

A dynamic radiographic classification system for surgical decision-making in Kümmell's disease based on Δ KA and vertebral compression ratio: a retrospective cohort study

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Abstract

Background

Kümmell's disease can be treated with percutaneous vertebral augmentation or posterior pedicle screw fixation with cement augmentation, but clinicians lack a simple imaging-based rule for choosing between them. This study developed a surgery-directed classification system based on the kyphotic angle difference between standing radiography and supine CT (Δ KA) and the vertebral compression ratio.

Methods

We retrospectively reviewed 102 consecutive patients with Kümmell's disease from a single center. Logistic regression identified independent predictors of surgical approach. ROC curve analysis and Youden's index determined cutoff values. Cohen's κ assessed interobserver reliability. Clinical outcomes were reviewed in 77 patients with follow-up.

Results

Δ KA (OR 1.966, 95% CI 1.382–2.797, $p < 0.001$) and compression ratio (OR 1.086, 95% CI 1.014–1.162, $p = 0.018$) independently predicted surgical strategy; age (OR 0.798, 95% CI 0.680–0.936, $p = 0.006$) was also retained. Cutoffs were 8° for Δ KA (sensitivity 0.920, specificity 0.865; AUC 0.948) and 43% for compression ratio (sensitivity 0.640, specificity 0.865; AUC 0.823). Interobserver reliability was substantial ($\kappa = 0.87$). Type A (Δ KA $< 8^\circ$, compression ratio $< 43\%$) is treated with vertebral augmentation; Type B (Δ KA $< 8^\circ$, compression ratio $\geq 43\%$) and Type C (Δ KA $\geq 8^\circ$) receive posterior screw fixation with cement augmentation.

Conclusions

The SDTCM-K system links two routine radiographic measurements to a concrete surgical plan. It adds to the literature a decision-oriented classification with validated cutoffs, which existing morphological staging systems do not provide.

Background

Thoracolumbar spine fractures at the T10–L2 junction are among the most common spinal injuries. The reported incidence of Kümmell's disease (a post-traumatic avascular necrosis following osteoporotic vertebral compression fracture first described by Hermann Kümmell in 1895) has increased in the elderly population [1]. Its pathophysiology involves osteoporosis, biomechanical alterations, and vertebral ischemic necrosis, leading to nonunion and progressive collapse [2]. Two mechanisms are central: (1)

microfractures compressing vertebral vasculature, causing ischemic necrosis; and (2) abnormal stress on the fractured vertebra impeding healing and exacerbating ischemia. This study focuses on Kümmell's disease in the thoracolumbar region, where fractures are prone to nonunion and pseudarthrosis.

The core treatment principles aim to restore spinal stability, correct sagittal imbalance, and address vertebral collapse. Minimally invasive techniques such as PVP and PKP are effective for mild kyphosis and minimal compression. For complex presentations, open surgery is required. Ou et al. [3] demonstrated superior outcomes with posterior versus anterior approaches, allowing direct decompression and stable long-segment fixation without the pulmonary risks of anterior surgery.

Current classification systems (Li, Formica) guide surgical management but have limitations: Li's staging lacks sagittal balance parameters, and Formica's classification does not fully account for fracture reduction difficulty. In our 102 patients, we observed significant variability in compression height and kyphotic angle between standing radiographs and supine CT, differing between patients who received vertebral augmentation alone versus those requiring screw fixation. This observation forms the basis of the present classification.

The primary objective is to develop a practical classification for Kümmell's disease based on the two most common surgical strategies: percutaneous vertebral augmentation (PVP/PKP) alone and posterior pedicle screw fixation with cement augmentation. Vertebral osteotomy was excluded due to its limited applicability.

Methods

Patient selection and grouping

We hypothesized that the dynamic kyphotic angle difference between standing radiography and supine CT (Δ KA) and the vertebral compression ratio are significant independent predictors of surgical approach in Kümmell's disease, and that optimal cutoff thresholds for these parameters can define a clinically useful surgery-directed classification system. This retrospective study utilized the orthopedic database of a university-affiliated hospital, approved by the institutional ethics committee (approval number: 2026-154-01-KY; approved on July 10, 2026). Inclusion criteria: age > 45 years; osteoporotic vertebral compression; minor trauma followed by delayed recurrent pain; radiographic "vacuum fissure sign" or "fluid sign" with vertebral instability; confirmed osteoporosis. Exclusion criteria: absence of osteoporosis; no vacuum or fluid sign; spinal deformity from tumors, tuberculosis, or ankylosing spondylitis. Patients were grouped by surgical procedure: kyphoplasty (PVP/PKP) or posterior pedicle screw fixation with cement augmentation (PPSF). All patients demonstrated symptomatic improvement postoperatively.

