was better ($P < 0.05$). For AVH, MVH, and Cobb angle, the CAT group exhibited significantly greater improvements at 1 month and 1 year postoperatively($P < 0.05$). PVP group showed significant deterioration in these parameters at 1 year compared with the 1-month assessment ($P < 0.05$).

Conclusion

Cement anchoring technique is a safer and more effective alternative for treating stage II KD. It effectively alleviates pain symptom, promotes better cement diffusion, prevents cement leakage, and effectively improve and maintain vertebral height and reduced kyphotic deformity.

INTRODUCTION

Kummell's Disease (KD) is a serious complication of osteoporotic vertebral compression fractures (OVCFs), characterized by delayed vertebral body collapse following initial symptomatic relief[1]. Its hallmark is a symptom-free interval after minor trauma, followed by progressive severe back pain,

kyphosis, and potential neurological deficits. Pathologically, KD involves vertebral non-union and osteonecrosis[2]. Radiologically, it is defined by the presence of an intravertebral vacuum cleft (IVC) or fluid sign on CT or MRI, which leads to persistent instability and severe pain requiring intervention[3]. Conservative management often fails due to this instability, making surgical stabilization necessary in many cases. KD was staged based on the severity of vertebral collapse and spinal cord compression[4]. Conservative management is typically indicated for Stage I KD, whereas Stage III KD, characterized by significant kyphosis and spinal cord compression, necessitates spinal canal decompression and deformity correction via combined anterior-posterior surgery. For Stage II KD, treatment focuses on pain relief and restoration of spinal stability [5–8].

Percutaneous vertebroplasty (PVP) and kyphoplasty (PKP) are minimally invasive procedures that involve the percutaneous injection of polymethylmethacrylate (PMMA) cement into the vertebral body. These techniques offer rapid recovery, effective pain reduction through stabilization of micromovements, and vertebral augmentation, making them widely used in the treatment of OVCFs[9]. In KD, vertebral pseudarthrosis is frequently observed in patients with Stage II disease[10]. Associated proliferative sclerosis at the margins of the pseudarthrosis can impede vertebral height restoration and compromise the distribution of bone cement. Furthermore, inadequate interdigitation of PMMA with the surrounding cancellous bone reduces construct stability and increases the risk of cement displacement.

Therefore, this study evaluates the clinical efficacy of a bone cement anchoring technique (CAT) - involving an optimized puncture approach and controlled cement injection - during PVP for Stage II KD. The findings are expected to provide a foundation for optimizing treatment protocols and improving prognostic assessment.

METHODS

Patient Characteristics

From 2020.1 to 2024.6, 182 patients were diagnosed with KD continuously. 68 cases were stage I KD, 27 cases were stage III KD, 9 cases received conservative treatment, and 17 cases lost to follow-up. Finally, 71 cases were included in this study including 38 in the PVP group and 33 in the CAT group.

The choice of method is surgeon-dependent based on their standard clinical practice. Specifically, XH X routinely use traditional PVP, while GQ Z exclusively use CAT technique this procedure. Patients were allocated to these surgeons based primarily on outpatient clinic schedules and appointment availability, rather than specific patient characteristics (such as disease severity or bone quality).

Inclusion Criteria:

1)Age ≥ 55 years;

2)Preoperative Visual Analogue Scale (VAS) pain score ≥ 7 points;

3)Duration of disease ≥ 6 months;

4)Multimodal imaging consistent with single-level KD with stage II: Body height loss ≥ 20%, with an IVC sign and adjacent degenerative disc disease. Preoperative X-ray and CT show the linear or semilunar radiolucent shadow within a collapsed vertebral body, representing the IVC. Preoperative MRI provides include a diffuse low-intensity T1-weighted MRI pattern, and a fluid-intensity and diffuse low-intensity T2-weighted MRI pattern.

5)Bone mineral density (BMD) assessed by dual-energy X-ray absorptiometry (DXA) yielding a T-score ≤ -2.5;

6)Absence of major surgical contraindications, tolerance for local anesthesia, and ability to cooperate intraoperatively;

7)Follow-up duration ≥ 12 months.

Exclusion Criteria:

1)Concurrent spinal cord or cauda equina compression requiring decompression;

2)Multi-level KD;

3)Pathological fractures secondary to infections or malignancy;

4)Active infection at the surgical site or systemic sepsis;

5)Significant coagulation disorders;

6)Decompensated major organ dysfunction conferring high surgical risk.

Conventional PVP Procedure

All procedures were performed by the same surgical team. A standardized bilateral transpedicular approach was strictly adhered to in all patients, using uniformly supplied instrumentation and PMMA cement.

