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ORIGINAL RESEARCH ARTICLE

Postoperative complications of vertebral augmentation for osteoporotic vertebral compression fractures: A multicenter descriptive clinical and imaging study

Xiaoming Zhao[1], Yingang Zhang[1], and Jun Gao[2]*

[1]Department of Orthopedics, The First Affiliated Hospital, Xi'an Jiaotong University, Xi'an, Shaanxi, China

[2]Department of Orthopedics, Xi'an Fengcheng Hospital, Xi'an, Shaanxi, China

Abstract

Introduction: Osteoporotic vertebral compression fractures (OVCFs) are a major source of pain and disability in older adults. Percutaneous vertebroplasty and kyphoplasty stabilize the fractured vertebra and often provide rapid analgesia, yet procedure-related events remain clinically relevant. In particular, the behavior of polymethyl methacrylate (PMMA) cement—leakage, endplate breach, and nonuniform fill—can be underrecognized without targeted imaging follow-up. Such characterization may guide safer injection technique and postoperative surveillance strategies.

Objective: This study aims to evaluate the incidence and imaging characteristics of postoperative complications after vertebral augmentation in patients with OVCFs and to provide hypothesis-generating clinical imaging observations.

Methods: Clinical and imaging data from patients with OVCFs who underwent percutaneous vertebroplasty or percutaneous kyphoplasty at three medical centers between 2023 and 2025 were retrospectively reviewed. A single commercial low-viscosity PMMA cement product was used intraoperatively for all patients. The types and incidence of complications during postoperative follow-up were systematically recorded, and descriptive analyses were performed alongside imaging findings.

Results: Among 102 patients (154 treated vertebrae; ≥12-month follow-up), 41 developed postoperative complications. Cement-related findings were frequent: leakage in 11 patients (10.78%), uneven intravertebral distribution in 8, cement penetration through the endplate into the intervertebral disc in 5, and aseptic loosening or displacement in 7. Six patients had adjacent vertebral refractures and two had other adverse events. Most complications caused no severe neurological dysfunction and improved with symptomatic treatment. Imaging follow-up revealed recurring patterns of location and morphology across complication categories.

Conclusion: Postoperative complications after vertebral augmentation for OVCFs were heterogeneous, with cement-related imaging findings being relatively common. This descriptive observational imaging series summarizes these patterns and situates them within prior literature on PMMA behavior, generating hypotheses for future prospective, quantitative, and biomechanical investigations.

***Corresponding author:**
Jun Gao
(gaojun201303@163.com)

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1. Introduction

Osteoporotic vertebral compression fractures (OVCFs) are among the most common types of spinal fractures in the elderly population and have become a major global public health concern.[1,2] Epidemiological studies indicate that approximately 1.5 million fractures each year in the United States are directly related to osteoporosis, of which more than 500,000 are OVCFs.[3] Such fractures often result in persistent low back pain and limited mobility, severely impairing patients' quality of life and independence, and are associated with a markedly increased risk of disability and mortality in elderly individuals.[4-6] Conventional conservative treatments, including bed rest, analgesia, and activity restriction, show limited efficacy in some patients, while prolonged immobilization may further lead to complications, such as pulmonary infection, deep vein thrombosis of the lower extremities, muscle weakness, and spinal deformity.[4]

Percutaneous vertebroplasty (PVP) and percutaneous kyphoplasty (PKP), as minimally invasive spinal interventional techniques, have been widely applied in the clinical management of OVCFs.[7-9] These procedures involve the percutaneous injection of polymethyl methacrylate (PMMA) bone cement into the affected vertebral body to enhance vertebral stability, partially restore vertebral height, and correct kyphotic deformity.[10,11] In addition, the local thermal and chemical effects generated during cement polymerization may contribute to pain relief.[11,12] Consequently, PVP and PKP have achieved relatively consistent clinical acceptance in terms of short-term analgesia and functional improvement.[7-9] However, with prolonged follow-up, complications related to vertebral augmentation have gradually attracted increasing attention.[13,14] Previous studies have reported various adverse events after PVP or PKP, including bone cement leakage, uneven cement distribution, adjacent vertebral refracture, cement penetration through the endplate into the intervertebral disc, and aseptic loosening or displacement of bone cement.[15,16] Several studies have further hypothesized that cement handling and the material or biological behavior of PMMA (e.g., stiffness mismatch, bioinert interface, and limited remodeling) may contribute to certain postoperative imaging findings; nevertheless, direct clinical evidence linking specific cement properties to complications remains limited, particularly in studies with systematic imaging follow-up.[17-20]

Therefore, we conducted a multicenter retrospective study of patients with OVCFs treated with PVP or PKP to systematically describe the incidence, types, and imaging patterns of postoperative complications. By using a single commercial low-viscosity PMMA cement in all cases, we aim to reduce material heterogeneity across centers. Mechanistic interpretations in this manuscript are therefore presented as hypothesis-generating observations and are discussed in the context of existing literature rather than as causal conclusions. This descriptive imaging series is intended to provide practical references for postoperative surveillance and to inform future prospective and quantitative research.