Data collection and radiological evaluation

Demographic and surgical data were recorded, including age, gender, and surgical approach. Preoperative standing full-length anteroposterior and lateral radiographs of the spine, CT, and MRI examinations were obtained for all patients.

Two independent observers measured imaging parameters using PACS. Vertebral measurements included: vertebral compression height, normal vertebral height, radiographic kyphotic angle, CT kyphotic angle, scoliosis angle, thoracic kyphosis (TK), thoracolumbar kyphosis (TLK), lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), and sagittal vertical axis (SVA). Clinical assessment utilized the Visual Analog Scale (VAS) for pain and the Oswestry Disability Index (ODI) for functional status.

New indicators

During the analysis, we observed that standing X-rays consistently demonstrated greater severity of spinal kyphosis angle and vertebral compression compared with supine CT scans. This dynamic disparity (the difference between weight-bearing and non-weight-bearing imaging) was considered a potential indicator of spinal instability. Accordingly, two parameters were selected as classification factors: (1) the angular difference between standing radiography and CT (ΔKA), reflecting dynamic instability; and (2) the degree of vertebral compression (compression ratio), reflecting structural collapse severity. Both are objective, readily measurable, and widely used in clinical practice.

Statistical analysis

Data were analyzed using IBM SPSS 27 (IBM Corp). Continuous variables were compared using t-tests or Mann-Whitney U tests; categorical variables using chi-square or Fisher's exact tests. Multivariate logistic regression identified independent predictors of surgical approach. ROC curves and Youden's index determined optimal thresholds. Model calibration was assessed using the Hosmer-Lemeshow test. Interobserver reliability was evaluated using Cohen's κ coefficient. A p-value < 0.05 was considered significant. This study was reported in accordance with the STROBE guidelines (Strengthening the Reporting of Observational Studies in Epidemiology). During manuscript preparation, the authors used large language models for language editing and formatting; the authors reviewed and take full responsibility for the final content.

Results

Patient demographics

This study included 102 patients (33 males, 69 females). Mean age was 71.7 ± 7.7 years in the kyphoplasty group and 63.4 ± 6.7 years in the screw fixation group. Mean standing kyphosis angle was $21.2 \pm 9.6^\circ$ versus $32.2 \pm 10.1^\circ$; CT kyphotic angle was $15.9 \pm 7.8^\circ$ versus $19.3 \pm 8.8^\circ$. Demographic data are summarized in Tables 1–4.

Table 1
Baseline demographic and clinical characteristics of the study population

Variable	PVP/PKP group, n = 52	PPSF + cement group, n = 50	P value
Age (yrs)	71.7 ± 7.7	63.4 ± 6.7	< 0.001
Sex (male/female)	8/44	25/25	< 0.001
Kyphosis angle of DR,°	21.2 ± 9.6	32.2 ± 10.1	< 0.001
Kyphosis angle of CT,°	15.9 ± 7.8	19.3 ± 8.8	0.096
Angular Difference(DR,CT),°	5.3 ± 3.1	12.9 ± 4.4	< 0.001
Vertebral body compression height, (mm)	13.7 ± 3.2	12.1 ± 3.9	0.056
Normal height of the vertebrae,(mm)	19.1 ± 2.6	24.1 ± 3	< 0.001
Degree of vertebral compression,%	29 ± 9.6	49.9 ± 14.3	< 0.001
Scoliosis angle (°)	4.3 ± 3.1	4.5 ± 4.4	0.822
TK	46.6 ± 14.8	43.8 ± 17.7	0.48
TLK	26.6 ± 13.6	29.3 ± 11.4	0.412
LL	33.7 ± 16.8	34.3 ± 14.4	0.882
SS	28.9 ± 12.4	28.9 ± 10.5	0.997
PT	27.9 ± 10.3	24.4 ± 8.9	0.171
PI	59.4 ± 12.9	55.6 ± 11.6	0.235
SVA	39.4 ± 32.4	36.8 ± 36.5	0.761
<i>Values are mean ± SD or counts.</i>			

