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EDITORIAL

Dear Colleagues,

We are delighted to present to you the new issue of the Journal of Turkish Spinal Surgery (JTSS), the official scientific publication of the Turkish Spine Surgery Society. The continuous advancement of surgical techniques, the improved understanding of spinal biomechanics, and the rapid development of technology have all contributed to an increase in both the quantity and diversity of scientific publications in the field of spine surgery. The primary objective of our journal is to deliver high-quality, engaging, and innovative scientific studies related to spine surgery to our readers, and to contribute to the scientific literature by publishing the latest developments through the valuable submissions of our authors. JTSS will steadfastly continue its efforts to achieve its goals in this field.

In this issue, we have prepared a range of articles that we believe will capture your interest, spanning from minimally invasive procedures to deformity treatment. I would like to extend my sincere gratitude to the esteemed researchers who have shared their work with us, to the reviewers who supported our processes with their meticulous evaluations despite their demanding schedules, and to our editorial team who worked with great dedication throughout the publication process.

My hope is that our readers will accompany the development of our journal not only as followers but also as active contributors. Sharing your clinical experiences, research results, and unique perspectives with us will be the most valuable contribution to the scientific heritage of Turkish spine surgery.

Wishing to meet again in future issues where scientific production increases, collaboration strengthens, and our clinical practice becomes even richer...

Co-Editor-in-Chief

Ender Köktekir, M.D.,

ORIGINAL ARTICLE
144

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THE RELATIONSHIP BETWEEN FACET JOINT OSTEOARTHRITIS AND MULTIFIDUS FATTY ATROPHY IN SPINAL OSTEOARTHRITIS: RETROSPECTIVE OBSERVATIONAL STUDY

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ABSTRACT

Objective: Facet joint osteoarthritis (FJO) is a prominent condition among the degenerative spinal pathologies and is recognized as one of the key causes of chronic low back pain (LBP). Multifidus fatty atrophy (MFA) occurs as an effect of muscle degeneration, with the muscle tissue being replaced by the formation of surrounding adipose tissue. The aim of this study is to investigate the association between FJO and MFA. The study aims to demonstrate that FJO is more than just a cartilage-related issue in the facet joint, which suggests more extensive clinical implications.

Materials and Methods: A retrospective study was conducted based on the review of magnetic resonance imaging (MRI) scans collected between April 2021 and September 2021 in a population of 79 patients experiencing chronic LBP FJO and MFA parameters were evaluated at the L4-L5 level using MRI. T2-weighted high-resolution axial images were acquired. Two experienced clinicians examined image sets individually.

Results: The relationship between FJO and MFA was assessed using the Kappa coefficient. The statistical analysis confirmed a moderate yet significant association between the two conditions ($p<0.05$, Kappa=0.234).

Conclusion: The findings indicate that analysis of the multifidus muscle should not be ignored in the diagnosis of facet joint disease. A broader approach to diagnosis that includes both FJO and MFA will provide more accurate and improved therapeutic outcomes in patients with chronic LBP.

Keywords: Facet joint, multifidus, spine, osteoarthritis, low back pain

INTRODUCTION

Facet joint osteoarthritis (FJO) is a common form of degenerative spinal disease and contributes notably to the development of chronic low back pain (LBP)[1]. The facet joints located in the back of the spine are crucial in allowing spinal movement[2]. A characteristic feature of FJO is cartilage degradation in the facet joints with a decrease in joint space; it has been found to contribute 15-45% to chronic LBP[3,4]. Magnetic resonance imaging (MRI) is most often utilized in FJO diagnosis owing to its improved ability to visualize soft tissue and bone structures[5].

The multifidus muscle is essential in the provision of spinal stabilization and is located near the facet joints[6]. Degeneration of the multifidus muscle leads to multifidus fatty atrophy (MFA), where muscle is replaced by adipose tissue[7]. MFA is a common finding in patients with chronic LBP and compromises spinal stabilization by reducing the functional ability of the multifidus muscle[8]. Due to their association in spinal degeneration, it is believed that MFA is correlated with FJO[9].

The aim of this research is to prove that FJO not only involves the cartilage surrounding the joint but also affects the surrounding muscular tissues[10]. It is argued that the

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surrounding anatomical tissues are vital in the assessment of spinal degenerative diseases[11].

MATERIALS AND METHODS

During this retrospective study, MRI evaluations of 79 patients with chronic LBP collected between April 2021 and September 2021 were analyzed. Criteria for inclusion in the study included the absence of spinal infections, spinal cord injuries, spinal tumors, fractures, deformities, previous lumbosacral surgery, and certain comorbidities (cerebrovascular events, muscle diseases, etc.). These criterias were established to ensure a homogeneous patient group for the study. Informed consent was obtained from each participants, and the study was approved by the Institutional Ethics Committee İstanbul Yeni Yüzyıl University (decision number: 2025/06-1603, date: 17.06.2025).

FJO and MFA at the L4-L5 level were examined using MRI. The imaging was performed with high-resolution axial T2-weighted sections. All images were independently evaluated by two experienced spine surgeons.

The classification of FJA used was that of Grogan et al.[3], which consists of four stages:

- **Stage 1:** The entire joint surface is overlaid with thick cartilage, and an intercartilaginous band of low-signal-intensity is continuous between the plates of cartilage.
- **Stage 2:** The joint surface is entirely covered with cartilage but with patches of erosion and irregularity.
- **Stage 3:** The joint surface is only partly overlaid with cartilage, while bone is present within the joint.
- **Stage 4:** The cartilage is nearly lost with fragments of cartilage being apparent.

The visual staging of MFA was classified according to Kjaer et al.[7] into three categories (Figure 1):

- **Normal:** Contains 0-10% fat.
- **Mild:** Contains 10-50% fat.
- **Severe:** Contains >50% fat.

Statistical Analysis

Data was analyzed using SPSS software version 22.0. To measure the agreement the levels of FJO and MFA, the Kappa statistic was used, and the statistical significance was based on a p-value of less than 0.05.

RESULTS

This study retrospectively evaluated the relationship between FJO and MFA at the L4-L5 level in 79 patients with chronic LBP. The demographic data and clinical findings of the patients are described in detail below.

The average age of the 79 participants was 39.5 [(standard deviation ±10.6) range, (minimum age 24)-(maximum age 47)], and the cohort consisted of 45 males (57%) and 34 females (43%).

FJO and MFA were evaluated using MRI, and the criteria for classification were outlined below:

FJO degrees

- **Stage 1:** 18 patients (22.8%)
- **Stage 2:** 38 patients (48.1%)
- **Stage 3:** 16 patients (20.3%)
- **Stage 4:** 7 patients (8.9%)

MFA degrees

- **Normal** (0-10% body fat): 12 (15.2%)
- **Mild** (10-50% fat): 33 patients (41.8%)
- **Severe** (>50% fat): 34 (43.0%)

FJO degrees in patients with normal MFA: stage 1 in 7 patients, stage 2 in 2 patients, stage 3 in 1 patient, stage 4 in 2 patients.
FJO degrees in patients with mild MFA: stage 1 in 4 patients, stage 2 in 22 patients, stage 3 in 6 patients, stage 4 in 1 patient.
FJO degrees in patients with severe MFA: stage 1 in 7 patients, stage 2 in 14 patients, stage 3 in 9 patients, stage 4 in 4 patients.
The correlation between the levels of MFA and FJO was evaluated using the Kappa statistic. A statistically significant correlation ($p<0.05$, Kappa: 0.234) was found between the levels of FJO and MFA.

DISCUSSION

This study thoroughly examined the relationship between FJO and MFA. Our findings demonstrated a statistically significant relationship between FJO and MFA. These results are consistent with some studies in the literature and highlight the need to consider spinal degenerative diseases from a broader perspective[1,6,8,11]. The study by Guven et al.[12]

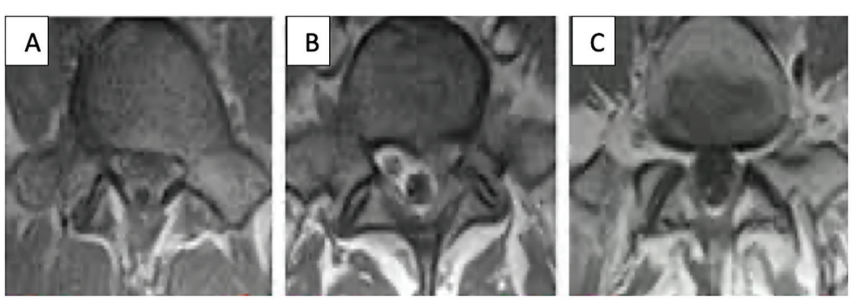

Figure 1. The visual staging of multifidus muscle fatty atrophy was classified into three categories[7]: A) normal, contains 0-10% fat, B) mild, contains 10-50% fat, C) severe, contains >50% fat

directly investigates the relationship between FJO and lumbar paraspinal muscle atrophy. The results showed a significant relationship between the extent of fatty infiltration in the functional cross-sectional area of the multifidus muscle and the FJO, but none for the erector spinae or the psoas muscle.

The current study showed a statistically significant, yet relatively weak relationship between the severity of FJO and the degree of MFA ($p<0.05$, Kappa: 0.234). This finding suggests that muscle tissue degenerative changes can occur in patients who have FJO. A study by Fujiwara et al.[11] compared the association of FJO and the degeneration of the intervertebral disc. Their study concluded that FJO is associated with degenerative changes in adjacent anatomical structures beyond disc degeneration. The present study adds to the literature by illuminating the association of MFA and FJO. The study by Faur et al.[13] further support the clinical relevance of MFA in LBP and its association with disc degeneration. Lower multifidus muscle cross-sectional area has been associated with several degenerative conditions of the lumbar spine, including disc degeneration, Modic changes, endplate defects, facet arthrosis, and disc herniations, and may show a dose-response relationship as the number of pathologies increases. These findings are suggestive that multifidus atrophy and spinal degenerative change may be the result of related underlying mechanisms or that they are part of related degenerative processes[14].

The multifidus muscle is important for spinal stabilization, and degeneration can intensify LBP[6]. Danneels et al.[8] reported cases of MFA among patients suffering from chronic LBP, which contributed to diminished spinal stability. In addition, our study revealed an association for MFA and FJO, and it suggests that FJO may affect the function of the multifidus muscle. Our finding is consistent with the current literature for the importance of the multifidus muscle in maintaining spinal stability.

Perolat et al.[1] state that FJO is often seen as one causative factor underlying the onset of chronic LBP. Our study suggests that FJO should be considered in the paradigm of myofascial pain syndrome and that combined consideration of both conditions can optimize the efficacy of therapeutic and diagnostic procedures. As such, it is recognized that FJO involves more than just cartilage degeneration in the joint, as it affects the surrounding muscular structures as well.

Literature on the relationship between FJO and MFA is somewhat scant. However, certain studies have focused on the relationship between degenerative changes in the multifidus muscle and spinal disorders. Kjaer et al.[7] demonstrated that the prevalence of fatty degeneration in the multifidus muscle is related to LBP and negatively affects spinal stability. This study adds to the literature by clarifying the relationship between FJO and MFA.

The study of Chua et al. [15] investigated the association of the morphological characteristics of facet joint arthropathy with multifidus muscle atrophy in patients suffering from degenerative lumbar spinal stenosis. The results showed that strong correlations occurred among excessive facet overhang and high-grade atrophy and fatty infiltration of the deep part of the multifidus, but not with the other morphological parameters.

Yu et al. [16] demonstrated that FJO is strongly associated with MFA, characterized by decreased cross-sectional area, increased muscle-fat ratio. These findings support that FJO should not be understood only as cartilage degeneration of the localized cartilage, but should be considered as a whole-joint complex dysfunction involving the paraspinal musculature[16].

Our findings are in keeping with the existing literature and highlight an association between facet osteoarthritis and the multifidus muscle. Nevertheless, this retrospective nature of our study, coupled with this small sample size, introduces certain limitations. Larger population prospective studies would potentially be able to provide more information about this association.

CONCLUSION

This study clarifies the association of FJO and MFA, highlighting the need to consider fatty atrophy of the multifidus muscle in the evaluation of degenerative spinal disorders. Concurrent consideration of FJO and MFA in the clinical context could lead to better management of LBP.

Ethics

Ethics Committee Approval: The study was obtained from each participants, and the study was approved by the Institutional Ethics Committee İstanbul Yeni Yüzyıl University (decision number: 2025/06-1603, date: 17.06.2025).

Informed Consent: Informed consent was obtained from all participants. All participants gave both verbal and written informed consent.

Footnotes

Authorship Contributions

Surgical and Medical Practices: C.M.A., S.K., Y.K., M.N.E., R.G.U., M.T., Concept: C.M.A., S.K., M.N.E., M.T., Design: C.M.A., Y.K., R.G.U., M.T., Data Collection or Processing: C.M.A., S.K., Y.K., M.N.E., R.G.U., M.T., Analysis or Interpretation: C.M.A., S.K., Y.K., M.N.E., R.G.U., M.T., Literature Search: C.M.A., S.K., M.N.E., M.T., Writing: C.M.A., S.K., Y.K., M.N.E., M.T.

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ORIGINAL ARTICLE

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FACTORS AFFECTING FUNCTIONAL STATUS IN INDIVIDUALS WITH KNEE OSTEOARTHRITIS AND LUMBAR DEGENERATIVE DISEASE

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ABSTRACT

Objective: This study aimed to investigate the interaction between functional impairment due to lumbar degenerative disease and knee osteoarthritis (KOA) in individuals presenting with concurrent low back and knee pain. We evaluated the relationship between the knee injury and osteoarthritis outcome score (KOOS) and the Oswestry disability index (ODI).

Materials and Methods: This study retrospectively analyzed 114 patients experiencing both chronic low back and knee pain. Functional status was assessed using KOOS and ODI scores obtained from hospital records. Radiographic evaluations included sagittal vertical axis, thoracic kyphosis, lumbar lordosis, spinopelvic parameters, spinal canal measurements, and Kellgren-Lawrence (K-L) grading for KOA severity. Spearman correlation and multivariate logistic regression were used to analyze associations.

Results: The mean age was 62.5±10.1 years, and 86% of the patients were female. KOOS and ODI scores showed a moderate negative correlation ($r=-0.61$). KOOS was identified as an independent predictor of disability ($\beta=-0.0614$, $p<0.001$). No significant relationship was found between ODI and age, body mass index, or K-L grade. Among spinopelvic parameters, sacral slope (SS) showed a significant negative correlation with ODI ($r=-0.23$, $p<0.05$). Additionally, the presence of scoliosis was associated with higher ODI scores ($p<0.05$), while spondylolisthesis was associated with lower KOOS scores ($p<0.05$).

Conclusion: KOOS scores are significantly associated with back-related disability in individuals with coexisting KOA and lumbar spine degeneration. Structural variations such as SS and scoliosis may also influence functional outcomes. Lower KOOS may indicate greater disability in patients with concurrent knee and back pain, emphasizing the need to prioritize knee-related symptoms in management.

Keywords: Knee osteoarthritis, lumbar degenerative disease, functional status, KOOS, ODI

INTRODUCTION

Knee osteoarthritis (KOA) and lumbar spine degeneration (LSD) are two important musculoskeletal pathologies that are frequently encountered in elderly individuals and significantly reduce the quality of life(1,2). Both diseases are accompanied by pain, limitation of movement, functional and sensory loss and often occur simultaneously(3-5). Chronic low back pain (LBP) is common in patients with KOA, and this phenomenon has even been defined as “knee-spine syndrome”(6).

The majority of studies on KOA and LSD have focused on the effects of the alignment of the lumbar spine and pelvic morphologies, and have confirmed a correlation between changes in the sagittal position of the spine and KOA(7,8). In the literature, single-dimensional evaluations focused on the knee or waist are generally prominent, and comprehensive studies measuring the functional status of patients in a way that covers both regions are on the agenda(9,10).

This study examined the relationship between knee function, as assessed by the knee injury and osteoarthritis outcome score (KOOS), and back disability, as measured by the Oswestry disability index (ODI). This is the first study to jointly evaluate the relationship between spinopelvic parameters and KOOS scores, which reflect knee function, and ODI in individuals with KOA and LBP. This holistic approach is rare in the literature, as it reveals the impact of KOOS not only on knee function but also on overall quality of life. We aimed to determine whether these two important joint regions interact with each

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other at a functional level in individuals with concurrent knee and back diseases, and to emphasize the necessity of a holistic perspective in clinical management.

MATERIALS AND METHODS

Ethical approval for this study was obtained from the University of Health Sciences Türkiye, Gülhane Training and Research Hospital's Ethics Committee (approval no: 2024-511, date: 05.11.2024). This retrospective cross-sectional study involved patients who attended the Orthopedics and Traumatology Outpatient Clinic of University of Health Sciences Türkiye, Gülhane Training and Research Hospital due to chronic low back and knee pain. Following clinical evaluations, patients' functional statuses were assessed using the ODI and the KOOS, both of which had previously been administered as part of routine outpatient care and were available in the hospital records.

Radiological data were obtained from the institutional picture archiving and communication system and the national e-Nabız health database. Only patients with adequate imaging, including previously acquired anteroposterior and lateral radiographs of the lumbar and thoracic spine, pelvic X-rays, and lumbar magnetic resonance imaging scans were included in the study. Patients without sufficient radiological data were excluded. All patients completed the KOOS and ODI forms during their outpatient clinic examination, on the same day, simultaneously with the radiological evaluation. Incomplete forms were excluded from the study.

All radiological measurements were performed by a single trained physician (U.Y.) to maintain measurement consistency. Spine alignment parameters such as sagittal vertical axis (SVA), thoracic kyphosis, lumbar lordosis, pelvic tilt (PT), pelvic incidence (PI), and sacral slope (SS) were measured. In addition, sagittal spinal canal diameters (L1-S1 levels) and canal cross-sectional areas were recorded. The Kellgren-Lawrence (K-L) scale was applied to assess the severity of KOA. Structural abnormalities such as scoliosis and spondylolisthesis were also noted.

The relationships between clinical scores and radiological findings were examined using comparative and correlational statistical analyses. Patients younger than 18 or older than 80 years, those with a history of spinal or knee surgery, individuals with neuromuscular disorders, and those with a diagnosis of malignancy were excluded from the study.

Two validated and reliable instruments were used to assess functional status: the KOOS and the ODI. The KOOS is a comprehensive tool that evaluates symptoms and functional limitations related to the knee joint, with scores ranging from 0 to 100. KOOS includes five subcomponents: symptoms, pain, daily activity, sports/recreation, and quality of life. The total KOOS score in this study was derived by averaging these components, with higher scores representing improved knee performance and reduced symptoms[11].