2. Methods

2.1. Study design

In this study, we conducted a multicenter, retrospective observational clinical investigation. Patients were recruited from the Department of Spine Surgery of the First Affiliated Hospital of Xi'an Jiaotong University, the Department of Orthopedics of Hancheng Branch of the First Affiliated Hospital of Xi'an Jiaotong University, and the Department of Spine Surgery of the Xi'an Fengcheng Hospital. Clinical and imaging data of patients who underwent PVP or PKP for OVCFs between 2023 and 2025 were retrospectively collected. The study protocol was approved by the Ethics Committee of the First Affiliated Hospital of Xi'an Jiaotong University (Approval No. XJTU1AFCRC2019SJ-025) and was conducted in strict accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all individual participants included in this study.

2.2. Study population

2.2.1. Case source and sample size

Based on the inclusion and exclusion criteria, a total of 102 eligible patients were enrolled. Among them, 69 patients underwent PVP and 33 patients underwent PKP. All patients met the indications for vertebral augmentation and completed at least a 12-month postoperative follow-up.

2.2.2. Inclusion criteria

Patients were included if they m*et a*ll of the following criteria:

(i) A confirmed diagnosis of osteoporosis based on

bone mineral density testing (T-score ≤ −2.5), with no definite history of severe spinal trauma.

(ii) A clear diagnosis of recent thoracic or lumbar osteoporotic vertebral compression fracture based on medical history, physical examination, and imaging examinations (X-ray, computed tomography [CT], and magnetic resonance imaging [MRI]).

(iii) MRI showing low signal intensity on T1-weighted images and high signal intensity on T2-weighted images and short tau inversion recovery (STIR) sequences in the fractured vertebral body.

(iv) The presence of definite low back pain directly attributable to the vertebral fracture, with poor response to conservative treatment and an established indication for surgical intervention.

(v) A non-burst fracture pattern without clinical manifestations of spinal cord or nerve root injury.

(vi) Complete preoperative data, a postoperative follow-up period of no less than 12 months, and the availability of complete clinical and imaging follow-up data.

2.2.3. Exclusion criteria

Patients were excluded if any of the following conditions were present:

(i) Vertebral augmentation performed for non-osteoporotic diseases such as vertebral hemangioma, multiple myeloma, or spinal metastatic tumors.

(ii) Concomitant severe cervical spondylosis, spinal canal stenosis, lumbar disc herniation, or other spinal disorders that could interfere with postoperative evaluation.

(iii) Postoperative complications clearly unrelated to vertebral augmentation.

(iv) Severe cardiac, pulmonary, hepatic, or renal dysfunction, coagulation disorders, psychiatric disorders, or communication impairments that precluded tolerance of surgery or adequate cooperation with the procedure.

(v) Incomplete clinical, imaging, or follow-up data.

2.3. Bone cement material

In this study, the same PMMA bone cement (PALACOS® LV, Heraeus Medical GmbH, Italy) was used intraoperatively in all patients. This low-viscosity bone cement consists of a powder component (PMMA, barium sulfate, and benzoyl peroxide) and a liquid component (methyl methacrylate, N,N-dimethyl-p-toluidine, and hydroquinone), and is suitable for vertebral augmentation in osteoporotic vertebral fractures.

2.4. Surgical procedures

2.4.1. Percutaneous vertebroplasty

Patients were placed in the prone position with soft pads under the chest and abdomen to reduce intra-abdominal pressure. Under fluoroscopic guidance using a C-arm X-ray system, the target vertebra and puncture entry point were identified. After routine disinfection and draping, local anesthesia was administered. A puncture needle was advanced through the pedicle into the anterior one-third of the affected vertebral body. Under continuous fluoroscopic monitoring, the prepared PMMA bone cement was slowly injected, with close observation of cement dispersion. Injection was immediately discontinued if abnormal leakage or neurological irritation symptoms occurred. After complete cement polymerization, the puncture needle was removed, and the entry site was compressed and dressed.

2.4.2. Percutaneous kyphoplasty

The patient positioning and puncture approach were similar to the method described in Section 2.4.1. After placement of the puncture needle into the vertebral body, a balloon tamp was inserted through the working channel and gradually inflated with contrast medium to restore vertebral height and create a cavity for bone cement. Once a satisfactory reduction was achieved, the balloon was removed, and PMMA bone cement was injected into the vertebral body under fluoroscopic guidance until the cavity was adequately filled. The puncture instruments were removed after cement hardening. The surgical procedures and perioperative management protocols were consistent across the three participating centers.