Table 3
Perioperative parameters

Item	Operation time(min)	Length of postoperative hospital stay(d)	Intraoperative blood loss(mL)	P value
PVP/PKP group	21.18 ± 3.67	3.12 ± 0.15	6.5 ± 1.85	< 0.001
PPSF + cement augmentation group	124.34 ± 24.95	8.05 ± 2.6	147.86 ± 20.54	< 0.001
<i>Values are mean ± SD.</i>				

Table 4
Multivariate logistic regression analysis of factors associated with surgical approach

Independent Variable	Multivariate Analysis		
	OR	95% CI	P value
Age (yrs)	0.798	0.680–0.936	0.006
Angular Difference (Δ KA),°	1.966	1.382–2.797	< 0.001
Degree of vertebral compression, %	1.086	1.014–1.162	0.018
<i>Outcome coding: 1 = PPSF with cement augmentation, 0 = PVP/PKP.</i>			

Among the 77 patients (75.5% of the cohort) with available postoperative follow-up data, 35 had undergone percutaneous vertebral augmentation (PVP/PKP) and 42 had undergone posterior pedicle screw fixation with cement augmentation. In the augmentation group, 7 patients (20.0%) reported persistent mild pain at 3 months postoperatively; 2 cases of cement leakage through the vertebral cortex were observed. In the screw fixation group, 1 case (2.4%) of screw loosening was identified, and 3 patients (7.1%) reported persistent mild pain. The observed complication rates are consistent with those reported in the literature for these procedures.

Multivariate analysis of surgical treatment

In the multivariate logistic regression analysis, variables identified as significant in univariate analysis were entered into the model. The model revealed that age (OR 0.798, 95% CI 0.680–0.936, $p = 0.006$), the angular difference between standing radiography and CT (Δ KA; OR 1.966, 95% CI 1.382–2.797, $p < 0.001$), and the degree of vertebral compression (OR 1.086, 95% CI 1.014–1.162, $p = 0.018$) independently influenced the choice of surgical approach for Kümmell's disease (Table 4). Specifically, higher Δ KA and greater vertebral compression were associated with an increased likelihood of posterior pedicle screw fixation, whereas older age was associated with a higher likelihood of vertebral

augmentation alone. The Hosmer-Lemeshow test indicated adequate model fit ($\chi^2 = 5.49$, $df = 8$, $p = 0.70$).

ROC curve analysis confirmed discriminative ability: for ΔKA , AUC was 0.948 (95% CI 0.907–0.989, $p < 0.001$); for compression ratio, AUC was 0.823 (95% CI 0.745–0.901, $p < 0.001$). Youden's index yielded optimal cutoffs of 8° for ΔKA (sensitivity 0.920, specificity 0.865) and 43% for compression ratio (sensitivity 0.640, specificity 0.865). Interobserver reliability was substantial ($\kappa = 0.87$).

SDTCM-K classification

Based on the multivariate analysis, two classification factors, vertebral compression ratio and ΔKA , were used to differentiate surgical approaches. A three-tier classification system, SDTCM-K, is proposed: Type A ($\Delta KA < 8^\circ$ and compression ratio $< 43\%$) is indicated for percutaneous vertebroplasty or kyphoplasty alone; Type B ($\Delta KA < 8^\circ$ but compression ratio $\geq 43\%$) and Type C ($\Delta KA \geq 8^\circ$, regardless of compression ratio) require posterior pedicle screw fixation combined with cement augmentation. Representative case examples are illustrated in Figs. 1–4.

Discussion

This retrospective analysis introduces SDTCM-K, a classification system based on two radiographic criteria: the degree of vertebral compression and the dynamic angular difference between standing and supine imaging (ΔKA). It applies mainly to Kümmell's disease of mild to moderate severity. The system links quantifiable imaging parameters to specific surgical indications, which makes the basis for treatment choice explicit.

Kyphoplasty is a common treatment for Kümmell's disease with demonstrated efficacy [4], but is reserved for mild cases. Severe kyphotic deformity or neurological impairment requires screw fixation with cement augmentation. Clear clinical standards distinguishing these indications remain lacking, motivating the present classification.

SDTCM-K uses standing radiography and CT to assess two parameters: dynamic angular change (ΔKA) and vertebral height loss. Unlike Li's staging and Formica's classification, which do not adequately incorporate sagittal balance or fracture reduction difficulty, SDTCM-K brings quantitative instability metrics into surgical decision-making. The three types are:

Type A ($\Delta KA < 8^\circ$, compression ratio $< 43\%$): Presents with the vertebral fracture sign and/or fluid sign on imaging, comparable to the early stages (e.g., Li's Types I–II). Osteoplasty procedures such as kyphoplasty or vertebroplasty may be considered after evaluation.

