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Research Article

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Title page

Percutaneous vertebroplasty for neoplastic vertebral compression fractures in patients with spinal metastases: a single-center retrospective case series

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Abstract

Background: Neoplastic vertebral compression fractures resulting from spinal metastases substantially impair health-related quality of life in patients with cancer. Identifying a safe, minimally invasive palliative option to relieve mechanical pain in this population remains a clinical challenge. **Objective:**To assess the

intermediate-to-long-term clinical outcomes of percutaneous vertebroplasty (PVP) for pathological vertebral compression fractures in patients with spinal metastases, with a focus on pain relief and functional improvement. **Methods:** We retrospectively reviewed 89 patients with histologically confirmed solid tumors and imaging-confirmed spinal metastases who underwent PVP for painful neoplastic vertebral compression fractures between 2018 and 2023. All procedures were performed under local anesthesia and fluoroscopic guidance. Visual analogue scale (VAS), Oswestry Disability Index (ODI), analgesic use, cement leakage, complications, and local recurrence were recorded. Follow-up was based on outpatient and imaging records. **Results:** 89 patients (male 48, female 41; mean age 62.03 ± 2.17 years) were included. Mean follow-up was 36 months. VAS decreased from 7.71 ± 1.11 preoperatively to 5.82 ± 1.34 at 1 month and remained improved at last follow-up (median 36 months). ODI improved from 52.0% ± 8.3% preoperatively to 28.4% ± 6.7%. HAMA decreased from 18.2 ± 4.6 preoperatively to 11.3 ± 3.8 at 1 month ($P<0.05$). Cement leakage was observed in 23 patients (25.8%), all asymptomatic. No pulmonary cement embolism or neurological deterioration occurred. All patients received subsequent radiotherapy, chemotherapy, or systemic therapy according to the original oncologic treatment plan after PVP. Local progression at the index level, including adjacent-level refracture in 3 cases, was observed in 5 cases. **Conclusion:** At intermediate-to-long-term follow-up (mean 36 months), pain scores and functional status remained improved compared with baseline in this cohort of spinal metastasis patients treated with PVP for pathological vertebral compression fractures. PVP appears acceptable for intermediate-to-long-term palliation in carefully selected cases, pending validation in larger comparative studies.

Keywords: percutaneous vertebroplasty; spinal metastases; pathological vertebral compression fracture; case series; intermediate-to-long-term outcome

Introduction

The spine is the central pillar of the axial skeleton, providing structural support for the trunk while protecting the spinal cord, nerve roots, and thoracoabdominal viscera(1). Because of its rich vascular network and abundant red marrow, the spine is among the most common skeletal sites for hematogenous dissemination from solid tumors(2). Spinal metastases occur in more than 30% of patients with malignant tumors during their disease course, with lung, colorectal, and hepatic primaries prevailing in Asian cohorts and breast, prostate, and melanoma in Western populations(3, 4). As metastatic deposits replace vertebral body cancellous bone, mechanical integrity is progressively lost, frequently resulting in pathological vertebral compression fractures(5). These fractures produce severe, often refractory mechanical back pain, height loss, spinal instability, and, in advanced cases, neural compression with motor deficit—all of which markedly reduce quality of life and limit tolerance of oncologic treatments(6). Consequently, achieving durable palliation of mechanical pain and preserving vertebral stability have become key management goals in this population.

The pathogenesis of spinal metastases is complex, involving tumor cell colonization within vertebral cancellous bone and disruption of local bone remodeling. Metastatic deposits alter the vertebral microenvironment and drive lytic, blastic, or mixed osseous destruction, which compromises trabecular integrity and predisposes to pathological vertebral compression fractures(7). In parallel, tumor-derived inflammatory mediators (e.g., IL-6, IL-8, prostaglandins) contribute to persistent cancer-related pain, while expanding tumor tissue or fractured bone fragments may encroach on the spinal canal, causing cord or nerve root compression that manifests as radicular pain, sensory deficit, or paraparesis(7, 8). Furthermore, refractory back pain or cancer-related pain frequently precipitate anxiety and other negative affective states, which further erode patients' tolerance of oncologic care(9). Such complications amplify physical distress

and restrict mobility, and they are associated with reduced survival expectancy. Accordingly, the primary management goal in this setting is not oncologic cure but symptom-directed palliation aimed at pain control, preservation of mobility, and maintenance of quality of life.