Patients were placed in a prone position on a spinal operating table with the thoracoabdominal region elevated to maintain physiological lordosis. Oxygen saturation was monitored continuously throughout the procedure to ensure adequate ventilation. Real-time observation of the patient's lower limb sensation and movement was conducted to ensure no spinal cord compression. The pedicle puncture entry point, determined based on preoperative 3D CT reconstruction, was targeted at the superolateral quadrant of

the pedicle projection—corresponding to the 10 o'clock position for left pedicles and the 2 o'clock position for right pedicles. After standard skin preparation with povidone-iodine and alcohol and sterile draping, local anesthesia was administered via infiltration down to the periosteum using 1% lidocaine. Intraoperative biplanar fluoroscopy was used to confirm the pedicle projection. The puncture needle trajectory was dynamically adjusted within safe zones—defined as medial to the pedicle wall on the anteroposterior view and at least 3 mm anterior to the posterior vertebral wall on the lateral view—using appropriate craniocaudal (5–10°) and lateral (15–25°) angulation to avoid spinal canal violation or cord injury. The needle was advanced to the anterior third of the vertebral body. After establishing the working channel, PMMA cement was prepared to a doughy or thread-pulling phase. Before cement injection, 40 mg of methylprednisolone sodium succinate was administered intravenously to mitigate potential allergic reaction to the cement. The cement was injected incrementally under continuous fluoroscopic guidance, with close monitoring of its dispersion to prevent leakage. The injection was stopped when cement symmetrically occupied the anterior three-quarters of the vertebral body, reached the posterior one-quarter, made contact with the superior and inferior endplates, or when leakage occurred.

Cement- Vertebral body- Pedicle Anchoring Technique

Given the characteristics of the IVC in stage II KD, the following technical modifications were implemented: (1) Bilateral targeted puncture strategy: All patients underwent bilateral transpedicular punctures. One needle was positioned centrally within the IVC, while the contralateral needle was placed within the normal trabecular bone. (2) Debridement of sclerotic bone: Before cement injection, the marginal proliferative sclerotic tissue surrounding the IVC was meticulously drilled and removed using a specialized fine drill (diameter 3.5 mm). Under fluoroscopic guidance, the drill was slowly advanced to penetrate the sclerotic bone. Drilling was performed with gentle manual pressure and a rotating motion until a loss of resistance was felt, indicating passage through the sclerotic shell into the underlying cancellous bone or the cleft. The fine drill should be close to the upper and lower endplates for better cement dispersion (Fig. 2). (3) Cement tail formation: The puncture needle was gradually withdrawn during cement injection to form a dense cement tail within the pedicle tract. These maneuvers were designed to enhance the "anchoring effect" between the cement within the cleft and the surrounding normal bone, thereby optimizing postoperative outcomes. (4) A fractional cement injection protocol was adopted. Injection was temporarily paused for 1–2 minutes once the cement front advanced along the fracture line toward the vertebral periphery. This interval allowed partial polymerization of the cement at the periphery, after which injection was resumed.

Postoperative Management

Postoperative management was standardized for all patients throughout the study period. In addition to the use of a rigid orthosis for 6–8 weeks and an initial consultation with a rehabilitation specialist, all patients followed a uniform, staged rehabilitation protocol. This protocol included passive range-of-motion exercises starting from postoperative day 1, gradual ambulation with assistance, and a

standardized home-based exercise program focusing on core stability and back extensor strengthening, which was provided to each patient in writing. Adherence to this protocol was reinforced during follow-up visits at 1, 3, 6, and 12 months. Standardized anti-osteoporotic pharmacotherapy was administered, which included daily calcium supplementation (500–600 mg of elemental calcium in addition to 400 mg from dietary intake) and vitamin D (800–1200 IU). Patients were instructed to take bisphosphonates regularly on a daily or weekly basis[11].

Clinical and radiological evaluation

The following parameters were compared among the two groups: gender, age, BMI, lumbar BMD, duration of disease (months), fracture type (wedge or biconcave), compression ratio, operative time (minutes), volume of cement injected (mL), incidence of cement leakage, cement distribution and pattern, VAS scores preoperatively and at 1 month and 1 year postoperatively, and Oswestry Disability Index (ODI) scores preoperatively and at 3 months and 1 year postoperatively. Anterior vertebral height (AVH), middle vertebral height (MVH), posterior vertebral height (PVH), Cobb angle were measured before operation, 1 month and 1 year after operation. All measurements were independently performed by two experienced spine surgeons.