Type B ($\Delta KA < 8^\circ$, compression ratio $\geq 43\%$): Corresponds to intermediate stages (e.g., Li's grades II–III), where posterior instrumented fusion combined with cement augmentation is often required. This aligns with reported outcomes using pedicle screw fixation combined with PVP [5].

Type C ($\Delta KA \geq 8^\circ$, regardless of compression ratio): Denotes severe vertebral damage, commonly associated with posterior wall collapse, spinal instability, or neurologic deficits, mandating complex reconstruction through posterior pedicle screw fixation with cement augmentation.

Liang et al. [5] reported significant Cobb angle correction in 32 cases treated with pedicle screw fixation and PVP, consistent with our Type B and C patients. For severe Type C cases, vertebral osteotomy may be necessary after careful evaluation, with supporting evidence from a small case series [6]. The treatment goal remains neural decompression and restoration of sagittal balance.

Postoperative VAS and ODI scores indicated that both vertebral augmentation (PVP/PKP) and posterior fixation effectively alleviated pain and improved function (Table 2).

Table 2
Postoperative clinical outcomes at 1 and 3 months

PVP/PKP group		Before operation	1 day after operation	3 months after operation	P value (1 day)	P value (3 months)
	VAS	7.23 ± 0.54	1.47 ± 0.28	0.65 ± 0.28	< 0.001	< 0.001
	ODI(%)	45.34 ± 2.36	22.06 ± 1.69	13.76 ± 2.67	< 0.001	< 0.001
PPSF + cement group	VAS	8.49 ± 1.21	2.69 ± 0.56	0.87 ± 0.45	< 0.001	< 0.001
	ODI(%)	63.56 ± 3.9	37.15 ± 2.49	15.2 ± 3.05	< 0.001	< 0.001
<i>P values are for within-group comparison with the preoperative baseline.</i>						

No significant differences were observed between PVP and PKP in clinical efficacy [7], although PKP may offer a biomechanical advantage for kyphosis correction [8]. Our findings agree with the literature [9] showing no difference in leakage rates: PKP-related leakage may stem from iatrogenic cortical damage during balloon expansion, while PVP-related leakage is attributable to injection technique and cement viscosity.

Posterior pedicle screw fixation is a cornerstone of surgical management, offering minimal invasiveness, three-dimensional fixation, and anatomical reduction. For advanced disease, the strategy incorporates vertebral augmentation and fusion to address pain and sagittal imbalance [10]. Consistent with WFNS guidelines [11], our technique emphasizes an intermediate screw at the fracture level to strengthen the construct and promote indirect reduction.

Impaired sagittal balance is a recognized risk factor for osteoporotic vertebral compression fractures (OVCFs). Lin et al. [12] reported that an SVA > 3.81 cm significantly increases fracture risk. In our cohort,

a notable proportion of patients demonstrated a positive association between SVA magnitude and vertebral compression severity, attributable to anterior center-of-gravity shift increasing thoracolumbar load.

The clinical relevance of specific SVA thresholds remains debated [13]. Patients with osteoporosis have heightened risk of sagittal imbalance [14], explained by skeletal factors (microstructure deterioration reducing vertebral load-bearing capacity) and muscular factors (paraspinal atrophy contributing to “osteoporotic sarcopenia”).

Limitations: This study has several limitations. First, the retrospective single-center design introduces selection bias; the classification thresholds were derived post hoc from clinical decisions, carrying a risk of circular reasoning. Second, the modest sample size ($n = 102$) may affect model stability. Third, while the follow-up rate of 75.5% (77/102) is acceptable for a retrospective study, 24.5% lost to follow-up may introduce attrition bias. Fourth, no external validation cohort was included. Fifth, the classification does not account for neurological status, bone quality, or comorbidities, all of which influence surgical decision-making.

A thoracolumbar fracture superimposed on pre-existing sarcopenia accelerates muscular deterioration, creating a disability cycle [15]. Vertebral height loss disrupts alignment, increasing anterior column stress and reducing lumbar lordosis [16]. Although SVA was not directly incorporated into SDTCM-K, its association with fracture severity supports the biomechanical rationale for Δ KA and compression ratio as classification criteria. In this study, these parameters were selected because they serve as direct clinical manifestations of these pathomechanisms.

Conclusions

The SDTCM-K system uses standard radiographic and CT parameters to capture dynamic instability and compression severity and links them directly to surgical planning. Diagnostic criteria are matched to the two main surgical strategies, with the aim of improving patient outcomes.

