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Comparison of Bilateral and Unilateral Applications of Percutaneous Vertebroplasty and Kyphoplasty Procedures

Authors' Contribution:
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Background: Vertebral fractures result from degenerative, osteoporotic, or traumatic spinal loading. Treatment options include conservative management, segmental fusion, and percutaneous vertebroplasty/kyphoplasty (PVP/BKP) performed using unilateral or bilateral pedicular approaches. This study compared vertebral height restoration, pain and disability outcomes, and complication rates between unilateral and bilateral PVP/BKP techniques.

Material/Methods: This retrospective analysis encompassed 150 patients (99 women, 51 men) who underwent PVP/BKP between January 2021 and January 2024. Patient comorbidities and fracture characteristics, including number and type (crush, biconcave, wedge), were recorded. Preoperative and postoperative computed tomography images were evaluated to measure anterior, middle, and posterior vertebral column heights in the sagittal plane. Pain and functional status were assessed using the visual analog scale (VAS) and Oswestry Disability Index (ODI) preoperatively, on postoperative day 1, and at 1 month postoperatively.

Results: No significant differences ($P>0.05$) were observed between unilateral and bilateral groups regarding age, sex distribution, comorbidity rates, fracture number or type, anterior or posterior column height gain, total vertebral height gain, complication rates, or VAS and ODI scores. The bilateral group demonstrated a greater increase in middle column height ($P<0.05$). Both groups showed significant reductions ($P<0.05$) in VAS and ODI scores at 1 day and 1 month postoperatively.

Conclusions: Unilateral and bilateral PVP/BKP techniques provide significant pain relief and functional improvement with comparable clinical outcomes. Considering factors such as high comorbidity burden, cement-related risks, shorter procedure and anesthesia duration, and lower cost, the unilateral approach may be preferable in selected patients.

Keywords: Kyphoplasty • Pain Management • Spinal Fractures • Vertebroplasty

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Introduction

Vertebrae are indispensable components of the skeletal system that play a fundamental role in maintaining the body's structural stability. Vertebral fractures result from decreased mineralization of the bone matrix, increased mechanical loading, or the presence of pathological mass lesions [1]. The primary etiological factors include osteoporosis, trauma, and malignancy-related processes. The vertebrae most commonly affected are the first and second lumbar vertebrae, as well as the 12th thoracic vertebra [2]. The thoracolumbar region experiences nearly 40% of all spinal cord injuries, with reported neurological deficit rates ranging from 15% to 30% [3].

Osteoporosis represents a major public health concern, affecting approximately 200 million women worldwide, and most commonly manifests as vertebral compression fractures. According to Borgström, 15.8 million of the 20 million patients with osteoporosis in the EU6 [European Union plus Sweden] are women [4]. Osteoporotic compression fractures are most frequently observed at the L1 and L2 levels; no significant association has been demonstrated between total vertebral height loss and pain severity [5]. Trauma constitutes the second most common cause of vertebral fractures. The global incidence of traumatic spinal fractures has been reported as 10.5 cases per 100 000 individuals, corresponding to approximately 768 473 new cases annually worldwide; 48.8% of these cases require surgical intervention [6].

Malignancies represent the third most common etiological factor. Metastases, the most common tumors involving bone tissue, occur in approximately 30% of patients diagnosed with cancer. According to the National Institute for Health and Care Excellence, spinal metastatic involvement develops in approximately 3% to 5% of patients with cancer, corresponding to an estimated 9000 to 15 000 cases annually among nearly 390 000 new cancer diagnoses each year. A meta-analysis reported the incidence of clinically apparent spinal metastases as 15.67%; pathological vertebral compression fractures were identified in approximately 12.6% of these patients [7]. Percutaneous vertebroplasty (PVP) and balloon kyphoplasty (BKP) are minimally invasive interventional procedures used in the management of vertebral collapse. Relative to open surgical approaches, these techniques are associated with lower complication rates; they may be considered for pain palliation and prevention of further vertebral height loss in selected patients [8]. This study compared vertebral height restoration, pain and disability outcomes, and complication rates between unilateral and bilateral PVP/BKP techniques.

Material and Methods

This retrospective study included 150 patients who underwent 197 PVP or BKP procedures at the Department of Neurosurgery, University of Health Sciences Türkiye, Haseki Training and Research Hospital, between January 10, 2021, and January 23, 2024. Inclusion criteria were the presence of up to 3 vertebral fractures, absence of congenital spinal deformities, and availability of preoperative and postoperative (1 day and 1 month) follow-up data. Exclusion criteria were a history of spinal infection, more than 3 vertebral fractures, and mortality during the study period.

