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Clinical and radiological outcome comparison of unilateral vs. bilateral percutaneous vertebroplasty for osteoporotic vertebral compression fractures

Osteoporotik omurga kompresyon kırıklarında tek taraflı ve çift taraflı perkütan vertebroplasti uygulamalarının klinik ve radyolojik sonuçlarının karşılaştırılması

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ABSTRACT

Aim: Vertebral compression fractures are a common cause of pain and disability in the elderly population. Percutaneous vertebroplasty is an established minimally invasive intervention, yet the optimal approach (unilateral or bilateral) remains controversial. This study focused on comparing the clinical and radiological outcomes of unilateral versus bilateral percutaneous vertebroplasty in patients with painful osteoporotic vertebral compression fractures.

Material and Methods: A retrospective review was conducted on 203 patients (73 males, 130 females; mean age 65.3 ± 8.9 years) with 309 treated vertebral levels from 2014 to 2024. Patients underwent either unilateral (n = 104) or bilateral (n = 99) PVP. Pain and disability were assessed using the Visual Analog Scale (VAS) and Oswestry Disability Index (ODI), while radiological outcomes included anterior vertebral height restoration and segmental Cobb angle correction.

Results: Both approaches provided significant pain relief and functional improvement. Bilateral PVP achieved lower postoperative VAS (1.9 vs 2.1, p = 0.040) and ODI scores (23.1% vs 26.3%, p = 0.020) compared to unilateral PVP. Radiologically, bilateral procedures resulted in superior anterior height restoration (25.8% vs 19.2%, p = 0.001) and greater Cobb angle correction (9.1° vs 6.4°, p = 0.001). Cement leakage rates were similar in both groups (≈4%), with no symptomatic complications.

Conclusion: Unilateral and bilateral PVP are both safe and effective for osteoporotic VCFs. Bilateral PVP demonstrated superior radiological correction, whereas unilateral PVP remains advantageous due to reduced operative burden. Treatment decisions should be individualized based on patient anatomy and procedural goals.

Keywords: Bilateral percutaneous vertebroplasty, unilateral percutaneous vertebroplasty, vertebral compression fracture, vertebroplasty

ÖZ

Amaç: Vertebra kompresyon kırıkları (VKK) , yaşlı popülasyonda ağrı ve fonksiyon kaybının en yaygın nedenlerinden biridir. Perkütan vertebroplasti (PVP), minimal invaziv ve kanıtlanmış bir tedavi yöntemidir; ancak optimal yaklaşımın (tek taraflı ve ya çift taraflı) olması gerektiği halen tartışmalıdır. Bu çalışmanın amacı, ağrılı osteoporotik VKK'lerde tek taraflı ve çift taraflı PVP uygulamalarının klinik ve radyolojik sonuçlarını karşılaştırmaktır.

Gereç ve Yöntemler: 2014–2024 yılları arasında 203 hasta (73 erkek, 130 kadın; ort. yaş 65,3 ± 8,9 yıl) ve toplam 309 vertebra düzeyi retrospektif olarak incelendi. Hastalara tek taraflı (n = 104) veya çift taraflı (n = 99) PVP uygulandı. Klinik değerlendirmede VAS ve Oswestry Disabilite İndeksi (ODI) kullanılırken, radyolojik sonuçlarda anterior vertebra yüksekliği restorasyonu ve segmental Cobb açısı düzelmesi değerlendirildi.

Bulgular: Her iki yaklaşım da anlamlı ağrı azalması ve fonksiyonel iyileşme sağladı. Çift taraflı PVP, tek taraflı PVP'ye kıyasla daha düşük postoperatif VAS (1,9 vs 2,1; p = 0,040) ve ODI skorları (%23,1 vs %26,3; p = 0,02) ile sonuçlandı. Radyolojik olarak çift taraflı girişimler, daha yüksek anterior yükseklik restorasyonu (%25,8 vs %19,2; p = 0,001) ve daha fazla Cobb açısı düzelmesi (9,1° vs 6,4°; p = 0,001) sağladı. Sement kaçağı oranları her iki grupta benzerdi ve semptomatik komplikasyon görülmedi.

Sonuç: Hem tek taraflı hem de çift taraflı PVP, osteoporotik VKK tedavisinde güvenli ve etkili yöntemlerdir. Çift taraflı PVP daha üstün radyolojik düzelme sağlarken, tek taraflı PVP daha az cerrahi yük nedeniyle avantajlıdır. Tedavi seçimi, hasta anatomisi ve prosedürel hedefler göz önünde bulundurularak bireyselleştirilmelidir.