The ODI is a widely used questionnaire developed to assess functional disability associated with LBP pain. Scoring on the ODI ranges from 0 to 100, with higher scores reflecting increased functional limitation. This index is widely used to assess the impact of LBP on everyday functioning[12].

Statistical Analysis

Data analysis was conducted using IBM SPSS Statistics (v22.0, IBM Corp., Armonk, NY, USA). Results for continuous variables were expressed as mean ± standard deviation, whereas categorical variables were described using frequency and percentage distributions. The distribution characteristics of the data were assessed using the Shapiro-Wilk test.

To further explore factors influencing ODI scores, a multivariable logistic regression analysis was performed by categorizing patients based on the ODI median value: ≤39 (indicating good function) and >39 (indicating poor function). KOOS total and subscale scores, as well as other demographic and radiological variables, were included in regression models. Model fit and multicollinearity were evaluated.

The extent of KOA was evaluated based on the K-L grading criteria and grouped into low severity (grades 0-2) and high severity (grades 3-4).

Between-group comparisons were conducted using the Mann-Whitney U test for non-parametric data and the independent samples t-test for parametric data. Relationships between two continuous variables were evaluated using Spearman's rank correlation analysis.

To identify factors associated with ODI scores, a multivariable logistic regression analysis was performed. Additionally, alternative models were constructed to assess the impact of KOOS total and subscale scores on functional outcomes. Model fitness and multicollinearity diagnostics were considered, and simplified models were used for reanalysis when appropriate. A p-value of <0.05 was considered statistically significant for all analyses.

RESULTS

A total of 114 patients were included in the study. The mean age of the participants was 62.5±10.1 years, and the mean body mass index (BMI) was 28.3±5.1 kg/m^2. 86% of the participants were female (n=98), 14% were male (n=16). The mean ODI score was 35.3±18.8, and the KOOS score was 48.7±20.9 (Table 1).

According to Spearman's correlation analysis, a negative, moderate correlation was found between KOOS and ODI scores (r=-0.61). Logistic regression analysis revealed that the KOOS score was an independent predictor of functional impairment in individuals with an ODI greater than 39 (β=-0.06, p<0.001) (Figure 1). Other variables (age, BMI, K-L score) were not found to be significant (Table 2).

According to the K-L score, the patients were divided into two groups: Group 1 (K-L 0-2) and Group 2 (K-L 3-4). The mean ODI was 39.99 in Group 1 and 38.08 in Group 2. According to the Mann-Whitney U test result, this difference was not statistically significant (p=0.5069) (Figure 2).

The effects of spinal alignment parameters such as SVA, thoracic kyphosis, lumbar lordosis, and on ODI were investigated. There was a slight positive association observed between lumbar lordosis and ODI scores (r=0.07), while slight negative correlations were found with thoracic kyphosis (r=-0.09) and SVA (r=-0.10). None of these correlations were found to be statistically significant.

Table 1. Demographic and clinical characteristics

	Mean ± SD or n (%)
Age (years)	62.5±10.1
Sex (F/M)	98/16 (86/14%)
BMI (kg/m^2)	28.3±5.1
ODI	35.3±18.8
KOOS	48.7±20.9
Lumbar lordosis (°)	47.5±12.3
Thoracic kyphosis (°)	40.1±10.5
Sagittal spinal canal diameters (mm)	
L1-2 anterior-posterior diameter	12.43±1.55
L2-3 anterior-posterior diameter	11.43±1.81
L3-4 anterior-posterior diameter	10.76±2.38
L4-5 anterior-posterior diameter	10.30±1.89
L5-S1 anterior-posterior diameter	11.55±1.54
Spinal canal area (cm^2)	
L1-2 area	1.34±0.34
L2-3 area	1.14±0.32
L3-4 area	0.99±0.29
L4-5 area	0.90±0.34
L5-S1 area	1.03±0.27
Spinopelvic parameters (°)	
PI	53.89±10.63
PT	16.77±7.90
SS	36.52±10.98
Structural findings	
Scoliosis (present)	29 (25.4%)
Spondylolisthesis (present)	27 (23.7%)

SD: Standard deviation, BMI: Body mass index, ODI: Oswestry disability index, KOOS: Knee injury and osteoarthritis outcome score, PI: Pelvic incidence, PT: Pelvic tilt, SS: Sacral slope

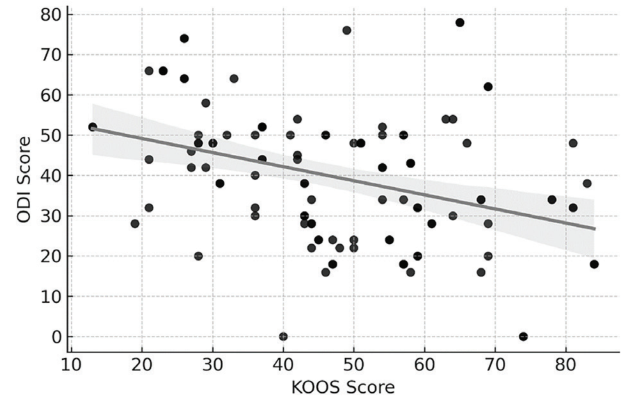

Figure 1. Correlation graph between KOOS and ODI scores. A negative correlation is observed between KOOS and ODI scores. As KOOS increases (knee function improves), ODI decreases (back function improves). KOOS: Knee injury and osteoarthritis outcome score, ODI: Oswestry disability index

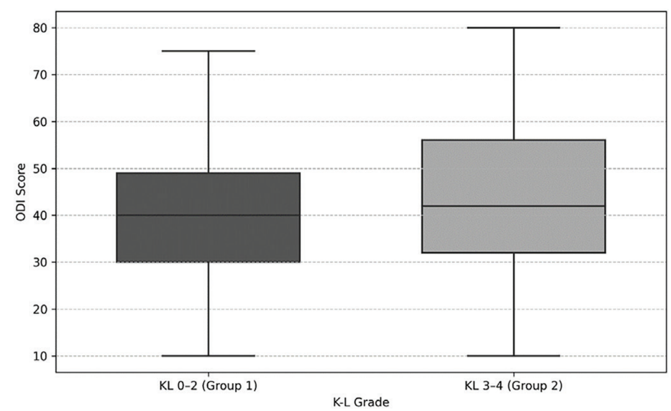

Figure 2. Comparison of ODI scores between patients with low (K-L grade 0-2, Group 1) and high (K-L grade 3-4, Group 2) radiographic knee osteoarthritis severity. ODI: Oswestry disability index, K-L: Kellgren-Lawrence

Table 2. Multivariate logistic regression analysis for predicting high disability (ODI >39)

	β coefficient	OR	95% CI (lower-upper)	p-value
KOOS total	-0.06	0.94	0.91-0.97	<0.001
KOOS symptoms	-0.02	0.98	0.95-1.01	0.12
KOOS pain	+0.01	1.01	0.97-1.05	0.71
KOOS daily activities	-0.02	0.98	0.94-1.02	0.29
KOOS sports	-0.02	0.98	0.96-1.00	0.09
KOOS quality of life	+0.01	1.01	0.98-1.04	0.68
Age	+0.03	1.03	0.98-1.09	0.22
BMI	-0.03	0.97	0.90-1.04	0.41
K-L score	-0.34	0.71	0.40-1.25	0.23

ODI: Oswestry disability index, OR: Odds ratio, CI: Confidence interval, KOOS: Knee injury and osteoarthritis outcome score, BMI: Body mass index, K-L: Kellgren-Lawrence

Sagittal L1-S1 levels were evaluated. No statistically significant correlation was found between these diameters and ODI or KOOS scores (all p>0.05). Cross-sectional spinal canal areas were also measured. A weak positive correlation was found between L5-S1 area and KOOS score (r=0.21, p<0.05), indicating that greater canal area may be associated with better knee function. Spinopelvic parameters were analyzed. Among them, SS showed a significant negative correlation with ODI (r=-0.23, p<0.05), suggesting that a lower SS is associated with higher disability. No significant correlations were found for PI or PT. Among the patients, 29 (25.4%) had scoliosis and 27 (23.7%) had spondylolisthesis. The presence of scoliosis was significantly associated with higher ODI scores (p<0.05), while spondylolisthesis was significantly associated with lower KOOS scores (p<0.05) (Table 3).

DISCUSSION

In this study, we aimed to investigate the interaction between lumbar degenerative disease and KOA in patients presenting with concurrent back and knee complaints. The KOOS score is a measure that evaluates symptoms and functional capacity of the knee joint; higher scores indicate better knee function. In our study, the negative correlation between KOOS score and ODI indicates that disability in the lumbar region decreases as knee function improves. This finding suggests that improving the functional status of the knee in clinical practice may provide not only a local benefit but also positive effects on general physical capacity.

Muraki et al.[13] emphasized the overlapping symptomatology between lumbar spine diseases and KOA, showing that lower extremity joint dysfunction may affect quality of life due to the involvement of the lumbar spine. Iijima et al.[14] conducted a study on 260 participants with KOA, showing that accompanying back pain in individuals with knee pain has significant negative effects on quality of life and functional capacity. Again, Kim et al.[15] in a nationwide survey conducted with a large sample of participants, knee pain and LBP are important factors affecting the quality of life in people over 50 years of age. Our study also supports this perspective and quantitatively demonstrates that ODI scores are higher in patients with more severe knee symptoms.

There is strong scientific evidence that physical function deteriorates and quality of life decreases with increasing radiographic severity (K-L score) in patients with KOA[16-18]. However, radiographic severity and quality of life or disability in KOA are not always correlated. While some patients may have minimal complaints despite severe radiographic findings of osteoarthritis, some patients may have severe symptoms despite minimal radiographic findings[19,20]. Our findings align with the systematic review by Bedson and Croft[20], which documented a considerable discrepancy between clinical symptoms and radiographic osteoarthritis. According to their review, only 15-76% of patients with knee pain had radiographic KOA, and similarly only 15-81% of those with radiographic KOA reported knee pain[20]. These results suggest that radiographic severity does not consistently correlate with patient-reported symptoms or disability, and that multiple factors-such as pain definitions, imaging protocols, and demographic characteristics-contribute to this discordance. According to Yasuda et al.[21], K-L grade progression was linked to increased ODI scores in females, while ODI remained relatively stable across K-L grades in males. In our study, when patients were divided into two groups according to the radiographic stage of KOA, no significant difference was found in terms of ODI scores

Table 3. Correlation between radiological parameters and functional scores

		ODI (r)	ODI (p-value)	KOOS (r)	KOOS (p-value)
Canal diameters (mm)	L1-2	-0.04	0.66	0.11	0.24
	L2-3	0.0	0.98	0.11	0.25
	L3-4	-0.1	0.27	0.07	0.45
	L4-5	0.07	0.45	0.12	0.19
	L5-S1	-0.02	0.85	0.1	0.29
Canal area (cm^2)	L1-2	0.08	0.37	0.17	0.06
	L2-3	0.05	0.59	-0.01	0.93
	L3-4	0.01	0.95	0.07	0.48
	L4-5	0.13	0.18	0.14	0.13
	L5-S1	-0.03	0.72	0.21	<0.05
Spinopelvic parameters (°)	PI	-0.06	0.54	-0.17	0.07
	PT	0.08	0.40	-0.02	0.84
	SS	-0.23	<0.05	-0.12	0.22
Structural conditions	Scoliosis		<0.05		
	Spondylolisthesis				<0.05

ODI: Oswestry disability index, KOOS: Knee injury and osteoarthritis outcome score, PI: Pelvic incidence, PT: Pelvic tilt, SS: Sacral slope between the high-stage and low-stage KOA groups. This may be due to the simultaneous evaluation of patients with knee and LBP in our study. This finding suggests that the severity of structural degeneration in the knee does not always reflect the functional status of the low back.

Another noteworthy finding is that sagittal plane radiological parameters, such as SVA, thoracic kyphosis, and lumbar lordosis did not significantly influence the level of disability. This finding aligns with the results previously reported by Niu et al.[22], who, in their cross-sectional study involving 435 patients with non-specific chronic LBP, found that only the spino-sacral angle and age were significantly associated with disability. At the same time, other sagittal parameters failed to predict patient-reported functional outcomes such as the ODI. Interestingly, while Niu et al.[22] reported no significant correlation between SS and ODI, our study identified a significant negative correlation between SS and ODI. This finding suggests that sacral inclination may indeed influence functional status, highlighting the importance of evaluating individual differences in pelvic morphology more closely. Collectively, these observations emphasize that subjective functional scores, such as KOOS and ODI, may better reflect the real-life burden experienced by patients than structural imaging alone. Therefore, incorporating patient-reported outcome measures into the clinical assessment of degenerative spinal and knee disorders is essential for a more comprehensive evaluation. Another notable finding was that although the KOOS subscales were not statistically significant, the total KOOS score remained a significant predictor of disability. This suggests that cumulative burden across multiple domains-pain, symptoms, function, and quality of life-may influence resulting disability more than any single subdomain.

The study's retrospective design and modest sample size constitute notable limitations that may affect the robustness and generalizability of the conclusions. The fact that the number of female patients in our study was significantly higher than that of male patients raises the possibility that the results may be biased by gender. This imbalance should be evaluated carefully, considering the potential effects of gender on pain threshold, disability perception, and functional scores. The use of a single observer for radiological measurements may be considered a limitation, although the primary objective of the study was not to assess the reliability of these measures. Additionally, patients' previous medical treatment history was not included, which may have affected the KOOS and ODI scores.

CONCLUSION

This study demonstrated that lower KOOS scores were significantly associated with higher levels of back-related disability index. Lower SS values were linked to greater disability, while the presence of scoliosis was associated with increased ODI scores. In contrast, patients with spondylolisthesis had significantly lower KOOS scores, indicating reduced knee function. These findings underscore the importance of evaluating both lumbar spine and knee function simultaneously in cases of degenerative musculoskeletal disorders. We recommend that knee-related symptoms may contribute more to disability, especially in patients with low scores on KOOS subscales, and therefore, knee-focused treatment approaches should be prioritized.

Ethics

Ethics Committee Approval: This retrospective study was notified to our Local Ethics Committee and authorized by University of Health Sciences Türkiye, Gülhane Training and Research Hospital's authorities (approval no: 2024-511, date: 05.11.2024).

Informed Consent: This study retrospectively analyzed 114 patients experiencing both chronic low back and knee pain, the need for informed consent was waived.

Footnotes

Authorship Contributions

Surgical and Medical Practices: E.Y., Concept: H.Y.T., Design: U.Y., H.Y.T., Data Collection or Processing: A.A., Analysis or Interpretation: E.Y., Literature Search: A.A., Writing: U.Y.

Conflict of Interest: No conflict of interest was declared by the authors.

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COMPARISON OF THE CLINICAL EFFICACY OF TRANSFORAMINAL AND INTERLAMINAR EPIDURAL STEROID INJECTIONS IN PATIENTS WITH LUMBAR DISC HERNIATION: A RETROSPECTIVE STUDY

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ABSTRACT

Objective: This study aimed to compare the effects of transforaminal epidural steroid injection (TFESI) and interlaminar epidural steroid injection (ILESI) techniques on pain management, functional improvement, and neuropathic pain in patients diagnosed with lumbar disc herniation (LDH).

Materials and Methods: This retrospective cohort included 124 patients who underwent epidural steroid injections between 2024 and 2025. Patients were divided into two groups according to the injection technique: TFESI and ILESI. Pain intensity was assessed using the visual analog scale (VAS), functional status with the Oswestry disability index (ODI), and neuropathic pain with the douleur neuropathique 4 (DN4) questionnaire. Patient satisfaction and injection-related complications were comprehensively reported. Assessments were performed at baseline and at the 1st, 2nd, 3rd, and 6th months post-injection.

Results: In the TFESI group, VAS, ODI, and DN4 scores demonstrated significant reductions at all follow-up points ($p<0.001$). Patient satisfaction was notably higher in the TFESI group. Complication rates remained low in both groups, with no statistically significant difference ($p=1.000$).

Conclusion: In patients with LDH, TFESI provides greater pain relief and functional improvement compared to the interlaminar approach. While both methods are safe, the transforaminal technique appears to be a more effective and targeted treatment option.

Keywords: Lumbar disc herniation, transforaminal injection, interlaminar injection, epidural steroid, pain management, VAS, ODI, DN4

INTRODUCTION

Lumbar disc herniation (LDH) is one of the most common causes of low back pain and significantly impairs quality of life. Extrusion of disc material through the intervertebral space can compress the nerve roots, leading to severe radicular pain and functional loss. In patients unresponsive to conservative treatments, invasive pain management strategies such as spinal injections have gained prominence[1,2].

Epidural steroid injections aim to reduce inflammation, thereby alleviating pain and improving functional recovery. Various anatomical approaches can be employed for these injections; however, the interlaminar and transforaminal routes are the most frequently utilized. While interlaminar injections provide a broader epidural spread, transforaminal injections offer a more targeted drug delivery[3].

Several reports in the literature have highlighted the clinical effectiveness of both techniques, yet the need for comparative evidence to guide clinical decision-making remains[4,5]. In this context, we designed a retrospective study to compare the effects of transforaminal epidural steroid injection (TFESI) and interlaminar epidural steroid injection (ILESI) on pain control, functional improvement, and patient satisfaction in patients with LDH.

Drug administration near the dorsal root ganglion makes TFESI more specific[6,7], and this method is particularly effective in patients with unilateral radicular pain[8,9]. Conversely, ILESI is preferred in cases with multiple disc pathologies due to its wider epidural distribution[10,11]. Randomized controlled trials

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(RCTs) have demonstrated the superior efficacy of TFESI over both methods for pain management[12-14].

MATERIALS AND METHODS

Study Design and Ethical Approval

In this single-center retrospective cohort study was conducted between 2024 and 2025 at a tertiary pain management clinic. Electronic medical records were reviewed to identify consecutive patients diagnosed with LDH who underwent either TFESI or ILESI. The study was carried out in accordance with the principles of the Declaration of Helsinki and approved by the University of Health Sciences Türkiye, Adana City Training and Research Hospital Local Ethics Committee (approval no: 584, date: 10.07.2025).

Inclusion and Exclusion Criteria

Inclusion criteria were: (I) age ≥18 years, (II) LDH confirmed by magnetic resonance imaging, (III) treatment with TFESI or ILESI, (IV) availability of at least two follow-up visits among baseline, 1-, 2-, 3-, and 6-month assessments; and (V) documented symptom duration retrievable from medical records. Exclusion criteria included: marked spinal stenosis, spondylolisthesis, or previous lumbar surgery; active infection, coagulopathy, or progressive neurological deficits; occurrence of major post-injection complications (e.g., epidural hematoma, permanent neurological deficit); and critical missing data.