To determine the reliability of the radiographic evaluations, all images were independently assessed by two spine surgeons who were blinded to the clinical outcomes. To minimize bias and measurement error, each parameter was measured multiple times, and the average value was calculated for analysis according to standardized criteria. Prior to formal assessment, both assessors underwent a calibration session to ensure consistent interpretation. Interrater reliability was quantified using Cohen's kappa coefficient (κ).

The vertebral compression ratio was assessed using the Genant visual semi-quantitative method[12], calculated as the ratio of the height at the most compressed point of the fractured vertebra to the height of its posterior wall or to the posterior wall height of adjacent non-fractured vertebrae. The severity of compression was graded as follows: Grade I (mild, 0–25%), Grade II (moderate, > 25–40%), and Grade III (severe, > 40%).

Cement pattern was classified into two patterns based on X-ray: spongy or blocky[13]. Cement distribution was evaluated using a modified 9-point scale[14]. On postoperative anteroposterior and lateral radiographs, satisfactory dispersion was defined as cement filling either: (1) the entire vertebral body, contacting the superior and inferior endplates, anterior and posterior walls, and both lateral walls; or (2) the anterior three-quarters of the vertebral body, reaching the superior and inferior endplates and both lateral walls. All other distribution patterns were classified as poor dispersion.

The AVH, MVH and PVH were measured on lateral radiographs as the perpendicular distances from, respectively, the anterior wall, midpoint, and posterior wall of the vertebral body to the horizontal line connecting the superior and inferior endplates of the same vertebra. The Cobb angle was measured on

lateral radiographs as the angle formed between the line parallel to the superior endplate of the vertebra cephalad to the fractured vertebra and the line parallel to the inferior endplate of the vertebra caudal to the fractured vertebra.

Cement leakage was identified by the intraoperative observation of extravertebral material and subsequently confirmed via postoperative three-dimensional CT.

Statistical Analysis

Statistical analyses were performed using SPSS software (version 25.0). Continuous data conforming to normal distribution and homogeneity of variance are expressed as mean±standard deviation (M ± SD) and compared using the t-test. Categorical data were compared using the Chi-square (χ^2) test. Statistical significance was defined as $P < 0.05$.

RESULTS

General Information

A total of 71 cases were continuously enrolled in this study: 38 cases in PVP group and 33 cases in the CAT group. All patients were followed up for more than one year postoperatively. The patient recruitment flow and study procedures are summarized in Fig. 1.

No significant differences were observed in gender, age, BMI, BMD, duration of disease, fracture type, compression ratio or follow-up time between two groups ($P > 0.05$). These findings indicate that both groups were comparable in baseline characteristics. Detailed information was presented in Tables 1.

Surgical Outcomes

All procedures were completed successfully without major complications. No significant differences were found in operative time. However, the CAT group used more cement injected (5.73 ± 1.32ml / 4.92 ± 0.91ml, $P < 0.05$) and lower cement leakage (27.27% / 52.63%, $P < 0.05$) than PVP group. The spongy distribution pattern was higher in the CAT group (21/33 cases, 63.63% vs. 11/38 cases, 28.95%, $P < 0.05$). The satisfactory cement distribution was significantly higher in the CAT group (19/33 cases, 57.57% vs. 14/38 cases, 36.84%, $P < 0.05$) (Table 2).

Postoperative Pain Relief / Functional Improvement

No significant intergroup differences were observed in VAS or ODI scores preoperatively ($P > 0.05$). The change in each score was calculated as the difference between the final follow-up and preoperative values. In accordance with established thresholds, the minimal clinically important difference (MCID) was defined as a reduction of 9.5 points for the ODI and 2.2 points for the VAS[15].

At subsequent follow-ups, both VAS and ODI scores improved significantly in two groups ($P < 0.05$, compared with preoperative scores). The change in VAS and ODI both exceeded the MCID values of 2.2

and 9.5 respectively, indicating clinically meaningful improvements. Nevertheless, the postoperative improvement of VAS and ODI scores in CAT group was better than that in PVP group ($P < 0.05$). Detailed data are provided in Tables 3 and 4.