Management of metastatic pathological vertebral compression fractures is palliative, comprising conservative and surgical options. Conservative measures, including opioids, non-steroidal analgesics, bisphosphonates, and denosumab, provide transient relief of mild pain but are inadequate for moderate-to-severe mechanical back pain(10). Prolonged use of opioids in particular is limited by tolerance, dependence, constipation, and other adverse effects, and none of these agents restore vertebral stability(11, 12). Surgical stabilization achieves more definitive mechanical support and faster analgesia; however, open procedures in this population carry high morbidity, with postoperative complication rates reported up to 66.7% and surgical site infection rates as high as 30%(13). Thus, appropriate selection of the surgical procedure in these patients is especially critical.

Surgical management of pathological vertebral compression fractures due to spinal metastases can be classified into open and minimally invasive procedures. Compared with open decompression and instrumented fixation, minimally invasive approaches are associated with less soft-tissue trauma, reduced intraoperative blood loss, shorter hospital stay, and earlier mobilization, which may help preserve functional independence in this frail population(14). Percutaneous vertebroplasty (PVP), as a representative vertebral augmentation technique, stabilizes the fractured vertebra by intravertebral polymethylmethacrylate (PMMA) injection, thereby reducing mechanical micro-motion and providing rapid pain relief(15). Although PVP carries risks such as cement leakage and potential iatrogenic injury to vertebral endplates(16), it was widely validated for osteoporotic vertebral compression fractures with an

acceptable safety profile(17). Nevertheless, evidence on its intermediate-to-long-term palliative outcomes in patients with neoplastic vertebral compression fractures from spinal metastases remains limited.

Accordingly, this study aimed to evaluate the intermediate-to-long-term (24-48 month) pain control and functional outcomes of PVP as a palliative stabilization procedure in this population.

Materials and Methods

Study design

This was a single-center retrospective case series. Consecutive patients treated between January 2018 and December 2023 were reviewed. The study included patients with pathological vertebral compression fractures (pVCFs) secondary to spinal metastases. The diagnosis of spinal metastatic pVCF was established based on imaging and, where available, histopathology(6). All enrolled patients underwent PVP under local anesthesia. This study was conducted in accordance with relevant ethical guidelines and regulations and was approved by the Ethics Review Board of The 960th Hospital of PLA (approval No. 100057). This study is a single-center retrospective observational case series. No prospective intervention allocation was performed; all patients underwent PVP according to routine clinical indication. Therefore, clinical trial registration does not applicable.

Detailed inclusion criteria

Patients were included if all of the following were met: (1) Documented history of a malignant solid tumor with prior systemic anticancer treatment; (2) Oligometastatic disease with no more than 3 skeletal metastatic lesions, and involvement of no more than 2 consecutive vertebral bodies; (3) Imaging evidence (CT and MRI) confirming vertebral compression fracture at the metastatic level; (4) Histologically confirmed metastatic involvement of the vertebra by biopsy (core needle or intraoperative specimen); (5)

Presence of at least one of the following: back pain, anxiety, restricted trunk function, or non-specific systemic/local symptoms (e.g., constipation, abdominal distension).

Exclusion criteria

Patients were excluded if they met any of the following: (1) No confirmed history of malignancy, or no evidence of metastatic disease from a known primary tumor; (2) Vertebral compression fracture not attributable to tumor metastasis (e.g., osteoporotic, traumatic, or iatrogenic fracture); (3) Prior PVP, kyphoplasty, or other spinal surgery at the index level that could confound outcome assessment; (4) Coexisting conditions that could independently cause vertebral compression fracture, with the primary cause of fracture being indeterminate; (5) Incomplete baseline clinical or imaging data, or loss to follow-up before the first postoperative assessment.

Surgical technique

All procedures were performed with the patient in the prone position, with both iliac crests padded to restore mild lumbar lordosis. Local infiltration anesthesia was administered as previously described. Under biplane fluoroscopic guidance, a bone biopsy needle was introduced through the unilateral pedicle into the anterior one-third of the vertebral body. A working cannula was advanced over the needle, and the tract was sequentially dilated as needed. PMMA bone cement, at doughy consistency, was then injected slowly under continuous fluoroscopy, with approximately 3 mL delivered per treated vertebra. Injection was stopped once satisfactory cement dispersion within the vertebral body was achieved, and the needle was withdrawn after complete polymerization of the cement. No attempt was made to fill the entire vertebral body (Fig1).

