E-ISSN 2147-5903

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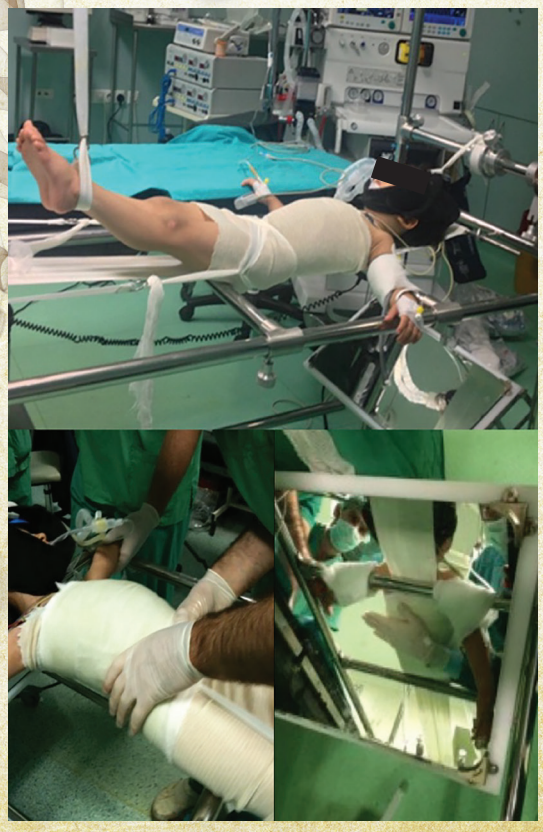
JOURNAL OF TURKISH SPINAL SURGERY



JULY
2026
VOLUME: 37
ISSUE: 3

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The journal is published online.

Owner: Ahmet Esat Kiter on behalf of the Turkish Spine Society

Responsible Manager: Metin Özalay

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Web: www.galenos.com.tr
Publisher Certificate Number: 14521

Printing Date: July 2026

E-ISSN 2147-5903
International scientific journal published quarterly.

JOURNAL OF TURKISH SPINAL SURGERY

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JOURNAL OF TURKISH SPINAL SURGERY

EDITORIAL

Bridging Innovation, Clinical Practice, and Fundamental Knowledge in Spine Care

The current issue of the Journal of Turkish Spine Surgery presents a broad spectrum of studies that collectively reflect the multidisciplinary and continuously evolving nature of modern spine care. Covering topics from pediatric deformity and spinal oncology to lumbar disc surgery, anatomical research, rehabilitation, sports medicine, and technical innovation, this issue highlights the diversity of challenges encountered by spine specialists while emphasizing the importance of evidence-based clinical decision-making.

One of the defining characteristics of spine surgery is the necessity to integrate knowledge from multiple disciplines. Advances in surgical techniques alone are insufficient to optimize patient outcomes unless they are accompanied by improvements in diagnosis, conservative management, anatomical understanding, biomechanics, rehabilitation, and complication prevention. The articles presented in this issue exemplify this comprehensive approach.

The management of early-onset scoliosis remains one of the most demanding areas in pediatric spine surgery. The study evaluating the efficacy of serial derotational casting contributes to the ongoing discussion regarding growth-preserving treatment strategies. Conservative interventions capable of delaying or reducing the need for surgical procedures are of considerable interest, particularly in young children where preserving spinal and thoracic growth is critical. As treatment paradigms continue to evolve, high-quality clinical data regarding non-operative techniques remain invaluable.

Complications continue to represent a major concern across all fields of spine surgery. The investigation into the timing and mechanisms of unplanned reoperations following surgery for spinal metastases addresses an issue of increasing clinical importance. Patients undergoing surgery for metastatic spinal disease often present with complex medical conditions, limited physiological reserve, and diverse oncological backgrounds. Better understanding of the causes and temporal patterns of early reoperations has the potential to improve perioperative planning, optimize patient selection, and ultimately reduce morbidity in this vulnerable patient population.

Lumbar disc herniation remains among the most frequently treated spinal disorders worldwide. The single-center experience examining fragmentectomy in Carragee type I and III lumbar disc herniations revisits an enduring surgical debate regarding the extent of disc removal necessary to balance recurrence risk with preservation of disc function. As minimally invasive philosophies continue to influence spine surgery, studies evaluating procedure-specific outcomes remain highly relevant for daily clinical practice.

The relationship between spinal health, posture, and physical activity is another recurring theme in this issue. The assessment of trunk asymmetry and postural disorders in Optimist and Laser class sailors expands our understanding of how sport-specific biomechanical demands influence musculoskeletal development. Such investigations not only contribute to sports medicine but may also provide valuable insights into preventive strategies for young athletes participating in asymmetric sports. Similarly, the case-control study investigating plantar cutaneous sensation and postural control in individuals with non-specific chronic low back pain reflects the growing appreciation of sensorimotor mechanisms underlying chronic spinal disorders. Contemporary management of chronic low back pain increasingly recognizes the importance of proprioception, balance, and neuromuscular control alongside structural pathology. Research exploring these interactions may facilitate the development of more comprehensive rehabilitation programs.

Anatomical precision remains the foundation of safe spinal instrumentation. The morphometric analysis of dry human atlas (C1) and axis (C2) vertebrae provides valuable anatomical data relevant to C1-C2 screw placement. As upper cervical fixation techniques become increasingly sophisticated, population-specific morphometric studies continue to play an essential role in improving surgical safety and minimizing neurovascular complications. Such investigations also serve as important educational resources for both trainees and experienced surgeons.

Technical innovation has historically driven many of the major advances in spine surgery. The Technical Note describing the Z-Rod technique for geometry-independent removal of pedicle screws represents the practical ingenuity frequently required in revision spinal procedures. Although revision surgery often presents unique intraoperative challenges, simple and reproducible technical

solutions can substantially improve operative efficiency and reduce unnecessary instrumentation-related difficulties. Sharing these experiences contributes meaningfully to the collective surgical knowledge of our community.

Taken together, the studies included in this issue demonstrate the remarkable breadth of contemporary spine research. They remind us that progress in spine care depends not only on groundbreaking technological developments but also on careful clinical observation, meticulous anatomical investigation, thoughtful rehabilitation research, and continuous refinement of surgical techniques. Each contribution adds another piece to the complex puzzle of optimizing patient care.

Another noteworthy aspect of this issue is the strong contribution of researchers from multiple institutions across Türkiye. Such collaboration reflects the growing academic productivity of the national spine community and its increasing engagement with clinically relevant research questions. Continued multicenter collaboration, standardized methodologies, and prospective investigations will undoubtedly strengthen the scientific impact of future studies.

As editors, we sincerely thank all authors for submitting their valuable work, the reviewers for their careful and constructive evaluations, and our readers for their continued support of the Journal of Turkish Spine Surgery. The strength of any scientific journal depends upon the commitment of its contributors and the integrity of its peer-review process. Together, these efforts foster scientific dialogue and ultimately contribute to improving patient outcomes.

We hope that the articles presented in this issue will stimulate further discussion, inspire future research, and provide practical insights for clinicians involved in the care of patients with spinal disorders. As spine surgery continues to evolve through innovation, collaboration, and evidence-based practice, we remain committed to serving as a platform for the dissemination of high-quality scientific knowledge.

Enjoy reading this issue.

Co-Editor-in-Chief

Ender Köktekir, M.D.,

ORIGINAL ARTICLE

J Turk Spinal Surg 2026;37(3):91-96

91

DOI: 10.4274/jtss.galenos.2026.58561

THE EFFICACY OF THE SERIAL DEROTATIONAL CASTING IN EARLY ONSET SCOLIOSIS

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ABSTRACT

Objective: Serial derotational casting (SDC) is widely used in the management of early onset scoliosis (EOS) to control deformity and preserve thoracic growth; however, factors associated with curve progression remain incompletely defined. This study aimed to evaluate the clinical and radiographic outcomes of SDC and to explore factors associated with progression.

Materials and Methods: Thirty patients with EOS (20 girls, 10 boys) treated with SDC (≥2 casts) were retrospectively reviewed. Etiologies were congenital (n=18), syndromic (n=6), and idiopathic (n=6). Radiographs were evaluated at pre-cast, post-first-cast, and final follow-up. Progression was defined as a ≥5° increase in the main Cobb angle. Repeated-measures non-parametric tests assessed temporal changes, and univariate analyses explored associations with progression.

Results: At final follow-up, 23/30 patients (76.6%) were classified as stable/regressive, and 7/30 patients (23.4%) were classified as progressive. Mean age at first cast was 49.8±26.7 months, with a mean follow-up of 25.9±13.0 months. Heights at T1-T12 increased in both groups. In the stable/regressive group, the main Cobb angle improved after the first cast (from 59.4° to 48.6°) and remained relatively stable (58.5° at final follow-up), whereas, in the progressive group, it increased to 73.0°. Thoracic curve location was significantly associated with progression in univariate analysis (p=0.026), while other variables were not significant.

Conclusion: SDC effectively controlled deformity and preserved thoracic growth in most EOS patients. As the cohort was predominantly non-idiopathic (congenital), findings reflect surgical delay and growth preservation rather than curve regression. Thoracic curve location may be associated with a higher risk of progression; however, this finding should be interpreted cautiously due to the limited sample size. SDC appears to function primarily as a temporizing strategy, and close follow-up is essential. Further prospective studies are needed to clarify predictors of treatment response.

Keywords: Early onset scoliosis, serial derotational casting, elongation-derotation-flexion, thoracic curve, progression

INTRODUCTION

Early onset scoliosis (EOS) is defined as a spinal deformity with onset before 10 years of age, regardless of etiology[1,2]. Although this definition is straightforward, the underlying causes including idiopathic, neuromuscular, syndromic, and congenital demand individualized management strategies for each patient. Left untreated, progressive EOS can lead to severe spinal deformity, thoracic insufficiency syndrome, impaired lung development, and even life-threatening cardiopulmonary compromise[3,4].

The treatment philosophy for EOS has evolved from early definitive fusion to growth-friendly systems, such as growing rods, vertical expandable prosthetic titanium rib, and magnetically controlled growing rods. Despite their ability to maintain spinal growth, these approaches are associated with high complication rates, diminished correction with repeated lengthenings, and frequent unplanned reoperations[5,6]. Consequently, non-surgical strategies such as casting have regained importance to delay or avoid invasive procedures during early childhood.

Serial Derotational Casting (SDC), first described by Cotrel and Morel[7] and later popularized by Mehta[8], applies elongation-

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Received: 03.03.2026 **Accepted:** 26.04.2026 **Publication Date:** 06.07.2026
Cite this article as: Celilov R, Beydemir A, Kaymakoğlu M, Ayvaz M, Demirkıran HG, Yazıcı M. The efficacy of the serial derotational casting in early onset scoliosis. J Turk Spinal Surg. 2026;37(3):91-96

derotation-flexion (EDF) forces to correct deformity during rapid growth. SDC is widely accepted as a safe and effective non-surgical treatment, capable of controlling curve progression and maintaining thoracic growth. Idiopathic EOS patients, particularly those younger than two years and with moderate curves (<45°), show the most favorable outcomes with SDC, sometimes achieving complete resolution of deformity[9]. Several studies have also demonstrated its utility in congenital, syndromic or neuromuscular scoliosis, where although full correction is rarely achieved, SDC provides significant delay of surgical intervention (average 2-3 years) and allows continued thoracic growth[10,11].

Predictors of successful outcomes with SDC include early initiation (<2 years of age), final in-cast Cobb angle ⩽10°, rib-vertebral angle difference (RVAD) <20°, and higher body mass index[12]. However, recurrence of deformity during adolescence remains a concern even after initial success, highlighting the need for long-term follow-up until skeletal maturity[13].

The aim of the present study was to evaluate the clinical and radiographic outcomes of SDC in EOS patients, to identify risk factors associated with curve progression, and to determine the contribution of casting as a temporizing measure before growth-friendly surgical procedures.

MATERIALS AND METHODS

Ethical approval for this study was obtained from the Hacettepe University Non-Interventional Clinical Research Ethics Committee (approval no: GO 15/805-26, date: 16.12.2015). The study was conducted in accordance with the principles of the Declaration of Helsinki. Due to the retrospective nature of the study, the requirement for informed consent was waived by the ethics committee. After approval of the institutional review board, we retrospectively reviewed patients diagnosed with EOS and treated with SDC between 2009 and 2016 at our institution. A total of 53 patients were identified, of whom 18 were excluded due to inadequate follow-up (less than 24 months), missing radiographs or fewer than two cast applications. The final study cohort included 30 patients treated by three independent spinal surgeons (M.A., H.G.D., M.Y.).