Patient Groups and Subgroups

Patients were divided into two main groups according to the injection technique: TFESI and ILESI. Symptom duration was calculated in months as the time from symptom onset to the injection date, based on patient statements, initial clinic notes, and discharge reports. It was analyzed both as a continuous variable and categorically: acute (<3 months), subacute (3-6 months), and chronic (>6 months). This classification was used in subgroup analyses to assess changes in primary outcomes visual analog scale (VAS), Oswestry disability index (ODI), douleur neuropathique 4 (DN4) according to symptom duration.

Concomitant Treatments

Use of analgesics (non-steroidal anti-inflammatory drugs, acetaminophen, weak/strong opioids), adjuvant medications (gabapentinoids, tricyclic anti-depressants, serotonin-norepinephrine reuptake inhibitors), and physical therapy/exercise programs during the 4 weeks prior to the procedure and the 6-month follow-up period were recorded as binary variables (yes/no). Dosage and treatment duration were noted when available. These variables were reported descriptively and included as covariates in multivariable models to minimize confounding effects.

Injection Level

The injection level was verified through procedure notes and fluoroscopic images, and recorded as L4-L5 or L5-S1. Selection was based on symptomatology and the predominant pathology confirmed by imaging. Injection level was used both descriptively and in subgroup analyses.

Interventional Techniques

All procedures were performed under sterile conditions and fluoroscopic guidance by experienced pain specialists at the same center. Hemodynamic parameters and oxygen saturation were monitored throughout the procedure. When not contraindicated, epidural placement was confirmed with non-ionic contrast. The injection solution in both techniques consisted of 40 mg triamcinolone mixed with 0.25% bupivacaine; the total volume was adjusted according to clinical judgment.

TFESI and Supraneural Technique

With the patient in prone position, the c-arm was rotated to provide an oblique view of the target foramen. Following skin anti-sepsis and local anesthesia, a 22G needle was advanced into the superior-anterior quadrant of the neural foramen, aligned with the inferior border of the pedicle and superior margin of the foramen, and positioned above the exiting nerve root (supraneural placement, commonly referred to as the "safe triangle" approach). After confirming negative aspiration, 1-2 mL of contrast was injected to verify radicular spread and exclude intravascular or intrathecal placement. The steroid-local anesthetic mixture was then administered slowly. This technique was designed to deliver the drug directly to the dorsal root ganglion and inflamed nerve root. Due to potential vascular and neurological risks, meticulous anatomical targeting was essential. Recent literature has compared supraneural and infraneural (retrodiskal/Kambin's triangle) approaches, discussing their safety and efficacy dimensions (e.g., SIAMESE protocol; interventional comparative studies)[15,16].

ILESI

With the patient in prone position, the target interlaminar space was centered under anteroposterior fluoroscopic view. Using either midline or paramedian entry, the epidural space was identified with the loss-of-resistance technique, followed by epidurogram confirmation with contrast. The same steroid-local anesthetic mixture was then injected into the epidural space. This approach is often preferred when a wider epidural distribution is desired.

Outcome Measures and Follow-up

Clinical assessments were conducted at baseline (pre-procedure) and at the 1st, 2nd, 3rd, and 6th months after injection.
- **Primary outcomes:** Pain intensity (VAS, 0-10), functional status (ODI, 0-100%), and neuropathic pain component (DN4).
- **Secondary outcomes:** Patient satisfaction at 6 months (rated on a three-point scale: good/fair/poor) and procedure-related complications (e.g., paresthesia, dural puncture, transient weakness, infection), collected from prospective complication forms and medical records.

Endpoints

The primary endpoint was ΔVAS (baseline to 6-month change) and the group×time interaction. Secondary endpoints included changes in ODI and DN4, 6-month satisfaction, and complication rates. Age, sex, and body mass index (BMI) balance between groups were reported descriptively. Symptom duration, injection level, and concomitant treatments were considered potential confounders and incorporated into analyses.

Statistical Analysis

All analyses were performed using IBM SPSS Statistics v26.0. Distribution of continuous variables was evaluated with the Shapiro-Wilk test and visual methods. Normally distributed variables were expressed as mean ± standard deviation, and non-normally distributed variables as median (interquartile range). Categorical variables were summarized as numbers (%). Between-group comparisons at baseline were conducted using independent t-tests or Mann-Whitney U tests, and categorical variables with chi-square or Fisher's exact tests.

Time-course analyses were performed using two complementary approaches:

1. Linear mixed-effects models (LMM): Including group (TFESI/ILESI), time (baseline, 1, 2, 3, 6 months), and group×time interaction, with covariates age, sex, BMI, symptom duration (acute/subacute/chronic), injection level (L4-L5/L5-S1), and concomitant therapies. Random intercepts at the subject level were specified, and covariance structures [autoregressive model of order (1) vs. unstructured] were compared using Akaike information criterion. Significant interactions were followed by Bonferroni-adjusted pairwise comparisons of marginal means.

2. Repeated-measures analysis of variance (RM-ANOVA): With a two-factor (group×time) design. Greenhouse-Geisser correction was applied when Mauchly's sphericity test was violated. Bonferroni correction was used for multiple comparisons.

Patient satisfaction was analyzed with ordinal logistic regression (proportional odds assumption checked). Complications were analyzed with chi-square/Fisher tests, with risk ratios, 95% confidence interval (CI) reported. Missing follow-up data were primarily handled with LMM under the missing at random assumption. Complementary RM-ANOVA analyses were conducted using complete cases, and in scenarios where missingness exceeded 10%, multiple imputation (m=20; predictive mean matching) was performed for sensitivity analyses.

All tests were two-tailed, with $p<0.05$ considered statistically significant. Effect sizes (partial η^2, Cohen's d, odds ratio with 95% CI) were systematically reported. Table footnotes explicitly described statistical adjustments (Bonferroni, Greenhouse-Geisser, etc.).

Note (TFESI supraneural): Recent comparative studies and safety/efficacy discussions regarding supraneural versus infraneural approaches were referenced (e.g., BMJ Open SIAMESE protocol, 2023; Interventional Pain Medicine, 2024).

RESULTS

A total of 124 patients were included in the study, with 64 undergoing TFESI and 60 receiving ILESI. The groups were comparable in terms of age, sex, and BMI (Table 1). The distribution of injection levels was also similar (L4-L5≈64-66%, L5-S1≈34-36%). Use of concomitant therapies during baseline and follow-up was comparable between groups (analgesics: TFESI 82.8%, ILESI 88.3%; adjuvants: 37.5% vs. 36.7%; physical therapy: 32.8% vs. 30.0%) (Table 2).

Pain (VAS)

Baseline VAS values did not differ significantly between groups (TFESI: 7.22±1.08, ILESI: 7.47±1.09; $p>0.05$). At 6 months, VAS scores were 1.81±1.49 in TFESI and 4.35±1.33 in ILESI, with a statistically significant intergroup difference (Welch $t=-10.04$, $p<0.001$). The baseline-to-6-month change (ΔVAS) was -5.41±1.23 for TFESI and -3.12±1.20 for ILESI. The between-group ΔVAS difference (TFESI-ILESI) was -2.29 (95% CI: -2.63 to -1.95), $t=-13.24$, $p<0.001$, with a large effect size (Cohen's d=-2.39).

Table 1. Baseline demographic and clinical characteristics of patients

Variable	TFESI (n=64)	ILESI (n=60)	p-value
Age (years, mean ± SD)	47.8±13.8	50.8±15.7	>0.05
Sex (male/female)	0/64	52/8	>0.05
BMI (kg/m^2, mean ± SD)	27.95±6.42	27.44±7.48	>0.05
Baseline VAS	7.22±1.08	7.47±1.09	>0.05
Baseline ODI	64.52±8.94	64.33±8.86	>0.05
Baseline DN4	6.34±1.12	6.50±1.21	>0.05
Symptom duration (months)	Median (IQR)	Median (IQR)	>0.05
Injection level L4–L5	41 (64.1%)	40 (66.7%)	>0.05
Injection level L5–S1	23 (35.9%)	20 (33.3%)	

Baseline demographic and clinical characteristics of patients in TFESI and ILESI groups. TFESI: Transforaminal epidural steroid injection, ILESI: Interlaminar epidural steroid injection, VAS: Visual analog scale, ODI: Oswestry disability index, DN4: Douleur Neuropathique 4, IQR: Interquartile range, SD: Standard deviation, BMI: Body mass index

Table 2. Concomitant treatments			
Variable	**TFESI (n=64)**	**ILESI (n=60)**	**p-value**
Analgesic use	53 (82.8%)	53 (88.3%)	>0.05
Adjuvant use	24 (37.5%)	22 (36.7%)	>0.05
Physical therapy/exercise	21 (32.8%)	18 (30.0%)	>0.05

Concomitant use of analgesics, adjuvants, and physical therapy before and after the procedure. TFESI: Transforaminal epidural steroid injection, ILESI: Interlaminar epidural steroid injection

Table 3. Temporal changes in VAS, ODI, and DN4

Outcome	Baseline (Mean ± SD)	1 month	2 months	3 months	6 months	Group×time interaction (p-value)
VAS (TFESI)	7.22±1.08	↓	↓	↓	1.81±1.49	<0.001
VAS (ILESI)	7.47±1.09	↓	↓	↓	4.35±1.33	
ODI (TFESI)	64.52±8.94	↓	↓	↓	25.41±9.74	<0.001
ODI (ILESI)	64.33±8.86	↓	↓	↓	40.67±8.88	
DN4 (TFESI)	6.34±1.12	↓	↓	↓	3.34±1.49	0.37 (NS)
DN4 (ILESI)	6.50±1.21	↓	↓	↓	5.05±1.77	

Group×time interactions for VAS, ODI, and DN4. DN4 interaction not consistently significant; however, 6-month differences were significant. TFESI: Transforaminal epidural steroid injection, ILESI: Interlaminar epidural steroid injection, VAS: Visual analog scale, ODI: Oswestry disability index, DN4: Douleur Neuropathique 4, NS: Not significant, SD: Standard deviation

In LMM, the group×time interaction for VAS was significant (all time-point p<0.001, Bonferroni-corrected), with trajectories illustrated in Figure 1 (Table 3).

Function (ODI)

Baseline ODI values were comparable (TFESI: 64.52±8.94, ILESI: 64.33±8.86; p>0.05). At 6 months, ODI was 25.41±9.74 for TFESI and 40.67±8.88 for ILESI (Welch t=-9.13, p<0.001). ΔODI was -39.11±8.09 in TFESI and -23.67±7.12 in ILESI, with a between-group difference of -15.44 (95% CI: -16.96 to -13.93), t=-20.24, p<0.001. The effect size was very large (Cohen's d=-3.58). The group×time interaction was also significant for ODI (p<0.001, Bonferroni-corrected), with time-series results shown in Figure 2 (Table 3).

Neuropathic Component (DN4)

Baseline DN4 values were similar between groups (TFESI: 6.34±1.12, ILESI: 6.50±1.21; p>0.05). At 6 months, DN4 scores were 3.34±1.49 for TFESI and 5.05±1.77 for ILESI (Welch t=-5.78, p<0.001). ΔDN4 was -3.00±0.79 in TFESI and -1.45±1.00 in ILESI, with a between-group difference of -1.55 (95% CI: -1.86 to -1.24), t=-9.89, p<0.001, Cohen's d=-1.80. In mixed-effects models, the group×time interaction for DN4 was not consistently significant across all time points (p≈0.37). However, both the 6-month difference and ΔDN4 comparisons were statistically significant in favor of TFESI (all p<0.001). Temporal changes are illustrated in Figure 3 (Table 3).

Symptom Duration Subgroups (Acute vs. Chronic)

As requested by reviewers, additional analyses were conducted for acute (<3 months) and chronic (>6 months) subgroups (Table 4).

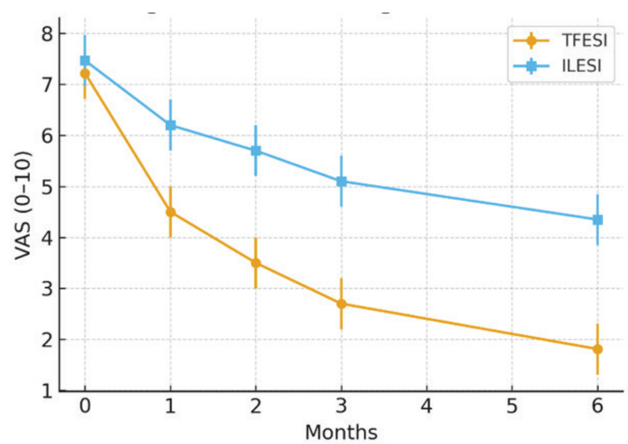

Figure 1. VAS change over time. Dots represent group means; error bars show 95% confidence intervals. Group×time interaction was significant in mixed-effects models (p<0.001). TFESI: Transforaminal epidural steroid injection, ILESI: Interlaminar epidural steroid injection, VAS: Visual analog scale

- For ΔVAS, TFESI superiority was evident in both acute (-5.54±0.98 vs. -3.09±1.20; Δ=-2.45, 95% CI: -3.10 to -1.81; t=-7.66, p<0.001) and chronic (-5.35±0.80 vs. -3.29±0.94; Δ=-2.06, 95% CI: -2.52 to -1.60; t=-8.95, p<0.001) subgroups.
- For ΔODI, between-group differences were also significant in acute (Δ=-14.88, 95% CI: -17.10 to -12.65; t=-13.48, p<0.001) and chronic (Δ=-16.52, 95% CI: -19.06 to -13.97; t=-13.16, p<0.001) subgroups.
- For ΔDN4, differences were significant in acute (Δ=-1.22, 95% CI: -1.71 to -0.73; t=-4.99, p<0.001) and chronic (Δ=-1.62, 95% CI: -2.08 to -1.16; t=-7.04, p<0.001) subgroups.

These subgroup findings confirm the superiority of TFESI over ILESI in improving pain, function, and neuropathic components in both acute and chronic cases. Considering that DN4 may not always be a strong indicator in acute LDH, DN4 changes were interpreted in conjunction with VAS/ODI outcomes across subgroups.

Patient Satisfaction (6 Months)

Satisfaction was assessed at 6 months using a three-level scale (good/fair/poor) (Table 5). In exploratory dichotomous analysis (good/fair vs. poor), group differences were significant across all cases (Fisher p=0.016). Subgroup analyses showed:

- Acute: ILESI 52.2% (12/23) vs. TFESI 20.8% (5/24), p=0.036.
- Chronic: ILESI 48.4% (15/31) vs. TFESI 30.8% (8/26), p=0.278.

In ordinal logistic regression, however, group effect was not consistently retained as an independent determinant (adjusted p>0.05). These findings suggest that satisfaction is a subjective, multifactorial outcome.

Safety

Procedure-related complication rates were 14.10% (9/64) in TFESI and 13.33% (8/60) in ILESI, with no significant difference (Fisher p=1.000). The most common events were transient paresthesia or needle trauma. No major complications were observed.

Covariates and Effect of BMI

In multivariable linear models adjusted for group, baseline values, symptom duration, injection level, and concomitant treatments, BMI did not significantly affect ΔVAS (p=0.387), ΔODI (p=0.431), or ΔDN4 (p=0.400). Thus, treatment response was independent of BMI.

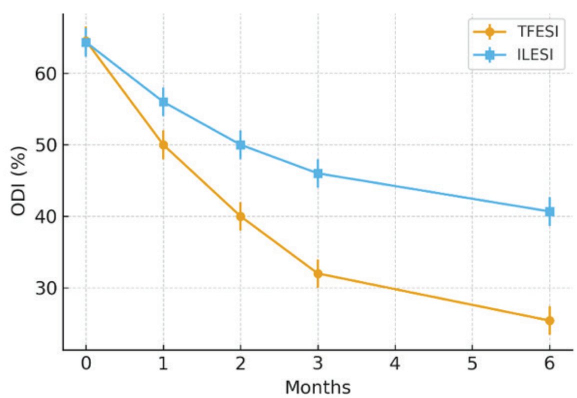

Figure 2. ODI change over time. TFESI consistently showed significantly lower ODI scores compared with ILESI at all follow-up points (Bonferroni-corrected p<0.001). TFESI: Transforaminal epidural steroid injection, ILESI: Interlaminar epidural steroid injection, ODI: Oswestry disability index

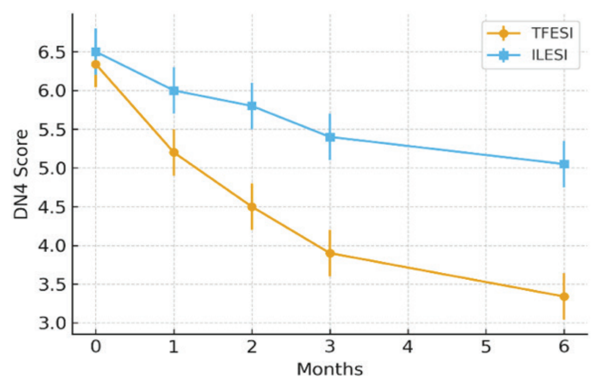

Figure 3. DN4 change over time. DN4 reductions were more pronounced in the TFESI group, particularly in the chronic subgroup. Although the group×time interaction was not consistently significant (mixed model p≈0.37), the 6-month difference was significant (p<0.001). TFESI: Transforaminal epidural steroid injection, ILESI: Interlaminar epidural steroid injection, DN4: Douleur Neuropathique 4

Table 4. Subgroup analyses by symptom duration (acute vs. chronic)

Outcome	Subgroup	TFESI (Mean ± SD)	ILESI (Mean ± SD)	Δ Difference (95% CI)	t-value	p-value
ΔVAS	Acute	-5.54±0.98	-3.09±1.20	-2.45 (-3.10 to -1.81)	-7.66	<0.001
ΔVAS	Chronic	-5.35±0.80	-3.29±0.94	-2.06 (-2.52 to -1.60)	-8.95	<0.001
ΔODI	Acute	-39.88±6.50	-24.99±7.10	-14.88 (-17.10 to -12.65)	-13.48	<0.001
ΔODI	Chronic	-40.35±6.20	-23.83±6.90	-16.52 (-19.06 to -13.97)	-13.16	<0.001
ΔDN4	Acute	-3.00±0.85	-1.78±0.66	-1.22 (-1.71 to -0.73)	-4.99	<0.001
ΔDN4	Chronic	-3.01±0.88	-1.39±0.70	-1.62 (-2.08 to -1.16)	-7.04	<0.001

Subgroup analyses of pain (VAS), function (ODI), and neuropathic component (DN4) by symptom duration (acute vs. chronic). TFESI: Transforaminal epidural steroid injection, ILESI: Interlaminar epidural steroid injection, VAS: Visual analog scale, ODI: Oswestry disability index, DN4: Douleur Neuropathique 4, SD: Standard deviation, CI: Confidence interval

Table 5. Patient satisfaction (6th month)

Symptom Group	Intervention	Poor	Fair	Good
Acute	ILESI	6	12	5
Acute	TFESI	0	5	19
Chronic	ILESI	3	15	13
Chronic	TFESI	0	8	18
Subacute	ILESI	2	0	4
Subacute	TFESI	0	4	10

Patient satisfaction assessed at the 6th month using a three-point scale (good/fair/poor). Analyses were performed with Fisher's exact test.
TFESI: Transforaminal epidural steroid injection, ILESI: Interlaminar epidural steroid injection

Reporting Notes

All multiple comparisons were Bonferroni-corrected, and Greenhouse-Geisser correction was applied in RM-ANOVA when sphericity was violated. Temporal trajectories with 95% CIs are presented in Figures 1-3. Detailed numerical summaries are provided in Tables 3-4, and satisfaction distributions in Table 5.