Abbreviations

AUC: area under the curve; CI: confidence interval

CT: computed tomography; Δ KA: kyphotic angle difference between standing radiography and supine CT

LL: lumbar lordosis; MRI: magnetic resonance imaging; ODI: Oswestry Disability Index

OR: odds ratio; OVCF: osteoporotic vertebral compression fracture

PACS: picture archiving and communication system; PI: pelvic incidence

PKP: percutaneous kyphoplasty; PPSF: posterior pedicle screw fixation

PT: pelvic tilt; PVP: percutaneous vertebroplasty; ROC: receiver operating characteristic

SDTCM-K: Surgical Decision-Tailored Classification for Kümmell's disease

SPSS: Statistical Package for the Social Sciences; SS: sacral slope; SVA: sagittal vertical axis

TK: thoracic kyphosis; TLK: thoracolumbar kyphosis; VAS: visual analog scale

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Shandong University of Traditional Chinese Medicine (approval number: 2026-154-01-KY; approved on July 10, 2026) and was performed in accordance with the 1964 Declaration of Helsinki and its later amendments. Informed consent was obtained from all participants.

Consent for publication

Written informed consent for publication was obtained from the participants whose imaging data are presented.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available because they contain patient medical information, but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

LZY and WJG conceived the study. LZY wrote the original draft. WJG and LNH supervised the study and acquired funding. ZCY, WCF, HLY, XX and LZJ contributed to data collection, imaging measurements, analysis and manuscript revision. All authors read and approved the final manuscript.