Patient demographics including sex, age at first casting, and comorbidities were recorded. Etiology was classified as idiopathic, neuromuscular, syndromic, or congenital. Curve extent was classified based on the number of vertebrae included in the major Cobb angle. Curves spanning ⩽5 vertebrae were defined as short-segment, and those spanning ⩾6 vertebrae as long-segment. Radiographic parameters measured were: T1-T12 spinal height, T2-T12 kyphosis, L1-L5 lordosis, Cobb angle of the main and compensatory curves, pelvic obliquity and coronal balance. Measurements were obtained from standard standing posteroanterior and lateral radiographs at three time points: prior to the first cast (pre-cast), on the day after the initial cast application (post-first-cast), and at final follow-up. Radiographs obtained during the casting period were taken in-cast to evaluate deformity control under corrective forces. All radiographic assessments were performed by one author under supervision of two experienced spine surgeons (M.A., H.G.D.).

Patients were categorized into two groups based on curve progression of the main deformity at final follow-up. Patients with ⩽5° change in the major Cobb angle were classified as stable group, whereas those with ⩾5° increase were classified as progressive.

Derotational Casting Technique

The EDF technique, initially described by Cotrel and Morel[7] and later refined by Mehta[8], was used for all patients. Casts were applied under general anesthesia with the patient positioned on a Risser or Cotrel casting table, allowing longitudinal traction through the head and pelvis. Corrective forces were applied by molding at the apex of deformity while maintaining elongation and lateral flexion. Casts were typically over-the-shoulder for thoracic curves and under-the-shoulder for lower apices. Anterior and posterior windows were routinely cut to preserve respiration, reduce thoracic compression, and allow abdominal motion (Figure 1). Casts were changed at 2-4 month intervals depending on patient age and growth. This protocol is consistent with international series reporting on EDF casting in idiopathic and non-idiopathic EOS[8,14]. Reported complications of casting, such as skin irritation, gastrointestinal discomfort, or transient pulmonary symptoms were monitored, though no major adverse events occurred in this cohort.

Statistical Analysis

All analyses were performed using SPSS version 18.0 (IBM, USA). Descriptive statistics were presented as means ± standard deviation for continuous variables and as frequencies and percentages for categorical variables. Comparisons between the stable/regressive and progressive groups were performed using the Mann-Whitney U test for continuous variables and Fisher's exact test for categorical variables. The Friedman test, a non-parametric repeated-measures analysis, was used to evaluate changes in radiographic parameters including major and compensatory Cobb angle, T2-T12 thoracic kyphosis, L1-L5 lordosis, T1-T12 spinal height, pelvic obliquity, and coronal balance. Changes were assessed across three time points: pre-cast, post-first-cast, and final follow-up. Pairwise comparisons were conducted using Wilcoxon signed-rank tests with Bonferroni correction.

To explore factors associated with curve progression, defined as a ⩾5° increase in Cobb angle, univariate analyses were performed. Fisher's exact test was used for categorical variables and Mann-Whitney U test for continuous variables. In addition, univariate logistic regression analysis was performed to estimate odds ratios (ORs) with 95% confidence intervals (CIs). Due to the limited number of events in the progressive group, multivariate logistic regression analysis was not performed to avoid model overfitting. Therefore, the findings regarding potential predictors should be interpreted as exploratory.

All statistical tests were two-tailed, and a p-value ⩽0.05 was considered statistically significant.

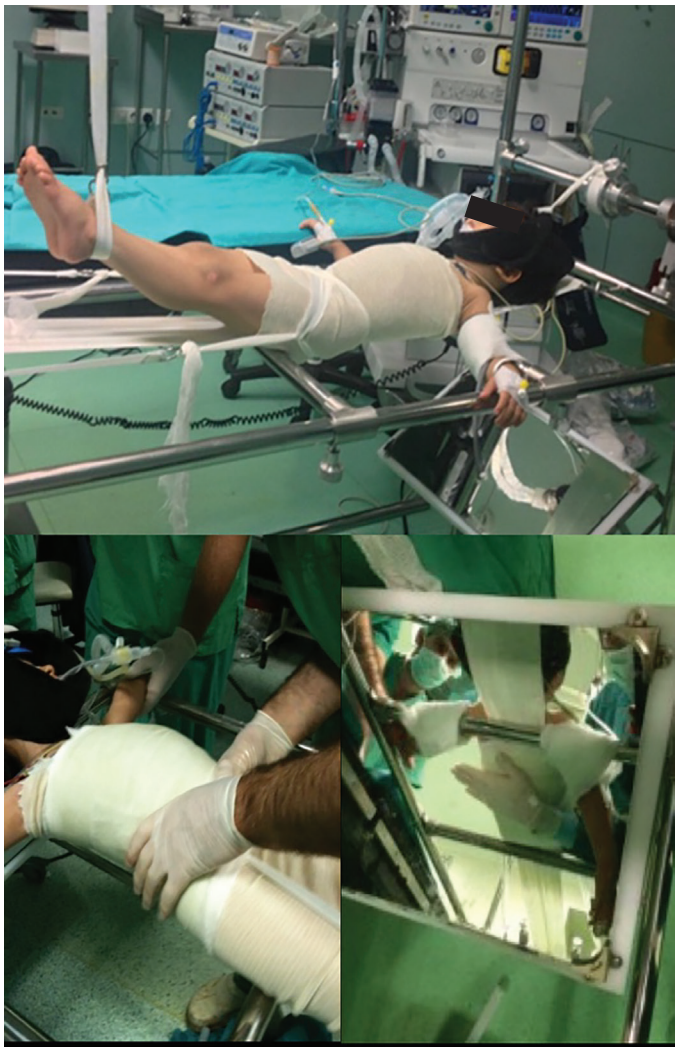

Figure 1. Preparation of the patient under traction for manipulation and casting. The wrapped cast is molded with the palm by applying pressure over the rib prominences at the apex of the thoracic curve, from posterior to anterior and from lateral to medial

RESULTS

A total of 30 patients with EOS met the inclusion criteria (20 girls, 10 boys). Eighteen patients were excluded due to inadequate follow-up or missing data, and five patients with pure kyphosis were not analyzed. At final evaluation, 23/30 (76.6%) patients were classified as stable/regressive and 7/30 (24.4%) as progressive. Etiology distribution was congenital (n=18), syndromic (n=6), and idiopathic (n=6). The distribution of progression across etiological groups was as follows: 3/18 in congenital, 3/6 in syndromic, and 1/6 in idiopathic patients. The mean age at the start of casting was 51.3±28.8 months in the stable group and 45.1±19.5 months in the progressive group. Mean follow-up was 24.5±13.4 months in the stable group and 30.4±13.4 months in the progressive group. Patients underwent 5.3±3.4 casts (stable) and 6.1±1.7 casts (progressive). Sex, etiology, age at first cast, presence of a kyphotic component, curve extent, and most radiographic baselines did not differ significantly between groups; only curve location was associated with progression, with thoracic curves over-represented in the progressive group (p=0.026). During follow-up, surgical intervention was performed in 9 patients overall, including 6 patients (26%) in the stable/regressive group and 3 patients (42.8%) in the progressive group (Table 1).

T1-T12 spinal height increased from 13.9±2.5 cm to 15.6±2.5 cm in the stable group and from 13.7±2.8 cm to 14.4±2.2 cm in the progressive group (overall p=0.536). T2-T12 kyphosis, L1-L5 lordosis, main and compensatory Cobb angles, pelvic obliquity, and coronal balance showed within-group time effects but no significant between-group differences in final values (Table 2). Post-hoc comparisons indicated significant time-point changes inside groups (footnotes in Table 2).

In univariate analysis, thoracic curve location was significantly associated with progression. Thoracic curves were more frequently observed in the progressive group and demonstrated higher odds of progression compared with lumbar and thoracolumbar curves (OR: 9.00, 95% CI: 1.32-61.14; p=0.026). Other variables, including sex, etiology, curve extent, and the presence of a kyphotic component, were not significantly

Table 1. Demographic and clinical characteristics

Variable	Stable/regressive (n=23)	Progressive (n=7)	p-value
Sex (F/M)	14/9	6/1	0.228*
Etiology (congenital/syndromic/idiopathic)	15/3/5	3/3/1	0.357*
Age at first cast (months)	51.3±28.8	45.1±19.5	0.603^
Kyphosis status (normal/+)	15/8	4/3	0.515*
Curve extent (short-segment/long-segment)	1/22	1/6	0.418*
Curve location (thoracic/lumbar+thoracolumbar)	5/18	5/2	**0.026***
Follow-up (months)	24.5±13.4	30.4±13.4	-
Number of casts	5.3±3.4	6.1±1.7	-
Patients operated, n (%)	6 (26%)	3 (42.8%)	-

^: Mann-Whitney U test, *: Fisher's exact test

associated with progression. Although some variables showed trends toward higher odds, these did not reach statistical significance. Age at first cast was also not significantly associated with progression (OR: 1.51, 95% CI: 0.33-6.88; p=0.603) (Table 3).

DISCUSSION

In this EOS cohort managed with SDC, most patients achieved a stable/regressive course (76.6%) with measurable thoracic growth, confirming SDC's role in early deformity control and growth preservation; our progression rate is consistent with reports that casting can modulate curves during rapid growth while maintaining T1-T12 height[11,15]. The magnitude of early radiographic response we observed, particularly the initial improvement after the first cast, also mirrors prior series underscoring that the first application delivers the largest correction, with subsequent casts consolidating the effect[12].

Thoracic curve location was the only factor significantly associated with progression in univariate analysis, suggesting a potential thoracic-specific vulnerability under casting forces. This finding is biomechanically plausible, given chest-wall coupling and the relative rigidity of the rib-vertebra complex, which may limit EDF-driven derotation near thoracic apices[16]. Although the literature seldom isolates location as a sole risk factor, segment-level observations that lumbar components improve more readily under casting are congruent with our finding that thoracic localization signals a higher failure risk[12]. However, this finding should be interpreted with caution due to the limited sample size and the small number of progression events in our cohort. Given that only seven patients were classified in the progressive group, performing a reliable multivariate regression analysis was not feasible, as it would increase the risk of model overfitting. Therefore, only univariate associations were evaluated, and these findings should be considered exploratory and hypothesis-generating. Furthermore, while thoracic curve location reached statistical significance in the univariate analysis, the extremely wide 95% CI of the OR (OR: 9.00; 95% CI: 1.32-61.14) substantially limits the precision and reliability of this estimate, and the finding should therefore be interpreted as preliminary and hypothesis-generating rather than conclusive.

Etiology, sex, and age at initiation were not significantly associated with progression in our univariate analysis. Although these variables showed a trend toward higher odds of progression, the analysis likely lacked sufficient statistical power to detect statistical significance. This pattern is consistent with prior literature suggesting that idiopathic patients tend to respond more favorably, whereas non-idiopathic cases primarily benefit from surgical delay and growth preservation rather than substantial curve correction[10,17]. Accordingly, the

Table 2. Radiographic parameters

Parameters	Stable/regressive (n=23)			Progressive (n=7)			p-value
	Pre-cast	Post 1st cast	Final follow-up	Pre-cast	Post 1st cast	Final follow-up	
T1-T12 height (cm)	13.9±2.5	-	15.6±2.5	13.7±2.8	-	14.4±2.2	0.536[1]
T2-T12 kyphosis (°)	44.0±17.7	37.1±15.8	41.3±17.1	50.1±24.5	31.0±22.0	45.2±26.3	0.858[2]
L1-L5 lordosis (°)	40.2±14.9	28.9±9.6	39.2±12.0	42.5±13.0	32.5±16.0	33.0±15.4	0.980[3]
Main Cobb (°)	59.4±20.8	48.6±19.1	58.5±26.1	54.8±13.8	55.2±13.2	73.0±16.0	0.181[4]
Compensatory Cobb (°)	21.0±26.6	16.5±23.9	26.7±33.8	23.5±33.2	25.4±31.9	23.0±30.8	0.825[5]
Pelvic obliquity (°)	5.0±5.0	-	4.9±7.5	0.4±0.7	-	1.8±2.4	0.131[6]
Coronal balance (cm)	1.8±1.4	-	3.5±5.9	1.1±0.6	-	1.1±0.6	0.196[7]

Note: Statistical analysis across time points was performed using the Friedman test for repeated-measures, with post-hoc pairwise comparisons conducted using the Wilcoxon signed-rank test with Bonferroni correction. Superscript numbers indicate significant within-group pairwise comparisons across time points

Table 3. Univariate analysis of factors associated with curve progression

Variable		OR	95% CI	p-value
Sex	Female vs. male	3.86	0.40-37.58	0.228
Etiology	Syndromic vs. idiopathic	5.00	0.34-72.77	0.357
	Congenital vs. idiopathic	1.00	0.08-11.93	0.357
Age at first cast	Per 1-month increase in age	1.51	0.33-6.88	0.603
Curve location	Thoracic vs. other	9.00	1.32-61.14	**0.026***
Curve extent	Short-segment vs. long-segment	3.67	0.20-67.66	0.418
Kyphotic component	Present vs. absent	1.41	0.25-7.90	0.515

Odds ratios were calculated using univariate logistic regression analysis. For continuous variables, odds ratios (OR) represent the change in risk per one-unit increase. *: p<0.05, CI: Confidence interval

predominance of congenital cases in our cohort may have influenced the overall interpretation of treatment success.