Anahtar Kelimeler: Çift taraflı perkütan vertebroplasti, osteoporotik kompresyon fraktürü, tek taraflı perkütan vertebroplasti, vertebroplasti

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Highlights

- Both unilateral and bilateral percutaneous vertebroplasty provided significant pain reduction and functional recovery in patients with osteoporotic vertebral compression fractures.
- Bilateral vertebroplasty achieved superior vertebral height restoration and greater segmental Cobb angle correction compared with the unilateral technique.
- Unilateral vertebroplasty remains an efficient alternative because of its lower procedural burden, supporting individualized technique selection according to anatomy and treatment goals.

INTRODUCTION

Vertebral compression fractures (VCFs) represent a major cause of pain, disability, and reduced quality of life in elderly populations, particularly among individuals with osteoporosis, trauma history, or metastatic spinal disease (1-3). These fractures may lead to chronic pain, progressive deformity, immobility, and increased morbidity. Conservative treatment often fails to provide adequate symptom relief and prolonged immobilization may further exacerbate comorbidities (4,5). Since its first use by Galibert et al. in 1987 for vertebral hemangioma, percutaneous vertebroplasty (PVP) has become a widely accepted minimally invasive procedure for osteoporotic and neoplastic VCFs (6). The technique involves transpedicular injection of polymethylmethacrylate (PMMA) cement into the collapsed vertebral body to achieve stabilization and pain reduction.

PVP can be performed via unilateral or bilateral transpedicular access; however, the optimal approach remains controversial. Bilateral injection allows for more symmetrical cement distribution and greater potential for kyphotic correction, whereas unilateral injection reduces operative time, radiation exposure, and procedural risks. The objective of this study was to evaluate and compare the clinical and radiological outcomes associated with unilateral and bilateral percutaneous vertebroplasty (PVP) in a clearly characterized group of patients presenting with symptomatic osteoporotic vertebral compression fractures.

MATERIAL and METHODS

Patient Selection and Data Collection

In this retrospective clinical observational study, the medical data of patients who received PVP treatment for osteoporotic VCF at our institution between 2014 and 2024 were analyzed. The inclusion criteria were; 1) severe axial pain that persisted despite four weeks of conservative treatment including bed rest, analgesics, orthoses, 2) Vertebral body height loss less than 50%, 3) absence of spinal canal compromise and neurological deficit. Exclusion criteria comprised individuals with known coagulopathies, active systemic or spinal infections, posterior vertebral wall destruction, severe and uncontrolled cardiopulmonary conditions that would contraindicate the procedure and malignancy. Ethics committee approval was obtained from University of Health Science, Umraniye Training and Research Hospital (Ethical ID: 284733070). Written informed consent form was obtained from all patients prior to intervention.

Radiological Evaluation

Preoperative and postoperative imaging assessments including computed tomography (CT) and magnetic resonance imaging (MRI) were performed for all patients. Measurements of the anterior vertebral body height were obtained from CT images for both the fractured vertebra and the adjacent levels. The rate of anterior height recovery was determined using the following formula: (postoperative anterior height – preoperative anterior height) divided by the mean anterior height of the adjacent upper and lower vertebrae, multiplied by 100.

The segmental Cobb angle was defined by the angle formed between the superior endplate of the vertebra above and the inferior endplate of the vertebra below the affected level. Additionally, standing radiographs were acquired at the 3rd, 6th, and 12th postoperative months for follow-up evaluation.

Clinical Evaluation

Pain intensity was quantified using the Visual Analog Scale (VAS), where 0 indicated no pain and 10 represented the most severe pain imaginable. Functional impairment was assessed using the Oswestry Disability Index (ODI), a validated tool for measuring disability related to spinal conditions. The clinical scores were recorded preoperatively and on the 10th postoperative day.

Surgical Technique

PVP was conducted in either the angiography suite or the operating room using a standard transpedicular approach under fluoroscopic guidance. The procedure was performed under local anesthesia and sedation. All patients were continuously monitored with ECG, pulse oximetry, and blood pressure tracking. An intravenous line was placed for administration of sedatives, analgesics, antibiotics, and anti-

emetics as needed. Moderate sedation was used in select cases to enhance patient comfort.