DISCUSSION

In this single-center retrospective cohort, TFESI demonstrated superiority over ILESI in terms of pain (VAS), function (ODI), and neuropathic component (DN4) outcomes up to 6 months. This superiority remained consistent across both acute and chronic subgroups. Safety profiles were comparable, and patient satisfaction was found to be sensitive to non-technical and contextual factors. Multivariable models indicated that treatment response was independent of BMI.

Our findings, when considered alongside RCTs reporting similar outcomes between TFESI and ILESI in chronic unilateral radiculopathy (n=64)[17], a meta-analysis indicating TFESI's short-term advantage in pain control (9 RCTs+4 observational studies; total n=931)[18], and registry cohort data showing TFESI was more likely to achieve ≥50% reduction in leg pain (n=73)[19], support the clinical advantage of target-specific distribution in radicular phenotypes.

The supraneural (subpedicular/safe triangle) approach of TFESI facilitates ventral epidural delivery of the injectate to the dorsal root ganglion and adjacent nerve root. However, meticulous planning is required due to foraminal anatomy and potential variations of radiculomedullary arteries (anatomical and safety reviews)[20]. In this context, prospective non-inferiority protocols comparing supraneural and infraneural approaches aim to provide high-quality evidence regarding safety and efficacy balance[21].

Although DN4 was originally developed as a screening and stratification tool, it may reflect longitudinal changes in neuropathic symptom burden. In a post-breast surgery pain cohort (n=163), DN4 successfully stratified probable versus definite neuropathic pain[22]. Furthermore, a multicenter validation study (n=291) confirmed its accuracy in daily clinical practice[23]. In our study, reductions in DN4 scores were significant in favor of TFESI, and these changes paralleled improvements in VAS and ODI. This suggests that DN4, while secondary, may serve as a meaningful follow-up measure when interpreted alongside pain and function outcomes.

Large single-center series (n=290) have shown that Press-Ganey-based satisfaction scores do not correspond directly with pain reduction and are influenced by contextual variables such as age and insurance type[24]. Similarly, an earlier series (n=35) reported 83% satisfaction at 3 months, emphasizing the role of psychosocial factors in patient perception of outcomes[25]. In our data, although exploratory subgroup analysis suggested differences in acute cases, ordinal models did not confirm technique as an independent predictor. Thus, satisfaction should be interpreted as a secondary, multidimensional outcome, adjusted for confounders.

A comparative study (n=343) found no significant differences in 3-month VAS, ODI, or patient-reported outcomes measurement information system changes across BMI categories[26]. Likewise, in a single-level TFESI series (n=162), short-term success was similar between obese and non-obese patients[27]. In line with these results, our multivariable models confirmed that BMI had no independent effect on TFESI or ILESI efficacy.

This study contributes to the literature by (I) demonstrating the consistent superiority of TFESI across acute and chronic subgroups, (II) reporting DN4 as a longitudinal outcome alongside VAS and ODI, and (III) analyzing patient satisfaction within the framework of contextual determinants using multivariable statistical models. Strengths include the use of LMM and RM-ANOVA to test group×time interactions, and the incorporation of symptom duration and injection level into analytic models. Limitations are its single-center retrospective design and the contextual sensitivity of satisfaction measurement. These findings warrant confirmation through prospective, multicenter, protocol-driven trials.

CONCLUSION

In this study, TFESI was found to be superior to ILESI in terms of pain (VAS), function (ODI), and neuropathic component (DN4) outcomes up to 6 months, with consistent advantages observed in both acute and chronic subgroups. Although DN4 was originally designed as a screening tool, when interpreted alongside improvements in VAS and ODI, reductions in DN4 provide clinically meaningful information. Safety profiles of both techniques were similar, with no major complications observed, and multivariable analyses confirmed that treatment response was independent of BMI.

Clinically, TFESI may be considered the preferred option in the presence of a radicular phenotype and a targetable level, whereas ILESI remains a rational alternative in diffuse or midline patterns. Patient satisfaction was shown to be sensitive to contextual and non-technical factors, highlighting the importance of expectation management and standardization of concomitant therapies. These findings should be validated in prospective, multicenter trials employing standardized supraneural/infraneural techniques and predefined patient-reported outcomes.

Ethics

Ethics Committee Approval: The study was carried out in accordance with the principles of the Declaration of Helsinki and approved by the University of Health Sciences Türkiye, Adana City Training and Research Hospital Local Ethics Committee (approval no: 584, date: 10.07.2025).

Informed Consent: In this single-center retrospective cohort study was conducted between 2024 and 2025 at a tertiary pain management clinic.

Footnotes

Authorship Contributions

Surgical and Medical Practices: A.Y., Ç.K., Concept: A.Y., Ç.K., Design: A.Y., Ç.K., Data Collection or Processing: A.Y., Ç.K., Analysis or Interpretation: A.Y., Ç.K., Literature Search: A.Y., Ç.K., Writing: A.Y., Ç.K.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

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ASYMMETRIC PEDICLE SUBTRACTION OSTEOTOMY FOR ADULT FIXED CORONAL DEFORMITY: SURGICAL STRATEGY AND OUTCOMES BASED ON MALALIGNMENT SUBTYPE

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ABSTRACT

Objective: This study aimed to evaluate the radiological and clinical outcomes of asymmetric pedicle subtraction osteotomy (APSO) in the treatment of rigid coronal malalignment (CM), and to investigate the impact of deformity subtype-based on the Obeid classification-on surgical strategy and outcomes.

Materials and Methods: A total of 24 patients with rigid CM underwent APSO between 2015-2020. Patients were classified as type 1 or type 2 CM according to the T1 plumbline deviation. Radiological parameters, including Cobb angle, coronal vertical axis (CVA), sagittal vertical axis, pelvic incidence-lumbar lordosis (PI-LL) mismatch, and thoracic kyphosis, were compared pre- and postoperatively. Clinical outcomes were assessed using the visual analogue scale (VAS) and Oswestry disability index (ODI) scores at baseline, postoperative day 10, and one-year. Surgical maneuvers were stratified based on CM subtype. Statistical analysis included paired and independent t-tests and chi-square tests, with p<0.05 considered significant.

Results: Radiographic correction was significant across the cohort, with mean Cobb angle improving from 34.8° to 8.1° (p<0.001), CVA from 9.1 cm to 2.2 cm (p<0.001), and PI-LL mismatch from 21.1° to 7.8° (p<0.001). Clinical scores improved significantly at both postoperative time points (VAS: 8.7 to 3.1; ODI: 84.5% to 27.4%, p<0.001). Type 2 CM patients required more extensive correction techniques, including interbody cages (88.9% vs. 40.0%, p=0.002), iliac screws (77.8% vs. 13.3%, p<0.001), and kickstand rods (66.7% vs. 6.7%, p<0.001), compared to type 1 CM patients. The overall complication rate was 16.7%, including dural tear (n=1), proximal junctional kyphosis (n=2), and implant loosening (n=1); no neurological deficits were observed.

Conclusion: APSO provides effective three-dimensional correction in patients with rigid coronal deformity, yielding favorable clinical and radiological outcomes at one-year follow-up. CM subtype plays a critical role in surgical planning, in the need for distal extension and lumbosacral interventions. When tailored to deformity morphology, APSO is a safe and reliable alternative to more aggressive osteotomy techniques.

Keywords: Asymmetric osteotomy, pedicle subtraction osteotomy, rigid deformity, coronal deformity, adult spinal deformity

INTRODUCTION

Coronal malalignment (CM) is defined as a lateral displacement of the T1 plumbline from the midline of the sacrum by more than 2 cm[1]. Although frequently associated with sagittal imbalance in adult spinal deformity (ASD), CM can also occur as an isolated deformity due to lower extremity length discrepancy, hip contractures, or neurological conditions such as Parkinson's disease or Pisa syndrome[2]. Clinically, CM is associated with functional limitations including gait disturbances, difficulty in standing, and impaired quality of life. Moreover, CM may contribute to pelvic obliquity and lumbosacral fractional curves, further complicating surgical correction[3].

Several studies have demonstrated that persistent or postoperative CM negatively affects patient-reported outcomes, particularly in patients undergoing long-segment spinal fusion[4-6]. In this context, appropriate correction of the coronal plane has become increasingly recognized as a critical goal in ASD surgery.

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While posterior instrumentation alone may suffice in flexible deformities, rigid curves often require osteotomies to restore alignment. Vertebral column resection (VCR) remains the most feasible technique for fixed multiplanar deformities but is associated with high complication rates, including neurological injury, excessive blood loss, and prolonged operative time[7,8]. Pedicle subtraction osteotomy (PSO) was initially described by Thomasen[9] in 1985 for patients with ankylosing spondylitis. Although it has been traditionally used for sagittal correction, it can be modified asymmetrically to achieve coronal realignment with less morbidity[10].

Asymmetric PSO (APSO) involves greater bone resection on the convex side of the deformity. It has emerged as a viable alternative to VCR in selected patients with rigid coronal deformities. However, data on the outcomes of APSO remain limited, and prior studies have often lacked standardized classification-based comparisons[10,11].

This study aims to evaluate the radiological and clinical outcomes of patients who underwent APSO for rigid coronal deformity and to assess whether outcomes differ between CM types as defined by the Obeid classification. Additionally, we aim to highlight practical surgical strategies tailored to CM subtypes.

MATERIALS AND METHODS

Study Data and Patient Selection

This retrospective clinical study included 24 patients who underwent APSO for rigid coronal deformity between January 2015 and March 2020. All patients were operated on a single institution by the same surgical team. Inclusion criteria were age >18 years, rigid (the rigidity was evaluated according to the positional changes in the curve magnitude, including supine-standing position and lateral bending), coronal deformity with or without sagittal imbalance, a minimum clinical and radiological follow-up period of 12 months, and radiographic confirmation of fixed deformity which is uncorrectable with postural and positional maneuvers. Exclusion criteria were neuromuscular scoliosis, spinal tumors, infections, and prior surgery with osteotomy.

Institutional Review Board approval was obtained from University of Health Sciences Türkiye, Ümraniye Training and Research Hospital Ethics Committee (approval no: 436, date: 26.12.2024), and informed consent was acquired from all patients prior to inclusion.

Radiological and Clinical Evaluation

Preoperative planning was based on standing anteroposterior/lateral full spine X-rays. Cobb angle of the coronal deformity, coronal vertical axis (CVA), sagittal vertical axis (SVA), spinopelvic harmony pelvic incidence-lumbar lordosis (PI-LL) mismatch, LL between L1 and S1, and thoracic kyphosis (TK) between T2 and T12 were calculated.

CM was accepted as a CVA >4 cm. Sagittal imbalance was defined as either SVA >5 cm or PI-LL mismatch >11°. Thoracolumbar computed tomography and magnetic resonance images were also obtained to determine the fused vertebral segments, neural compression, ankylosis, and bone quality. The flexibility of the deformity was assessed through the alterations of the curve between supine and standing radiological images. Bending films were obtained when necessary. According to the Obeid classification[1], the CM was grouped into two types: in type 1 CM, the T1 plumbline is on the side of the concavity of the main curve (Figure 1), and in type 2 CM, the T1 plumbline is on the convexity of the main curve (Figure 2).

The visual analogue scale (VAS) score and Oswestry disability index (ODI) scores were evaluated preoperatively, on the 10th postoperative day, and 1st year. Perioperative complications and revision surgeries were also recorded.

Surgical Technique

All surgeries were performed under general anesthesia in the prone position. A midline posterior incision and subperiosteal dissection for exposure of the posterior spinal elements are performed. Pedicle screws are inserted bilaterally at the planned levels above and below the osteotomy site. A temporary rod is placed on one side for stabilization. Laminectomy and bilateral facetectomies are performed at the index level, followed by wide decompression of the spinal canal. The pedicles of the target vertebra are removed, and a wedge-shaped resection of the vertebral body is carried out using osteotomes and rongeurs under fluoroscopic guidance. On the convex side, a wider wedge of the vertebral body is resected, including partial removal of the adjacent disc if necessary, while the concave side is preserved more to allow asymmetric closure. The anterior cortex on the concave side is left intact to serve as a hinge. After achieving the desired correction via controlled closure of the osteotomy gap, final rods are placed, compression is applied, and the construct is secured. Hemostasis and layered closure follow.

Different surgical maneuvers were employed for CM type 1 and type 2 patients. In type 1 CM, correction mainly targets the apical segment of the primary curve. Distraction was applied to the concave side of the osteotomy level. The convex side was allowed to collapse with controlled closure of the wedge. No additional iliac fixation was routinely required. A unilateral interbody cage was inserted in the L4-L5 or L5-S1 disc space, depending on lumbosacral flexibility. Coronal balance was confirmed intraoperatively using a T-square tool. Type 2 CM is frequently associated with a prominent lumbosacral fractional curve and pelvic obliquity. Therefore, correction involves both the apex and the lumbosacral region. Distraction was applied on the concave side of the apical curve. Simultaneous compression was applied to the convex L5-S1 junction to reduce lumbosacral obliquity. Additional correction maneuvers included insertion of unilateral transforaminal lumbar interbody fusion (TLIF) cages at L4-5 or L5-S1, bilateral iliac screws for enhanced pelvic anchorage, and placement of kickstand rods on the convex side to correct severe

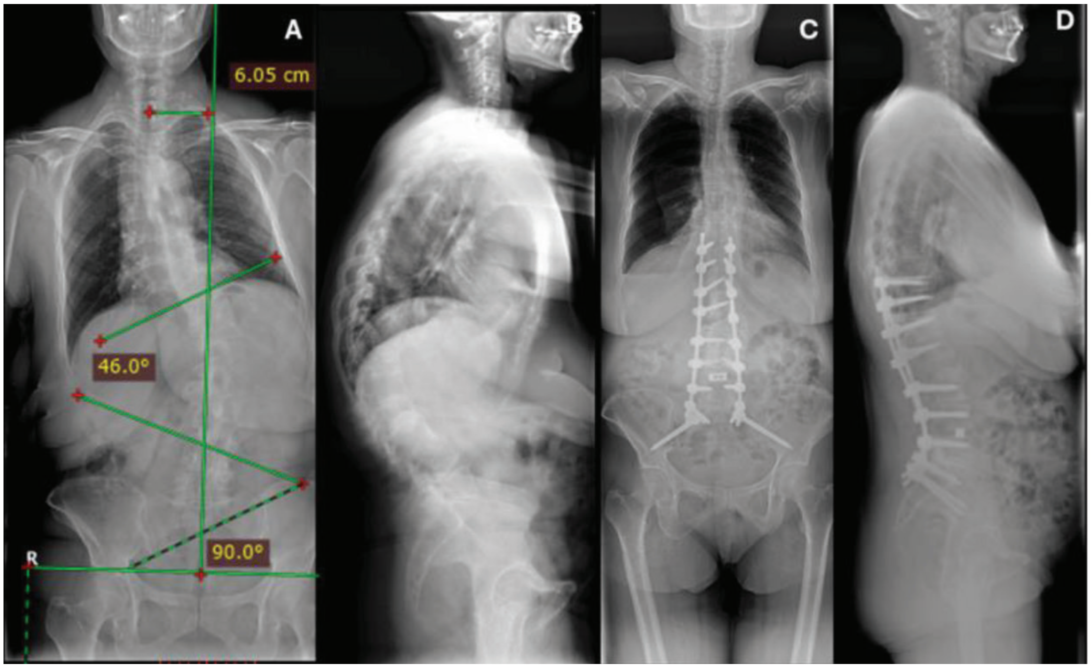

Figure 1. Pre- and postoperative radiographs of a 68-year-old female patient with Obeid type 1 CM (A, B). Preoperative standing AP and lateral scoliosis radiographs. The main thoracolumbar curve shows a Cobb angle of 46°, with a CVA of 6.05 cm. The T1 plumbline lies on the concavity of the curve, consistent with type 1 CM. The patient had a PI-LL mismatch of 15° and a TK of 33° (T11-L2) (C, D). Postoperative radiographs after L2 APSO and T10-iliac posterior instrumentation. A unilateral TLIF cage was placed at L4-L5 with additional decompression. Coronal and sagittal alignment was successfully restored. AP: Anteroposterior, CVA: Coronal vertical axis, CM: Coronal malalignment, PI: Pelvic incidence, LL: Lumbar lordosis, TK: Thoracic kyphosis, APSO: Asymmetric pedicle subtraction osteotomy, TLIF: Transforaminal lumbar interbody fusion

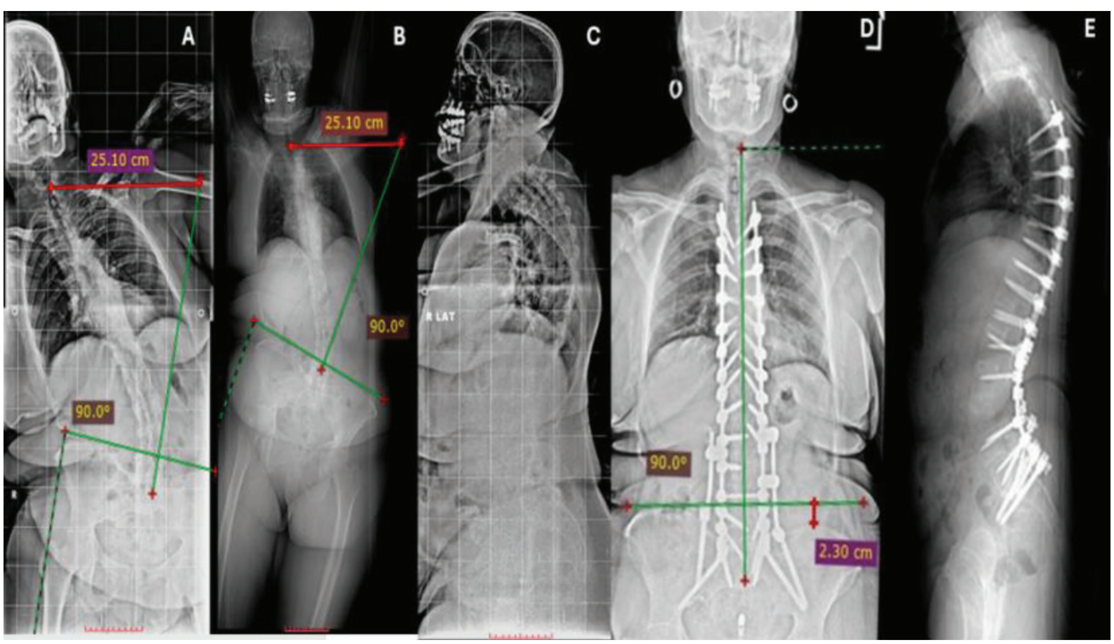

Figure 2. Pre- and postoperative imaging of a 55-year-old female patient with Obeid type 2 CM and pelvic obliquity (A, B). Standing AP scoliosis radiograph and CT scanogram demonstrate a 25.1 cm coronal shift and fixed pelvic obliquity due to leg length discrepancy. The T1 plumbline lies on the convex side of the main curve (C). Preoperative lateral radiograph shows preserved sagittal balance (D, E). Postoperative AP and lateral images following L3 APSO and T4-iliac pedicle screw instrumentation. Two kickstand rods were used to correct the lumbosacral fractional curve. Despite correction of spinal alignment, the pelvic obliquity persisted with a residual 2.3 cm leg length discrepancy. CM: Coronal malalignment, AP: Anteroposterior, CT: Computed tomography, APSO: Asymmetric pedicle subtraction osteotomy

obliquity. Correction was titrated to avoid overcorrection of the thoracolumbar segment relative to the fractional curve. Final alignment was checked using intraoperative fluoroscopy and T-square assessment.