In contrast to our finding of no significant association between age at initiation and progression, multiple studies, including longer-term follow-ups and a meta-analysis, have demonstrated clear advantages of earlier treatment initiation (e.g., <20 months or <1.8 years) for curve resolution and magnitude of correction. In our cohort, the relatively higher mean age at initiation is likely related to the predominance of congenital cases, in which the primary goal of casting is often to delay surgical intervention rather than to achieve curve regression. Therefore, the lack of a statistically significant association between etiology and progression in our study, as well as the observed age-related findings, may reflect both the limited sample size and the heterogeneity of the cohort rather than a true absence of effect. The results should therefore be interpreted with caution, particularly when applied to idiopathic EOS populations[9,18].

The heterogeneous composition of the cohort should also be considered when interpreting these findings. Congenital, syndromic, and idiopathic scoliosis differ substantially in their natural history and response to casting. Although subgroup comparisons would be valuable, the limited number of patients in each etiological group precluded meaningful statistical analysis. Therefore, the results reflect the overall cohort and should be interpreted with caution when applied to specific etiological subgroups.

The radiographic course observed in our cohort, characterized by early correction followed by curve stabilization and incremental thoracic height gain, aligns with prior evidence suggesting that SDC functions as a temporizing strategy while preserving thoracic growth in both idiopathic and non-idiopathic EOS[11,15]. In our cohort, 9 patients ultimately required surgical intervention, further supporting the interpretation of SDC as a growth-preserving and temporizing strategy rather than a definitive treatment. Accordingly, the observed rate of stable/regressive curves should be interpreted as reflecting short-term control of the deformity and delay of surgery rather than permanent stabilization. In addition, adolescent recurrence remains a recognized risk even after strong early responses, underscoring the need for long-term surveillance through skeletal maturity[9].

Clinical implications follow directly: prioritize early casting when feasible; apply meticulous thoracic molds (over-the-shoulder application, apex-focused derotation, judicious windows) and closer follow-up for thoracic curves; and set realistic goals in non-idiopathic EOS around growth preservation and surgical delay rather than complete correction. Strengths include the use of a standardized casting technique and repeated-measures radiographic assessment.

Study Limitations

This study has several limitations. The retrospective design limits the ability to establish causal relationships. The relatively small number of patients in the progressive subgroup may have reduced the statistical power of the analysis. In addition, the limited number of progression events precluded the use of multivariate analysis and restricted the ability to identify independent predictors.

Some well-established predictors reported in the literature, such as RVAD and the "final cast ⩽10°" threshold, were not available for all patients and therefore could not be included in the analysis. The absence of these parameters represents an important limitation and reduces the completeness of the predictive analysis. In addition, all radiographic measurements were performed by a single observer, which may introduce measurement bias, and intraobserver variability was not formally assessed. Future studies should incorporate independent double-reading with formal ICC analysis to enhance methodological reliability. The heterogeneous distribution of etiologies within the cohort, along with the small number of patients in each subgroup, further limited the ability to perform subgroup analyses.

Future prospective studies with larger cohorts are required to better clarify predictors of treatment success with SDC[19].

CONCLUSION

SDC effectively controlled deformity and preserved thoracic growth in the majority of patients with EOS. Thoracic curve location was associated with progression in univariate analysis; however, this finding should be interpreted cautiously due to the limited sample size. These findings emphasize the importance of meticulous thoracic molding, timely initiation of treatment when feasible, and close longitudinal surveillance, particularly for thoracic curves. Given the potential for progression over time, sustained follow-up through growth remains essential. Larger prospective studies are warranted to confirm these findings and to better define patient- and curve-specific factors influencing long-term outcomes.

Ethics

Ethics Committee Approval: Ethical approval for this study was obtained from the Hacettepe University Non-Interventional Clinical Research Ethics Committee (approval no: GO 15/805-26, date: 16.12.2015).

Informed Consent: Due to the retrospective nature of the study, the requirement for informed consent was waived by the ethics committee.

Footnotes

Authorship Contributions

Surgical and Medical Practises: M.A., H.G.D., M.Y., Concept: R.C., H.G.D., M.Y., Design: R.C., M.K., H.G.D., M.Y., Data Collection or Processing: R.C., A.B., M.K., Analysis or Interpretation: R.C., A.B., M.A., H.G.D., M.Y., Literature Search: R.C., A.B., M.K., Writing: R.C., A.B., H.G.D.

Conflict of Interest: No conflict of interest was declared by the authors. Two of the authors of this article (M.A. and M.Y.) is a member of the Scientific Board of this journal. They had no involvement in the peer-review process or editorial decision regarding this manuscript. The peer-review process and editorial decision were handled independently by another editor.

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

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ORIGINAL ARTICLE

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J Turk Spinal Surg 2026;37(3):97-104

DOI: 10.4274/jtss.galenos.2026.02419

MECHANISM-SPECIFIC TIMING OF UNPLANNED REOPERATIONS WITHIN 30 DAYS AFTER SPINAL METASTASIS SURGERY

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ABSTRACT

Objective: This study evaluated the 30-day incidence, mechanisms, and timing of unplanned reoperation after surgery for spinal metastases.

Materials and Methods: This retrospective cohort study included adults who underwent surgery for spinal metastases between June 2020 and September 2025. Patients who died within 30 postoperative days were excluded because complete ascertainment of observed 30-day reoperations was not possible. Intradural metastases were also excluded. Thirty-day returns to the operating room were adjudicated as planned staged procedures or unplanned reoperations. Unplanned reoperations were further classified as technical, tumor-related, mechanical, or wound-related after a review of clinical notes and imaging. Continuous variables were compared using the Wilcoxon rank-sum test, and categorical variables were compared using Fisher's exact test.

Results: A total of 127 patients met the eligibility criteria. Six procedures that occurred within 30 days were adjudicated as planned, staged operations, leaving 121 patients in the analytic cohort. Eighteen patients (14.9%) underwent an unplanned reoperation within 30 days. The median time to unplanned reoperation was 14.5 days (Q1-Q3, 2.5-26.5). Technical events occurred earliest [n=4; median postoperative day (POD) 2], followed by tumor-related events (n=4; median POD 6), mechanical events (n=5; median POD 22), and wound-related events (n=5; median POD 25). Timing differed across mechanisms (p=0.023). Metastatic spinal tumor frailty index >1 was more frequent in the reoperation group (83.3% vs. 42.7%, p=0.0018).

Conclusion: Unplanned early reoperation after spinal metastasis surgery showed distinct mechanism-specific timing patterns. Technical failures clustered earliest, whereas mechanical and wound-related failures occurred later. A mechanism-based description may provide a more precise framework for reporting very early postoperative returns to the operating room.

Keywords: Spinal metastasis, reoperation, complications, timing, surgical outcomes

INTRODUCTION

Surgery for spinal metastases aims to preserve or restore neurological function, relieve pain, and maintain spinal stability in a medically fragile population[1-3]. In this setting, an unplanned return to the operating room (OR) is one of the most consequential postoperative events because it can prolong hospitalization, delay rehabilitation, and postpone systemic therapy or postoperative radiotherapy[4,5].

Most published series in metastatic spine surgery report reoperation as a pooled outcome[4,6,7]. Although useful for overall benchmarking, that approach does not distinguish between clinically different early return to OR scenarios. Revision for an implant malposition, repeat decompression for persistant or recurrent tumor-related compression, surgery for instability progression, and operative treatment of wound complications do not reflect the same mechanism or timing patterns.

A further challenge is that not all secondary operations within the early postoperative period represent postoperative failure in the same way. In metastatic spine surgery, some procedures are intentionally staged as part of a planned treatment strategy and should not be interpreted as unplanned postoperative events. Separating planned staged procedures from true unplanned reoperations may therefore improve interpretability when evaluating very early operative returns.

The present study was designed as a descriptive analysis of unplanned reoperation within 30 days after the index surgery for spinal metastases. The aims were to determine the 30-day incidence of these events, describe their timing according to the dominant clinical mechanism, and compare baseline characteristics between patients with and without unplanned early reoperation. We hypothesized that unplanned reoperations within the first postoperative month would show mechanism-specific temporal clustering rather than a uniform distribution across the 30-day period.

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Received: 03.04.2026 **Accepted:** 04.05.2026 **Publication Date:** 06.07.2026

Cite this article as: Baydar AT, Taşkala B. Mechanism-specific timing of unplanned reoperations within 30 days after spinal metastasis surgery. J Turk Spinal Surg. 2026;37(3):97-104

MATERIALS AND METHODS

Study Design and Patient Selection

This retrospective cohort study was conducted at a single tertiary referral center after University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital Institutional Ethics Committee approval (approval no: KAEK/15.10.2025.370, date: 21.10.2025). The requirement for informed consent was waived due to anonymized use of data and the retrospective nature of the study. Adult patients who underwent surgery for spinal metastases between June 2020 and September 2025 were screened. Patients with intradural metastases were excluded.

The study endpoint was observed unplanned reoperation within 30 days of the index procedure. Because this endpoint required a patient to remain alive and under postoperative observation long enough for complete ascertainment of an early return to the OR, patients who died before completing the 30-day postoperative window were excluded from the primary incidence analysis. This design was chosen to study very early observed operative returns rather than all postoperative adverse events in a competing risk framework. These exclusions are shown in the patient flow diagram (Figure 1), and the potential for survivorship bias is addressed in the discussion.

Endpoint Definition and Reoperation Adjudication

The primary outcome was unplanned reoperation within 30 days of the index procedure. All returns to the OR within this period were reviewed independently by 2 neurosurgeons using operative reports, inpatient progress notes, discharge summaries and all available spinal imaging. Each case was first adjudicated as either a planned staged procedure or an unplanned reoperation. Planned staged procedures were defined as secondary operations intentionally anticipated as part of the treatment strategy and were recorded separately rather than counted as outcome events.

For unplanned reoperations, each event was then assigned to the dominant subtype for descriptive analysis: technical, tumor-related, mechanical, or wound-related. Technical events included revision for implant or screw malposition. Tumor-related events included repeat surgery for persistent or recurrent neural compression primarily attributable to epidural or osseous tumor burden. Mechanical events included progressive deformity, early instability progression, or delayed implant/cage migration not primarily attributable to tumor