2.5. Postoperative management and follow-up

After surgery, patients were routinely maintained in the supine position, with monitoring of vital signs as well as motor and sensory function of the lower extremities. Early postoperative X-ray or CT examinations were performed to assess bone cement distribution and detect potential leakage. Patients were advised to avoid strenuous activities within the first three weeks postoperatively and to wear a lumbar brace for protection. All patients received standardized anti-osteoporosis therapy, including calcium and vitamin D supplementation, with additional agents such as calcitonin administered when necessary.

Each participating center followed its routine clinical imaging protocols; however, all centers adhered to a pre-specified minimum imaging set for this study. This included intraoperative fluoroscopy during cement injection and

early postoperative anteroposterior and lateral radiographs and/or CT within 24–72 h to evaluate cement distribution and detect early leakage. Follow-up imaging primarily relied on radiographs at scheduled visits (recommended at 1, 3, 6, and 12 months when feasible). Additional CT or MRI (including T1-weighted, T2-weighted, and STIR sequences) was performed when new or aggravated pain, neurological symptoms, or suspected new fractures occurred. All imaging examinations were reviewed in the local picture archiving and communication system with side-by-side comparison to immediate postoperative images.

2.6. Outcome measures

The primary outcome measure was the occurrence of complications during postoperative follow-up after vertebral augmentation. All patients routinely underwent anteroposterior and lateral spinal radiography or CT within 24–72 h postoperatively to evaluate bone cement distribution and detect early complications. Follow-up was recommended at 1, 3, 6, and 12 months postoperatively (or according to the actual follow-up schedule of the study).

To identify the type of complication, additional CT or MRI examinations were performed when new-onset or aggravated thoracolumbar pain, radiating pain in the lower extremities, numbness, or weakness occurred. Complications were recorded at the patient level (any event during follow-up) and, when possible, at the treated-vertebra level. Because multiple vertebrae could be treated in one patient and more than one complication could occur in the same patient or vertebra, subtype counts were not mutually exclusive. Complications were independently assessed by two spine surgeons and one radiologist who were blinded to treatment group; discrepancies were resolved by consensus discussion. Formal interobserver reliability statistics were not calculated; this is acknowledged as a study limitation.

2.6.1. Cement leakage

Cement leakage was defined as bone cement breaching the cortical boundary of the vertebral body and extending into extravertebral structures, including paravertebral soft tissues, the spinal canal or intervertebral foramen, the venous system, or the intervertebral disc. Diagnosis was based on intraoperative fluoroscopy and postoperative X-ray or CT findings. The leakage location (e.g., anterior, posterior, lateral, spinal canal, intervertebral foramen, and paravertebral veins) and the presence of corresponding clinical symptoms (e.g., neurological irritation or cardiopulmonary abnormalities) were recorded. The leakage pathway was further classified according to the Yeom classification: Type B (via the basivertebral vein), Type S (via the segmental vein), and Type C (via cortical defects).

2.6.2. Uneven intravertebral cement distribution

The intravertebral distribution pattern of bone cement was evaluated primarily using postoperative CT, with X-ray as a supplementary modality. A semi-quantitative grading system was applied to improve reproducibility:

(i) Grade 1 (good): Cement crossed the vertebral midline and was relatively evenly dispersed within the vertebral body, with contact with at least one of the superior or inferior endplates.
(ii) Grade 2 (fair): Cement did not cross the midline or showed localized, clustered distribution but still provided basic mechanical support.
(iii) Grade 3 (poor): Cement was markedly confined to one side or a limited area, presenting obvious "clumping/void" patterns with potential mechanical insufficiency.

2.6.3. Adjacent vertebral fracture

Adjacent vertebral fracture was defined as a new fracture occurring in the vertebral body immediately above or below the previously augmented vertebra during follow-up. Diagnostic criteria included: (i) new-onset or aggravated localized pain; (ii) imaging evidence meeting any of the following—X-ray or CT showing further loss of vertebral height or morphological changes, graded using the Genant semi-quantitative method (mild, moderate, or severe according to the degree of height loss); and (iii) MRI findings indicative of an acute fracture, such as bone marrow edema with high signal intensity on T2-weighted or STIR images, used to confirm a new fracture.

2.6.4. Intradiscal cement leakage

Intradiscal cement leakage was defined as penetration of bone cement through the superior or inferior endplate into the adjacent intervertebral disc space, identified as high-density cement within the disc space on X-ray or CT images. The direction of penetration (cranial or caudal) and the extent of disc involvement were recorded, with semi-quantitative grading based on the affected disc area (e.g., <1/3, 1/3–2/3, >2/3). When preoperative and postoperative MRI data were available, the degree of disc degeneration was additionally documented using the Pfirrmann classification.

2.6.5. Aseptic loosening, displacement, or migration of bone cement

Aseptic loosening was considered when follow-up X-ray or CT demonstrated changes in the position of the cement

mass compared with immediate postoperative images, or when a persistent radiolucent zone or separation was observed at the cement–bone interface, after excluding infection. The direction of displacement (e.g., anterior, lateral, toward the spinal canal) and associated clinical manifestations, such as pain aggravation or neurological symptoms, were recorded.