Statistical Analysis

All statistical analyses were performed using Microsoft Excel version 16.91 (Microsoft Corp., Redmond, WA). Continuous variables were presented as mean ± standard deviation. The distribution of variables was assessed visually and analytically; given the approximate normal distribution, parametric tests were employed.

Preoperative and postoperative values for radiographic and clinical parameters (e.g., Cobb angle, CVA, PI-LL mismatch, LL, SVA, VAS, and ODI scores) were compared using paired t-tests, assuming matched dependent samples.

Subgroup comparisons between patients with type 1 and type 2 CM were performed using the independent-samples t-test for continuous variables and Pearson's chi-square test for categorical variables (e.g., presence of interbody fusion, iliac screw usage, and kickstand rod placement).

The level of statistical significance was set at $p<0.05$, with all p-values reported as two-tailed. No correction for multiple comparisons was applied due to the exploratory nature of the subgroup analyses. Confidence intervals (95%) were calculated where relevant but not reported in the text to preserve clarity.

RESULTS

A total of 24 patients, consisting of 16 females and 8 males, underwent asymmetric APSO for rigid coronal deformity. The mean age was 64.2±8.1 years (range: 43-75), and the mean follow-up duration was 13.6±1.2 months. Thirteen patients (54.2%) had undergone prior spinal surgery, including 5 with a history of previous instrumentation. According to the Obeid classification, 15 patients (62.5%) had type 1 CM, while 9 patients (37.5%) were classified as type 2.

Radiologically, significant improvements were observed in coronal and sagittal alignment following surgery. The mean preoperative Cobb angle of the main curve was 34.8±13.9 degrees, which improved to 8.1±4.6 degrees postoperatively ($p<0.001$, paired t-test). Similarly, the mean CVA decreased from 9.12±3.6 cm to 2.18±1.3 cm ($p<0.001$), while the PI-LL mismatch improved from 21.1±6.7 degrees to 7.8±5.1 degrees ($p<0.001$). LL increased significantly from 33.4±10.8 degrees to 50.212.1 degrees ($p=0.041$). Although TK showed a slight reduction from 27.3±11.2 to 25.6±10.9 degrees, this change did not reach statistical significance ($p=0.18$). The SVA decreased significantly from 4.9±2.1 cm to 2.3±1.5 cm ($p=0.013$) (Table 1).

When comparing CM subtypes, patients with type 1 CM achieved a mean Cobb angle correction of 27.3±8.5 degrees, whereas those with type 2 CM achieved 24.8±7.9 degrees; this difference was not statistically significant ($p=0.29$, independent-samples t-test). CVA correction was also comparable between groups (6.4±2.1 cm vs. 7.3±2.6 cm, $p=0.18$). The degree of improvement in PI-LL mismatch and SVA was similar in both groups ($p=0.67$ and $p=0.49$, respectively). However, significant differences were found in surgical strategies between CM types. Interbody fusion was performed in 88.9% of patients with type 2 CM, compared to 40.0% in type 1 ($p=0.002$, chi-square test). Iliac screws were used in 77.8% of type 2 patients versus only 13.3% in type 1 ($p<0.001$), and kickstand rods were employed in 66.7% of type 2 cases compared to just 6.7% of type 1 ($p<0.001$) (Table 2).

Clinically, all patients demonstrated significant functional and pain-related improvement. The mean preoperative VAS score was 8.7±1.2, which decreased to 2.3±1.4 on postoperative day 10 and remained stable at 3.1±2.4 at the one-year follow-up ($p<0.001$ for both comparisons). ODI scores showed a similar trend, improving from a preoperative mean of 84.5±14.2% to 22.6±8.9% at day 10 and 27.4±10.7% at one year (both $p<0.001$, paired t-test) (Table 3).

The overall complication rate was 16.7% (n=4). One patient experienced an intraoperative dural tear, which we repaired successfully without postoperative cerebrospinal fluid (CSF) leakage or neurological deficit. Two patients developed proximal junctional kyphosis (PJK), one of whom required revision surgery. One patient experienced implant loosening and pseudoarthrosis, necessitating reoperation with extension of fusion levels. No permanent neurological deficits were observed. The mean length of hospital stay was 3.2±1.4 days.

Table 1. Preoperative and postoperative comparison of radiological spinal parameters

Parameter	Preoperative	Postoperative	p-value
Cobb angle (°)	34.8±13.9	8.1±4.6	<0.001
CVA (cm)	9.12±3.6	2.18±1.3	<0.001
PI-LL mismatch (°)	21.1±6.7	7.8±5.1	<0.001
LL (°)	33.4±10.8	50.2±12.1	0.041
TK (°)	27.3±11.2	25.6±10.9	0.18
SVA (cm)	4.9±2.1	2.3±1.5	0.013

Radiographic measurements include coronal Cobb angle, CVA, PI-LL mismatch, LL, TK, and SVA. CVA: Coronal vertical axis, PI: Pelvic incidence, LL: Lumbar lordosis, TK: Thoracic kyphosis, SVA: Sagittal vertical axis

Table 2. Comparison of surgical parameters and outcomes between CM type 1 and type 2 patients

Parameter	Type 1 CM (n=15)	Type 2 CM (n=9)	p-value
Cobb angle correction (°)	27.3±8.5	24.8±7.9	0.29
CVA correction (cm)	6.4±2.1	7.3±2.6	0.18
PI-LL correction (°)	13.2±5.7	12.5±6.3	0.67
SVA correction (cm)	2.6±1.4	2.3±1.3	0.49
Interbody fusion performed (%)	40.0%	88.9%	0.002
Iliac screw use (%)	13.3%	77.8%	<0.001
Kickstand rod used (%)	6.7%	66.7%	<0.001

CM: Coronal malalignment, CVA: Coronal vertical axis, PI: Pelvic incidence, LL: Lumbar lordosis

Table 3. Clinical outcomes assessed by VAS and ODI scores

Time point	VAS	ODI (%)	p-value (VAS/ODI)
Preoperative	8.7±1.2	84.5±14.2	-
Postop day 10	2.3±1.4	22.6±8.9	<0.001/<0.001
Postop 1 year	3.1±2.4	27.4±10.7	<0.001/<0.001

VAS: Visual analog scale, ODI: Oswestry disability index

DISCUSSION

Rigid spinal deformities often require osteotomies to achieve adequate correction in both sagittal and coronal planes. APSO evolved as a less invasive alternative to CR for selected cases with fixed coronal deformities. In our series with 24 patients, APSO provided significant improvement in radiographic and clinical outcomes, supporting its feasibility and efficacy, even in the presence of sagittal imbalance.

Recent studies have emphasized the importance of coronal alignment in ASD surgery. Postoperative residual CM has been associated with poor clinical outcomes[5,12,13]. Ploumis et al.[5] reported that CM was present in 20.4% of ASD patients who underwent long-segment posterior spinal fusion and the incidence increased in the long-term follow-up. Zhang et al.[12] retrospectively reviewed 121 patients who underwent long-segment spinal fusion and found that Cobb angularity more than 20 degrees was associated with poor outcomes, thus it should be avoided during surgery. A preoperative CM greater than 3 cm towards the convexity has also been linked to worse postoperative results[4]. Even though some studies did not find a direct correlation between CM and patient-reported scores[14,15] others have reported significantly lower the scoliosis research society-22 patient questionnaire and ODI scores with persistent CM[16]. In our series, we observed significant improvement in CVA, PI-LL mismatch, and clinical outcomes across all patients at one-year follow-up.

Our surgical planning was established through the Obeid classification, which categorizes the CM according to the position of T1 plumbline relative to the concavity or the convexity of the main curve[1]. While other classification models-such as Bao et al.[4] CSVL-based types and the angular threshold recommendations by Zhang et al.[12] provide a descriptive framework, their utilization is limited in surgical guidance. Buell et al.[13] and the international spine study group modifiers further integrate sagittal parameters but are less operative in nature. The Obeid system was selected in our practice due to its criteria for applicability and feasibility of real-time surgical planning.

In our series, correction strategies were explicitly projected relative to the CM subtype. In type 1 CM, where the plumbline is on the concavity of the main curve, correction was maintained through asymmetric wedge resection and concave distraction at the apical segment. Minimal distal extension of the instrumentation and selective interbody fusion were typically adequate. However, type 2 CM, which is characterized with convex plumbline deviation and lumbosacral curve required a more extensive correction strategy. In both studies, Lewis et al.[17] and Theologis et al.[18] demonstrated the critical impact of L4 and L5 tilt and lumbosacral fractional curve on coronal balance; therefore, we performed additional interventions, including compression at the convex L5-S1 junction, TLIF cages at L4-5 or L5-S1, and frequent use of bilateral iliac screws and kickstand rods. We utilized a t-square tool following final rod contouring to ensure coronal alignment intraoperatively, as described by Kurra et al.[19] and a previous report by our team. This deformity-specific, graduated surgical strategy allowed for consistent and reproducible correction in both CM types, hence minimizing the need for more aggressive osteotomies such as VCR[20].

Asymmetric osteotomies have been shown initially for patients with congenital scoliosis secondary to a hemivertebra[21,22]. APSO evolved as an alternative to VCR, which is associated with significant complications and high morbidity rates. APSO is reported to be associated with less blood loss, shorter duration of surgery, and less morbidity than VCR[11]. Bakaloudis et al.[23] performed APSO in patients with kyphoscoliosis secondary to various etiologies. Several studies reported APSO in ASD. Thambiraj and Boszczyk.[24] performed APSO in 2 patients with lumbar and thoracic coronal deformity, respectively. Obeid et al.[25] performed APSO in the T5 vertebra in a patient with posttraumatic kyphoscoliosis. Chan et al.[11] performed APSO in 14 patients with coronal deformity of varying etiologies including iatrogenic coronal imbalance, pseudoarthrosis, adjacent segment disease, and congenital scoliosis with hemivertebra. Authors reported improvement in sagittal and coronal spinopelvic parameters and patient-reported outcomes. In their series, 11 patients had medical or surgical complications, including L5 radiculopathy, pseudoarthrosis and rod breakage. They concluded that APSO may provide favorable correction in CVA, SVA and PI-LL mismatch. Our results were consistent with the previous reports suggesting improvement in SVA and CVA, along with sagittal spinopelvic parameters[11].

Our 16.7% complication rate is consistent with the previous literature. One of the four patients who experienced complications, had intraoperative dural tear during neural decompression. She was managed with primary repair and had neither CSF leak nor neurological deficit. Two patients developed PJK, one required revision surgery due to progressive kyphotic deformity. In the last patient with a history of rheumatoid arthritis, extended instrumentation and revision with anterior support were necessary due to pseudoarthrosis and loosening of S1 and iliac screws. This complication profile is considerably more favorable than those reported in the literature for more aggressive osteotomy techniques. The Scoli-RISK-1 study, which evaluated the high-risk 3-column osteotomies reported a complication rate of 73.7% for VCR and 46.9% for PSO[26]. Similarly, Chan et al.[11] described complications in 11 out of 14 patients who underwent APSO, including delayed-onset L5 radiculopathy, pseudoarthrosis, and rod breakage. Toyone et al.[27] reported four complications in 14 APSO cases, including one dural tear, two patients with cephalad hook dislodgement, and one rod breakage. Lau et al.[28], in a comparative study of APSO versus PSO, found no significant difference in complication rates but noted that APSO was associated with extended intensive care unit stay and hospitalization. In our study, there were no cases of permanent neurological deficit, infection, or mortality, and all patients were discharged after a mean postoperative stay of 3.2±1.4 days. The low rate of complications may be attributed to the short follow-up period. We believe that preoperative patient selection and careful surgical planning are fundamental in preventing possible complications.

Study Limitations

This study has several limitations. It is retrospective and lacks a control group, limiting direct comparison with other techniques. The follow-up period was limited to one year, and long-term functional outcomes remain unknown. Further studies with long-term follow-up are necessary to evaluate the rate of mechanical complications, including pseudoarthrosis, adjacent segment pathologies, instrumentation failure, curve progression and correction loss. The relatively small sample size limits the ability to draw definitive conclusions regarding the superiority or overall success of this surgical technique compared to other methods. The sample size is relatively small. Finally, the choice of surgical strategy was based on the surgeon's experience rather than a fixed protocol. Despite these limitations, our findings support the role of APSO as a feasible and effective alternative for managing rigid coronal deformity with correct indications depending on the deformity morphology. Larger prospective studies are needed to confirm these results and optimize surgical planning.

CONCLUSION

APSO is a feasible and efficient surgical technique for the correction of rigid coronal spinal deformities and provides radiographic alignment and improvement in functional outcomes at one-year follow-up. Our findings demonstrate that APSO can be successfully performed in both type 1 and type 2 CM with tailored intraoperative strategies based on the deformity subtype. The necessity for utilization of more extensive correction maneuvers including kickstand rods and iliac fixation in type 2 CM, highlights the importance of patient-specific surgical strategies.

Even though APSO may not fully replace more aggressive techniques such as VCR, it may provide a less morbid alternative for selected cases with fixed deformity. Future prospective studies with larger patient population and a longer follow-up duration are necessary to validate our findings and to establish standardized surgical guidelines for deformity-specific APSO application.

Ethics

Ethics Committee Approval: Institutional Review Board approval was obtained from University of Health Sciences Türkiye, Ümraniye Training and Research Hospital Ethics Committee (approval no: 436, date: 26.12.2024).

Informed Consent: Informed consent was acquired from all patients prior to inclusion.

Footnotes

Authorship Contributions

Surgical and Medical Practices: M.Y., S.D., Concept: S.D., Design: B.S., Data Collection or Processing: B.S., Analysis or Interpretation: A.F.R., Literature Search: G.G.Ö., Writing: B.S., L.A.

Conflict of Interest: No conflict of interest was declared by the authors.

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METASTATIC TUMORS OF THE SPINAL CORD; SECONDARY INTRAMEDULLARY TUMORS

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ABSTRACT

Objective: Intramedullary tumor metastasis in the spinal cord is a rare clinical entity but is increasing in incidence due to advances in primary tumor treatment and longer survival. The authors present one of the most extensive patient series yet on intramedullary spinal cord metastasis to provide treatment guidance for improved quality of life.

Materials and Methods: All spinal tumor cases treated between January 2012 and May 2021 at the Neurosurgery Department, Bahçeşehir University Faculty of Medicine, were screened for intramedullary spinal cord metastasis.

Results: Fifty-one patients were treated for spinal intramedullary lesions during the study period, of which 11 were diagnosed with radiologically and (or) pathologically confirmed intramedullary spinal cord metastasis (median age at presentation: 50 years, 54.5% female). Ten of these 11 patients received surgical intervention, and five (45.5%) were previously treated for primary breast cancer. The metastatic spinal lesion was cervical in 5 patients (45.5%), thoracic in two (18.2%), and within the conus medullaris in three (27.3%). The patient not receiving surgical intervention presented with a lesion at C2. Eight of 11 patients (72.7%) had accompanying intracranial metastasis, and 7 (63.6%) required additional neurosurgical interventions. Seven patients (63.6%) also presented with systemic metastasis requiring radiotherapy, systemic chemotherapy, or both, among whom four patients (36.4%) received post-operative radiotherapy. The median overall survival was only six months, but the median Modified McCormick scale score for neurological status improved (decreased) significantly post-surgery (2.5 vs. 4 pre-surgery, p<0.001).

Conclusion: Despite effective local and systemic treatment modalities, overall survival is short among patients with intramedullary spinal cord metastasis. Therefore, the main aims of surgery are to prevent further neurological decline and improve health-related quality of life.

Keywords: Spinal cord, metastasis, surgical excision

INTRODUCTION

Intramedullary metastasis of the spinal cord accounts for only 0.6% of all spinal cord tumors, and thus is rarely encountered in neurosurgical practice(1). However, it is estimated to account for 4.2%-8.5% of metastases diagnosed in the central nervous system (CNS), and is expected to increase in frequency with continued advances in primary tumor treatment(2). Metastatic spinal tumor has deleterious effects on health-related quality of life and so warrants careful review of past cases to provide guidance for best possible treatment. This study reviews radiologically and (or) pathologically confirmed intramedullary spinal cord metastasis cases treated at a single neurosurgery department over a 9-year period.