Demographic and clinical data were collected, including age, sex, comorbidities (coronary artery disease, hypertension, chronic obstructive pulmonary disease, diabetes mellitus, and deep vein thrombosis), fracture morphology and number, unilateral or bilateral procedural approach, procedure type (PVP or BKP), postoperative vertebral height gain or loss, preoperative and postoperative visual analog scale (VAS) and Oswestry Disability Index (ODI) scores, and cement-related complications. The study protocol was approved by the Scientific Research Ethics Committee under decision number 22-2024, and written informed consent was obtained from all participants.

Statistical Analysis

Descriptive statistics were expressed as mean±standard deviation, median, minimum and maximum values, frequencies, and percentages. Variable distributions were assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. For non-normally distributed continuous independent variables, the Mann-Whitney U test was used; continuous dependent variables were analyzed using the Wilcoxon signed-rank test. Categorical independent variables were evaluated using the chi-square test. All analyses were performed via SPSS version 27.0 (IBM Corp., Armonk, NY, USA).

Results

In total, 150 patients were included in the study: 99 (66%) women and 51 (34%) men (mean age, 66.5 years [range, 20-89 years]). Among these patients, 110 had at least 1 comorbid condition, including coronary artery disease, hypertension, diabetes mellitus, chronic obstructive pulmonary disease, malignancy, osteoporosis, and deep vein thrombosis. Overall 197 procedures were performed: 100 (50.7%) were PVP and 97 (49.3%) were BKP (**Table 1**).

Regarding fracture number, 100 patients (66.7%) had a single vertebral fracture, 31 (20.7%) had 2 fractures, and 19 (12.7%) had 3 fractures. Lumbar fractures were observed in 109 patients (72.7%), thoracic fractures in 64 (42.7%), and combined thoracolumbar fractures in 23 (15.3%). Among fracture types, 12 (8%) were classified as crush, 64 (42.7%) as biconcave, and 21 (14%) as wedge; the remaining 53 fractures were unclassified. The bilateral group demonstrated significantly greater middle

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Table 1. Demographic and clinical characteristics of the patient groups.

Parameters	Unilateral (n=49)		Bilateral (n=101)		*P*
	Mean±SD/n (%)	Median	Mean±SD/n (%)	Median	
Age (years)	63.8±11.9	64.0	64.4±13.0	67.0	0.424 m
Sex					
Female	29 (59.2%)		70 (69.3%)		0.220 χ^2
Male	20 (40.8%)		31 (30.7%)		
Comorbidities					
Absent (-)	15 (30.6%)		25 (24.8%)		0.447 χ^2
Present (+)	34 (69.4%)		76 (75.2%)		
CAD	24 (49.0%)		44 (43.6%)		0.532 χ^2
HT	24 (49.0%)		43 (42.6%)		0.459 χ^2
DM	24 (49.0%)		43 (42.6%)		0.459 χ^2
COPD	24 (49.0%)		42 (41.6%)		0.392 χ^2
Malignancy	4 (8.2%)		23 (22.8%)		0.029 χ^2
Osteoporosis	6 (12.2%)		8 (7.9%)		0.393 χ^2
DVT	0 (0.0%)		1 (1.0%)		1.000 χ^2

Abbreviations: CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; DVT, deep vein thrombosis; HT, hypertension; m, Mann-Whitney U test; SD, standard deviation; χ^2, chi-square test.

Table 2. Comparison of height restoration between unilateral and bilateral groups.

Parameters	Unilateral		Bilateral		*P*
	Mean±SD	Median	Mean±SD	Median	
Height gain (mm)					
Anterior column	1.04±1.34	0.60	1.21±1.55	0.70	0.315 m
Middle column	0.89±1.10	0.50	1.44±1.66	0.80	0.038 m
Posterior column	0.46±0.78	0.10	0.79±1.46	0.30	0.215 m
Total vertebral					
Height gain (%)	0.05±0.05	0.04	0.08±0.08	0.05	0.123 m

Abbreviations: m, Mann-Whitney U test; SD, standard deviation.

column height gain than the unilateral group ($P<0.05$); however, no significant difference was observed between groups regarding total vertebral height gain (**Table 2**).