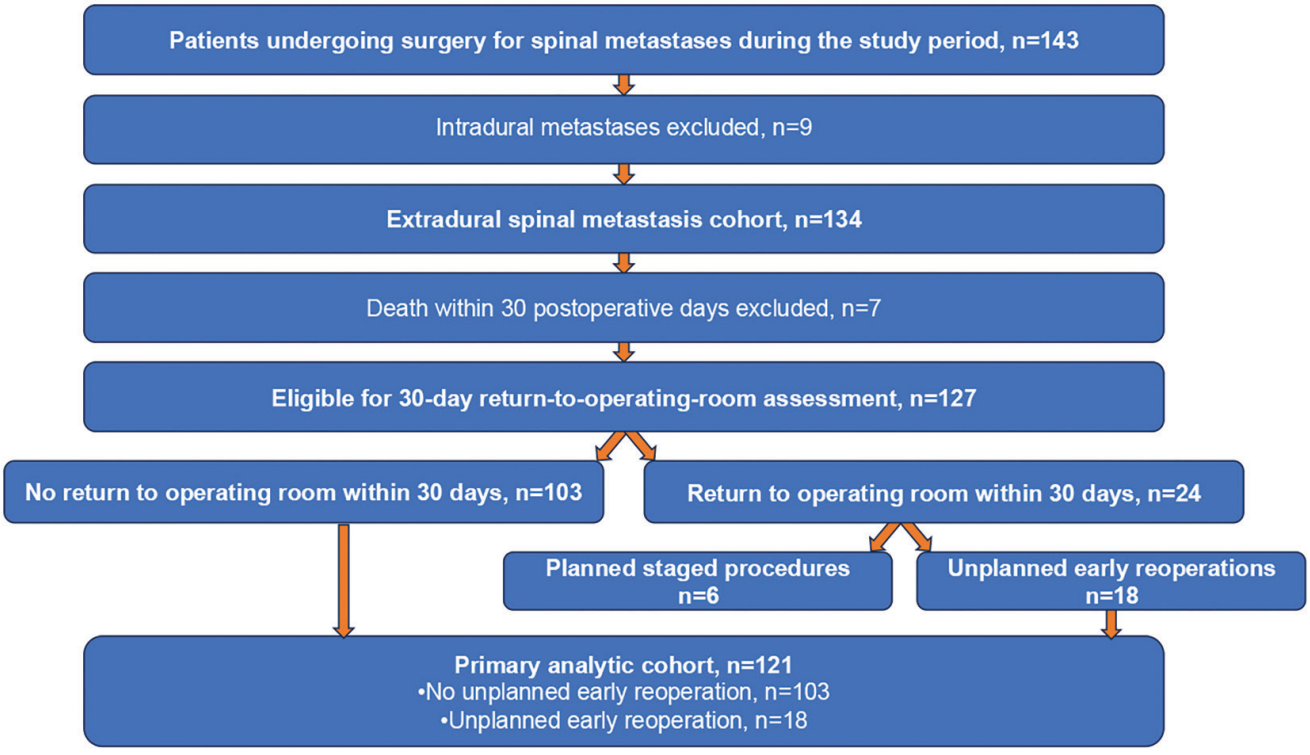

Figure 1. Patient flow diagram. Flow diagram of cohort assembly and endpoint adjudication. Of 143 patients who underwent surgery for spinal metastases during the study period, 9 with intradural metastases and 7 who died within 30 postoperative days were excluded, leaving 127 eligible for 30-day return to operating room assessment. Among these, 24 patients returned to the operating room within 30 days: 6 planned staged procedures and 18 unplanned early reoperations. The primary analytic cohort therefore comprised 121 patients, including 103 patients without unplanned early reoperation and 18 with unplanned early reoperation

progression. Wound-related events included infection, wound breakdown, epidural abscess, cerebrospinal fluid fistula, or other wound problems requiring operative treatment. Discrepancies between adjudicators were resolved by consensus.

Recorded Variables

Recorded variables included age, sex, body mass index, operative duration, perioperative transfusion, Bilsky grade-epidural spinal cord compression, Eastern Cooperative Oncology Group (ECOG) status, metastatic spinal tumor frailty index (MSTFI), spinal instability neoplastic score (SINS) category, extent of involved segments, index surgery type, tumor level grouped as cervical, thoracic, lumbar or sacral and tumor growth categories as slow, moderate-, rapid-growth according to Tomita et al.[8]. Bilsky grade was classified according to the epidural spinal cord compression scale described by Bilsky et al.[9]. SINS was categorized as stable (0-6), potentially unstable (7-12), or unstable (13-18) according to the original description by Fisher et al.[3]. MSTFI was defined according to De la Garza Ramos et al.[10] as a metastatic spine-specific frailty index incorporating anemia, chronic lung disease, coagulopathy, electrolyte abnormality, pulmonary circulation disorder, renal failure, malnutrition, non-elective admission, and surgical approach; for this study, scores >1 were analyzed as elevated frailty burden. Tumor growth category was assigned from the primary pathology using a Tomita-style classification as slow-, moderate-, or rapid-growth[8]. Primary tumors explicitly categorized in the original Tomita framework were classified accordingly; histologies not specifically listed were pragmatically mapped to the nearest biologically comparable growth group for descriptive analysis. Index surgeries were grouped into 4 categories: decompression-only, short-segment posterior stabilization with tumor separation, long-segment posterior stabilization with tumor separation and corpectomy-involving procedures.

Statistical Analysis

Continuous variables are presented as median (Q1-Q3) and categorical variables as number (percentage). Continuous variables were compared with the Wilcoxon rank-sum test and categorical variables with Fisher's exact test. Differences in time to reoperation across mechanism-specific subtypes were assessed with the Kruskal-Wallis test, followed by Bonferroni-adjusted pairwise Wilcoxon testing. Analyses were performed in R version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria) using the base stats package. Because only 18 primary events were observed, multivariable modeling was not pursued.

RESULTS

A total of 127 patients met final eligibility criteria. Six procedures within 30 days were adjudicated as planned staged operations and excluded from the primary endpoint analysis. The final analytic cohort therefore consisted of 121 patients, of whom 18 (14.9%) underwent unplanned reoperation within 30 days (Figure 1).

Baseline demographic, disease-related, and operative characteristics of the analytic cohort stratified by unplanned early reoperation status are summarized in Table 1. Age showed a non-significant trend toward younger patients in the reoperation group (median 55.5 vs. 63.0 years, p=0.085). Sex, body mass index, Bilsky grade 3, ECOG 3-4 status, perioperative transfusion, operative duration, tumor level, extent of vertebral involvement, Tomita-style tumor growth category, index surgery group, and SINS category did not differ significantly between groups (all p>0.05). MSTFI >1 was more frequent among patients with unplanned early reoperation than among those without reoperation (83.3% vs. 42.7%, p=0.0018).

Thoracic lesions predominated in both groups, accounting for 59.2% of patients without early reoperation and 72.2% of those with early reoperation. The extent of vertebral involvement was most commonly >4 vertebrae in the no-reoperation group (37.9%) and 2 vertebrae in the reoperation group (38.9%), without a statistically significant between-group difference. Tomita-style tumor growth category also did not differ significantly between groups (p=0.527), with rapid-growth primaries accounting for 46.6% of patients without early reoperation and 61.1% of those with unplanned early reoperation. Index surgery was distributed across all 4 predefined operative categories, with no meaningful difference between groups: decompression-only in 32.0% vs. 27.8%, short-segment posterior stabilization in 25.2% vs. 27.8%, long-segment posterior stabilization in 30.1% vs. 33.3%, and corpectomy-involving procedures in 12.6% vs. 11.1% in patients without versus with unplanned early reoperation, respectively (Table 1).

A case-level summary of all 18 unplanned early reoperations is presented in Table 2. These consisted of 4 technical, 4 tumor-related, 5 mechanical, and 5 wound-related reoperations. Median time to unplanned reoperation was 14.5 days (Q1-Q3, 2.5-26.5; range, 1-29). A clear temporal gradient was observed across mechanisms: technical events occurred earliest (n=4, median POD 2, range 1-4), followed by tumor-related events (n=4, median POD 6, range 2-28), mechanical events (n=5, median POD 22, range 15-29), and wound-related events (n=5, median POD 25, range 13-28) as illustrated in Figure 2. Overall timing differed across subtypes (Kruskal-Wallis p=0.023), although Bonferroni-adjusted pairwise comparisons were not significant.

The second procedures performed after unplanned early reoperation also differed across subtypes (Table 2). All 4 technical reoperations were treated with screw revision. Among tumor-related events, 4 patients underwent separation surgery alone for recurrent radicular symptoms associated with persistent tumor-related compression. Mechanical reoperations were managed with implant revision in the case of cage migration and with additional stabilization in the remaining 4 cases, including long-segment stabilization in 3 and short-

Table 1. Baseline demographic, disease-related, and operative characteristics of the analytic cohort stratified by unplanned early reoperation status

Variable	No unplanned early reoperation (n=103)	Unplanned early reoperation (n=18)	p-value
Age, years	63.0 (54.0-69.5)	55.5 (48.2-62.0)	0.085
Female sex	30 (29.1%)	5 (27.8%)	1.000
BMI, kg/m^2	25.4 (23.1-28.4)	24.3 (23.5-25.2)	0.527
Bilsky grade 3	47 (45.6%)	8 (44.4%)	1.000
ECOG 3-4	33 (32.0%)	6 (33.3%)	1.000
MSTFI >1	44 (42.7%)	15 (83.3%)	**0.0018**
Perioperative transfusion	57 (55.3%)	11 (61.1%)	0.798
Operative duration, min	235.0 (150.0-315.0)	300.0 (185.0-340.0)	0.451
Tumor level			0.769
Cervical	9 (8.7%)	1 (5.6%)	
Thoracic	61 (59.2%)	13 (72.2%)	
Lumbar	32 (31.1%)	4 (22.2%)	
Sacral	1 (1.0%)	0 (0.0%)	
Tumor growth category (Tomita-style)			0.527
Slow	48 (46.6%)	6 (33.3%)	
Moderate	7 (6.8%)	1 (5.6%)	
Rapid	48 (46.6%)	11 (61.1%)	
Extent of vertebral involvement			0.202
1 vertebra	25 (24.3%)	5 (27.8%)	
2 vertebrae	23 (22.3%)	7 (38.9%)	
3 vertebrae	16 (15.5%)	0 (0.0%)	
>4 vertebrae	39 (37.9%)	6 (33.3%)	
Index surgery group			0.968
Decompression-only	33 (32.0%)	5 (27.8%)	
Short-segment posterior stabilization	26 (25.2%)	5 (27.8%)	
Long-segment posterior stabilization	31 (30.1%)	6 (33.3%)	
Corpectomy-involving procedures	13 (12.6%)	2 (11.1%)	
SINS category			0.926
Stable (0-6)	11 (10.7%)	2 (11.1%)	
Potentially unstable (7-12)	63 (61.2%)	12 (66.7%)	
Unstable (13-18)	28 (27.2%)	4 (22.2%)	

Values are presented as median (Q1-Q3) or n (%), unless otherwise indicated. Continuous variables were compared using the Wilcoxon rank-sum test and categorical variables using Fisher's exact test. Tumor growth category was assigned from the primary pathology using a Tomita-style classification as slow-, moderate-, or rapid-growth. Histologies not explicitly listed in the original Tomita framework were pragmatically assigned to the most biologically comparable growth group for descriptive purposes. BMI: Body mass index, ECOG: Eastern Cooperative Oncology Group, MSTFI: Metastatic spinal tumor frailty index, SINS: Spinal instability neoplastic score

segment stabilization in 1. Wound-related reoperations consisted of dural and wound repair for the 2 cerebrospinal fluid fistulas, wound washout and repair for 2 wound infections, and abscess drainage with wound repair for 1 epidural abscess/wound infection case.

When subtype was examined in relation to index surgery, technical events followed 3 long-segment posterior stabilization procedures and 1 short-segment posterior stabilization procedure. Tumor-related reoperations followed 2 long-segment and 2 short-segment posterior stabilization procedures. Mechanical reoperations followed 4 decompression-only procedures and 1 corpectomy-involving procedure. Wound-related reoperations followed 1 decompression-only procedure, 2 short-segment posterior stabilization procedures, 1 long-segment posterior stabilization procedure, and 1 corpectomy-involving procedure. Thus, the relationship between complication subtype and index surgery was not limited to the mechanical subgroup alone.

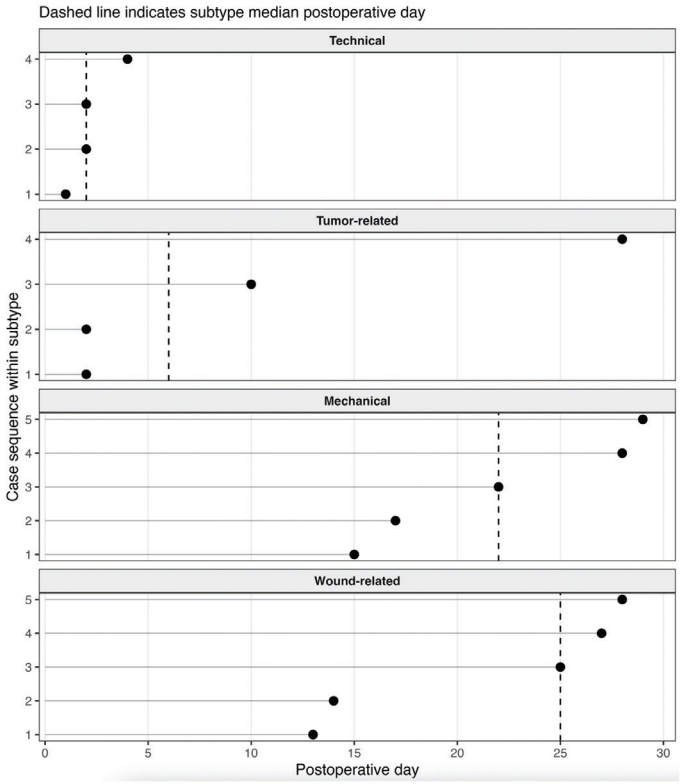

Figure 2. Timing of unplanned early reoperations by mechanism-specific subtype. Each dot represents 1 unplanned early reoperation plotted according to postoperative day on the x-axis. Panels are stratified by mechanism-specific subtype, and dashed vertical lines indicate the median postoperative day within each subtype. The y-axis denotes case sequence within subtype. Technical events occurred earliest, followed by tumor-related events, whereas mechanical and wound-related events clustered later within the 30-day postoperative period