Clinical and safety evaluation

Postoperative plain radiographs (anteroposterior and lateral views) were obtained to assess PMMA distribution within the vertebral body, restoration of vertebral height, and segmental spinal stability. Clinical pain and functional status were evaluated using the Visual Analog Scale (VAS) for back pain, the Hamilton Anxiety Scale (HAMA), and the Oswestry Disability Index (ODI).

Follow-up

Assessments were performed at 24 h, 1, 3, 6, 12, 24 and 36 months. At each visit, VAS, ODI, HAMA, and radiographs were recorded, and all complications/adverse events (cement leakage, neurologic deficit, infection, adjacent fracture, rehospitalization) were documented. Survival status was confirmed at last follow-up.

Observation indicators

Outcomes included VAS (0-10), HAMA (14-item, 0-56; lower = milder anxiety), and ODI (0-50). A descriptive response category was defined as: marked (substantial pain relief, independent walking), partial (mild pain, independent walking), or minimal (needs assistive device). Marked + partial = combined response rate (descriptive). All scales were assessed at baseline and at each follow-up point, with the final assessment at median 36 months.

Statistical Analysis

Analyses used SPSS 26.0 (IBM). Continuous data are shown as mean ± SD and compared by paired t test; categorical data as n (%), compared by χ^2 test (Fisher's exact test if applicable). Two-sided $P < 0.05$ was significant.

Results

A total of 89 patients were included [verify: 48 Male, 41 Female], with a mean age of 62.03 ± 2.17 years. All patients successfully underwent PVP, with a mean operative time of 32.16 ± 7.12 min. No

suspected cement allergy or PMMA-related toxicity occurred. Cement leakage was observed in 23 patients (25.8%), all asymptomatic or conservatively managed. All incisions achieved primary healing, with no surgical-site infection during follow-up (Table 1). Based on the postoperative pain-mobility classification, the combined response rate (marked + partial response) was 88.8% (79/89) (Table 2). Compared with preoperative baseline, VAS scores (Table 3), HAMA scores (Table 4), and ODI scores (Table 5) were significantly improved at follow-up (all two-sided $P < 0.01$).

Table 1. Characteristics of the study population

Demographics	Total
Garden, n (%)	89
Male	48 (53.9%)
Female	41 (46.2%)
Age (years), (mean ± SD)	62.03 ± 2.17
BMI, (mean ± SD)	23.52 ± 3.21
Primary malignancy, n (%)	
Lung cancer	35 (39.3%)
Breast cancer	15 (16.9%)
Prostate cancer	10 (11.2%)
Gastrointestinal	12 (13.5%)
Renal / Thyroid / Other	17 (19.1%)
Hypertension, n (%)	35 (39.3%)
CHD, n (%)	15 (16.9%)
Diabetes, n (%)	20 (22.5%)
Fractured level, n (%)	
Thoracic (T1–T10)	20 (22.5%)
Thoracolumbar (T11–L2)	30 (33.7%)
Lumbar (L3–L5)	35 (39.3%)
Multiple levels	4 (4.5%)
Symptom duration before PVP (months), (mean ± SD)	3.2 ± 1.8
Surgical side, n (%)	
Left transpedicular	30 (33.7%)
Right transpedicular	50 (56.2%)
Parapedicular	9 (10.1%)
mean operative time (min), (mean ± SD)	32.16 ± 7.12
Cement volume per level (mL), (mean ± SD)	3.20 ± 0.80

BMI = body mass index, CHD = coronary heart disease

Table 2. Postoperative pain − mobility response classification [n (%)]

total	marked	partial	minimal	combined response rate
89	41 (46.1)	38 (42.7)	10 (11.2)	79 (88.8)

Table 3. VAS scores before and after PVP (P)

Preoperative	Postoperative VAS

VAS	24h	1Month	3Month	6Month	12Month	24Month	36Month
7.72 ± 1.01	6.42 ± 1.24	5.72 ± 1.34	5.51 ± 1.29	5.21 ± 1.31	5.05 ± 1.28	4.71 ± 1.26	4.83 ± 1.16

All postoperative VAS scores were significantly lower than preoperative (7.71 ± 1.01), $P < 0.01$ vs. preoperative.

Table 4. HAMA scores before and after PVP (P)

Preoperative ODI	Postoperative ODI						
	24h	1Month	3Month	6Month	12Month	24Month	36Month
18.14 ± 4.06	14.35 ± 4.11	11.37 ± 3.86	10.83 ± 3.64	10.42 ± 3.59	10.41 ± 3.94	9.72 ± 3.13	10.05 ± 3.26

All postoperative HAMA scores were significantly lower than preoperative (18.14 ± 4.06), $P < 0.01$ vs. preoperative.