The patient was positioned prone and draped in a sterile manner. Local anesthetic was administered to the skin and underlying soft tissues. After local anesthesia and sterile preparation, a trocar was carefully advanced through the pedicle into the anterior third of the fractured vertebral body (Figure 1). Polymethylmethacrylate (PMMA) bone cement of medium viscosity was then injected under continuous biplanar fluoroscopy to ensure controlled filling and to minimize the risk of cement leakage. The injection was terminated once adequate vertebral body opacification and stabilization were achieved. After cement injection was completed, the trocar was carefully removed, bleeding was controlled with manual pressure and a sterile dressing was placed over the entry site. Given the minimally invasive technique, no suturing was necessary.

Statistical Analysis

All statistical evaluations were performed using SPSS software (version 25.0; IBM Corp., Armonk, NY, USA). The distribution of variables was tested for normality with the Shapiro-Wilk test. Intergroup comparisons between unilateral and bilateral PVP were carried out using either the independent samples t-test or the Mann Whitney U test, depending on distribution. For intragroup analyses, preoperative and postoperative differences in clinical (VAS, ODI) and radiological outcomes were assessed using paired t tests or Wilcoxon signed rank tests, as appropriate. Categorical data were analyzed using the Pearson chi square test or Fisher's exact test. P value below 0.05 was accepted as indicative of statistical significance.

RESULTS

A total of 203 patients were included in the study, comprising 130 females (64.0%) and 73 males (36.0%), with a mean age of 65.3±8.9 years (range: 45-82 years). A total of 309 vertebral levels were treated, with the most frequently affected site being the L1 vertebra, accounting for 31.8% of all interventions. The mean follow-up was 9 months (range:6-48) (Table 1). Among the cohort, 104 patients underwent unilateral PVP, while 99 patients received the pro-

Table 1: Baseline Demographic and Clinical Characteristics of Patients

Variable	Unilateral PVP (n = 104)	Bilateral PVP (n = 99)	Total (n = 203)	p value
Age (years), mean ± SD	65.1 ± 8.7	65.6 ± 9.1	65.3 ± 8.9	0.720 [a]
Sex (female), n (%)	67 (64.4)	63 (63.6)	130 (64.0)	0.910 [b]
Number of treated levels, mean ± SD	1.46 ± 0.7	1.52 ± 0.6	1.49 ± 0.7	0.530 [c]
Most frequent level (L1), n (%)	31 (29.8)	28 (28.3)	59 (29.1)	0.811 [b]

[a] Independent-samples t-test. [b] Pearson's chi-square test. [c] Mann–Whitney U test