2.6.6. Other adverse events

Other adverse events included infection, allergic reactions, and thermal or neurological complications. Infection was suspected in cases of persistent postoperative local pain, fever, or elevated inflammatory markers, and was diagnosed based on imaging findings (MRI or CT) and, when necessary, aspiration or culture results. Allergic reactions included perioperative manifestations such as skin rash, bronchospasm, or blood pressure fluctuations. Thermal injury or neurological complications were defined as new-onset neurological deficits or irritation symptoms occurring shortly after surgery, recorded after excluding mechanical compression on imaging.

2.7. Statistical analysis

Statistical analyses were performed using SPSS 22.0 (IBM Corp., Armonk, USA). Continuous variables are presented as the mean ± standard deviation, and categorical variables are expressed as counts and percentages. Baseline characteristics between the PVP and PKP groups were compared using Welch's *t*-test for continuous variables and the chi-square test for categorical variables. The incidence of postoperative complications was summarized descriptively. Exploratory comparative analyses of complication predictors (e.g., PVP vs. PKP, thoracic vs. lumbar, or cement distribution patterns vs. specific complications) and multivariable models were not performed due to limited event counts per category, non-independence of observations in multi-level cases, and incomplete availability of potential covariates in this retrospective dataset.

3. Results

3.1. Baseline patient characteristics

A total of 102 patients with OVCFs who met the inclusion criteria were enrolled in this study. Sixty-nine patients underwent PVP and 33 underwent PKP. The mean age in the PVP group was 59.01 ± 12.36 years (range: 40–80 years), including 41 males (59.4%) and 28 females (40.6%). The mean age in the PKP group was 63.03 ± 10.59 years (range: 40–80 years), including 20 males (60.6%) and 13 females (39.4%).

At the patient level, 28 thoracic and 41 lumbar procedures were performed in the PVP group, while 14 thoracic and 19 lumbar procedures were performed in the PKP group. There were no statistically significant differences between the two groups in terms of age (independent-samples *t*-test, $p = 0.094$), sex distribution (χ^2 test, $p = 0.909$), or distribution of surgical levels (χ^2 test, $p = 0.859$), indicating good comparability of baseline characteristics between the groups (Table 1).

In total, 154 vertebral bodies were treated in this study. Overall, 42 patients underwent thoracic vertebral procedures and 60 patients underwent lumbar vertebral procedures.

3.2. Surgical outcomes and follow-up

All patients successfully underwent PVP or PKP, and no life-threatening perioperative adverse events were observed.

Table 1. Baseline patient characteristics in the percutaneous vertebroplasty or percutaneous kyphoplasty groups

Variable	PVP (*n* = 69)	PKP (*n* = 33)	*p*-value
Age (years), mean ± standard deviation	59.01 ± 12.36	63.03 ± 10.59	0.094
Male, *n* (%)	41 (59.4)	20 (60.6)	0.909
Female, *n* (%)	28 (40.6)	13 (39.4)	
Surgical level (per patient)			
Thoracic spine, *n* (%)	28 (40.6)	14 (42.4)	0.859
Lumbar spine, *n* (%)	41 (59.4)	19 (57.6)	

Notes: Data are presented as mean ± standard deviation or as number of patients (percentage). Welch's *t*-test was used for continuous variables, and the chi-square test was used for categorical variables.
Abbreviations: PKP: Percutaneous kyphoplasty; PVP: Percutaneous vertebroplasty.

Complete postoperative follow-up data were obtained for all patients, with a minimum follow-up duration of 12 months. Among the 102 patients, 61 patients (involving 98 treated vertebrae) showed no complications during surgery or follow-up, whereas the remaining 41 patients (involving 54 treated vertebrae) developed postoperative complications during the follow-up period.

3.3. Incidence of postoperative complications after vertebral augmentation

During follow-up, multiple postoperative complications were observed. Unless otherwise specified, the following incidences are reported per patient, and subtype counts are not mutually exclusive.

Cement leakage occurred in 11 patients (10.78%). Some patients had leakage at more than one site. The distribution of leakage sites was as follows: anterior vertebral margin in 6 cases, posterior margin in 2, intervertebral foramen in 1, and lateral vertebral margin in 4 cases. Uneven intravertebral cement distribution was observed in eight patients (7.84%), mainly characterized by localized cement aggregation without uniform filling of the vertebral body. Penetration of bone cement through the vertebral endplate into the intervertebral disc occurred in five patients (4.90%), including cranial penetration in three cases and caudal penetration in two cases. Aseptic loosening, detachment, or displacement of bone cement was identified in seven patients (6.86%), with anterior displacement in five cases and lateral displacement in two cases. Adjacent vertebral refractures occurred in six patients (5.88%), all involving vertebrae adjacent to the previously augmented levels. In addition, two other postoperative adverse events were observed (1.96%), including one vertebral infection and one allergic reaction.