Table 5. ODI scores before and after PVP (P)

Preoperative ODI	Postoperative ODI						
	24h	1Month	3Month	6Month	12Month	24Month	36Month
52.02 ± 8.34	40.15 ± 7.38	28.42 ± 6.76	27.68 ± 6.54	26.96 ± 6.42	26.57 ± 6.35	25.83 ± 6.22	25.85 ± 6.21

All postoperative ODI scores were significantly lower than preoperative (52.02 ± 8.34), $P < 0.01$ vs. preoperative.

Typical Case

A 42-year-old man presented with a 6-month history of insidious low back pain that had been managed conservatively. Two weeks prior to admission, the pain acutely worsened after coughing and was accompanied by restricted lumbar mobility. On physical examination, marked tenderness and percussion tenderness were noted over the L3 spinous process, with markedly limited lumbar flexion and extension. Non-enhanced and contrast-enhanced CT of the lumbar spine showed a compression fracture of the L3 vertebral body; the posterior vertebral wall and pedicles appeared intact, though neoplastic involvement could not be excluded (Fig. 2). Lumbar MRI demonstrated abnormal signal intensity within L3, consistent with an acute (fresh) vertebral compression fracture (Fig. 3), accounting for the patient's back pain. Whole-body PET-CT revealed a primary lung malignancy with metastatic deposits in L3 and the right iliac bone (Fig. 4). The preoperative VAS score was 8/10. Preoperative ODI was 52% (severe disability),

reflecting pain-limited mobility and impaired daily activities. HAMA score was 18, indicating definite anxiety likely related to cancer diagnosis and refractory back pain.

After definitive diagnosis and exclusion of surgical contraindications, the patient underwent PVP of L3 under local anesthesia. Immediate postoperative pain relief was reported, with the VAS score decreasing from 8/10 to 6/10 (reduction of 2 points). At 1 month, anteroposterior and lateral radiographs showed homogeneous PMMA distribution within the L3 vertebral body, with a small amount of cement leakage into the vertebral body fracture line (paravertebral, asymptomatic); no epidural extravasation was seen (Fig. 5). The patient was able to walk independently without assistive devices at 1 month, and ODI decreased from 52% to 28% (partial response). HAMA decreased from 18 to 11, suggesting resolution of definite anxiety to subthreshold level.

During intermediate-to-long-term follow-up, pain control was sustained. VAS scores were 5/10 at 6 months, 5/10 at 12 months, 4/10 at 24 months, and 4/10 at the last follow-up (median 36 months), without increase compared with the early postoperative level. ODI remained at 24%-28% throughout follow-up, and the patient maintained independent ambulation without needing opioid escalation. HAMA scores remained in the 9-11 range (no definite anxiety). Serial radiographs showed no loss of vertebral height, no new adjacent-level fracture, and stable cement position. No re-intervention (open decompression or revision fixation) was required at the index level. At the last follow-up (36 months), the patient remained alive with controlled systemic disease on targeted therapy, and reported sustained improvement in daily activities.

Discussion

Patients with spinal metastases are at substantially higher risk of pVCFs than the general population(18). Untreated pVCFs in this setting can lead to severe mechanical back pain, neural

compression, and, rarely, pulmonary embolism related to embolized cement fragments. Without stabilization, the involved vertebra is prone to further height loss, adjacent-level fracture, or progression of fracture fragments into the spinal canal, which may cause sensory disturbance, motor weakness, or even paraparesis (7, 8, 18). These events markedly impair mobility and quality of life.

PVP provided used clinically for years and is well established for osteoporotic vertebral compression fractures in older adults, where it was associated with pain reduction and functional recovery(15, 16). More recently, minimally invasive vertebral augmentation techniques, including PVP, have been applied to pVCFs secondary to spinal metastases. In patients with limited life expectancy or poor tolerance for open surgery, such procedures have been reported as a feasible palliative option for vertebral stabilization and symptom control(19, 20). Nevertheless, most available evidence focuses on early (⩽12 months) pain relief, and data on intermediate-to-long-term (⩾24months) safety and symptom control after PVP for metastatic pVCFs remain limited.