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Figures

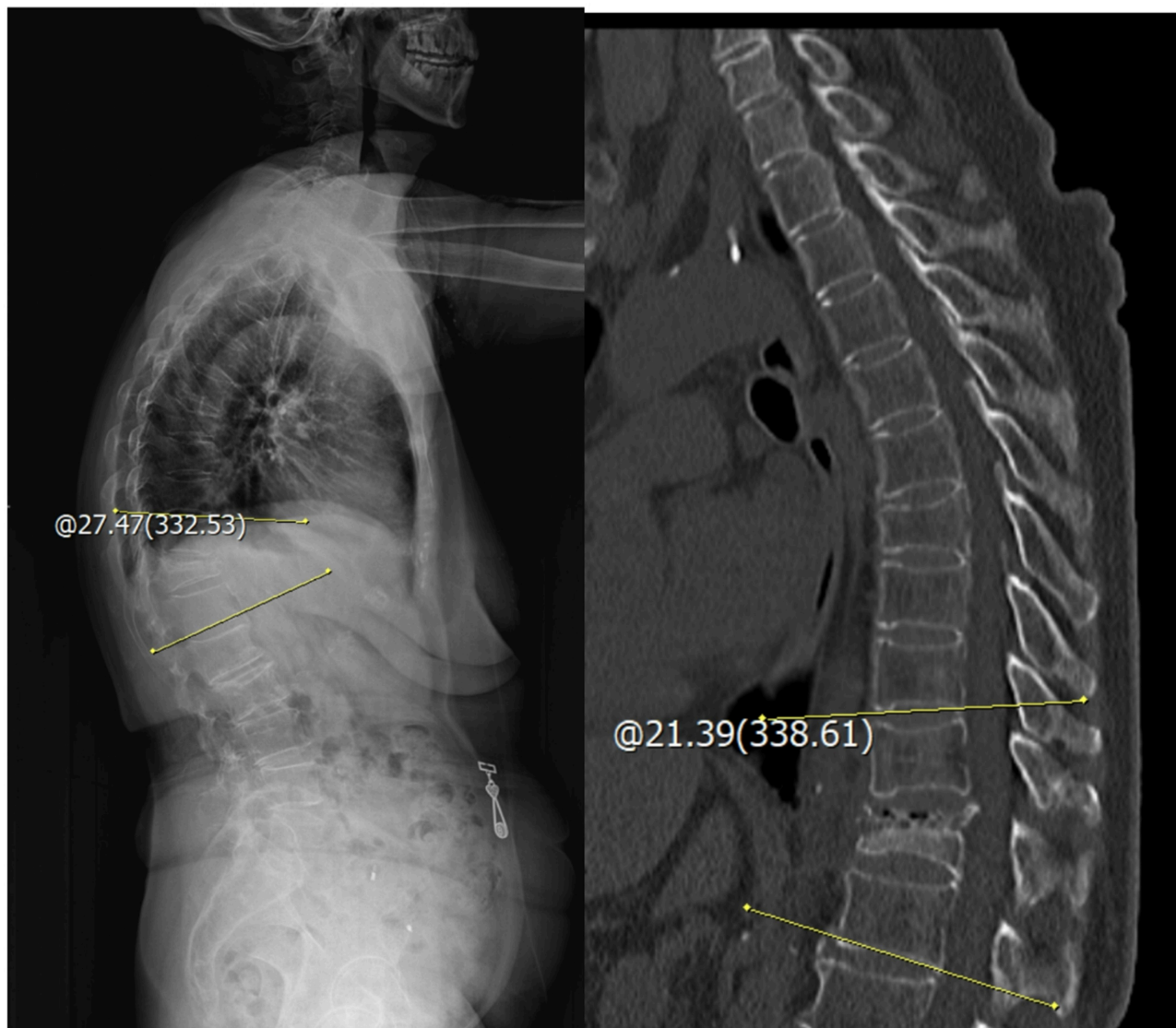


Figure 1

Type A example. (a) Standing lateral radiograph of a 71-year-old woman with two months of low back pain; (b) supine CT showing the same vertebra.