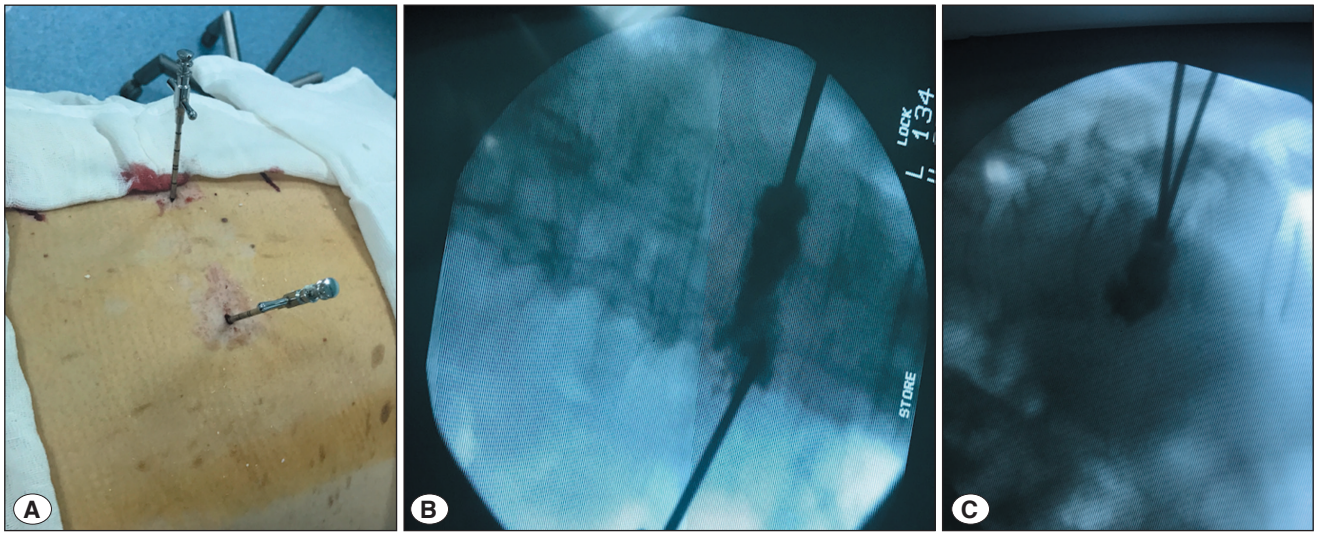

Figure 1: Bilateral percutaneous vertebroplasty for a symptomatic T11 compression fracture. **A)** Bilateral transpedicular cannulas positioned symmetrically for vertebral body access. **B)** Intraoperative anteroposterior fluoroscopic image showing stepwise PMMA injection under intermittent fluoroscopic control to ensure gradual filling and prevent cement migration. **C)** Lateral fluoroscopic view demonstrating homogeneous cement distribution within the vertebral body; serial imaging minimized the risk of leakage into venous structures, the spinal canal, or paravertebral tissues.

cedure bilaterally. The two groups did not differ significantly in terms of patient demographics or pre-treatment clinical status, including pain and disability indices (p=0.070, independent samples t-test). Both treatment modalities led to statistically significant reductions in pain and disability scores following the procedure (Figure 2).

Clinical Assessment

The unilateral group demonstrated a decline in mean VAS scores from 8.2±1.1 preoperatively to 2.1±0.9 postoperatively (p= 0.001, Wilcoxon Signed Rank test), while the bilateral group showed a reduction from 8.3±1.0 to 1.9±0.8 (p = 0.001, Wilcoxon Signed Rank test). The difference in postoperative pain scores was statistically significant in favor of bilateral intervention (p=0.04, Mann Whitney U test) (Table 2).

Similarly, the Oswestry Disability Index (ODI) improved from 68.5±11.3% to 26.3±9.2% in the unilateral group (p=0.001, Wilcoxon Signed Rank test) and from 69.2±10.8% to 23.1±8.4% in the bilateral group (p=0.001, Wilcoxon Signed Rank test), with a significant between-group difference postoperatively (p=0.020, Mann-Whitney U test). Pain relief, defined as a reduction of ≥4 points in VAS, was achieved in 89.4% of patients in the unilateral group and 91.2% in the

Table 2: Comparison of the treatment modalities and outcomes

	Unilateral (n = 104)	Bilateral (n = 99)	p-value
Pre-treatment clinical status			
Mean pre-op VAS score	8.2±1.1	8.3±1.0	0.700[c]
Mean pre-op ODI (%)	68.5±11.3	69.2±10.8	0.680[c]
Post-treatment outcomes			
Mean post-op VAS score	2.1±0.9	1.9±0.8	0.040[c]
Mean post-op ODI (%)	26.3±9.2	23.1±8.4	0.020[c]
Patients achieving ≥4-point VAS reduction, n (%)	93 (89.4)	90 (91.2)	0.723[b]
Radiographic outcomes			
Anterior vertebral height restoration (%)	19.2±4.7	25.8±5.1	0.001[a]
Cobb angle improvement (°)	6.4±2.3	9.1±2.6	0.001[a]
Complications			
Cement leakage, n (%)	4 (3.8)	4 (4.0)	0.943[b]
Symptomatic complications	None	None	

[a] Independent-samples t-test. [b] Pearson's chi-square test. [c] Mann–Whitney U test.