Table 2. Case-level summary of unplanned early reoperations within 30 days

Case	POD	Subtype	Indication	Second surgery
1	1	Technical	Screw malposition with aortic proximity	Screw revision
2	2	Technical	Symptomatic screw malposition	Screw revision
3	2	Technical	Symptomatic screw malposition	Screw revision
4	2	Tumor-related	Persistent epidural tumor compression	Separation
5	2	Tumor-related	Persistent epidural tumor compression	Separation
6	4	Technical	Symptomatic screw malposition	Screw revision
7	10	Tumor-related	Persistent epidural tumor compression	Separation
8	13	Wound-related	Cerebrospinal fluid fistula	Dural+wound repair
9	14	Wound-related	Cerebrospinal fluid fistula	Dural+wound repair
10	15	Mechanical	Cage malposition/migration	Implant revision
11	17	Mechanical	Progressive kyphosis/instability	Long-segment stabilization
12	22	Mechanical	Progressive kyphosis/instability	Short-segment stabilization
13	25	Wound-related	Wound infection	Wound washout and repair
14	27	Wound-related	Wound infection	Wound washout and repair
15	28	Mechanical	Progressive kyphosis/instability	Long-segment stabilization
16	28	Tumor-related	Residual/progressive tumor with recurrent radicular symptoms	Separation
17	28	Wound-related	Epidural abscess/wound infection	Abscess drainage+wound repair
18	29	Mechanical	Progressive kyphosis/instability	Long-segment stabilization

Planned staged procedures were excluded from this table and from the primary endpoint analysis. Each unplanned reoperation was classified according to the dominant clinical mechanism. POD: Postoperative day

DISCUSSION

Unplanned early reoperation after surgery for spinal metastases is a clinically important outcome in a medically fragile population undergoing surgery to preserve neurological function, relieve pain, restore stability, and maintain access to further oncologic treatment[1,2,11]. A second operation within the first postoperative month may prolong hospitalization, interrupt rehabilitation, and complicate the sequencing of radiotherapy or systemic therapy. Contemporary metastatic spine series have also linked early postoperative setbacks such as unplanned readmission to worse postoperative performance and, in some cohorts, shorter survival, supporting the clinical relevance of studying early return to the OR in greater detail[5,12,13]. In this retrospective single-center cohort, unplanned reoperation within 30 days after surgery for spinal metastases occurred in 14.9% of the analytic cohort after planned staged procedures were considered separately. The median time to reoperation was 14.5 days, and the observed events demonstrated a heterogeneous mechanism-based distribution across the early postoperative period. Technical reoperations clustered in the immediate postoperative phase, whereas tumor-related events tended to occur earlier within the 30-day window and mechanical and wound-related reoperations were more often encountered later.

Most published metastatic spine series report reoperation as a pooled endpoint[6,7,14]. While that approach is useful for broad benchmarking, it does not distinguish between clinically different early return-to-OR scenarios. The present study was intentionally restricted to unplanned reoperation within 30 days, with planned staged procedures adjudicated separately, and with additional subdivision of unplanned events according to dominant clinical mechanism. This approach does not attempt to provide a comprehensive account of all postoperative failures after metastatic spine surgery. Rather, it focuses on the very early postoperative interval and asks whether operative returns within that period show recognizably different timing patterns.

The overall 30-day incidence in this study lies within the broad range reported previously, although direct comparison across studies remains limited by differences in case mix, follow-up duration, and endpoint definitions. Tarawneh et al.[4] reported a pooled reoperation rate of 8.3% in a systematic review, Quraishi et al.[15] reported 10.7%, and Paulino Pereira et al.[6] observed reoperation in 18% of 647 surgically treated patients over a longer follow-up period. Patel et al.[7] further showed that 30-day unplanned readmission and reoperation after surgery for vertebral column metastases are strongly influenced by medical complexity. Against this background, the present series is best interpreted as a descriptive cohort that clarifies how a meaningful proportion of clinically important revision events occur very early and arise from mechanistically distinct processes.

Technical reoperations occurred earliest, which is consistent with the way implant malposition, inadequate decompression, or procedure-related neurological deterioration usually declare themselves through early imaging or early clinical worsening. Tumor-related reoperations followed shortly thereafter. In the current era of NOMS-based decision-making and separation surgery, the surgical objective is frequently decompression and stabilization rather than radical oncologic resection[2,11]. Within that framework, earlier tumor-related return to surgery may reflect persistent ventral compression or residual disease not adequately controlled by the index procedure, whereas later events within the same subgroup may reflect rapidly progressive epidural disease. This distinction also matters from a treatment-sequencing standpoint. In external cohorts, earlier initiation of postoperative radiotherapy has been associated with improved 1-year survival, while wound-focused studies have not demonstrated a clear wound-healing penalty from reasonably timed early postoperative radiotherapy[16,17]. Although our data cannot address causality in this pathway, they support the practical importance of avoiding preventable reoperation when postoperative oncologic treatment is time-sensitive. At the same time, the small number of tumor-related events and the retrospective nature of adjudication require cautious interpretation.

The pattern of second operations also supports the clinical coherence of the mechanism-based classification used in this study. Technical cases uniformly required screw revision, tumor-related cases underwent repeat decompression-oriented procedures with or without added short-segment stabilization, mechanical cases generally required implant revision or additional stabilization, and wound-related cases underwent dural repair, washout, or abscess drainage according to the underlying problem. Although these observations remain descriptive, the correspondence between indication and second procedure suggests that the adjudicated subtypes reflected clinically recognizable early return-to-OR scenarios rather than a purely semantic classification.

The mechanical subgroup is the most hypothesis-generating component of the present study. All five mechanical reoperations occurred in patients with SINS scores in the potentially unstable range (7-12), and four of the five followed decompression-only procedures. It should not be taken to imply that decompression without stabilization was inappropriate in any individual patient, nor that a specific operative choice directly caused the subsequent event. Surgical decision-making in metastatic spine disease is individualized and influenced by neurologic status, tumor burden, prognosis, construct feasibility, systemic condition, and goals of care[2,3,11]. However, it is compatible with the possibility that some lesions in the intermediate mechanical-risk range may destabilize soon after posterior decompression when additional load-sharing support is not provided. This interpretation is consistent with the original purpose of SINS as a framework for identifying lesions at risk of instability and guiding consideration of stabilization[3]. It is

also directionally consistent with prior reports showing that symptomatic construct failure and early mechanical revision remain relevant causes of treatment failure in metastatic spine surgery, including more recent work suggesting that early construct failure may represent a distinct clinical subgroup rather than simply a late extension of the same process[18,19]. Importantly, the mechanical subgroup in the present study was clinically heterogeneous, incorporating both progressive kyphosis/instability after non-instrumented decompression and delayed cage migration after reconstruction. Accordingly, the present data support only a limited descriptive observation: in this small cohort, early mechanical deterioration was encountered in a subset of patients with intermediate mechanical-risk lesions, and this pattern may warrant further study in larger series.

Wound-related reoperations formed the latest cluster in this cohort, occurring predominantly during the second to fourth postoperative weeks. This distribution is consistent with prior metastatic spine studies in which wound complications are among the most frequent reasons for revision[4,15,20,21]. Recent studies have linked wound complications in this population to factors such as nutritional status, extent of surgery, preoperative radiotherapy, systemic therapy exposure, and frailty[22-24]. The higher prevalence of MSTFI >1 in the reoperation group in our series is compatible with that broader literature. At the same time, the limited number of events and the absence of multivariable modeling mean that this finding should be interpreted cautiously. In the present study, MSTFI is better viewed as a marker associated with early reoperation burden rather than as an independently established predictor.

An important strength of the present study is that it did not treat all early secondary operations equivalently. Planned staged procedures were adjudicated separately and excluded from the primary endpoint, thereby allowing the reported incidence to reflect unplanned early operative returns rather than all 30-day reoperations. This distinction is particularly relevant in metastatic spine surgery, where intentionally staged treatment strategies may occur in selected cases. The study also moves beyond a purely pooled reoperation rate by providing case-level characterization of indication, timing, and secondary procedure.

Study Limitations

Several limitations should be acknowledged. First, this was a retrospective single-center study with a limited number of events, and the study was not powered for robust adjusted analyses or mechanism-specific modeling. Second, although reoperation adjudication was performed independently by 2 neurosurgeons with consensus resolution, some degree of classification uncertainty is unavoidable in retrospective chart-based event assignment. Third, the study was intentionally restricted to the 30-day postoperative interval and therefore does not capture later local progression, delayed wound complications, or late construct failure. The findings should therefore not be interpreted as a comprehensive analysis of failure after metastatic spine surgery. Fourth, patients who died before completing the 30-day observation window were excluded from the primary incidence analysis because the endpoint required complete ascertainment of an observed return to the OR. Although this approach was methodologically aligned with the chosen endpoint, it may have introduced survivorship bias by excluding patients with limited postoperative observation time and potentially high early complication burden. Finally, as with other retrospective institutional series, reoperations performed outside the index center may not have been fully captured.

CONCLUSION

Unplanned early reoperation after surgery for spinal metastases occurred in 14.9% of the primary analytic cohort and followed distinct mechanism-specific timing patterns. Technical events tended to occur earliest, whereas mechanical and wound-related events were generally observed later in the first postoperative month. In this cohort, mechanical reoperations were encountered in patients with SINS scores in the potentially unstable range, but this observation should be regarded as descriptive and hypothesis-generating, not causal. A mechanism-based description of very early unplanned operative returns may offer a more precise framework for reporting postoperative events after metastatic spine surgery, but the clinical implications of this approach require validation in larger studies.

Ethics

Ethics Committee Approval: This retrospective cohort study was conducted at a single tertiary referral center after University of Health Sciences Türkiye, Başakşehir Çam and Sakura City Hospital Institutional Ethics Committee approval (approval no: KAEK/15.10.2025.370, date: 21.10.2025).

Informed Consent: The requirement for informed consent was waived due to anonymized use of data and the retrospective nature of the study.

Footnotes

Authorship Contributions

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

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

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

Declaration of Generative AI and AI-assisted Technologies in the Writing Process: During the preparation of this manuscript, the authors used ChatGPT (OpenAI, San Francisco, USA) to assist with language editing, structural refinement, and improvement

of academic phrasing. All outputs generated by the AI tool were carefully reviewed, revised, and verified by the authors. The authors take full responsibility for the accuracy, originality, and integrity of the final manuscript. The use of AI was limited to writing support and did not influence the study data, statistical analyses, results, or conclusions.

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ORIGINAL ARTICLE

J Turk Spinal Surg 2026;37(3):105-109

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DOI: 10.4274/jtss.galenos.2026.24008

CLINICAL OUTCOMES OF FRAGMENTECTOMY FOR CARRAGEE TYPE I AND III LUMBAR DISC HERNIATIONS: A SINGLE-CENTER EXPERIENCE

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ABSTRACT

Objective: Fragmentectomy represents a tissue-preserving alternative to conventional microdiscectomy. Evidence specifically stratifying outcomes by Carragee lumbar disc herniation type remains limited. To evaluate the clinical outcomes and safety of fragmentectomy in patients with Carragee type I and type III lumbar disc herniations at a single center.

Materials and Methods: This retrospective study included 32 consecutive patients who underwent fragmentectomy for Carragee type I (n=18) or type III (n=14) herniations at the L3-S1 levels between 2020 and 2023. The primary outcomes were visual analog scale (VAS) and Oswestry disability index (ODI) scores at 6 and 12 months. Normality was assessed with the Shapiro-Wilk test, and parametric or non-parametric tests were applied accordingly. Subgroup analyses compared outcomes among Carragee subtypes.

Results: The mean follow-up was 18 months. VAS scores decreased from 8.20±1.10 preoperatively to 0.90±0.54 at 12 months ($p<0.001$; Cohen's d =5.06). ODI improved from 69.33±12.78 to 9.70±5.18 ($p<0.001$; Cohen's d =4.27). No significant difference was observed between Carragee subtypes at 12 months (VAS: $p=0.065$; ODI: $p=0.607$). Three patients (9.4%) required revision surgery. No intraoperative or postoperative complications were recorded.

Conclusion: Fragmentectomy may be an effective, tissue-preserving surgical option for carefully selected patients with Carragee type I and type III lumbar disc herniations. Prospective controlled studies are required to establish superiority over conventional microdiscectomy.