A structured summary of the typical timing, imaging modality, symptoms, and management of each complication type is provided in Table 2.

Table 2. Summary of postoperative complications, typical timing of detection, imaging modality, symptoms, and management (patient-level reporting)

Complication type	Number of patients, *n* (%)	Typical timing of detection	Primary imaging modality	Typical symptoms	Management/outcome
Cement leakage	11 (10.78%)	Intraoperative or ≤72 h	Fluoroscopy; X-ray/CT	Usually none; occasional irritation symptoms	Observation and symptomatic treatment; no severe neurological events observed
Uneven cement distribution	8 (7.84%)	≤72 h	CT (preferred); X-ray	Often asymptomatic; may relate to residual pain	Observation, brace as needed, anti-osteoporosis therapy
Intradiscal cement leakage	5 (4.90%)	≤72 h	X-ray/CT	Often asymptomatic; potential disc-related pain later	Close imaging follow-up; conservative management
Aseptic loosening/ displacement	7 (6.86%)	During follow-up (months)	X-ray/CT (comparison to baseline)	Possible pain aggravation	Conservative management and close follow-up; no reoperation required in this series
Adjacent vertebral fracture	6 (5.88%)	During follow-up	X-ray/CT; MRI for acute confirmation	New-onset/aggravated localized pain	Analgesia and intensified anti-osteoporosis therapy; additional imaging as indicated
Other adverse events (infection/allergy)	2 (1.96%)	Perioperative/early	Laboratory tests; X-ray, CT, or MRI as clinically indicated	Fever/pain or allergic manifestations	-

Abbreviations: CT: Computed tomography; MRI: Magnetic resonance imaging.

3.4. Complication management and follow-up outcomes

All 41 patients who developed postoperative complications received appropriate management according to the type of complication, including pharmacological treatment, imaging-based follow-up observation, and additional interventions when necessary. During the subsequent 6–12 months of follow-up, most patients experienced marked improvement or complete resolution of symptoms compared with their pre-treatment status. No severe neurological dysfunction or requirement for reoperation due to complications was observed.

3.5. Representative imaging findings

During postoperative follow-up, different types of complications exhibited representative imaging characteristics. To visually illustrate common bone cement-related complications after vertebral augmentation, three representative imaging patterns are presented (Figures 1-3).

3.5.1. Cement leakage

Cement leakage was mainly characterized by bone cement breaching the cortical boundary of the vertebral body and extravasating toward the anterior or lateral margins. X-ray and CT images clearly demonstrated cement distribution along the anterior or lateral aspects of the vertebral body, presenting as linear or patchy high-density radiographic findings (Figure 1).

3.5.2. Intradiscal cement leakage

In some cases, bone cement penetrated the vertebral endplate and entered the adjacent intervertebral disc. Imaging findings were characterized by high-density cement within the intervertebral disc space, typically located near areas of endplate thinning or disruption. CT images, particularly sagittal reconstructions, were helpful in delineating the spatial distribution of intradiscal cement (Figure 2).

3.5.3. Aseptic loosening or displacement of bone cement

On follow-up imaging, some cases demonstrated changes in the position of the bone cement with partial separation from the main vertebral body, manifested as anterior or lateral displacement of the cement mass. CT images and three-dimensional reconstructions further illustrated the interface between the bone cement and surrounding bone tissue, as well as the extent and direction of cement displacement (Figure 3).

4. Discussion

This multicenter retrospective study provides a descriptive characterization of postoperative complications after vertebral augmentation (PVP or PKP) for OVCFs. Across 102 patients (154 treated vertebrae) with at least a 12-month follow-up, complications were heterogeneous, including cement leakage, uneven intravertebral cement distribution, intradiscal cement leakage, aseptic loosening