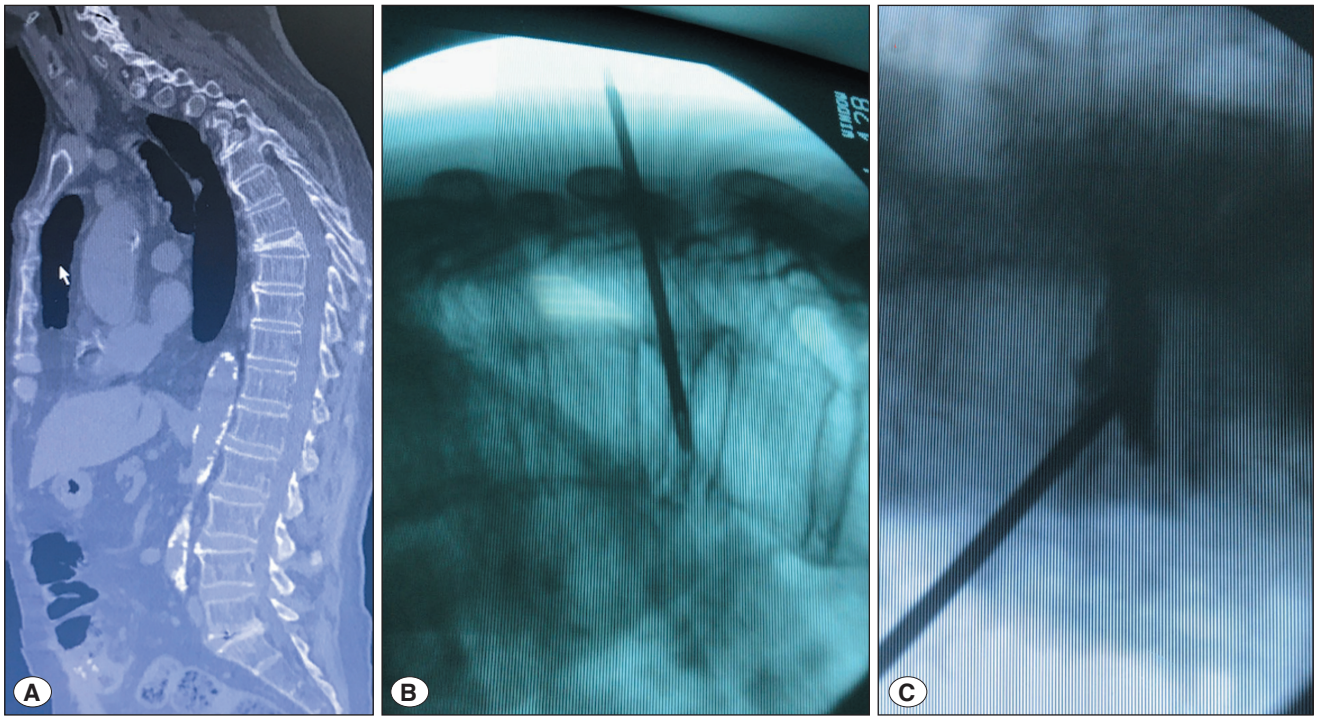

Figure 2: A) Lateral CT image showing a severe T8 compression (vertebra plana) with complete height loss and structural collapse, indicating instability and risk of kyphotic progression. **B)** Intraoperative lateral fluoroscopic view during unilateral percutaneous vertebroplasty. The transpedicular cannula is advanced stepwise under continuous imaging for safe positioning and controlled cement delivery. **C)** Post-procedural anteroposterior fluoroscopic image demonstrating satisfactory vertebral augmentation with partial height restoration and uniform PMMA distribution. Continuous imaging minimized the risk of cement leakage into adjacent structures.

bilateral group, with no statistically difference (p=0.66, chi square test).

Radiological Assessment

Similarly, local Cobb angle correction was greater in the bilateral group (9.1 ± 2.6° pre- vs. postoperative change, p = 0.001, Wilcoxon Signed Rank test) than in the unilateral group (6.4 ± 2.3°, p = 0.001, Wilcoxon Signed Rank test), with a significant intergroup difference (p = 0.001, Mann-Whitney U test).

Cement leakage was observed in eight cases, four from each group, corresponding to an overall incidence of 3.9%. Leakage rates were nearly identical between unilateral (3.8%) and bilateral (4.0%) procedures, with no statistically significant difference (p=0.93, Chi-square test). Importantly, none of the cases led to symptomatic or clinically significant complications.

DISCUSSION

Numerous studies have demonstrated that PVP is a reliable and minimally invasive intervention for patients with osteoporotic vertebral fractures who fail to achieve adequate symptom relief with conservative measures such as bed rest, immobilization, pharmacological therapy or orthotic bracing (7-9). In our study, we evaluated the radiological and clinical outcomes of patients who underwent either unilateral or bilateral PVP for osteoporotic VCF.

In comparing unilateral and bilateral approaches to PVP, it is essential to highlight the distinctive features of each technique. Bilateral PVP allows for more symmetrical cement distribution, providing biomechanically balanced load transmission across the vertebral body and potentially reducing the incidence of intravertebral microfractures. In contrast, unilateral PVP has been reported to achieve comparable radiological and clinical outcomes, while offering advantages such as shorter procedure time, lower radiation exposure, and greater cost-effectiveness (10).