Keywords: Fragmentectomy, lumbar disc herniation, Carragee classification, microdiscectomy, clinical outcomes

INTRODUCTION

Lumbar disc herniation (LDH) constitutes one of the most prevalent causes of radiculopathy and remains the underlying pathology in one of the most performed spinal procedures worldwide[1]. Surgical management encompasses a spectrum of technical approaches, ranging from aggressive subtotal discectomy to more conservative fragment-targeted strategies. Fragmentectomy, defined as the selective removal of the extruded or sequestered disc fragment without disrupt the intervertebral disc space, and conventional microdiscectomy, which additionally involves curettage of intradiscal material, represent two ends of this spectrum[2].

Fragmentectomy has been recognized as a suitable option for patients with a small annular defect, in whom preservation of disc structure is both feasible and desirable[3]. By avoiding unnecessary violation of the disc space, this approach aims to preserve the structural and biomechanical integrity of the anterior column, which may reduce postoperative low back pain and promote faster functional recovery[4,5]. Recent studies indicate that this technique may reduce the risk of recurrent herniation in carefully selected cases, particularly in Carragee type I and type III herniations, characterized by small annular defects and an otherwise competent disc.

The Carragee classification system provides a reproducible framework for identifying surgical candidates most likely to benefit from a limited approach[6]. Patients with large annular tears (type II) or intact annuli without free fragments (type IV) are generally considered less suitable and may require more extensive disc removal or complementary stabilization[7,8].

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Received: 29.11.2025 **Accepted:** 06.05.2026 **Publication Date:** 06.07.2026

Cite this article as: Günerbüyük C, Tepebaşılı MA, Gürpınar İ, Almas F, Karadağ MK, Özgen U, et al. Clinical outcomes of fragmentectomy for carragee type I and III lumbar disc herniations: a single-center experience. J Turk Spinal Surg. 2026;37(3):105-109

Despite growing interest in tissue-preserving discectomy, evidence specifically stratifying outcomes by Carragee herniation type remains limited. The aim of this study was to evaluate clinical outcomes and safety of fragmentectomy in patients with Carragee type I and type III LDHs and to compare results between the two subtypes.

MATERIALS AND METHODS

Patient Selection

This retrospective study was conducted in accordance with the principles of the Declaration of Helsinki. The study was approved by the Atatürk University Faculty of Medicine Clinical Research Ethics Committee (approval no: B.30.2.ATA.0.01.00/110, date: 27.01.2022). All patients provided written informed consent prior to surgery.

Between 2020 and 2023, a total of 258 patients underwent surgery for LDH at our institution. Of these, 226 patients were excluded based on predefined criteria: herniation above the L3 level (n=41), previous spinal surgery (n=60), presence of spinal tumor or infection (n=11), Carragee type II or IV herniation morphology (n=89), and follow-up duration less than 6 months (n=25). The remaining 32 consecutive patients who met all inclusion criteria were enrolled, representing 12.4% of the overall surgical cohort.

Inclusion criteria were age ⩾18 years, minimum 6 months of follow-up, radiologically confirmed single-level Carragee type I or III LDH at L3-S1, and failure of conservative management for at least 6 weeks. Herniations above L3 were excluded to maintain homogeneity, as upper lumbar herniations present distinct anatomical and biomechanical characteristics.

Classification and Imaging

Disc herniations were classified using the four-type system of Carragee et al.[6]: type I (fragment-fissure) minimal annular defect with a single extruded or sequestered fragment; type II (fragment-defect) extruded fragments with a wide annular tear ⩾6 mm; type III (fragment-contained) intact annulus with fragments accessed through an oblique annular incision; type IV (no-fragment-contained) intact annulus without subannular free fragments (Figure 1A-B).

Classification was independently assessed by two spine surgeons on preoperative magnetic resonance imaging (MRI), with attention to annular defect size, fragment morphology, and disc integrity. Intraoperative confirmation was performed by the senior surgeon in all cases. Discordances, occurring in 3 of 32 cases (9.4%), were resolved by consensus, with intraoperative findings considered definitive. Throughout this manuscript, "fragmentectomy" refers to selective fragment removal without disc space entry, the term "sequestrectomy" used in some literature describes the same procedure[3,5].

Surgical Technique

All procedures were performed under general anesthesia in the prone position via a standard microsurgical approach with intraoperative fluoroscopic guidance. The decision to proceed with fragmentectomy followed a predefined two-stage algorithm. Preoperatively, candidates required MRI evidence of a Carragee type I or III herniation with an annular defect ⩽5 mm, absence of a wide annular tear, and a single well-defined fragment causing neural compression. Intraoperatively, fragmentectomy was confirmed when the defect was visually consistent with preoperative assessment and no residual loose material was identified after fragment removal and saline irrigation (Figure 1C). If a larger annular tear, multi-fragmented herniation, or residual fragments were encountered intraoperatively, the procedure was converted to limited microdiscectomy.

Outcome Measures

Patients were evaluated at 6 and 12 months postoperatively, and annually thereafter. Clinical assessments included neurological examination and patient-reported outcome measures. Pain intensity was quantified using the visual analog

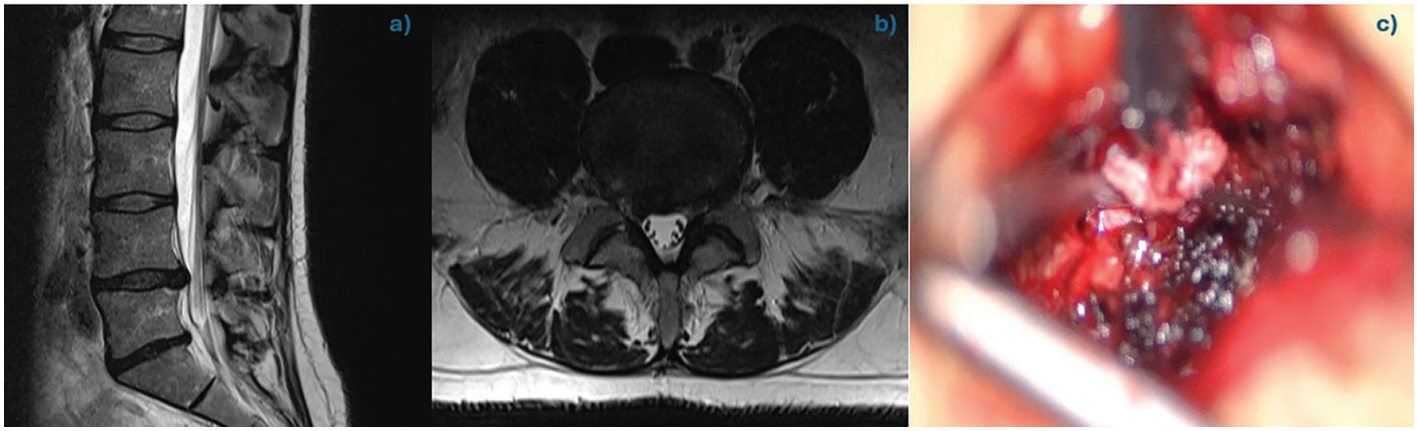

Figure 1. Sagittal T2-weighted MRI. **(a)** demonstrating L4-5 extruded disc fragment in a 47-year-old male patient with Carragee type III disc herniation. **(b)** Axial T2-weighted MRI showing the extruded fragment compressing the right L5 nerve root. **(c)** Intraoperative microscopic view of the fragmentectomy procedure. MRI: Magnetic resonance imaging

scale [(VAS); 0-10] and functional disability with the Oswestry disability index [(ODI); 0-100%]. MRI or computed tomography was performed when clinically indicated; routine postoperative imaging was not obtained in asymptomatic patients.

Statistical Analysis

Prior to parametric testing, normality of all continuous variables was assessed with the Shapiro-Wilk test, appropriate for n≤50. Variables satisfying normality were analyzed using paired t-tests and reported as mean ± standard deviation. VAS scores at 12 months violated normality (W=0.896, p=0.005) and were analyzed using the Wilcoxon signed-rank test, reported as median with interquartile range (IQR). Categorical variables were reported as frequencies and percentages. For subgroup comparisons between Carragee type I and III at 12 months, the Mann-Whitney U test was used for VAS (non-normal) and the independent-samples t-test for ODI (normal), following Levene's test for homogeneity of variance. Statistical significance was set at p<0.05. A post-hoc power analysis was performed to assess the adequacy of the sample size. All analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Normality test results are summarized in Table 1.

RESULTS

A total of 32 patients (14 women, 18 men; mean age: 48.6 years, range: 31-67) were included. Eighteen (56.3%) were classified as Carragee type I and 14 (43.7%) as Carragee type III. The most frequently affected level was L4-L5 (53.1%), followed by L5-S1 (34.4%) and L3-L4 (12.5%). Mean follow-up was 18 months (range 12-26). Baseline characteristics are presented in Table 2. Preoperatively, 7 patients (21.9%) presented with motor deficits, 4 with dorsiflexion weakness grade 3/5 and 3 with plantar flexion weakness, all accompanied by sensory loss in corresponding dermatomes. Eighteen patients (56.3%) had isolated sensory deficits, and 3 (9.4%) presented with severe refractory radicular pain unresponsive to at least 6 weeks of conservative treatment.

Most patients (29/32; 90.6%) achieved substantial or complete resolution of leg and low back pain within three weeks of surgery and returned to daily activities within a mean of two weeks. VAS scores decreased from 8.20±1.10 (median: 8.20; IQR: 7.63-8.42) preoperatively to 2.06±0.76 (median: 1.99; IQR: 1.39-2.47) at 6 months and to a median of 0.79 (IQR: 0.69-1.09) at 12 months. The preoperative-to-6-month reduction was significant (paired t-test, p<0.001; Cohen's d =4.29), as was the preoperative-to-12-month comparison (Wilcoxon signed-rank test, p<0.001). ODI scores improved from 69.33±12.78 preoperatively to 23.80±7.42 at 6 months and 9.70±5.18 at 12 months (both p<0.001; Cohen's d =3.10 and 4.34, respectively). Full outcome data are presented in Table 3.

Subgroup analysis revealed no statistically significant difference between Carragee type I (n=18) and type III (n=14) in VAS (Mann-Whitney U, p=0.065) or ODI (independent t-test, p=0.607) at 12 months, suggesting comparable outcomes across both subtypes. Subgroup data are presented in Table 4.

No intraoperative or postoperative complications were recorded. Three patients (9.4%) required revision surgery: one at 4 months due to a residual fragment causing persistent radiculopathy, and two at 7 and 11 months respectively due to recurrent herniation at the same level confirmed by MRI. All three achieved satisfactory recovery following revision. No clinically detected recurrence occurred among the remaining 29 patients; however, asymptomatic reherniations cannot be excluded given the absence of routine postoperative imaging.

Post-hoc power analysis confirmed >98% statistical power for both primary outcomes (VAS: Cohen's d =5.06, power=99.8%; ODI: Cohen's d =4.27, power=98.4%; α=0.05, n=32), indicating adequate power despite the modest sample size.

Table 1. Shapiro-Wilk normality test results and applied statistical methods

Variable	Shapiro-Wilk (W/p-value)
VAS-preoperative	W=0.975/p=0.648
VAS-6 months	W=0.975/p=0.636
VAS-12 months	W=0.896/p=0.005*
ODI-preoperative	W=0.977/p=0.703
ODI-6 months	W=0.965/p=0.373
ODI-12 months	W=0.958/p=0.236

*: Wilcoxon signed-rank test applied; data reported as median (IQR). VAS: Visual analog scale, ODI: Oswestry disability index, IQR: Interquartile range

Table 2. Patient demographics and baseline characteristics (n=32)

Variable	Value
Sex-female/male	14/18 (43.8%/56.3%)
Mean age (years)	48.6 (range: 31-67)
Mean follow-up (months)	18 (range: 12-26)
Carragee type I	18 (56.3%)
Carragee type III	14 (43.7%)
Herniation level-L3-L4/L4-L5/L5-S1	4 (12.5%)/17 (53.1%)/11 (34.4%)
Motor deficit	7 (21.9%)
Sensory deficit only	18 (56.3%)
Pain only	3 (9.4%)
Revision surgery	3 (9.4%)
Intraoperative complications	0 (0%)
Postoperative complications	0 (0%)

Table 3. VAS and ODI scores at preoperative, 6-month, and 12-month time points

Outcome measure	Preoperative	6 months	12 months
VAS score (0-10)			
Mean ± SD	8.20±1.10	2.06±0.76	0.90±0.54
Median (IQR)	8.20 (7.63-8.42)	1.99 (1.39-2.47)	0.79 (0.69-1.09)
p-value vs. preoperative	-	<0.001*	<0.001†
ODI score (0-100)			
Mean ± SD	69.33±12.78	23.80±7.42	9.70±5.18
Median (IQR)	69.07 (61.20-77.99)	24.24 (20.72-28.44)	9.68 (7.08-14.16)
p-value vs. preoperative	-	<0.001*	<0.001*

*: Paired t-test (normality confirmed), †: Wilcoxon signed-rank test (non-normal distribution), VAS: Visual analog scale, ODI: Oswestry disability index, SD: Standard deviation, IQR: Interquartile range

Table 4. Subgroup analysis: clinical outcomes by Carragee herniation type at 12 months

Outcome	Type I (n=18)	Type III (n=14)	p-value
VAS 12 months-median (IQR)	0.88 (0.75-1.24)	0.69 (0.56-0.94)	0.065‡
ODI 12 months-median (IQR)	8.79 (6.67-11.28)	11.20 (7.49-14.90)	0.607‡
VAS improvement (%)	89.3%	91.6%	0.412
ODI improvement (%)	85.8%	83.7%	0.539
Revision surgery-n (%)	1 (5.6%)	2 (14.3%)	0.562§

‡: Mann-Whitney U test, §: Fisher's exact test, VAS: Visual analog scale, ODI: Oswestry disability index, IQR: Interquartile range

DISCUSSION

This study evaluated clinical outcomes of fragmentectomy in 32 consecutive patients with Carragee type I and III LDHs. Both VAS and ODI scores demonstrated statistically significant and clinically large improvements sustained through 12 months of follow-up, with a zero-complication rate and a revision surgery rate of 9.4% consistent with the published fragmentectomy literature[3,9]. However, since no comparator group was included, it cannot be determined whether these outcomes reflect the efficacy of the technique itself or the favorable natural history of the selected patient population, which inherently comprised cases with smaller annular defects and more contained pathology.