MATERIALS AND METHODS

All patients treated at the Neurosurgery Department, Bahçeşehir University School of Medicine, between January 2012 and August 2021 were screened for intramedullary spinal cord metastasis. Inclusion criteria were: (I) radiological and/or histopathological confirmation of an intramedullary metastatic lesion within the spinal cord parenchyma, (II) management at our center during the study period, and (III) availability of baseline clinical examination and MRI, with a 4-week post-operative assessment for surgical cases [Modified McCormick scale (MMCS)]. No age restrictions were applied (adult and pediatric patients were eligible). Exclusion criteria were: (I) intradural extramedullary or leptomeningeal-only metastases without

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parenchymal intramedullary involvement, (II) primary intramedullary neoplasms, and (III) insufficient clinical or imaging documentation for analysis. During this period, 173 patients were treated surgically for spinal tumors, including 51 patients with spinal intramedullary neoplasms. Of this latter group, 11 had radiologically or pathologically confirmed intramedullary spinal cord metastasis (Table 1), 10 of which received surgical intervention based on radiological appearance and systemic condition. Written informed consent was obtained from all patients (or their legally authorized representatives) prior to surgery, and all surgical procedures were performed under neurophysiological monitoring. Neurological status was evaluated using the MMCS[3] (Table 2) at presentation and four weeks after surgery. Overall survival was defined as the time between surgery and all-cause death. The study was approved by the Local Ethics Committee of Bahçeşehir University School of Medicine (approval number: 2025-10/03, date: 01.07.2025).

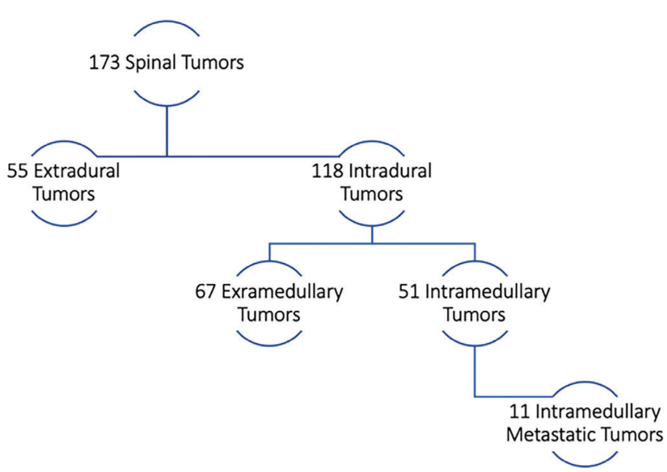
Statistical Analysis

All clinicodemographic data were analyzed using the Statistical Package for the Social Sciences for Windows 23.0 (IBM). Categorical variables are presented as frequency and percentage, while continuous variables are presented as median (minimum and maximum). Median post-operative survival was calculated by Kaplan-Meier curve analysis, and the effect of primary tumor surgery on survival was assessed by the log-rank test. Post-operative MMCS scores were compared to pre-operative scores using the Wilcoxon signed rank test. A p-value less than 0.05 was considered statistically significant for all tests.

RESULTS

Ten of 11 patients with confirmed intramedullary spinal cord metastasis received surgical treatment, of which two were in the pediatric age group (overall median age at presentation: 50 years, range: 7-65; 54.5% female). The most common primary

Table 1. Summary of the patient data



malignancy was breast cancer (5 of 11 patients, 45.5%), followed by lung cancer (2 patients, 18.2%), while mixed germ cell tumor, undifferentiated carcinoma, and granulocytic-myeloid sarcoma plus acute myeloid leukemia were the primary malignancies in one patient each (9.1%). The confirmed intramedullary spinal cord metastasis patient not treated surgically was a 35-year-old female with a previously operated gliosarcoma in the occipital region. She was admitted to the emergency room with sudden-onset loss of consciousness. Cranial magnetic resonance imaging with intravenous gadolinium enhancement revealed multiple supratentorial lesions with an accompanying intramedullary lesion at the C2 level. Due to poor neurological and systemic conditions, anti-oedematous treatment was performed, and the patient died on the seventh day of hospital admission.

The locations of the other metastasis lesions were as follows: cervical (5 patients, 45.5%), thoracic (2 patients, 18.2%), and conus medullaris (3 patients, 27.3%). One patient received surgical intervention twice for two different lesions six months apart, the first in the cervical region and the second in the thoracic region (Tables 3 and 4). Eight patients (72.7%) experienced recurrent intracranial metastasis during follow-up. Of these, seven patients (63.6%) required additional neurosurgical interventions, including gamma knife radiosurgery, craniotomy for intracranial metastasis, and ventriculoperitoneal (VP) shunt placement (Tables 3 and 4). The one patient with multiple intracranial lesions deemed ineligible for surgery received whole-brain radiotherapy.

Seven patients (63.6%) developed systemic metastasis requiring additional treatment (radiotherapy, systemic chemotherapy, or both). One patient was not further evaluated for systemic metastasis due to sudden neurological decline and death. Four patients (36.4%) also received post-operative radiotherapy to the surgical site. The median time from initial primary tumor diagnosis to intramedullary metastasis diagnosis was 12 months in our series (range: 0-129 months). The 12-month survival rate post-operatively was 18%, and the median overall survival rate was six months (range: 0.25-83) (Figure 1). There was no difference in median survival between patients with and without previous primary tumor surgery (Figure 2). The median MMCS score differed significantly following surgery

Table 2. Modified McCormick scale

Grade	Definition
I	Neurologically intact, normal ambulation, minimal dysesthesia
II	Mild motor or sensory deficit, functional independence
III	Moderate deficit, limitation of function, independent with external aid
IV	Severe motor or sensory deficit, limited function, dependent
V	Paraplegia or quadriplegia, even with flickering movement

Table 3. Pre- and post-operative summary of the patient data

Patient number	Age	Sex	Primary malignancy	Location	Pre-operative MMCS	Post-operative MMCS	Post-operative survival
1	46	Female	Breast	C4-5	II	I	83 months
2	33	Female	Breast	T11-12	IV	II	4 months
3	54	Female	Breast	Conus medullaris	II	I	18 months (under follow-up)
4	56	Female	Breast	Conus medullaris	III	II	2 months
5	65	Male	Lung	Conus medullaris	V	IV	6 months
6	50	Male	Lung	C7 T4-6	II III	I II	12 months 6 months
7	35	Female	Gliosarcoma	C2	N/A	N/A	1 week
8	7	Male	Mixed germ cell tumor (>95% yolk sac)	C3-5	IV	III	5 months
9	64	Male	Undifferentiated carcinoma	C5-7	V	IV	1 month
10	64	Female	Breast	C5-7	V	IV	6 months
11	10	Male	Granulocytic-myeloid sarcoma	T8-10	IV	III	7 months

MMCS: Modified McCormick scale, N/A: Not applicable

Table 4. Characteristics of the patient data

Characteristics	n (%) or median (min-max)
Sex	
Female	6 (54.5)
Male	5 (45.5)
Age, years	50 (7-65)
Primary malignancy	
Breast	5 (45.5)
Lung	2 (18.2)
Other	4 (36.4)
Primary tumor surgery	
No	4 (36.4)
Yes	7 (63.6)
Location	
Cervical	5 (45.5)
Cervical and thoracic	1 (9.1)
Conus	3 (27.3)
Thoracic	2 (18.2)
Pre-operative MMCS	4 (2-5)
Post-operative MMCS	2.5 (1-4)
Post-operative survival in months	6.0 (0.25-83.0)
Intracranial metastasis	
No	3 (27.3)
Yes	8 (72.7)
Systemic metastasis	
No	3 (27.3)
Yes	7 (63.6)
N/A	1 (9.1)

Table 4. Continued

Characteristics	n (%) or median (min-max)
Post-operative RT	
No	6 (54.5)
Yes	4 (36.4)
N/A	1 (9.1)
Post-operative KT	
No	3 (27.3)
Yes	7 (63.6)
N/A	1 (9.1)
Diagnosis-metastasis time period, months	12 (0-129)
RT history	
No	1 (9.1)
Yes	10 (90.9)
Additional neurosurgical intervention requirement	
No	4 (36.4)
Yes	7 (63.6)
Subtypes of additional neurosurgical intervention	
Gamma knife	1 (9.1)
Craniotomy	2 (18.2)
Craniotomy and gamma knife	2 (18.2)
VP shunt	1 (9.1)
VP shunt and gamma knife	1 (9.1)
Overall survival	
Alive	1 (9.1)
Exitus	10 (90.9)

MMCS: Modified McCormick scale, N/A: Not applicable, RT: Radiotherapy, KT: Chemotherapy, VP: Ventriculoperitoneal

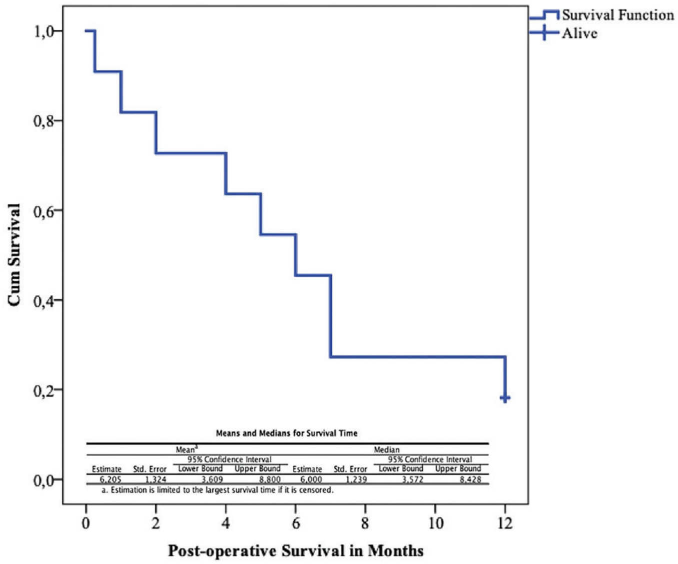


Figure 1. Twelve-month survival of all patients identified with confirmed intramedullary spinal cord metastasis

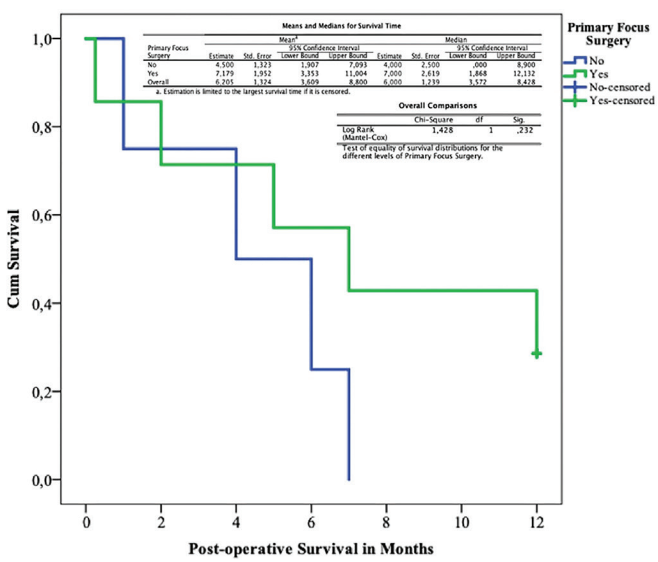


Figure 2. Twelve-month survival rates of patients with and without previous primary tumor surgery

compared to the pre-operative period (2.5 vs. 4.0, p<0.001) (Table 5). Illustrative pre- and post-operative neuroimages of intramedullary spinal cord metastasis in cervical and conus medullaris regions are presented in Figures 3 and 4, and histological images of an intramedullary spinal cord metastatic tumor are presented in Figure 5.

DISCUSSION

CNS metastatic tumors are usually intracranial, while intramedullary spinal cord metastases represent only 0.1%-8.5% of all CNS metastasis cases[4-6]. Metastases in the CNS originate most frequently from primary lung tumors, followed by breast cancers and lymphoma[6]. Patients with intramedullary spinal cord metastasis usually present with neurological deficits, most commonly sensory deficits and sphincter dysfunction. However, intramedullary spinal cord metastasis is the initial presentation in up to 22.5% of patients[5,7].

Table 5. Comparison of the pre-operative and post-operative MMCS

	Median	Minimum	Maximum	p-value
Pre-operative MMCS	4.00	2.00	5.00	<0.001
Post-operative MMCS	2.50	1.00	4.00	

MMCS: Modified McCormick scale

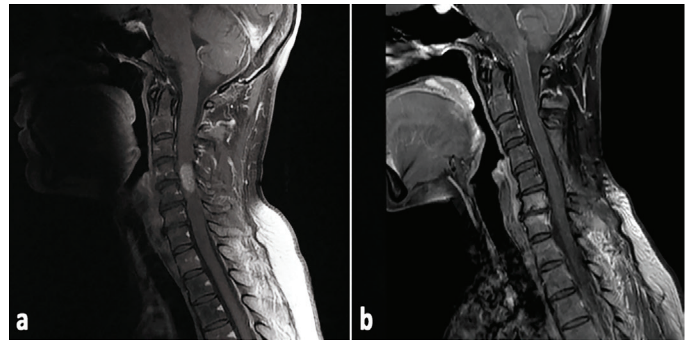


Figure 3. Neuroimaging examination of a patient with confirmed intramedullary spinal cord metastasis in the cervical region. The patient was a 46-year-old female with primary breast cancer. (a, b) Pre-operative (a) and post-operative (b), sagittal T1-weighted cervical MR images following IV gadolinium injection. MR: Magnetic resonance, IV: Intravenous

The characteristics of the current series are similar to those reported previously, although breast tumors were a more frequent origin. The most common site for intramedullary metastasis was the cervical region (Figures 3 and 5), consistent with previous reports[7,8], followed by conus medullaris and the thoracic segments (Figure 4). The median period from diagnosis of the primary tumor to detection of intramedullary metastasis in our series was 12 months, again consistent with previous studies[2], although the range was broad (0-129 months). Unfortunately, median overall survival time in the current series was only six months (range: 0.25-83), and only 18% of the patient population was alive by the twelfth post-operative month (Table 3). Nonetheless, survival times were actually longer than in previous reports[2,9,10]. Of the two patients surviving more than 12 months, one was alive after 83 months, and the other after 18 months. Survival time was not influenced by primary tumor treatment (Table 4), although much larger multicenter series are required to assess the influences of primary tumor characteristics and treatment modalities on survival. For instance, almost all patients in the current cohort had operable primary lesions, so comparisons with inoperable primary lesions were not possible. The relatively short survival durations in this and previous studies may be

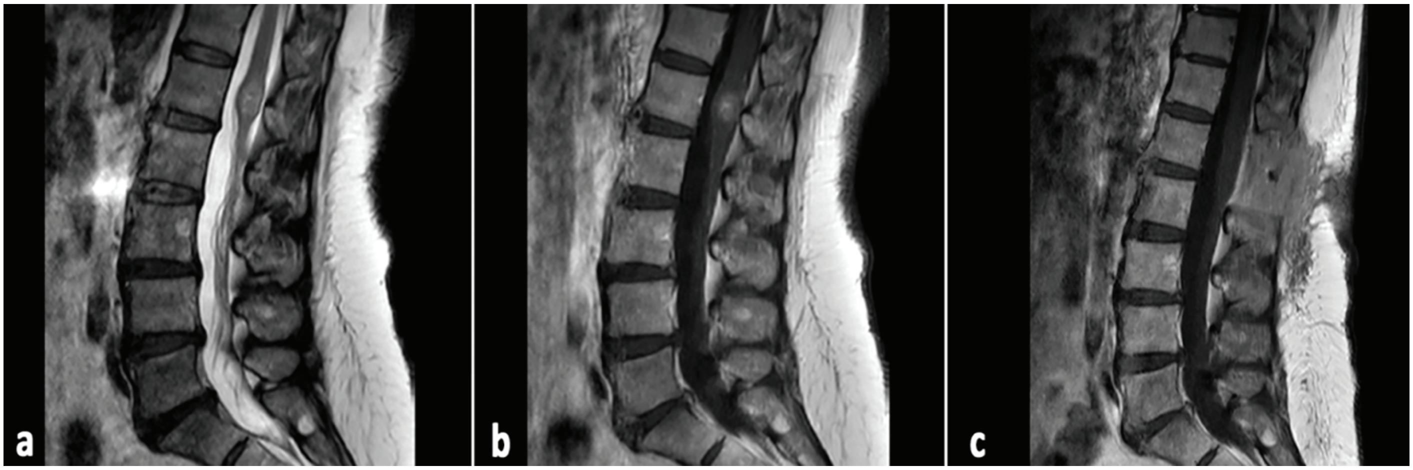


Figure 4. Neuroimaging examination of a patient with confirmed intramedullary spinal cord metastasis in the conus medullaris region. The patient was a 54-year-old female with primary breast cancer. (a, b) Pre-operative sagittal T2-weighted, (a) and sagittal T1-weighted, (b) lumbar MR image following IV gadolinium injection, (c) post-operative sagittal T1-weighted lumbar image following IV gadolinium injection. MR: Magnetic resonance, IV: Intravenous

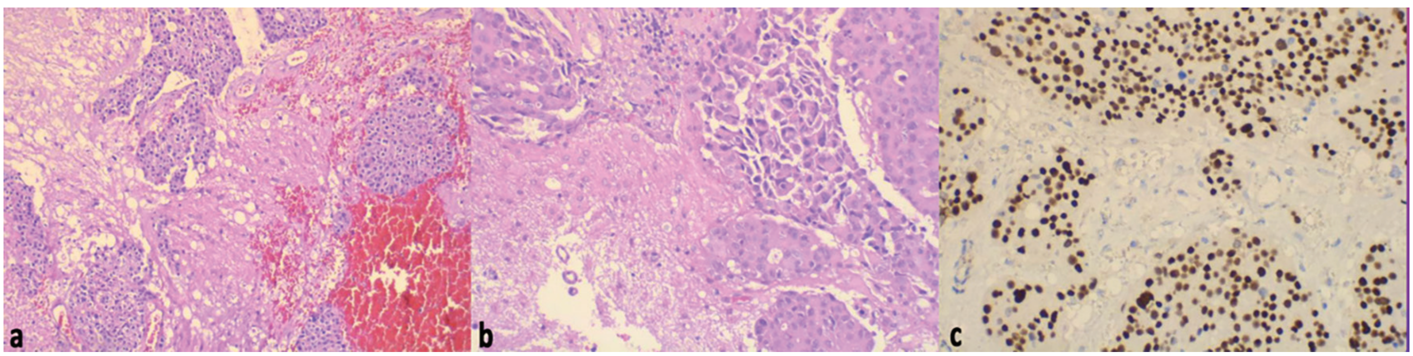


Figure 5. Histological analysis of confirmed intramedullary spinal cord metastasis in the cervical region. (a, b) Hematoxylin and eosin staining showing infiltration of metastatic islands into neuroglial tissue (a: ×100 magnification; b: ×200 magnification). (c) Immunostaining with the nuclear tumor cell marker GATA, consistent with breast cancer metastasis (×200 magnification)

explained by broader metastasis. Eight (72.7%) patients in this study either had accompanying intracranial metastasis at the time of intramedullary metastasis diagnosis or during follow-up, and seven required additional neurosurgical intervention (gamma knife radiosurgery, craniotomy, or VP shunt placement). There was, however, a significant decline in the MMCS score in the post-operative period ($p<0.001$), indicating improved neurological status. This finding supports the efficacy of surgical intervention for improving patient quality of life.