Radiological outcomes

The interrater agreement for the radiological outcomes was substantial, with a Cohen's kappa (κ) of 0.73 (95% CI: 0.67 to 0.81). Table 5 summarizes no significant intergroup differences at baseline ($P < 0.05$). For PVH, there were no significant statistical differences between or within the groups during follow-up. For AVH, MVH, and Cobb angle, significant improvements from preoperative baselines were observed in both groups (all $P < 0.05$). In intergroup comparisons at 1 month and 1 year postoperatively, however, the CAT group exhibited significantly greater improvements than the PVP group ($P < 0.05$). Moreover, within-group comparisons indicated that the PVP group showed significant deterioration in these parameters at 1 year compared with the 1-month assessment ($P < 0.05$), while vertebral height was maintained in the CAT group ($P > 0.05$). Figures 3, 4 presented typical case of cement- vertebral body- pedicle anchoring technique.

DISCUSSION

The pathogenesis and risk factors for KD

KD represents a complex pathological process characterized by delayed vertebral collapse. Initially, minor trauma induces microfractures in the vertebral endplate, disrupting critical nutrient vascular channels. This condition frequently occurs against a background of compromised bone strength, such as osteoporosis[16]. Concurrently, trauma-induced bleeding and edema markedly increase intraosseous pressure, further compressing venous structures and impeding venous outflow. These changes lead to osteocyte death and liquefactive necrosis of the bone marrow tissue[17]. Following an asymptomatic latent period lasting weeks to months—often misinterpreted as "healing"—inflammatory cytokines released from necrotic tissue activate osteoclasts[18]. As osteolysis progresses and necrotic material is resorbed, a cavity gradually forms within the vertebral body, filled with gas (primarily nitrogen derived from tissue breakdown) and/or fluid. Radiographically, this appears as the characteristic "vacuum cleft sign" (linear radiolucency on CT) or "fluid sign" (specific signal intensity on MRI)[19]. The formation of the sclerotic rim in KD involves repeated cycles of "mechanical stimulation–bone remodeling"[20, 21]. The development of this cavity indicates a critical loss of the vertebral body’s internal structural integrity, resulting in a sclerotic-rimmed pseudarthrosis. This sequence corresponds to stage II KD.

The shortcomings of PVP for treating KD with stage II

To prevent further collapse and potential compression on the spinal cord or nerves, PVP has emerged as a minimally invasive technique with distinct advantages in the management of OVCFs. However, its application in stage II KD presents several limitations.

First, the pseudarthrosis in KD is often bordered by a distinct rim of sclerotic bone. Cement injected during PVP tends to remain confined within the IVC, resulting in a fragmented and aggregated distribution rather than the desired interdigitated, spongeous pattern observed in OVCFs[22]. Marginal proliferative sclerosis significantly compromises cement dispersion. A less distributed, blocky cement pattern fails to interlock effectively with the surrounding cancellous bone[23]. In this study, cement pattern was mainly characterized by blocky, and the rate of satisfactory cement distribution by conventional PVP group was only 34.21% (13/38), which were significantly lower than that in CAT group. In a finite element analysis analysis, cement distribution patterns critically affect stress transfer and failure risk. When bone cement establishes contact with both cranial and caudal endplates, it effectively reduces stress concentration in the surrounding cancellous bone; conversely, any space between cement and endplates may lead to vertebral collapse and increase refracture risk[24]. The association between insufficient cement filling and chronic low back pain may be attributed to its limited role as a mere space-occupying material, which fails to offer sufficient mechanical stabilization. Conversely, the diffuse distribution pattern characteristic of the CAT technique could create a substantially larger cement-bone contact area. This expanded interface is hypothesized to enhance the localized chemical and thermal impacts of the cement, leading to more effective ablation of intravertebral pain-related nerve endings. In this study, the CAT group exhibited better improvement in VAS and ODI scores compared with the conventional PVP group during follow-up assessments, although both VAS and ODI scores showed significant improvement in both two groups.

Second, the dense sclerotic bone at the pseudarthrosis margins impedes effective cement penetration and anchorage into the surrounding cancellous bone. As a result, the cement fails to achieve adequate micro-mechanical interdigitation with adjacent trabeculae. This lack of biomechanical integration weakens anchorage strength and leads to poor interfacial stability. Stress concentration at the cement–bone interface or in unreinforced regions increases the risk of cement migration, subsidence, and further vertebral collapse[25].

Third, the sclerotic rim hinders the safe dispersion of cement into the surrounding bone matrix. This obstruction redirects cement flow along paths of least resistance within the cleft, substantially increasing the risk of cement leakage compared with conventional OVCFs. In this study, the rate of cement leakage by CAT group was 27.27% (9/33), which was significantly lower than that in conventional PVP group.

Several techniques have recently been proposed to optimize bone cement distribution, including the transverse process-pedicle approach[26], rotary cutter systems[27], hollow pedicle screws combined with kyphoplasty[28], and the stent-screw-assisted internal fixation (SAIF) technique[29]. However, these approaches may increase both surgical complexity and associated medical costs.