One of the primary concerns in both unilateral and bilateral PVP is the risk of cement leakage. A meta analysis identified intervertebral clefts, cortical disruption, low cement viscosity and excessive cement volume as key contributors to leakage risk (11). Baroud and Bohner reported that cement viscosity is a critical factor with a transition from low to medium viscosity reducing leakage rates to below 10% during the procedure (12). Technological refinements such as remote cement delivery systems have also been introduced to improve injection control and minimize radiation exposure for operators (13). Dai et al., through a finite element analysis model, found that bilateral transpedicular vertebroplasty biomechanically reduces stress concentrations within the vertebral body and intervertebral discs, offering superior stability compared to the unilateral technique (14). Furthermore, in vitro studies suggest that a cement volume of approximately 3 cm^3 is sufficient for effective vertebral restoration, with bipedicular injection providing more uniform distribution (15).

From a radiological perspective, especially in multilevel osteoporotic vertebral compression fractures, alterations in sagittal and coronal spinal balance must be considered. A study found that patients undergoing bilateral PVP exhibited more significant improvements in the coronal Cobb angle compared to those treated unilaterally (16). However, another investigation employing voxel-based morphometry suggested that unilateral vertebroplasty, when performed with symmetrical cement distribution, may offer comparable or superior outcomes (17). Consistent with prior reports, our results showed that the bilateral approach yielded significantly superior anterior vertebral height restoration and greater improvement in Cobb angle compared to the unilateral technique, suggesting that bipedicular access may facilitate more effective structural realignment.

In terms of clinical outcomes, most studies utilizing Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores have shown no statistically significant differences in long-term outcomes between unilateral and bilateral techniques (3,18-21). Our results are consistent with this evidence, showing that both approaches achieved significant and durable pain relief, with bilateral intervention providing slightly superior radiological correction. The advantages of unilateral PVP, namely reduced operative time, radiation exposure and cost, remain compelling and have been highlighted in several reports (19,22-28).

This study has several limitations. First, its retrospective and single-center design may introduce selection bias and limit the generalizability of the findings. Second, patients were not randomized to unilateral or bilateral procedures; thus, treatment decision may have been influenced by surgeon preference or anatomical considerations, potentially confounding the results. Third, although validated instruments such as VAS and ODI were used to assess pain and disability, these outcomes remain subjective and may be influenced by patient expectations. Another limitation is related to the assessment of segmental Cobb angle. In our study, measurements were obtained from pre- and postoperative CT scans, whereas the gold standard for evaluating sagittal and coronal alignment is standing whole-spine radiography. Therefore, our analysis reflects only the local angular correction at the treated level, and may not fully capture global spinal balance.

Conclusion

Although both unilateral and bilateral PVP are effective and safe interventions for managing osteoporotic VCF, current evidence suggests that neither technique offers a definitive

superiority in terms of long-term clinical outcomes. While bilateral PVP provides more symmetrical cement distribution and may offer certain biomechanical advantages, unilateral PVP remains a favorable alternative due to its shorter procedural duration, reduced radiation exposure, and cost-effectiveness. Ultimately, the choice between unilateral and bilateral approaches should be individualized, taking into account patient anatomy, fracture characteristics and procedural goals, while prioritizing both biomechanical integrity and clinical efficiency.

Author Contributions

Study conception and design: **Levent Aydın, Buse Sarıgül,** Data collection: **Levent Aydın, Buse Sarıgül, Gonca Gül Onduç,** Analysis and interpretation of results: **Levent Aydın, Saime Ayça Şahin,** Draft manuscript preparation: **Levent Aydın, Tufan Agah Kartum, Buse Sarıgül,** Critical revision of the article: **Ali Fatih Ramazanoglu, Buse Sarıgül,** Other (study supervision, fundings, materials, etc...): **Saime Ayça Şahin, Ali Fatih Ramazanoğlu.**

Conflicts of Interest

We declare that there are no conflicts of interest related to this study and no financial funding was received that could have affected the results. All authors have reviewed and approved the final version of the manuscript and the sequence of authorship has been agreed upon by all contributors.

Ethical Approval

Health Science University, Umraniye Training and Research Hospital (Ethical ID: 284733070).

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