Cement leakage is the most frequently reported adverse event of PVP, and symptomatic leakage (e.g., epidural or venous) requires vigilance, although massive pulmonary embolism is exceedingly rare(16). Some studies have linked cement leakage to residual postoperative pain, whereas others report that small, asymptomatic leaks—particularly into the disc space or paravertebral soft tissue—do not compromise clinical outcomes(21). In our cohort, all observed leakage events were asymptomatic, and no patient developed residual pain, new neurologic deficit, or functional deterioration attributable to leakage during a median 36-month follow-up. These findings support that small asymptomatic cement leakage is unlikely to affect intermediate-to-long-term pain or functional results after PVP in selected patients, although confirmation in larger series is needed.

Perioperative complications of PVP were comparable to those of other percutaneous cement-augmentation techniques. All procedures were technically successful, with no pulmonary embolism or major complications observed. VAS, ODI, and HAMA scores improved significantly versus preoperative baseline (all $P < 0.01$). During the median 36-month follow-up, no index-level or adjacent-level refracture was detected. The sustained symptom control may involve two plausible mechanisms: first, polymerization of PMMA generates local heat, which may cause partial destruction of adjacent tumor cells and nerve tissue, thereby contributing to analgesia(22); second, the solidified cement stabilizes the fractured vertebra, reducing mechanical pain caused by vertebral instability and abnormal micro-motion(15). These findings support PVP as an intermediate-to-long-term palliative option that provides sustained pain control and preserves mobility in selected patients with metastatic pathological vertebral compression fractures, rather than serving as an oncologic cure.

Limitations include single-center retrospective design, small sample, no control group, and confounding by concurrent oncologic therapy. Recent reports describe RFA combined with balloon kyphoplasty achieving rapid (≤24 h) analgesia with short follow-up(6), and PKP alone also shows benefit for pain and stability(23). Our data do not claim PVP is superior, nor do they suggest it is the optimal palliative strategy. Interpretation is inevitably shaped by concurrent systemic anticancer therapies and the progressive nature of underlying malignancy. Nevertheless, this series provides a scarce intermediate-to-long-term record (median 36 months) that PVP alone is associated with durable pain control, stable ODI, and preserved mobility in selected metastatic pVCFs. Prospective multicenter controlled trials comparing PVP, PKP, and RFA+PKP are needed.

Conclusions

In this cohort, PVP provided rapid analgesia within 24 h postoperatively, consistent with the early pain control reported for RFA combined with balloon kyphoplasty, yet with follow-up extended to a median of 36 months. Sustained reductions in VAS, ODI, and HAMA scores were observed, with no pulmonary embolism or major complications, supporting PVP as a minimally invasive palliative stabilization option associated with intermediate-to-long-term symptom control in selected patients with metastatic pathological vertebral compression fractures. Establishing standardized operative protocols and explicit patient selection criteria, followed by prospective multicenter validation, will be key to defining its role in routine clinical use.

List of abbreviations

Abbreviation	Full term
BMI	Body mass index
CT	Computed Tomography
CHD	Coronary heart disease
HAMA	Hamilton Anxiety Scale
IL-6	Interleukin-6
IL-8	Interleukin-8
MRI	Magnetic Resonance Imaging
ODI	Oswestry Disability Index
PET-CT	Positron Emission Tomography – Computed Tomography
PKP	Percutaneous Kyphoplasty
PMMA	Polymethylmethacrylate
pVCFs	Pathological Vertebral Compression Fractures
PVP	Percutaneous Vertebroplasty
RFA	Radiofrequency Ablation
RT	Radiotherapy
SD	Standard Deviation

VAS	Visual Analogue Scale (Back pain)

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Review Board of The 960th Hospital of PLA (approval No. 100057). Written informed consent was obtained from all individual patients prior to undergoing PVP.

Consent for publication

Written informed consent for publication of clinical details and any accompanying images was obtained from all individual participants included in the study. For the illustrative case presented in this manuscript, the patient provided specific written consent permitting the use of radiological images, intraoperative photographs, and longitudinal follow-up data. All data were anonymized prior to analysis and manuscript preparation. No identifiable personal information is included in this article.

Availability of data and materials

The data that support the findings of this study are available from the first author, Qian Gao, upon reasonable request.

Competing interests

The authors declare that they have no competing interests. No funding body played any role in the study design, data collection, analysis, interpretation, or manuscript writing.

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Authors' contributions

Qian Gao wrote the main manuscript text. Lu Li prepared Tables 1. Jian Qi prepared Tables 2, 3, 4. Sheng Sun prepared Figures 1, 2, 3, 4. All authors reviewed the manuscript.