Cement leakage occurred in 76 patients (50.7%). Among these, 8 patients (5.3%) had Yeom type B leakage, 15 (10%) had Yeom type S leakage, and 28 (18.7%) had Yeom type C leakage. No statistically significant difference in complication rates was observed between the unilateral and bilateral groups (**Table 3**).

No significant differences ($P>0.05$) were observed concerning reductions in preoperative and postoperative (1 day and 1 month) VAS scores or ODI values between patients with and without complications or between the unilateral and bilateral groups. However, both groups demonstrated significant decreases in VAS scores at 1 day and 1 month postoperatively compared with preoperative values ($P<0.05$) (**Table 4**).

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Table 3. Comparison of complications and distribution of cement leakage types.

Parameters	Unilateral (n=49)	Bilateral (n=101)	P
Complications, n (%)			0.183
Absent (-)	28 (57.1%)	46 (45.5%)	
Present (+)	21 (42.9%)	55 (54.5%)	
Overall complication distribution (N=150)	n	(%)	
Absent (-)	74	49.3%	
Present (+)	76	50.7%	
Cement leakage pattern (Yeom classification)			
In discal space	25	16.7%	
Yeom type B (intracanal)	8	5.3%	
Yeom type S (anterior)	15	10.0%	
Yeom type C (lateral)	28	18.7%	

Table 4. Comparison of VAS scores according to complication status.

VAS Score	Complication (-)	Complication (+)
Preoperative	8.6	8.6
Postoperative Day 1	2.1	2.1
Postoperative Month 1	1.8	1.7

Abbreviation: VAS, visual analog scale.

Mean operative times were 41.3 minutes in the unilateral group and 97.6 minutes in the bilateral group. For single-level fractures, 3 to 10 mL of bone cement were injected into the vertebral body; in patients with multilevel fractures, the cement volume per fracture level did not exceed 3 mL. Mean injected cement volumes were 3.7 mL in the unilateral group and 7.4 mL in the bilateral group, consistent with previously reported values in the literature [8,9].

Discussion

In the current clinical landscape, vertebral fractures represent a serious public health issue that may lead to higher morbidity and mortality rates than many other pathologies. Although there is broad consensus that the ideal treatment should be minimally invasive, rapidly applicable, and facilitate accelerated recovery while preventing kyphotic deformity and subsequent fractures, the comparative efficacy of percutaneous procedures versus conservative management remains a focus of ongoing debate [10]. The clinical efficacy of percutaneous cement injection is attributed to several synergistic mechanisms, including restoration of mechanical stability, neurotoxic and chemotoxic effects of the cement on nociceptors, and thermal neural degeneration within the vertebral body resulting from the exothermic polymerization reaction [11,12]. Comparative studies evaluating patients undergoing PVP or BKP versus conservative management have concluded that these surgical interventions are superior to conservative treatment [13,14]. Although it is commonly assumed that larger cement volumes provide greater stability, existing evidence suggests that unilateral procedures are more effective for pain palliation, particularly during the early postoperative period [8,9]. Furthermore, whereas vertebroplasty may provide superior pain relief relative to BKP in patients with osteoporotic vertebral fractures, the impact of both procedures on quality of life remains under investigation [15].

In a 2016 meta-analysis by Sun and Li comparing unilateral and bilateral approaches across 14 studies, the VAS was used for pain assessment in 9 studies. The analysis concluded that no significant difference in VAS scores existed between the unilateral and bilateral groups [15]. Similarly, a 2023 meta-analysis encompassing 2 studies found no significant difference in ODI scores [16]; another meta-analysis comparing patient demographic characteristics revealed no statistically significant differences in age (P=0.617) or sex (P=0.105) distributions [17]. Consistent with these findings, our study demonstrated no significant differences in age or sex distribution between the unilateral and bilateral groups (P>0.05). In the present study, which included 150 patients and 197 procedures, a reduction in VAS scores was observed on the first postoperative day, with no significant worsening of ODI scores at 1 day and 1 month postoperatively. Although both procedures are established methods for pain palliation, our study specifically compared unilateral and bilateral application techniques. We found no significant differences in preoperative,

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postoperative day 1, or 1-month VAS scores between the unilateral and bilateral groups ($P>0.05$), consistent with previous reports. Meta-analytical data also demonstrated no significant difference in ODI values between unilateral and bilateral groups [15]. Consistent with these findings, we detected no significant differences in preoperative, 1 day postoperative, or 1 month postoperative ODI values between groups ($P>0.05$), further supporting the published evidence.