The rationale for fragmentectomy lies in preserving the structural integrity of the intervertebral disc and segmental stability. In contrast to subtotal discectomy, which may compromise stability through extensive intradiscal material removal, fragmentectomy targets only the herniated fragment. Preserving annular competence is of particular importance, as the Carragee classification has demonstrated that annular defect morphology is a key determinant of recurrence risk and postoperative clinical course[6,10]. A historical shift toward conservative disc removal, exemplified by Williams'[11] early report of limited discectomy in over 500 patients, informed the contemporary practice of fragmentectomy. More recently, endoscopic approaches have reinforced the principle that limited exposure reduces tissue trauma; however, current evidence does not conclusively demonstrate superiority of endoscopic over open microsurgical techniques[12,13].

The subgroup analysis comparing type I and type III herniations revealed no statistically significant difference in VAS or ODI at 12 months. This finding suggests that both subtypes respond comparably to fragmentectomy, which is clinically relevant for patient selection. Type III herniations did not yield inferior outcomes. However, the limited subgroup sizes (n=18 and n=14) preclude definitive conclusions, and this observation requires validation in larger prospective cohorts.

For Carragee type II herniations recurrence risk following limited discectomy is higher[14]. While some advocate subtotal discectomy in such cases, extensive disc removal may paradoxically worsen long-term low back pain through accelerated disc height loss and facet joint overloading[15,16]. In our institution, type II cases requiring aggressive intervention are managed with discectomy and dynamic stabilization when appropriate. Fragmentectomy is reserved for type I and III herniations where smaller defects support a limited approach.

Preservation of disc height represents a further potential advantage of fragmentectomy. Maintaining disc height reduces facet joint loading and may delay posterior element degeneration[17]. Whether this biomechanical benefit translates into superior long-term outcomes compared with microdiscectomy remains to be demonstrated in prospective comparative studies.

Study Limitations

This study has several limitations. First, its retrospective single-center design introduces selection bias and limits generalizability. Patients with more favorable pathological anatomy may have been preferentially selected for fragmentectomy. Second, the absence of a control group precludes direct comparison with conventional microdiscectomy; observed improvements cannot be definitively attributed to the surgical technique. Third, follow-up was limited to a mean of 18 months, precluding assessment of late recurrence or long-term durability. Fourth, the lack of routine postoperative MRI means asymptomatic reherniations may be underreported. Finally, subgroup sizes limit the power of subtype comparisons. Future multicenter prospective controlled studies with standardized imaging follow-up are needed to validate these findings.

CONCLUSION

Fragmentectomy may represent an effective, tissue-preserving surgical option for carefully selected patients with Carragee type I and type III LDHs, with significant improvements in pain and functional outcomes and a low complication profile. No clinically significant difference was observed between the two Carragee subtypes. Whether these outcomes are superior to those of conventional microdiscectomy cannot be established without a prospective controlled design. Further comparative studies with larger cohorts and standardized follow-up are required.

Ethics

Ethics Committee Approval: The study was approved by the Atatürk University Faculty of Medicine Clinical Research Ethics Committee (approval no: B.30.2.ATA.0.01.00/110, date: 27.01.2022).

Informed Consent: All patients provided written informed consent prior to surgery.

Footnotes

Authorship Contributions

Surgical and Medical Practices: C.G., İ.G., U.Ö., M.Y.A., Ö.A., B.T.Ö., A.F.Ö., Concept: M.Y.A., Ö.A., B.T.Ö., A.F.Ö., Design: M.Y.A., A.F.Ö., Data Collection or Processing: C.G., M.A.T., İ.G., M.K.K., Analysis or Interpretation: M.A.T., F.A., M.K.K., Literature Search: M.A.T., F.A., A.F.Ö., Writing: C.G., M.A.T., F.A., M.Y.A., A.F.Ö.

Conflict of Interest: No conflict of interest was declared by the authors. Three of the authors of this article (Ö.A., B.T.Ö., and A.F.Ö.) is a member of the Scientific Board of this journal. They had no involvement in the peer-review process or editorial decision regarding this manuscript. The peer-review process and editorial decision were handled independently by another editor.

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

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ORIGINAL ARTICLE

J Turk Spinal Surg 2026;37(3):110-115

110

DOI: 10.4274/jtss.galenos.2026.40412

ASSESSMENT OF TRUNK ASYMMETRY AND POSTURAL DISORDERS IN OPTIMIST AND LASER CLASS SAILORS

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ABSTRACT

Objective: The relationship between sports participation, trunk asymmetry, and postural disorders remains controversial. This study aimed to investigate trunk asymmetry and associated postural disorders among licensed Optimist and Laser sailors.

Materials and Methods: This single-center cross-sectional study included licensed Optimist and Laser sailors aged 9-18 years. Postural assessment included the Adams forward-bending test; evaluation of shoulder, scapular, and lumbar asymmetry; scoliometer measurements; thoracic, knee, and ankle deformities; thoracic kyphosis; lumbar lordosis; and skinfold thickness measurements.

Results: A total of 58 licensed sailors were included. Five participants (8.6%) had an axial trunk rotation (ATR) greater than 5°, while one participant (1.7%) had an ATR greater than 7°. Mild shoulder asymmetry was observed in 25 sailors (43%), and mild scapular asymmetry was observed in 30 sailors (51%). Mild low-back asymmetry was identified in 13 sailors (22%), whereas moderate asymmetry was observed in seven sailors (12%). Anterior chest deformity was detected in 3 sailors (5%), lumbar lordosis in 10 sailors (17%), and thoracic kyphosis in 5 sailors (8%). No significant correlation was found between scoliometric measurements and skinfold thickness values ($p>0.05$). Significant correlations were identified between sailing duration and low-back asymmetry; between lumbar lordosis and thigh fat percentage; and between shoulder asymmetry and weekly training duration, calf fat percentage, scapular asymmetry, and low-back asymmetry.

Conclusion: Young sailors may demonstrate trunk asymmetry and postural alterations associated with repetitive asymmetric loading patterns. However, due to the cross-sectional design, the absence of a control group, and the lack of radiographic confirmation, no causal relationship between sailing participation and IS can be established. Further controlled longitudinal studies are required to clarify these associations.

Keywords: Idiopathic scoliosis, trunk asymmetry, sailing athletes, postural disorders

INTRODUCTION

Idiopathic scoliosis (IS) is a three-dimensional spinal deformity characterized by lateral curvature and vertebral rotation, affecting approximately 2-3% of adolescents during growth spurts[1,2]. Although the etiology of IS remains unclear, both genetic predisposition and environmental factors are believed to contribute to its development[3,4]. Among environmental factors, sports participation has attracted increasing attention because repetitive asymmetric loading patterns and intensive training during skeletal growth may influence spinal alignment[5].

The relationship between sports and IS remains controversial. Previous studies have reported increased scoliosis prevalence in athletes participating in gymnastics, dance, and swimming, potentially due to repetitive asymmetrical movements, generalized joint laxity, delayed maturation, and mechanical stress on the immature spine[6-8]. In contrast, other studies have suggested that regular sports participation may have either no effect or even a protective role against scoliosis progression[9]. Therefore, current evidence regarding the influence of sports on IS remains inconclusive.

Sailing is a physically demanding sport requiring prolonged asymmetric postures, trunk stabilization, and repetitive unilateral loading. Within this sport, the Optimist class serves as a starting point for boys and girls under the age of 15. Beyond this age, sailors often transition to single-seater

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Received: 09.02.2026 **Accepted:** 25.05.2026 **Publication Date:** 06.07.2026

Cite this article as: Metin Terzibaşıoğlu A, Aydın FY, Büyükaslan A, Soluk Özdemir Y, Çınar Ç. Assessment of trunk asymmetry and postural disorders in Optimist and Laser class sailors. J Turk Spinal Surg. 2026;37(3):110-115

vessels like the Laser 4.7, followed by Laser Radial, or European class[10]. Optimist and Laser classes, commonly practiced by children and adolescents, involve sustained counterbalancing maneuvers and asymmetrical muscle activation patterns. Despite these biomechanical characteristics, limited evidence exists regarding the frequency of axial trunk rotation (ATR) positivity and postural asymmetries among young sailors.

The primary hypothesis of this study was that young sailors participating in Optimist and Laser classes would demonstrate increased trunk asymmetry findings and postural alterations associated with repetitive asymmetric loading patterns during sailing. A secondary hypothesis was that sailing exposure and body composition parameters may be associated with the severity of postural asymmetries and ATR measurements.

Ethical Approval

The Ethics Committee of the University of Health Sciences Türkiye, Bakırköy Dr. Sadi Konuk Training and Research Hospital approved the design and protocol of the study in agreement with the principles of the Declaration of Helsinki and ethical standards for human experimentation (approval no: 2019-11-02, date: 10.06.2019). All participants and their parents were informed about the study. Signed informed consent was obtained from parents.

MATERIALS AND METHODS

This cross-sectional study was conducted among licensed Optimist and Laser class athletes from the İstanbul Sailing Club. The inclusion criteria were: (1) age between 9 and 18 years, (2) both genders, (3) participation in sailing training for at least four hours per week, and (4) active registration in a sailing sports club. The age range of 9-18 years was selected because this period corresponds to rapid skeletal growth and adolescence, during which IS most commonly develops and progresses. Furthermore, Optimist and Laser sailing categories are predominantly practiced within this age group. Exclusion criteria included previous spinal surgery, unwillingness to participate, or lack of parental consent.

A priori power analysis was not performed because the present study was designed as an exploratory pilot investigation evaluating postural disorders in a specific athletic population. This limitation has been acknowledged in the discussion section.

Female and male participants were not age-matched because the study aimed to evaluate all eligible licensed sailors available during the recruitment period. Additionally, the sailing population within the club consisted predominantly of male athletes. All participants were provided detailed information about the study's purpose, procedures, and data usage.

Data Collection

Postural examinations were performed visually in the standing position by two physiatrists with more than 10 years of experience and one physiotherapist with more than 5 years of experience in spinal deformities and scoliosis rehabilitation.

Demographic data, age at puberty, age at menarche, Tanner scale, body type, Adams forward-bending test, shoulder, scapula, and lumbar asymmetry, scoliometer results, spinal flexibility, thoracic deformity, back kyphosis, lumbar lordosis, scoliosis, leg length discrepancy, knee and ankle deformities, and skinfold thicknesses (SFTs) were recorded.

Position of shoulders in frontal and sagittal plane, spine alignment, knee, scapula position, lordosis, kyphosis, scoliosis, spina iliaca anterior superior, thoracic deformities (pectus carinatum/excavatum), knee deformities (genu varum, genu valgum, recurvatum), and foot deformities (pes planus, pes cavus, calcaneovalgus) were evaluated by visual observation[11]. Shoulder asymmetry was defined as inequality in shoulder height in the frontal and sagittal plane. Scapular asymmetry was evaluated according to differences in scapular prominence or position. Low-back asymmetry was defined as visible asymmetry in lumbar contour or waistline alignment during standing posture. Thoracic kyphosis and lumbar lordosis were assessed clinically in the sagittal plane by visual inspection. Increased thoracic kyphosis was defined as excessive posterior thoracic curvature, while increased lumbar lordosis was defined as excessive inward lumbar curvature relative to normal sagittal alignment.