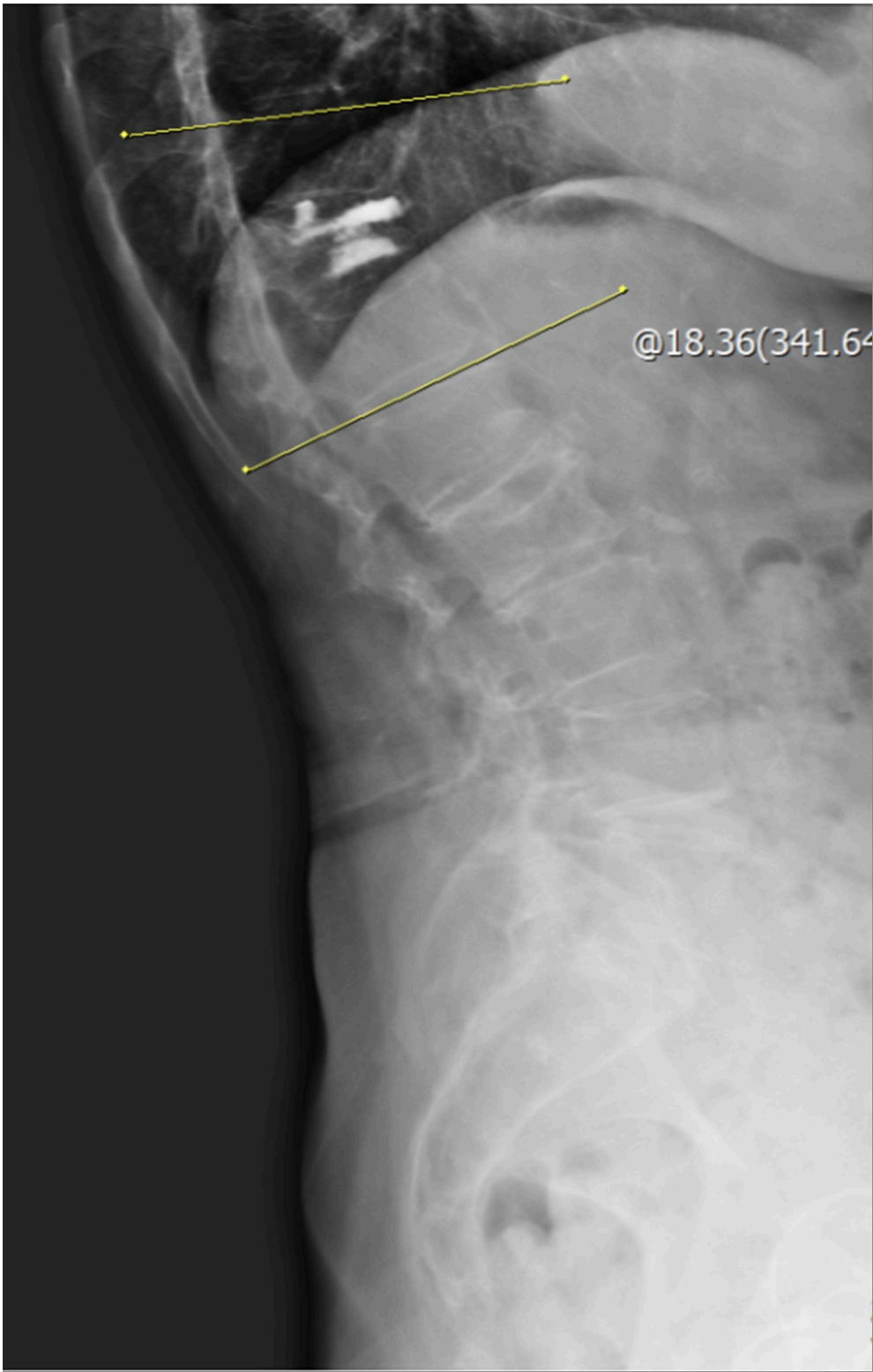


Figure 2

Type A treatment. Percutaneous vertebroplasty was chosen according to SDTCM-K Type A criteria.

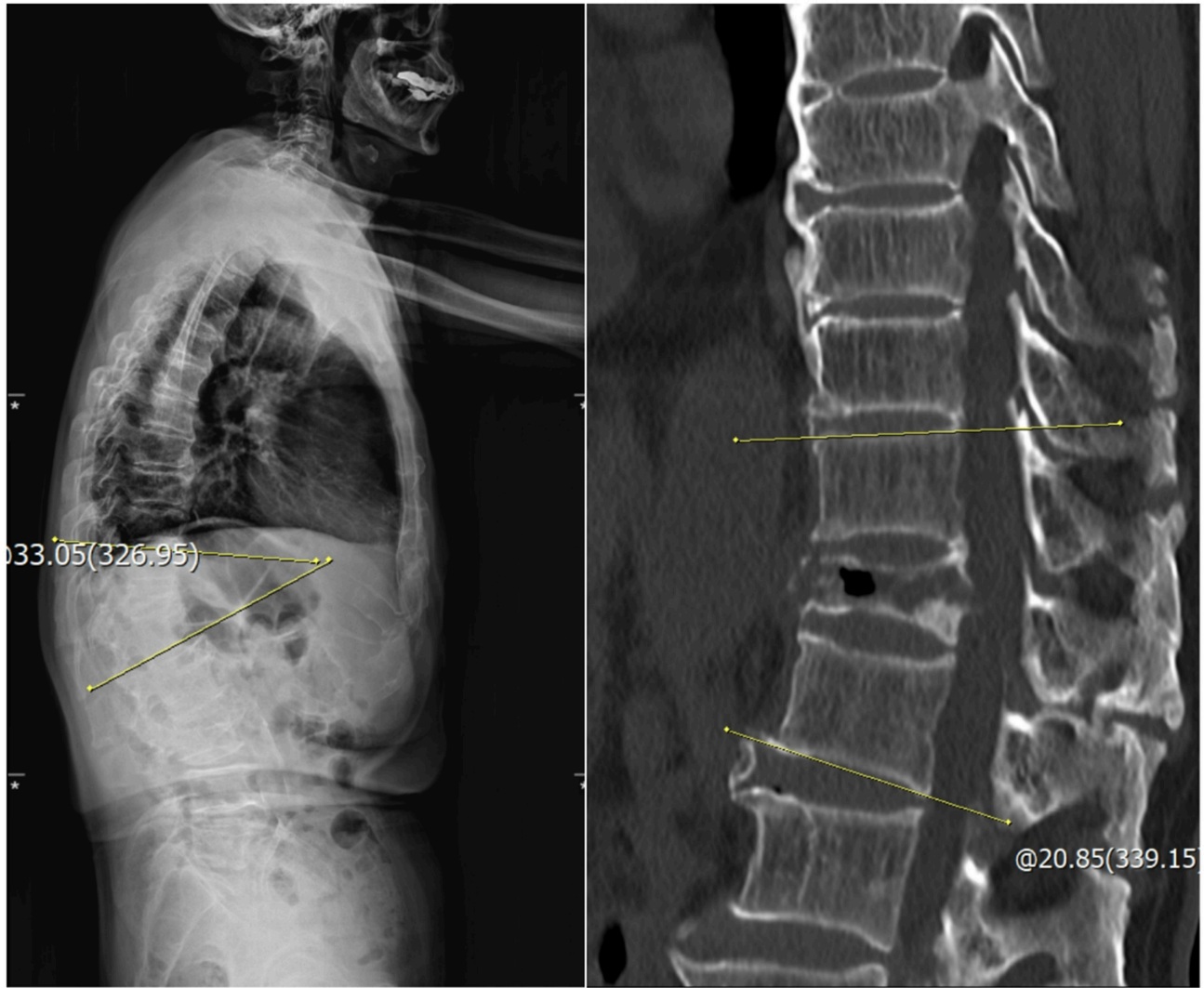


Figure 3

Type C example. (a) Standing lateral radiograph of a 75-year-old man with chest and back pain after a fall and limited mobility for more than eight months; (b) supine CT showing severe collapse and dynamic instability.