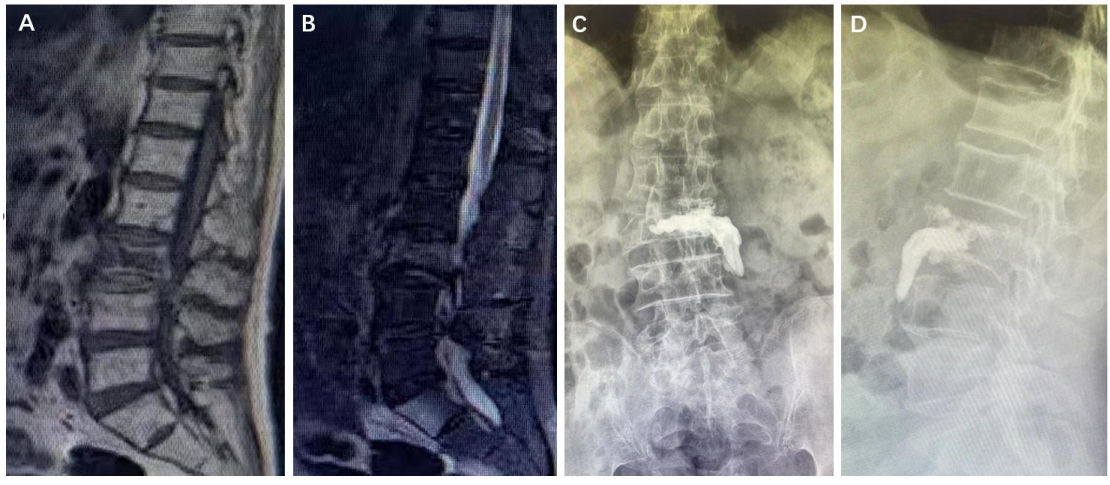

Figure 1. Inferior cement leakage following vertebral augmentation in a 71-year-old male with an osteoporotic L3 compression fracture. (A, B) Preoperative sagittal T2-weighted and fat-suppressed MRI demonstrating an acute compression fracture of L3. (C, D) Postoperative anteroposterior and lateral radiographs showing cement leakage extending inferiorly along the anterior margins of L3 and L4.

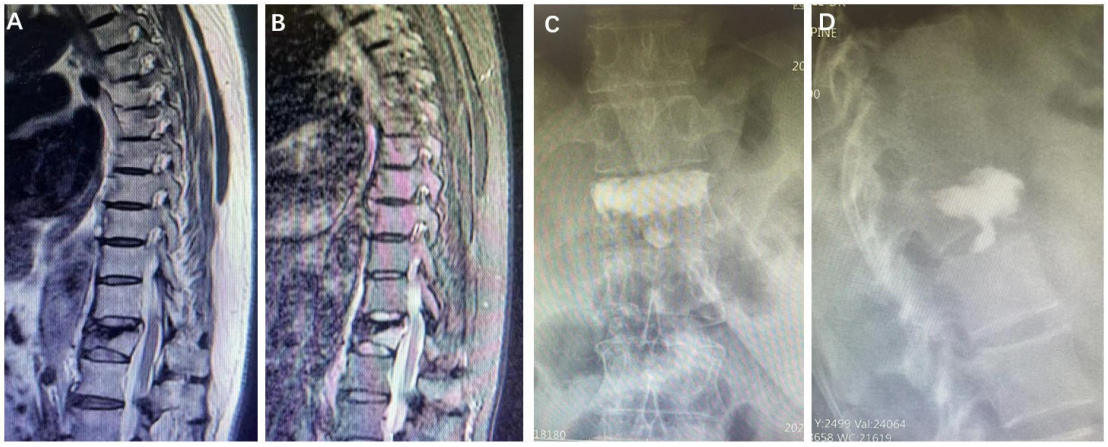

Figure 2. Cement migration into the intervertebral disc following vertebral augmentation in a 63-year-old female with an osteoporotic L2 compression fracture. (A, B) Preoperative sagittal magnetic resonance imaging demonstrating the acute L2 fracture. (C, D) Postoperative anteroposterior and lateral radiographs showing cement migration across the endplate into the adjacent L2–L3 intervertebral disc space.