According to the meta-analysis by Sun and Li, 9 of 14 studies compared operative time, injected cement volume, and cement leakage. Operative time was significantly shorter in the unilateral group than in the bilateral group. Eleven studies noted greater injected cement volumes in the bilateral group. Cement leakage was evaluated in 11 of the 14 studies; in 10 of those studies, no significant difference was observed between groups [15]. In the present study, cement leakage complications occurred in both the unilateral (42.9%) and bilateral (54.5%) groups. Mean operative times were 41.3 minutes for unilateral procedures and 97.6 minutes for bilateral procedures.

Regarding vertebral height restoration, Yılmaz et al demonstrated significant increases in vertebral body height with both unilateral and bilateral application techniques; however, no significant difference was observed between those approaches [17]. Similarly, a 2018 systematic review by Tan et al identified no statistically significant differences between unilateral and bilateral PKP in radiological parameters, including kyphosis angle reduction, Cobb angle improvement, vertebral height loss rate, and restoration of anterior and mid-posterior column height during short- or long-term follow-up [18]. In the present study, middle column height gain was significantly greater in the bilateral group than in the unilateral group. However, no significant difference between groups was observed regarding the percentage of total vertebral height gain, consistent with the existing literature.

Cement leakage remains a particularly common complication of PVP and BKP, with reports suggesting that leakage rates can reach 73% in both unilateral and bilateral approaches [19]. The meta-analysis by Sun and Li [15] showed total cement leakage rates of 25% (96/384) in the unilateral group and 29.88% (101/338) in the bilateral group; no statistically significant difference was noted. Furthermore, Liebschner et al suggested that achievement of a large filling volume via high-dose cement injection in bilateral procedures may not represent the optimal biomechanical configuration, given that excessive cement injection could increase vertebral body sensitivity to bone cement [19]. Within our cohort of 150 patients, cement leakage was observed in 76 cases (50.7%). Specifically, leakage occurred in 21 patients (42.9%) in the unilateral group and 55 patients (54.5%) in the bilateral group. The overall risk of complications was similar between the unilateral and bilateral groups, further supporting previous findings.

In the present study, percutaneous procedures were performed for 3 types of vertebral fractures: wedge, biconcave, and crush. Wedge fractures, which result from compression of the anterior portion of the vertebral body, represent more than 50% of all reported vertebral fractures and do not involve the posterior elements. Crush fractures are the least common type (13%) and involve collapse of the entire vertebral body, including the posterior column [20]. In our cohort, no significant differences ($P>0.05$) were observed in fracture number, location, or morphology between the unilateral and bilateral intervention groups.

Wan et al reported that unilateral BKP significantly reduced operative time, X-ray exposure, cement dosage, intraoperative blood loss, hospitalization costs, postoperative VAS scores, and surgical site edema compared with the bilateral approach. Furthermore, the Cobb angle, mean vertebral body height, cement leakage rate, and incidence of adjacent vertebral fractures remained comparable after treatment [21]. Relative to the bilateral technique, unilateral BKP effectively facilitates bone cement distribution across the midline to both sides while reducing surgical and radiation exposure, minimizing intraoperative trauma, shortening postoperative pain duration, and accelerating recovery [22]. Our study showed no statistically significant differences between unilateral and bilateral approaches regarding pain scores, total vertebral height gain, or cement leakage complications, suggesting that the bilateral approach offers no clear clinical advantage over the unilateral approach.

However, some limitations of our study should be acknowledged, including its limited sample size, single-center design, analysis restricted to a maximum of 3 vertebral segments, and follow-up limited to the first postoperative month. The short follow-up duration, small sample size, and lack of multicenter randomized controlled data represent the main limitations of this study.

Conclusions

This study evaluated unilateral and bilateral percutaneous cement application techniques. No statistically significant differences were observed between groups regarding VAS and ODI scores, total vertebral height gain, or cement-related complications. However, bilateral application yielded superior results in middle column height gain. Although both techniques provide effective pain relief and improvements in quality of life, the unilateral approach may be preferable for treating vertebral fractures, particularly in frail patients with low Karnofsky scores and clinically significant comorbidities such as congestive heart failure, diabetes, deep vein thrombosis, and obesity. This preference is supported by advantages including shorter operative time, reduced X-ray exposure, less iatrogenic vertebral trauma through lower cement volumes, shorter anesthesia duration, and lower surgical costs.

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