Advantages of “Cement- Vertebral body- Pedicle Anchoring Technique” in the treatment of KD with stage II

In stage II KD, achieving effective anchorage between the cement and vertebral body is critical to surgical success[30]. To address this, we introduced specific technical refinements, designated the “Cement–Vertebral Body–Pedicle Anchoring Technique.”

First, a bilateral transpedicular approach was consistently used for all patients. One puncture needle was accurately positioned within the IVC, while the contralateral needle was directed toward the region of normal cancellous bone. This approach enabled cement injection on both sides, promoting more stable integration between the trabecular bone and the IVC, thereby enhancing stability and support for the injured vertebra. Study in biomechanics have shown that bilateral PVP could balance the stress of the vertebral body, reduce the maximum stress of the intervertebral disc, and offer advantages in terms of stability compared with unilateral PVP. There were no obvious high-stress concentration regions on the anterior and middle columns of the vertebral body in bilateral PVP[31].

Second, prior to cement injection, a precision drill was used to meticulously abrade the sclerotic bone lining the IVC. This step aimed to increase the contact area available for cement interdigitation and anchorage[32]. It ultimately produced a spongy cement pattern with a high cement distribution score.

Third, during cement injection, a technique of simultaneous injection with gradual needle withdrawal was applied to form a continuous cement tail within the pedicle tract.

Fourth, a fractional cement injection protocol was adopted. Injection was temporarily paused for 1–2 minutes once the cement front advanced along the fracture line toward the vertebral periphery. This interval allowed partial polymerization of the cement at the periphery, after which injection was resumed. This method effectively reduced the risk of cement leakage along the fracture line.

Fifth, the CAT effectively improved and maintained vertebral height and reduced kyphotic deformity. Significant postoperative improvements in vertebral height and kyphosis angle were observed in both groups. However, mild deterioration of these parameters in conventional PVP group was noted at final follow-up, likely attributable to the natural progression of underlying osteoporosis[33]. While we do not have direct biomechanical testing data in this clinical study, the significant improvement in observed in CAT group provides indirect clinical evidence.

In terms of pain relief and functional recovery, the cement anchoring technique yielded significantly better outcomes in stage II KD compared with conventional PVP. Additionally, this technique did not increase operative time or medical costs compared with PVP for OVCFs, demonstrating its clinical feasibility.

Limitations

This study has several limitations. First, due to the retrospective design, grouping is not random, but based on established clinical pathways of different surgical teams. Although there is no significant difference in baseline data, it still cannot completely rule out potential bias caused by other unknown confounding factors. Second, Although we have proposed the advantageous principles of CAT, based on

previous biomechanical studies, this study is a clinical observation and lacks direct in vitro biomechanical testing data to quantitatively verify the strength changes of the cement bone interface. Future studies would benefit from a prospective design with a larger cohort and more comprehensive functional and radiographic outcome measures.

Cement anchoring technique is a safer and more effective alternative for treating stage II KD. It effectively alleviates pain symptom, promotes better cement diffusion, prevents cement leakage, and effectively improve and maintain vertebral height and reduced kyphotic deformity.

Abbreviations

KD
Kummell's Disease
OVCFs
Osteoporotic Vertebral Compression Fractures
IVC
intravertebral vacuum cleft
PVP
Percutaneous vertebroplasty
PKP
Percutaneous kyphoplasty
PMMA
Polymethylmethacrylate
BMD
Bone Mineral Density
DXA
dual-energy X-ray absorptiometry
VAS
Visual Analogue Scale
ODI
Oswestry Disability Index
AVH
Anterior Vertebral Height
MVH
Middle Vertebral Height
PVH
Posterior Vertebral Height

Declarations

2. Ethics approval and consent to participate

The study was approved by the Institutional Review Board (Beijing Friendship Hospital Capital Medical University (BJGH-EC/2014-029)). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.The requirement for written informed consent to participate was waived by the ethics committee due to the retrospective study design and the use of anonymized data.

3. Consent for publication

Not applicable.

4. Availability of data and materials

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

5. Competing Interests

The authors declare that they have no competing interests.

6. Funding

This research received no external funding.

7. Authors' contributions

NL, XH X and GQ Z have made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data. NL, XH X and GQ Z are involved in drafting the manuscript or revising it critically for important intellectual content. NL and XH X contributed to the work equally and should be regarded as co-first authors. GQ Z agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors have read and approved of the final manuscript.

8. Acknowledgements

Not applicable.

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Tables

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