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Figures

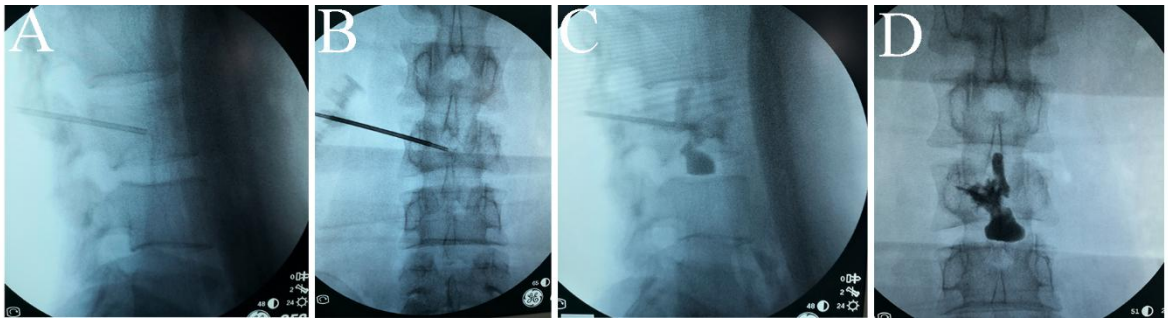
Figure 1. Intraoperative fluoroscopic images of percutaneous vertebroplasty (PVP) at L3. (A, B) C-arm fluoroscopy guided localization of the affected vertebra, followed by percutaneous transpedicular puncture and placement of the guidewire needle. (C, D) PMMA filled the L3 vertebral body homogeneously; focal cement leakage was observed from the fracture site into the L3/4 intervertebral disc space.

Figure 2. Lumbar CT images. (A) Sagittal reconstruction showing a pathologic compression fracture of L3 with vertebral height loss. (B) Axial view showing the L3 vertebral body. The posterior vertebral wall and pedicles remained intact; neoplastic involvement could not be excluded on imaging.

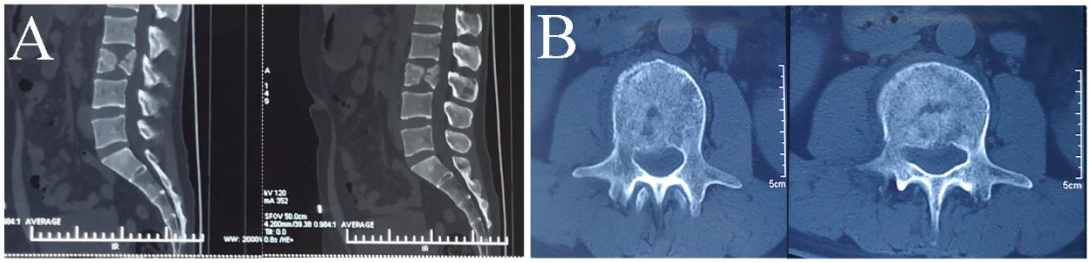
Figure 3. Preoperative lumbar MRI images. (A) Sagittal T2-weighted image (T2WI) showing a fresh fracture of L3 with hyperintense signal. (B) Sagittal fat-suppressed image showing the L3 vertebral body lesion.

Figure 4. PET-CT findings. (1) Nodular hypermetabolic soft-tissue lesion at the bronchial orifice of the dorsal segment of the right lower lobe, suggestive of right peripheral lung cancer. (2) Multiple bone metastases in the marrow of L3, L4, and L5 vertebral bodies and posterior elements, as well as the right iliac bone, with a pathologic fracture of L3.

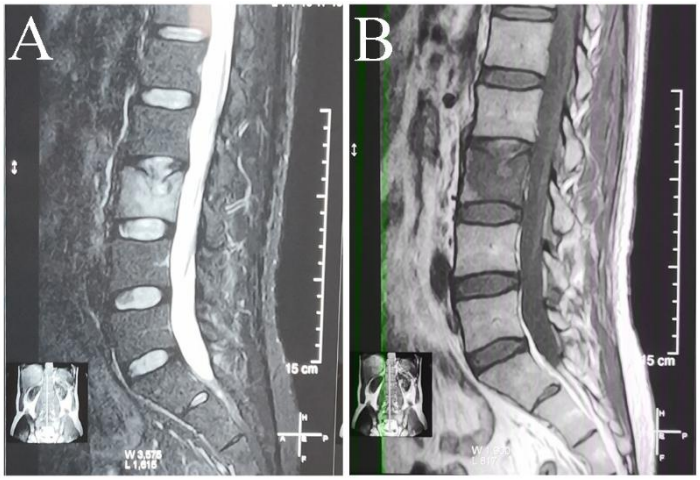
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