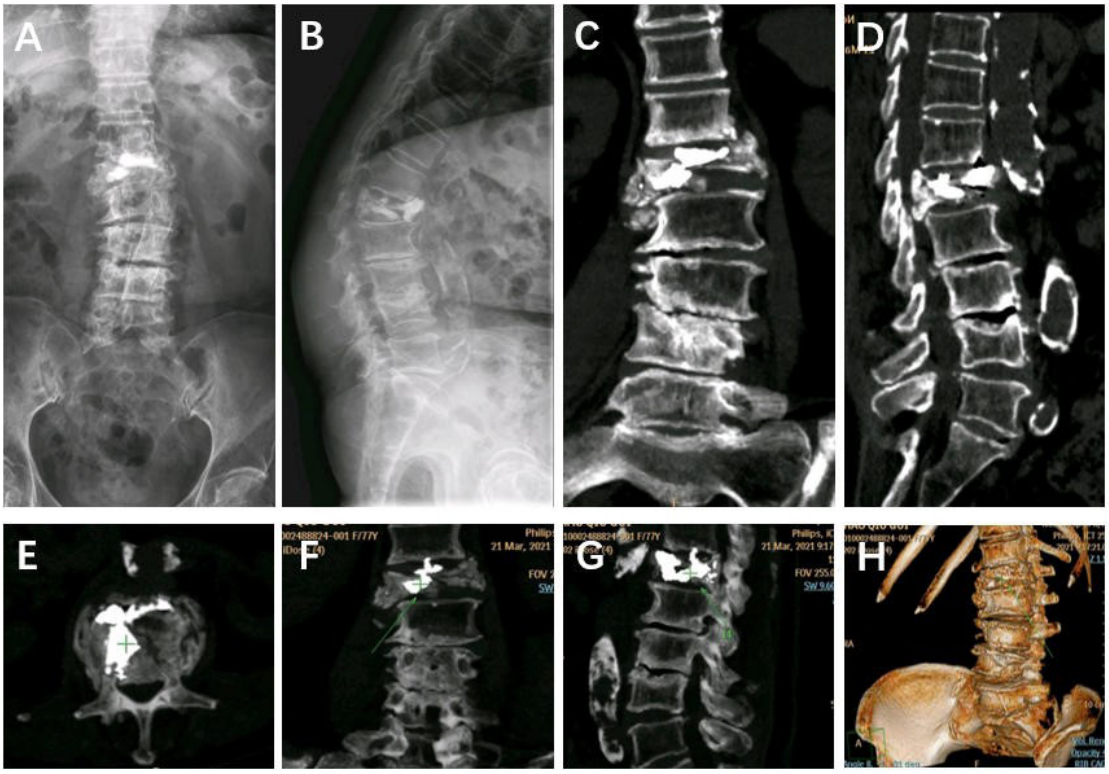

Figure 3. Lateral cement displacement following vertebral augmentation in a 68-year-old female with an osteoporotic L2 compression fracture. (A, B) Follow-up radiographs demonstrating lateral displacement of cement from the treated vertebral body. (C–H) Computed tomography images with three-dimensional reconstructions showing the spatial relationship between the displaced cement and surrounding vertebral structures.

or displacement, adjacent vertebral fracture, and rare other adverse events. Most complications did not result in severe neurological dysfunction in this series and were managed conservatively.

Importantly, the present work is positioned as an observational imaging study. The main contribution is the structured description of imaging patterns in their clinical context, based on multicenter follow-up and the use of a single PMMA cement product to reduce material heterogeneity. Any discussion of PMMA cement behavior or material properties is therefore intended to contextualize observations and generate hypotheses, rather than to establish causality.

4.1. Imaging patterns of cement leakage and intravertebral distribution

Cement leakage is one of the most common complications associated with vertebral augmentation. In the present study, the incidence of cement leakage was comparable to that reported in previous literature, with leakage predominantly occurring at the anterior and lateral margins of the vertebral body.[21,22] Although most leakage cases did not produce clinically significant symptoms, their potential risks warrant attention.[21] Uneven intravertebral cement distribution was also observed, manifested as heterogeneous filling patterns on postoperative imaging.[23] These findings should be interpreted primarily as imaging observations rather than evidence of material failure.

From a theoretical standpoint and based on prior studies, multiple factors may contribute to leakage and abnormal distribution. Cement handling during injection, including the rheological properties and viscosity evolution of PMMA, may influence intravertebral dispersion behavior to a certain extent.[23] Relatively limited flowability may hinder sufficient and uniform filling of trabecular spaces, leading to extrusion along paths of least resistance under localized pressure.[22] In addition, fixation between PMMA bone cement and bone tissue relies mainly on mechanical interlocking rather than bioactive bonding; this interfacial characteristic has been suggested to facilitate cement propagation along fracture clefts or areas of endplate weakness in some situations.[24]

Procedural and anatomical factors—including fracture morphology (e.g., pre-existing cortical disruption or intravertebral cleft), needle position, injection pressure, and timing—have also been discussed as potential contributors in the literature.[22-25] However, because the present retrospective dataset did not include quantitative rheological measurements, detailed injection parameters, cement volume metrics, or standardized fracture-pattern grading, the relative contribution of these factors cannot be determined from this study. Therefore, we present these explanations as hypothesis-generating context, and our structured imaging descriptions may help guide postoperative surveillance and inform future prospective studies with quantitative outcomes.

4.2. Imaging observation of cement loosening or displacement and clinical considerations

Aseptic loosening or displacement of cement was observed on follow-up imaging in a subset of patients. Similar imaging findings have been described previously and may reflect a multifactorial process, including progressive osteoporotic collapse, insufficient cement interdigitation, and long-term micro-motion at the cement–bone interface. PMMA is generally considered bioinert and does not osseointegrate with host bone, which has been proposed as a contributing factor in the literature.[26-30] However, imaging alone cannot confirm biological failure, and we did not perform histology or quantitative interface assessment. Therefore, we report these events descriptively, and prospective imaging and biomechanical studies are essential to clarify their predictors and clinical implications.

4.3. Adjacent fracture and intradiscal leakage: Observed patterns and potential contributing factors

Adjacent vertebral fracture and intradiscal cement leakage are clinically relevant late or follow-up findings. In this study, adjacent fractures occurred at levels neighboring the treated vertebrae, and intradiscal leakage was identified as high-density cement signals within the disc space. Prior biomechanical and clinical studies have suggested that these events may result from a combination of baseline osteoporosis severity, endplate integrity, cement contact with the endplate or disc, spinal alignment, and postoperative anti-osteoporosis management.[31-35] Cement stiffness mismatch and altered segmental load transfer have also been proposed as possible contributors in the literature.[32-34] Because the present study did not include quantitative measures of bone density severity, cement volume, injection pressure, or finite element modeling, these explanations should be viewed as hypotheses requiring targeted validation.