CONCLUSION

Despite advances in local and systemic treatments, the overall survival of patients with intramedullary spinal metastasis is relatively short, although there are rare cases of several for several years (Figure 3). Therefore, the main aim of surgery is to prevent further morbidity caused by the metastatic component of the primary tumor and to improve quality of life.

Ethics

Ethics Committee Approval: The study was approved by the Local Ethics Committee of Bahçeşehir University School of Medicine (approval number: 2025-10/03, date: 01.07.2025).

Informed Consent: Written informed consent was obtained from all patients (or their legally authorized representatives) prior to surgery, and all surgical procedures were performed under neurophysiological monitoring.

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Footnotes

Authorship Contributions

Surgical and Medical Practices: Z.O.T., D.K., Concept: G.D.O., Z.O.T., D.K., Design: G.D.O., Z.O.T., D.K., Data Collection or Processing: G.D.O., B.P., Analysis or Interpretation: G.D.O., B.P., Literature Search: G.D.O., B.P., Writing: G.D.O., B.P., Z.O.T., D.K.

Conflict of Interest: No conflict of interest was declared by the authors.
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ORIGINAL ARTICLE
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ASSESSING THE ADEQUACY OF ARTIFICIAL INTELLIGENCE MODELS IN ANSWERING SPINE SURGERY QUESTIONS FROM THE ORTHOPEDIC RESIDENCY TRAINING AND DEVELOPMENT EXAMINATION

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ABSTRACT

Objective: Artificial intelligence (AI) has undergone remarkable advancements in recent years, and its integration across various domains has been transformative. In the field of medicine, AI applications are rapidly expanding, offering novel opportunities for clinical practice, decision-making, and medical education. The present study sought to assess the performance and reliability of state-of-the-art AI models in addressing spine surgery questions from the Orthopedic Residency Training and Development Examination conducted in Türkiye between 2010 and 2023.

Materials and Methods: A total of 286 spine surgery questions were systematically analyzed. The reference standard was established using the official correct answers, which were subsequently compared with the outputs generated by three advanced AI models: Chat Generative Pre-trained Transformer-5.0 (ChatGPT-5.0), Gemini-Pro, and DeepSeek-V3. Model performance was evaluated in terms of accuracy, error rate, and non-response rate. Comparative analyses among models were performed using chi-square and McNemar tests with pairwise post-hoc comparisons. Wilson's method was employed to calculate 95% confidence intervals (CIs). In addition, subgroup analyses were conducted according to question categories and temporal strata.

Results: Gemini-Pro achieved the highest accuracy rate (85.3%), demonstrating statistically significant superiority over ChatGPT-5.0 (71.7%, $p<0.001$). The overall accuracy rates were as follows: Gemini-Pro, 85.3% (95% CI: 80.7-88.9; non-response 1.4%); DeepSeek-V3, 78.0% (95% CI: 72.8-82.4; non-response 3.8%); and ChatGPT-5.0, 71.7% (95% CI: 66.2-76.6; non-response 10.8%). Temporal analyses revealed that Gemini-Pro and DeepSeek-V3 performed better in earlier years, whereas Gemini-Pro consistently maintained superior and stable performance in the later periods. In contrast, ChatGPT-5.0 exhibited persistently lower accuracy across all intervals.

Conclusion: Gemini-Pro demonstrated the most consistent and robust performance across both overall and temporal analyses. These findings underscore the promising role of AI in orthopedic residency education, particularly in examination preparation. Nevertheless, integration of AI into training curricula should be approached with caution, as expert oversight remains indispensable to ensure reliability and clinical applicability.

Keywords: Artificial intelligence, ChatGPT, Gemini, DeepSeek, spine surgery

INTRODUCTION

With rapid technological advancements, the demand for instant and accessible information has increased exponentially across all domains, including healthcare. Artificial intelligence (AI) has driven a transformative shift in medicine, encompassing applications in diagnosis, surgical planning, and medical education(1). In high-risk surgical specialties such as orthopedics and spine surgery, AI-assisted tools are increasingly utilized for radiographic interpretation, clinical decision support, and simulation-based training. Chat Generative Pre-trained Transformer (ChatGPT) has demonstrated utility in the medical field through its ability to perform case-based analyses, making it particularly valuable for literature synthesis and clinical evaluation. Its strengths lie in analyzing complex clinical cases and contributing to academic assessments(2). Another AI model,

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Gemini, distinguishes itself with advanced reasoning capabilities and the capacity to manage complex tasks. Consequently, its integration into clinical decision-making processes has been recommended[3,4]. DeepSeek represents another widely implemented AI model. While it has been described as more dynamic and flexible in tracking developments within the medical literature, it has also been noted to lack the capability for image processing[5]. The most recent version, DeepSeek-V3, further introduces offline functionality, thereby enhancing data privacy[6]. Furthermore, comparative analyses indicate that while ChatGPT demonstrates superiority in literature synthesis, clinical reasoning, medical education, and patient communication, DeepSeek shows relative strength in surgical education, skill acquisition, patient education, and pre-operative planning[7].

Recent studies have demonstrated that large language models (LLMs) can generate clinically relevant responses to medical questions, thereby highlighting their potential role in postgraduate education and examination preparation[8]. LLMs have shown progressively improved performance on medical licensing and specialty board examinations, underscoring their potential applicability in medical education[9-11]. Prior research revealed that ChatGPT-3.5 achieved borderline-passing performance on the United States Medical Licensing Examination, whereas GPT-4 demonstrated superior outcomes on surgical knowledge assessments[12,13]. More recent reports have begun comparing emerging models such as Gemini and DeepSeek in clinical tasks[14,15].

In Türkiye, the Orthopedic Residency Training and Development Examination (UEGS), administered annually by the Turkish Society of Orthopedics and Traumatology Education Council (TOTEK), serves as a national standardized assessment of theoretical and clinical knowledge among orthopedic residents. The examination encompasses a broad spectrum of subspecialties, including trauma, arthroplasty, sports medicine, pediatric orthopedics, and spine surgery. Among these, spine surgery represents a particularly critical domain due to its technical complexity, steep learning curve, and the necessity for precise anatomical and biomechanical knowledge. Evaluating AI models on standardized board questions provides valuable insights into their capabilities, limitations, and potential integration into orthopedic training. Previous studies in other medical disciplines have explored LLM performance on certification and licensing examinations, reporting variable yet frequently promising levels of accuracy. In Türkiye, several investigations have assessed AI performance on national board examinations prepared by TOTEK, comparing model outputs against residents and/or practicing surgeons[16-18]. However, to date, no study has systematically evaluated AI performance within the context of orthopedic residency training in Türkiye, with a particular focus on the spine surgery subspecialty.

Accordingly, the present study aimed to address this gap by analyzing AI-generated responses to spine surgery questions from the UEGS administered between 2010 and 2025. Specifically, this study sought to (I) determine the adequacy of AI models in assessing spine surgery knowledge, (II) compare performance differences among distinct AI platforms, and (III) discuss the potential implications of AI integration into orthopedic residency education and assessment.

MATERIALS AND METHODS

Study Design

This study was designed as a retrospective, comparative analysis of AI model performance using a standardized national examination dataset. The investigation focused specifically on the spine surgery domain of the UEGS, administered by the TOTEK. The UEGS questions are text-based and do not include figures or tables.

Data Source and Question Selection

All UEGS questions administered between 2010 and 2025 were reviewed. Questions were obtained from official archives and verified resources accessible to orthopedic training programs. From the complete pool, questions pertaining to spine surgery were systematically identified and included. Eligible items covered anatomy, pathology, biomechanics, diagnosis, and the treatment of spinal disorders. Incomplete, or ambiguous questions were excluded. In total, 286 spine surgery questions were incorporated. The correct answer to each question, as provided by the official UEGS answer key, was used as the reference standard (gold standard) for performance evaluation. During the study period, three AI models were tested: ChatGPT-5.0 (OpenAI, San Francisco, CA, USA), Gemini-Pro (Alphabet, Mountain View, CA, USA), and DeepSeek-V3 (DeepSeek AI, Beijing, China). All models were accessed between July and August 2025 via publicly available or application programming interface-based interfaces under standardized conditions.

Testing Procedure

Each question was entered into the respective AI model in its original Turkish form. For models with limited Turkish language capabilities, parallel English translations were also used, and outputs were cross-validated for consistency. AI responses were recorded in a structured format: correct (C), incorrect (I), and no answer/unknown (N). All items were submitted individually to the models, ensuring that no duplicated entries were used. To minimize memory retention bias and potential performance inflation, each question was answered in a new session. Moreover, the entire test was repeated twice at three-day intervals for each model using the same procedure. For analysis, the mean values of responses across different trials were calculated.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY, USA). AI outputs were compared with the official answer key. Performance metrics were defined as follows: accuracy (%) = number of correct responses/total number of questions; error rate (%) = number of incorrect responses/total number of questions; [non-response rate (NR) %] = number of "n" responses/total number of questions. Comparative analyses across AI models were performed using the chi-square test for categorical outcomes. A p-value <0.05 was considered statistically significant. Subgroup analyses were additionally performed according to time intervals (2010-2015, 2016-2020, 2021-2025) and question categories (trauma, degenerative spine, deformity, oncology, infection, and general knowledge).

Ethical Approval

The study protocol was reviewed and approved by the Non-Interventional Clinical Research Ethics Committee of Afyonkarahisar Health Sciences University (approval number: 2025/11, date: 05.09.2025).

RESULTS

A total of 286 spine surgery questions from the UEGS were analyzed to determine accuracy, error, and NRs. Gemini-Pro achieved the highest accuracy (85.3%), demonstrating significantly superior performance compared with both ChatGPT-5.0 (71.7%) and DeepSeek-V3 (78.0%). The overall chi-square test indicated significant differences among the models (p<0.001). Pairwise comparisons revealed that the difference between ChatGPT-5.0 and Gemini-Pro was statistically significant (p<0.001), whereas no significant differences were observed for the other model pairs. NRs were generally low across all models, with Gemini-Pro yielding the lowest proportion of unanswered items. The performance metrics of each AI model are summarized in Table 1.

Temporal Analyses

Accuracy rates demonstrated variability across time intervals.

2010-2015: ChatGPT-5.0: 65.2% [95% confidence interval (CI): 55.1-74.2; NR: 16.3%); Gemini-Pro: 79.3% (95% CI: 70.0-86.4; NR: 2.2%); DeepSeek-V3: 79.3% (95% CI: 70.0-86.4; NR: 3.3%). Pairwise McNemar tests: ChatGPT-5.0 vs. DeepSeek-V3, p=0.0106; ChatGPT-5.0 vs. Gemini-Pro, p=0.0241; Gemini-Pro vs. DeepSeek-V3, p=1.0000.

2016-2020: ChatGPT-5.0: 74.7% (95% CI: 64.7-82.7; NR: 12.6%); Gemini-Pro: 89.7% (95% CI: 81.5-94.5; NR: 0.0%); DeepSeek-V3: 77.0% (95% CI: 67.1-84.6; NR: 3.4%). Pairwise McNemar tests: ChatGPT-5.0 vs. Gemini-Pro, p=0.0044; Gemini-Pro vs. DeepSeek-V3, p=0.0074; ChatGPT-5.0 vs. DeepSeek-V3, p=0.8318.

2021-2025: ChatGPT-5.0: 74.8% (95% CI: 65.8-82.0; NR: 4.7%); Gemini-Pro: 86.9% (95% CI: 79.2-92.0; NR: 1.9%); DeepSeek-V3: 77.6% (95% CI: 68.8-84.4; NR: 4.7%). Pairwise McNemar tests: ChatGPT-5.0 vs. Gemini-Pro, p=0.0146; Gemini-Pro vs. DeepSeek-V3, p=0.0525; ChatGPT-5.0 vs. DeepSeek-V3, p=0.6476.

These findings indicate that Gemini-Pro and DeepSeek-V3 outperformed ChatGPT-5.0 in the earlier period (2010-2015), while Gemini-Pro consistently demonstrated superior and more stable performance in subsequent years. The temporal performance trends are illustrated in Figure 1, with detailed results presented in Table 2.

Subgroup Analyses by Question Category

Subgroup analyses were conducted across six domains of spine surgery. DeepSeek-V3 achieved the highest accuracy in oncology questions, whereas Gemini-Pro outperformed the other models across all remaining categories. Specifically:

Trauma (n=42): Gemini-Pro, 83.0% (95% CI: 69.9-91.1)
Degenerative spine (n=56): Gemini-Pro, 87.5% (95% CI: 76.4-93.8)
Deformity (n=87): Gemini-Pro, 85.1% (95% CI: 76.1-91.1)
Oncology (n=42): DeepSeek-V3, 92.3% (95% CI: 66.7-98.6)
Infection (n=21): Gemini-Pro, 81.0% (95% CI: 60.0-92.3)
General knowledge (n=62): Gemini-Pro, 87.1% (95% CI: 76.6-93.3)

A comprehensive summary of category-specific performances is provided in Table 3.

DISCUSSION

This study represents the first systematic evaluation of AI model performance on spine surgery questions from the UEGS, a standardized national examination in Türkiye. The findings demonstrate that Gemini-Pro achieved a notably higher accuracy rate compared with ChatGPT-5.0 and DeepSeek-V3, suggesting that advanced LLMs may serve as a complementary tool in orthopedic education.

Across the complete dataset of 286 spine surgery questions, Gemini-Pro consistently outperformed the other models, attaining both the highest accuracy and the lowest NR.

Table 1. Accuracy, error, and non-response rates of AI models on spine surgery questions from the UEGS between 2010 and 2025

Model	Total (n)	Correct (n)	Correct (%)	Incorrect (n)	Incorrect (%)	Uncertain (n)	Uncertain (%)
ChatGPT-5	286	205	71.7	50	17.5	31	10.8
Gemini	286	244	85.3	38	13.3	4	1.4
DeepSeek	286	223	78.0	52	18.2	11	3.8

AI: Artificial intelligence, UEGS: Orthopedic residency training and development examination

These results are consistent with the growing body of literature demonstrating that LLMs are approaching passing-level performance on high-stakes examinations and surgical knowledge assessments[12,13]. Global reviews of exam performance have further underscored substantial heterogeneity among model families[5], and emerging reports suggest that DeepSeek may achieve performance comparable to other systems in certain clinical decision-support tasks[14,15]. In the present study, the 71.7% accuracy of ChatGPT-5.0 aligns with findings from other disciplines evaluating LLM performance on specialty board examinations[19]. Gemini-Pro's higher accuracy and DeepSeek-V3's acceptable, albeit lower, accuracy rates reflect the performance variability across AI architectures, in line with previous reports[20].

Several prior studies have assessed AI performance on Turkish orthopedic examinations. Yağar et al. [21] reported that ChatGPT-4o performed favorably on the Turkish Orthopedics and Traumatology Board Examination, particularly in basic science questions. Pamuk et al. [16] found that ChatGPT not only performed with high accuracy but also surpassed the majority of human examinees, outperforming 98.7% of candidates. Conversely, Yiğitbay[18] observed relatively limited performance of ChatGPT in the same context. Ayik et al. [22] compared multiple models and showed that ChatGPT-4 achieved the highest accuracy compared with ChatGPT-3.5 and Gemini on Turkish orthopedic progress examinations. Similarly, Lum[23] reported that ChatGPT exhibited low likelihood of success in the American Board of Orthopaedic Surgery Examination when benchmarked against residents.

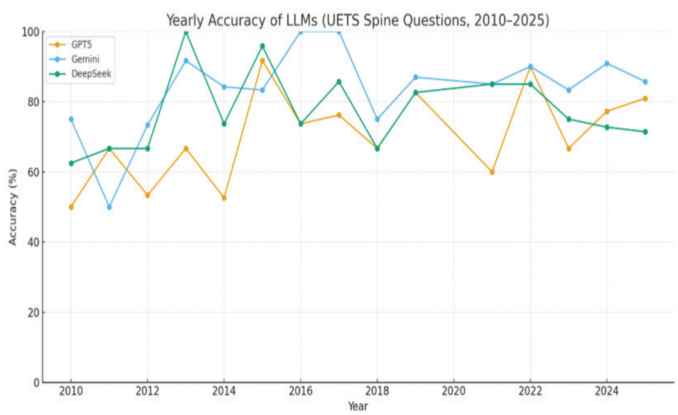

Figure 1. Yearly accuracy of LLMs (UETS Spine Questions, 2010-2025). LLMs: Large language models, UETS: Unified European Training Syllabus

Beyond examination settings, AI tools have also been investigated in clinical contexts. Demir and Kültür[24] compared ChatGPT-4o, DeepSeek-V3, and Gemini-Pro with orthopedic surgeons in patient assessment and decision-making, reporting that AI systems performed significantly worse on case-based scenarios but demonstrated comparable accuracy on knowledge-based questions. Karapınar et al. [17] specifically examined spine-related questions from orthopedic residency examinations and found that ChatGPT-3.5 and ChatGPT-4.0 provided answers equivalent to the knowledge level of a third-year resident.

The low NRs observed across all models suggest a general tendency to provide definitive answers. However, the presence of incorrect responses highlights the risk of misleading outputs. Thus, while AI tools may provide valuable support in exam preparation, interpretation of results should remain under expert supervision.