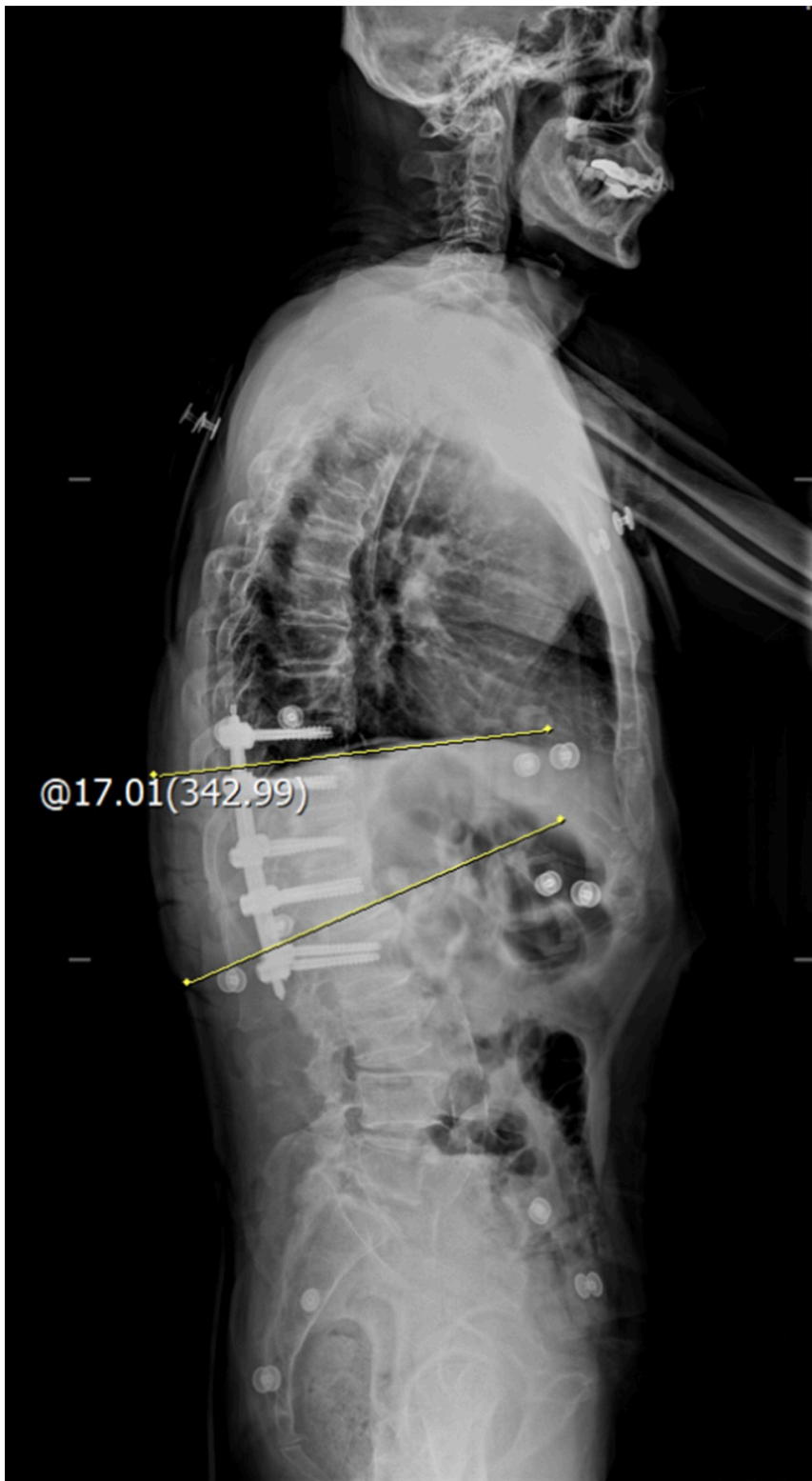


Figure 4

Type C treatment. Percutaneous pedicle screw fixation with cement augmentation was chosen according to SDTCM-K Type C criteria.