4.4. Other adverse events and peri-cement reactions

Other adverse events were rare in this cohort. PMMA bone cement releases heat during polymerization; this thermal effect is thought to contribute, to some extent, to pain relief, but it may also adversely affect surrounding tissues.[36] When cement is located close to nerve roots or the spinal cord, local temperature elevation may be associated with transient neural irritation, and excessive heat has been proposed to cause thermal injury to adjacent bone or soft tissues, potentially impairing local healing.[37,38] In addition, trace amounts of monomers or related byproducts released from PMMA *in vivo* may trigger peri-cement inflammatory responses or allergic reactions in susceptible individuals.[39]

In the present study, one infection case and one allergic reaction were observed; however, the small number of events and the observational nature of the dataset preclude further inference regarding causality or specific triggers. Clinically, careful perioperative monitoring, appropriate aseptic technique, and prompt evaluation of new symptoms remain essential, especially when patients develop fever, progressive pain, or systemic allergic manifestations during early follow-up.[40]

4.5. Study limitations

Several limitations should be acknowledged. First, this study is a retrospective observational study, and the analyses were primarily based on imaging follow-up findings and contextual interpretation of published literature; therefore, the results should be regarded as descriptive and hypothesis-generating rather than providing causal evidence. Second, the sample size and the number of events within each complication subtype were limited, and multi-level procedures introduced non-independence of observations. As a result, we did not perform robust exploratory predictor analyses or multivariable modeling (e.g., PVP vs. PKP, thoracic vs. lumbar), and systematic stratification by osteoporosis severity, fracture type/morphology, or number of treated levels was not feasible.

Third, follow-up intervals and imaging modalities were not fully standardized across all patients and centers; while early postoperative imaging was routinely obtained, additional CT or MRI during follow-up depended on clinical presentation, which may have introduced detection or verification bias for certain complication types. Fourth, important procedural covariates and quantitative parameters—including cement volume, injection pressure and timing, detailed needle position metrics, fracture morphology grading (e.g., endplate integrity or intravertebral cleft), and quantitative measures of cement distribution—were unavailable in the retrospective records, limiting mechanistic inference and preventing quantitative associations between technique-related factors and complications.

Fifth, we did not directly measure material-related parameters of PMMA cement (e.g., rheological behavior, elastic modulus, or monomer release), and we did not include biomechanical testing, histological validation, or quantitative imaging validation; thus, discussions of cement-related factors in this study should be interpreted as contextual hypotheses. Finally, although complications were adjudicated by two spine surgeons and one radiologist with consensus resolution, formal interobserver reliability statistics were not calculated. Collectively, these factors may restrict generalizability and highlight the need for larger prospective multicenter studies with standardized follow-up protocols, predefined imaging schedules, and quantitative outcomes.

5. Conclusion and future directions

Vertebral augmentation for OVCFs has demonstrated clear efficacy in pain relief and functional improvement; nevertheless, postoperative complications remain an important concern. Based on multicenter retrospective data, this study systematically summarized the types and imaging characteristics of postoperative complications from a clinical imaging perspective and explored their potential mechanisms at a theoretical level, in the context of previous research. Notably, this study did not directly measure specific material parameters of PMMA bone cement, such as rheological properties, elastic modulus, or biological activity. The analyses were primarily based on imaging follow-up findings and inferences from published literature; therefore, the conclusions should be interpreted as hypothesis-generating rather than providing causal evidence. Moreover, as a retrospective study with a relatively limited sample size, systematic statistical comparisons of complication patterns between PVP and PKP were not feasible, nor was it possible to further stratify the potential effects of osteoporosis severity, fracture type, or the number of treated levels on complication occurrence. These factors may limit the generalizability of the findings, which require validation in larger multicenter prospective studies.

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Conflict of interest

The authors declare that they have no commercial or financial relationships that could be perceived as a potential conflict of interest.

Author contributions

Conceptualization: Jun Gao
Formal analysis: Xiaoming Zhao
Investigation: Xiaoming Zhao
Methodology: Xiaoming Zhao, Jun Gao
Writing–original draft: Xiaoming Zhao
Writing–review & editing: Yingang Zhang, Jun Gao

Ethics approval and consent to participate

All participants provided written informed consent. All procedures were conducted in accordance with the Declaration of Helsinki (1964) and its later amendments.

Consent for publication

Written informed consent was obtained from all individual participants included in this study for participation and for the publication of their anonymized clinical data and imaging materials.

Availability of data

Data is available from the corresponding author upon reasonable request.

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