From an educational perspective, the integration of AI-based platforms into residency curricula could foster self-directed learning, enable immediate feedback, and promote standardization in exam preparation. Future investigations should incorporate larger datasets, extend analyses across different subspecialties, and explore interactive, real-time

Table 2. Binary McNemar comparisons by time periods

Period	Comparison	A wrong/B right (b01)	A right/B wrong (b10)	Discordant (n)	McNemar p-value (exact)
2010-2025 (Overall)	GPT5 vs DeepSeek	41	23	64	**0.0328**
2010-2025 (Overall)	GPT5 vs Gemini	56	17	73	**<0.0001**
2010-2025 (Overall)	Gemini vs DeepSeek	16	37	53	**0.0055**
2010-2015	GPT5 vs DeepSeek	18	5	23	**0.0106**
2010-2015	GPT5 vs Gemini	21	8	29	**0.0241**
2010-2015	Gemini vs DeepSeek	8	8	16	1.0000
2016-2020	GPT5 vs DeepSeek	12	10	22	0.8318
2016-2020	GPT5 vs Gemini	16	3	19	**0.0044**
2016-2020	Gemini vs DeepSeek	2	13	15	**0.0074**
2021-2025	GPT5 vs DeepSeek	11	8	19	0.6476
2021-2025	GPT5 vs Gemini	19	6	25	**0.0146**
2021-2025	Gemini vs DeepSeek	6	16	22	0.0525

GPT: Generative pre-trained transformer

Table 3. Subgroup analysis by question categories

Subtype/period	Model	Items (n)	Correct (n)	Accuracy (%)	95% CI (Accuracy)	Unknown (%)	Answered (n)	Coverage-adjusted accuracy (%)	95% CI (CA)	McNemar p-value: GPT-5 vs Gemini	McNemar p-value: GPT-5 vs DeepSeek	McNemar p-value: Gemini vs DeepSeek
Overall (2010-2025)	GPT-5	286	205	71.7%	66.2%-76.6%	10.8%	255	80.4%	75.1%-84.8%	**<0.0001**	**0.0328**	**0.0055**
	Gemini	286	244	85.3%	80.7%-88.9%	1.4%	282	86.5%	82.0%-90.0%			
	DeepSeek	286	223	78.0%	72.8%-82.4%	3.8%	275	81.1%	76.0%-85.3%			
Trauma	GPT-5	47	33	70.2%	56.0%-81.3%	8.5%	43	76.7%	62.3%-86.8%	0.1460	0.7539	0.2891
	Gemini	47	39	83.0%	69.9%-91.1%	0.0%	47	83.0%	69.9%-91.1%			
	DeepSeek	47	35	74.5%	60.5%-84.7%	2.1%	46	76.1%	62.1%-86.1%			
Degenerative	GPT-5	56	41	73.2%	60.4%-83.0%	8.9%	51	80.4%	67.5%-89.0%	**0.0386**	0.7905	0.1460
	Gemini	56	49	87.5%	76.4%-93.8%	0.0%	56	87.5%	76.4%-93.8%			
	DeepSeek	56	43	76.8%	64.2%-85.9%	3.6%	54	79.6%	67.1%-88.2%			
Deformity	GPT-5	87	58	66.7%	56.2%-75.7%	13.8%	75	77.3%	66.7%-85.3%	**0.0025**	**0.0072**	0.5488
	Gemini	87	74	85.1%	76.1%-91.1%	2.3%	85	87.1%	78.3%-92.6%			
	DeepSeek	87	71	81.6%	72.2%-88.4%	4.6%	83	85.5%	76.4%-91.5%			
Oncology	GPT-5	13	8	61.5%	35.5%-82.3%	23.1%	10	80.0%	49.0%-94.3%	0.3750	0.1250	1.0000
	Gemini	13	11	84.6%	57.8%-95.7%	0.0%	13	84.6%	57.8%-95.7%			
	DeepSeek	13	12	92.3%	66.7%-98.6%	0.0%	13	92.3%	66.7%-98.6%			
Infection	GPT-5	21	16	76.2%	54.9%-89.4%	4.8%	20	80.0%	58.4%-91.9%	1.0000	1.0000	0.6250
	Gemini	21	17	81.0%	60.0%-92.3%	4.8%	20	85.0%	64.0%-94.8%			
	DeepSeek	21	15	71.4%	50.0%-86.2%	9.5%	19	78.9%	56.7%-91.5%			
General knowledge	GPT-5	62	49	79.0%	67.4%-87.3%	9.7%	56	87.5%	76.4%-93.8%	0.2668	0.7744	0.1435
	Gemini	62	54	87.1%	76.6%-93.3%	1.6%	61	88.5%	78.2%-94.3%			
	DeepSeek	62	47	75.8%	63.8%-84.8%	3.2%	60	78.3%	66.4%-86.9%			

CI: Confidence interval, CA: California, GPT: Generative pre-trained transformer assessments with residents.

When evaluating AI performance, it is important to consider differences in question formats. Prior studies have demonstrated that the performance of LLMs may vary depending on whether the assessment involves multiple-choice questions (MCQ) or true/false questions. Isleem et al.[25] reported that ChatGPT's accuracy differed according to question type. In our study, the UEGS exam format was limited exclusively to true/false items. While this binary structure simplifies decision-making for AI and may yield higher accuracy compared to more complex MCQ, it simultaneously restricts the depth of reasoning and clinical judgment that can be assessed. Therefore, the findings should be interpreted within the context of this inherent limitation of the exam format.

Study Limitations

The limitations of this study include its retrospective design, lack of qualitative assessment of AI-generated responses, and potential heterogeneity in model versions over the study period. Moreover, given that the study focuses exclusively on spine surgery questions and employs a simple true/false format, the findings may not fully capture the breadth of medical knowledge or the complexity of clinical judgment. These findings establish an important foundation for the integration of AI into orthopedic residency education and underscore the need for multicenter, prospective studies to validate these results.

CONCLUSION

This study demonstrates that AI models can serve as supportive tools in orthopedic residency education and examination preparation. Among the evaluated systems, Gemini-Pro achieved significantly higher accuracy compared with ChatGPT-5.0 and DeepSeek-V3. The observed variability in performance across time underscores the dynamic evolution of AI capabilities. Larger, multicenter studies incorporating broader datasets and interactive educational modules will be essential to fully elucidate the role of AI in orthopedic training.

Ethics

Ethics Committee Approval: The study protocol was reviewed and approved by the Non-Interventional Clinical Research Ethics Committee of Afyonkarahisar Health Sciences University (approval number: 2025/11, date: 05.09.2025).

Informed Consent: This study was designed as a retrospective.

Footnotes

Authorship Contributions

Surgical and Medical Practices: B.K.Y., U.Y., Concept: B.K.Y., U.Y., Design: B.K.Y., U.Y., Data Collection or Processing: B.K.Y., Analysis or Interpretation: B.K.Y., Literature Search: B.K.Y., U.Y., Writing: B.K.Y.

Conflict of Interest: No conflict of interest was declared by the authors.

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TRANSFORAMINAL EPIDURAL INJECTION IN FAILED BACK SURGERY AFTER UBE

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ABSTRACT

Objective: To evaluate the effectiveness of transforaminal epidural steroid injection (TFESI) in patients with failed back surgery syndrome (FBSS) after unilateral biportal endoscopic (UBE) lumbar discectomy.

Materials and Methods: Between 2022 and 2024, 14 patients who underwent single-level UBE discectomy and continued to suffer from radicular pain were included. Patients without motor deficit or obvious recurrent/residual disc herniation were treated with TFESI. Pain relief was evaluated using the visual analog scale (VAS) and the MacNab criteria.

Results: Mean pre-procedure VAS score for leg pain was 6.14±1.35, which significantly decreased to 2.64±1.75 at the 6th week follow-up ($p<0.0001$). According to the MacNab criteria, 78.4% of patients reported "good" or "excellent" outcomes.

Conclusion: Transforaminal epidural injection appears to be a safe and effective option in managing FBSS after UBE. More comprehensive prospective randomized studies need to be conducted.

Keywords: Failed back surgery syndrome, transforaminal injection, biportal endoscopy, lumbar disc herniation

INTRODUCTION

Lumbar disc herniation (LDH) is frequently seen in our society due to reasons such as obesity related to poor nutrition, lack of regular exercise habits, and working in heavy labor. Although most LDH cases improve with conservative treatments, surgical options are necessary in cases of progressive motor deficit and prolonged pain where conservative treatments are insufficient. However, it is known that in 10-40% of patients who undergo surgery, back pain or radicular pain does not completely resolve[1-3]. This condition is defined in the literature as failed back surgery syndrome (FBSS)[1]. The exact cause of FBSS has not been established in cases where the surgical technique is assumed to be correct. Controversial indications, postoperative scar tissue, reherniation/residual disc, or iatrogenic instability can be counted among the causes[4,5]. Although FBSS can be treated with medication, injection (transforaminal or caudal), or reoperation, there is no standard. This study examined the effectiveness of transforaminal epidural steroid injection (TFESI), a low-risk minimally invasive treatment method, in cases of FBSS following unilateral biportal endoscopic discectomy (UBE). To our knowledge, this is the first study in the literature to investigate the effectiveness of transforaminal injection in FBSS following UBE.

MATERIALS AND METHODS

We retrospectively examined patients with FBSS who had undergone UBE single-level discectomy between 2022 and 2024 and were followed up for at least one year. Patients with persistent symptoms causing motor deficits and with evidence of recurrent or residual disc herniation on lumbar magnetic resonance imaging (MRI) underwent reoperation. TFESI was performed in patients without motor deficits whose complaints had improved but who continued to experience radicular pain and numbness, and in whom imaging revealed no obvious recurrent discopathy (Figure 1A-D).

All procedures were performed by a single surgeon with 5 years of UBE experience. TFESI was performed in the operating room under local anesthesia with C-arm fluoroscopic guidance. Using a 22-gauge spinal needle, anteroposterior and lateral imaging was obtained. After confirming the periradicular placement with contrast

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injection, a mixture of 40 mg methylprednisolone and 1 cc bupivacaine was administered (Figure 1E-F). Patients without complications (e.g., anaphylaxis, foot drop) were discharged two hours after the procedure.

Inclusion criteria were:

1. age between 18-65 years;
2. having initially achieved satisfactory recovery after single-level lumbar discectomy using the UBE technique, but later developing recurrent clinical symptoms within 6 months postoperatively, with MRI findings consistent with epidural fibrosis;
3. having had back and leg pain for at least 6 months;
4. not responding to conservative treatments.

Exclusion criteria were:

- previous microsurgical surgery;
- multilevel epidural fibrosis;
- prior surgery for multilevel disc herniation;
- prior lumbar fusion surgery;
- history of TFESI prior to UBE surgery;
- recurrent disc herniation on multiple occasions;
- sacroiliac or facet joint pain;
- lumbar spinal stenosis, spondylolysis, spondylolisthesis, or scoliosis.

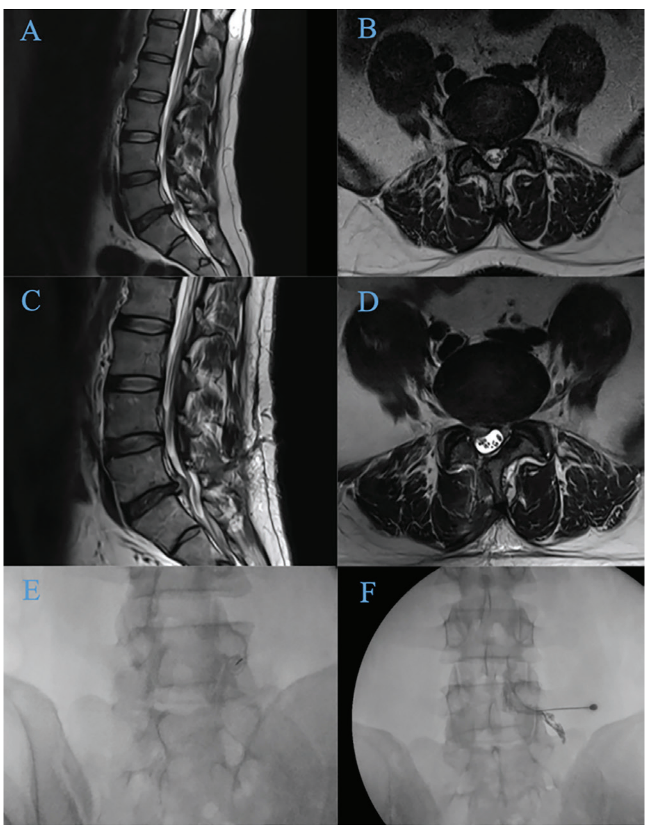

Figure 1. (A, B) Right L5-S1 disc herniation in a patient presenting with weakness in right ankle dorsiflextion. Sagittal and axial T2-weighted MRI. (C, D) MRI scan of a patient with persistent radicular pain in the right lower extremity despite no weakness in the right foot 2 months after surgery via the UBE approach. (E, F) Intraoperative fluoroscopic imaging of a patient undergoing TFESI due to radicular pain. MRI: Magnetic resonanca imaging, UBE: Unilateral biportal endoscopic, TFESI: Transforaminal epidural steroid injection

Clinical outcomes were evaluated using the visual analog scale (VAS) and the modified Macnab criteria. Pre- and post-procedure VAS scores (at 6 weeks) were compared.

This study was approved by the Ethics Committee of University of Health Sciences Türkiye, Sincan Training and Research Hospital (decision no: BAEK-2025-48, date: 22.07.2025). Written informed consent was obtained from all participants.

Statistical Analysis

Statistical analysis was performed using SPSS for Windows version 24.0 software (IBM Corp) Descriptive data were expressed as mean ± standard deviation, median (interquartile range 25th-75th) or number (frequency), where applicable. The normality of the distribution of continuous variables was tested using the Shapiro-Wilk test. The Mann-Whitney U test or Student's t-test was performed to compare quantitative variables.

RESULTS

In our institution, 14 of the 124 patients operated on using the UBE method (11.2%) experienced recurrence of pain immediately after the procedure or after a certain period of time, or residual pain affecting their daily lives. Since none of these patients had neurological deficits, revision surgery was not initially planned. TFESI was performed on the affected root. The study population consisted of 14 patients (8 female and 6 male) with a mean age of 47 years (range, 22-63 years). The most commonly operated level was L4-L5 (n=9), followed by L5-S1 (n=5).

The preoperative leg pain VAS score of the patients was 6.14±1.35 (4-8), while the post-operative leg pain VAS score at the one-and-a-half-month outpatient follow-up was found to be 2.64±1.75[1-8] (Table 1). This decrease was found to be statistically significant ($p<0.0001$).

The patients' satisfaction levels after the injection were measured using the MacNab criteria. Two patients (14.3%) were rated as excellent, 9 patients (64.3%) as good, 1 patient (7.1%) as fair, and 2 patients (14.3%) as poor (Figure 2). Revision surgery was required in 2 patients whose pain seriously affected their quality of life and who did not experience the expected benefit from the procedure.

Table 1. Pre-operative and post-operative leg pain VAS scores

	Mean ± SD	Minimum-maximum	p-value
Preoperative	6.14±1.35	4-8	
Postoperative (1.5 months)	2.64±1.75	1-8	<0.0001*

VAS: Visual analog scale, SD: Standard deviation

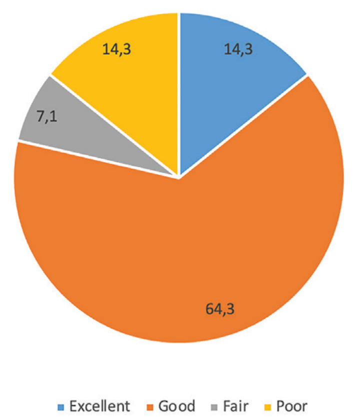

Figure 2. Patient satisfaction levels after injection (MacNab criteria)

DISCUSSION

In the present study, we evaluated the outcomes of TFESI in patients with FBSS following UBE. Our results demonstrated that, although TFESI was not effective in every single case, it provided significant pain relief and functional improvement in the majority of patients. These findings suggest that TFESI can be considered a useful and minimally invasive treatment option for managing persistent symptoms after UBE surgery.

Post-spinal surgery epidural fibrosis is excessive scar tissue formation secondary to the overproduction of fibrotic tissue replacing epidural fat tissue[5,6]. It can lead to central canal stenosis, nerve root irritation, and even epidural blockage. Periradicular scar tissue can reduce perfusion and lead to decreased venous return. Stenosis and circulatory impairment in the region result in inflammation and edema of the nerve root[7]. Since revision surgeries aimed at excising the scar tissue causing this neural damage are challenging and have high complication rates, minimally invasive procedures such as transforaminal injection may be considered for pain control in the management of such patients. This study evaluated the effectiveness of the transforaminal injection method in patients with FBSS who underwent endoscopic surgery. According to the results of the study, patients showed statistically significant improvement at their 6-week follow-up after TFESI.

The success rate of selective transforaminal nerve root block in unoperated cases has been reported to range from 18% to 90%[8]. TFESI is highly effective in the short term (6 weeks) and moderately effective in the long term for lumbar radicular pain, but its effects are limited in radicular pain in FBSS cases[9-11]. Devulder[12] found TFESI to be ineffective in FBSS. In their study, Mavrocordatos and Cahana[13] determined that TFESI was moderately effective in the treatment of failed back surgery. Celenlioglu et al.[5] reported that in 30 patient series, pain decreased by more than 50% in 60% of patients on the 21st day after TFESI. At 3 months post-procedure, the same level of comfort was maintained in 26% of patients[5].

Although different results have been reported in the literature, scar tissue development may be reduced in UBE because it is possible to preserve the epineural adipose tissue and less laminectomy/laminoplasty is performed. We predict that when the scar tissue density in the perineural tissue is low, the results of transforaminal injection may be as successful as procedures performed on non-operated patients. As scar tissue density decreases, the injection content administered to the area may achieve better penetration into perineural tissues. In summary, we achieved positive results in 78.4% of patients in our study. We achieved success rates close to those reported in the literature for TFESI procedures performed on non-operated patients. We believe these results may be an advantage of UBE, which is a minimally invasive approach.

Proper patient selection plays a critical role in achieving high success rates. Even with the UBE method, extensive scar tissue development is possible because each patient's response to surgery may differ. MRI can be used to suggest alternative treatment methods for such patients. On the other hand, using a 0-degree telescope during the UBE procedure may increase bone/ligamentum flavum excision, which could increase scar tissue formation. If the surgeon can perform the operation with minimal tissue damage using an angled (30-degree) telescope, it may also increase the success of minimally invasive injections that may be required.

Study Limitations

However, the study has some limitations. The main limitations are the small sample size, short follow-up period, non-repetition of injections, and the absence of a control group. The strongest aspect of this study is that it is, to our knowledge, the first study to investigate the efficacy of TFESI in patients with FBSS operated on using the UBE method and contributes to the knowledge base in the literature on this subject.

CONCLUSION

TFESI is a safe method for treating FBSS caused by epidural fibrosis following lumbar discectomy with UBE. Although the effectiveness of the method in cases following microsurgery is controversial in the literature, we believe that better results are possible in cases of FBSS following UBE. This method may increase comfort and shorten disability periods. Larger, long-term, prospective, randomized controlled studies are needed to better understand these methods are needed to better evaluate this method in the treatment of FBSS.

Ethics

Ethics Committee Approval: This study was approved by the Ethics Committee of University of Health Sciences Türkiye, Sincan Training and Research Hospital (decision no: BAEK-2025-48, date: 22.07.2025).

Informed Consent: Written informed consent was obtained from all participants.

Footnotes

Authorship Contributions

Surgical and Medical Practices: M.İ.Ö., O.K.D., Concept: O.K.D., Z.Ç., Design: M.İ.Ö., A.S., Data Collection or Processing: M.İ.Ö., O.K.D., Z.Ç., A.S., İ.S., Analysis or Interpretation: M.İ.Ö., Z.Ç., Literature Search: O.K.D., Z.Ç., İ.S., Writing: M.İ.Ö., O.K.D.

Conflict of Interest: No conflict of interest was declared by the authors.

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