Inter-rater and intra-rater reliability analyses were not performed, which represents a limitation of the study.

Measurements and Outcomes

ATR measurements were performed during the Adams forward-bending test using a standard scoliometer. Participants were instructed to bend forward with knees extended and palms together. Measurements were obtained at the thoracic and lumbar regions, and the highest ATR value was recorded for analysis. ATR angles were measured from the sacrum, lumbar, thoracic, and cervical spine for all participants using the scoliometer device labelled MIZUHO OSI (U.S. Patent no. 5,181,525). ATR measurements obtained using the scoliometer were used as screening parameters for trunk asymmetry. An ATR value of 5° was selected as the referral threshold based on previous scoliosis screening studies demonstrating that this cut-off provides acceptable sensitivity for detecting clinically significant spinal deformities[12]. Radiographic confirmation was not performed within the scope of this study.

SFT measurements were included to evaluate body composition characteristics and possible associations between adipose tissue distribution, body type, and postural asymmetry findings in adolescent sailors. Since body composition may influence biomechanical loading patterns and athletic performance, these measurements were explored as potential contributing factors.

All SFT measurements were assessed by the same individual on the right side as prescribed by the anthropometric standardization reference manual[13]. SFT measurements were made using a Holtain brand SFT caliper (Holtain Ltd., UK) with an accuracy of ±0.2 mm according to the protocol of Keys and

Brozek[14].

The average fat percentage of athletes was calculated according to the Yuhasz formula as follows: "% fat=0.153 (T+SS+A+SI)+5.788"[15]. Somatotypes (endomorphy, mesomorphy, ectomorphy) were assessed according to the method described by Heath-Carter[16].

Statistical Analysis

Continuous variables are reported as mean ± standard deviation or median (minimum-maximum) according to data distribution. The Shapiro-Wilk test was used to assess normality. Categorical variables were reported as percentages. Spearman correlation analysis was used to define associations between SFT and ATR. No correction for multiple comparisons was applied because the analyses were considered exploratory. P-values ≤0.05 indicated statistical significance with a 95% confidence interval. Analyses were performed using SPSS 22.0 (SPSS Inc., IBM, Armonk, NY, USA).

RESULTS

The study population consisted of 58 participants, with a mean age of 12.6±2.0 years. Gender distribution revealed that 12 (21%) were female, while 46 (79%) were male . Anthropometric measurements indicated a mean height of 157±13.7 cm and a mean weight of 47.6±13.1 kg. Regarding sailing experience, 6 (10%) had less than two years of experience, 41 (71%) had been sailing for 2 to 5 years, and 11 (19%) had more than five years of sailing experience. Tanner staging revealed that 16 (28%) of participants were classified as Tanner stage 1, while 14 (24%) were categorized as Tanner stage 2 in terms of sexual development. Notably, 98% of the participants were free from additional diseases. The Beighton score, a measure of joint laxity, was 1.2±1.8 for the upper extremity and 0.6±0.9 for the lower extremity. Body composition analysis indicated that 32 (55%) of the participants exhibited a mesomorphic body type, 15 (26%) were classified as endomorphic, and 11 (19%) as ectomorphic (Table 1). Furthermore, 34% of the participants were involved in sports activities other than sailing (Figure 1).

Postural assessment findings are summarized in Table 2. Among the participants, 5 (8.6%) exhibited an ATR angle greater than 5°, with only 1 (1.7%) exceeding 7°, all of whom were male. Leg length discrepancies were observed in 1 (1.7%) sailors. Head posture was generally normal in 50 (86%) participants. Shoulder asymmetry findings indicated that 25 (43%) had mild shoulder asymmetry, 5 (8%) had moderate shoulder asymmetry, and 1 (1.7%) exhibited severe shoulder asymmetry. Scapular asymmetry was mild in 30 (51%) and severe in 1 (1.7%). In terms of low-back asymmetry, 13 (22%) exhibited mild asymmetry, 7 (12%) had moderate asymmetry, and 1 (1.7%) had severe low-back asymmetry.

SFT measurements indicated that the highest values were observed in the abdomen, averaging 12.9±5.2, followed by the calf, triceps, suprailiacus, thigh, and biceps. Correspondingly, body fat percentage, calculated using the Yuhasz formula, was highest in the abdomen, followed by the calf, triceps, suprailiacus, thigh, and biceps in Table 3 (3.54±2.8, 3.45±2.7, 3.43±2.74, 3.35±2.81, 3.17±2.74, and 2.93±2.88, respectively).

Correlation analyses were performed to explore associations between ATR and SFT parameters, and results were summarized in Table 4. Scoliometric measurements at the thoracic 12 level showed a significant negative correlation with abdominal SFT (p=0.023, r=-0.298, and p=0.01). However, no significant correlations were observed between other scoliometric and SFT measurements (p>0.05).

Positive and significant correlations were observed between sailing time and low-back asymmetry (p=0.008, r=0.344), lumbar lordosis and thigh fat percentage (p=0.049, r=0.259), swimming and increased lumbar lordosis (p=0.002, r=0.391), and the presence of hip asymmetry while playing basketball, which was negatively correlated (p=0.027, r=-0.290), while positively correlated with knee deformity (p=0.003, r=0.377).

Table 1. Demographic characteristic of study population

Age (year) (mean ± SD)	12.6±2
Gender (female/male), (%)	12 (21%)/46 (79%)
Height (cm), (mean ± SD)	157±13.7
Weight (kg) (mean ± SD)	47.6±13.1
Beighton score (mean ± SD)	
Upper extremity	1.2±1.8
Lower extremity	0.6±0.9
Tanner stage (%)	
Stage 1	16 (28%)
Stage 2	14 (24%)
Stage 3	11 (19%)
Stage 4	12 (21%)
Stage 5	5 (8%)
Dental braces treatment (%)	21 (36%)
Sailing time (%)	
<2 years	6 (10%)
2-5 years	41 (71%)
>5years	11 (19%)
ADAMS test positive (%)	2 (3%)
Body type (%)	
Mesomorphic	32 (55%)
Endomorphic	15 (26%)
Ectomorphic	11 (19%)

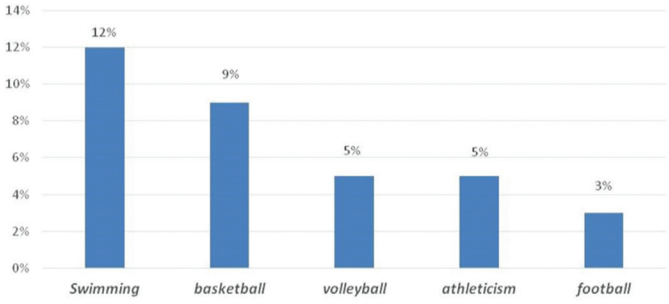

Figure 1. Sports activities other than sailing among the participants

Table 2. Postural assessment evaluation of participants

Axial trunk rotation, n (%)	
>5°	5 (8.6%)
>7°	1 (1.7%)
Head position, n (%)	
Normal	50 (86%)
Right	6 (10%)
Left	2 (3%)
Shoulder asymmetry, n (%)	
None	27 (47%)
Mild	25 (43%)
Moderate	5 (8%
Severe	1 (1.7%)
Scapula asymmetry, n (%)	
None	27 (47%)
Mild	30 (51%)
Moderate	1 (1.7%)
Severe	0
Low-back asymmetry, n (%)	
None	37 (64%)
Mild	13 (22%)
Moderate	7 (12%)
Severe	1 (1.7%)
Anterior chest deformity, n (%)	3 (5%)
Lomber lordosis, n (%)	10 (17%)
Thoracal kyphosis, n (%)	5 (8%)
Knee deformity, n (%)	9 (16%)
Foot deformity, n (%)	30 (52%)
The leg length discrepancy, n (%)	1 (1.7%)

Table 3. Body fat percentage of paticipants calculated using the Yuhasz formula

	Mean ± standard deviation	Median (minimum-maximum)
Triceps fat ratio (%)	3.43±2.74	4.51 (2.95-5.87)
Biceps fat ratio (%)	2.93±2.88	4.17 (3.39-5.39)
Sacroiliac fat ratio (%)	3.35±2.81	4.32 (3.6-6.45)
Abdomen fat ratio (%)	3.54±2.8	4.46 (3.39-7.04)
Thigh fat ratio (%)	3.17±2.74	4.37 (3.17-5.29)
Calf fat ratio (%)	3.45±2.7	4.61 (2.95-5.58)

Tanner stage exhibited positive correlations with lumbar asymmetry, increased lumbar lordosis, and thigh fat percentage (r=0.457, and p<0.001; r=0.443, and p=0.001; r=0.317 and p=0.016, respectively). Moreover, shoulder asymmetry demonstrated positive correlations with weekly training hours, calf fat percentage, scapular asymmetry, and low-back asymmetry (r=0.305, and p=0.020; r=0.288, and p=0.029; r=0.444, and p<0.001; r=0.639, and p<0.001, respectively). Scapular asymmetry was positively correlated with shoulder and low-back asymmetry (r=0.444 and p<0.001; r=0.445 and p<0.001, respectively).

Furthermore, the presence of low-back asymmetry, sailing time, Tanner stage, shoulder asymmetry, and scapular asymmetry was positively correlated with overall asymmetry (r=0.344, and p=0.008; r=0.457, and p<0.001; r=0.639, and p<0.001; r=0.445, and p<0.001, respectively). Body type exhibited negative correlations with sacroiliac and calf fat percentages (r=-0.268 and p=0.042; r=-0.303 and p=0.021, respectively). Additionally, the percentage of triceps fat and the percentages of biceps, sacroiliac, abdominal, thigh, and calf fat were positively correlated (r=0.854, p<0.001; r=0.935, and p<0.001; r=0.900, and p=0.000; r=0.888, and p<0.001; r=0.886, and p<0.001, respectively). Conversely, biceps fat percentage correlated negatively with increased dorsal kyphosis (r=-0.262, and p=0.047).

DISCUSSION

The present study evaluated trunk asymmetry findings and postural disorders in young Optimist and Laser sailors, a population that has received limited attention in the literature. The observed frequency of ATR positivity and postural asymmetry findings suggests that repetitive asymmetric loading during sailing may be associated with postural adaptations. However, because of the cross-sectional design and lack of a control group, the findings should be interpreted cautiously.

Previous studies evaluating sports participation and IS have primarily focused on gymnastics, dance, and swimming, whereas evidence regarding sailing athletes remains scarce. The current findings contribute to the limited literature by demonstrating associations between sailing duration, training intensity, shoulder asymmetry, lumbar asymmetry, and sagittal posture changes. One-handed sailing may be associated with repetitive asymmetric loading patterns that could contribute to postural asymmetries in predisposed individuals.

The relationship between exercise and sports and IS is controversial in the literature. For instance, Warren et al.[17] conducted a study with 75 professional dancers, and they found that 18 (24%) had AIS delayed onset of menstruation than healthy participants. Also, Hellström et al.[18] showed a 2- to 3-fold rise in the frequency of AIS among athletes compared to non-athletes by examining the thoracolumbar vertebrae radiographically. They concluded that male gymnasts had scoliosis more frequently than football players. On the other hand, according to McMaster et al.[19], dancing, skating, gymnastics/karate, and horseback riding protect from AIS progression. In addition, a large cross-sectional observational study comparing the prevalence of AIS among athletes and non-athletes showed that systematic sports practice was not associated with the development of AIS or affected the grade of the primary scoliotic curve[20].

Due to these contradictory results in the literature, this study we planned is essential in revealing the postural disorders of Optimist and Laser class licensed sailors and the relationship of this sport with scoliosis. Anthropometric measurements of professional athletes have gained importance because the

Table 4. Correlation between skin fold thickness and axial trunk rotation

		Sacrum	Lumbar 3	Thoracic 12	Thoracic 6-8	Cervical 7
Abdominal skin thickness	r	0.138	-0.155	-0.298*	-0.163	-0.016
	p	0.303	0.245	0.023	0.222	0.908
Thigh skin thickness	r	0.033	-0.175	-0.243	-0.173	-0.079
	p	0.805	0.188	0.066	0.193	0.553
Calf skin thickness	r	0.225	-0.025	-0.124	-0.033	0.034
	p	0.090	0.853	0.355	0.807	0.802
Triceps skin thickness	r	0.165	-0.133	-0.187	-0.134	0.052
	p	0.215	0.320	0.160	0.316	0.696
Biceps skin thickness	r	0.230	-0.071	-0.246	-0.120	0.109
	p	0.082	0.594	0.063	0.368	0.416
Suprailiac skin thickness	r	0.176	-0.092	-0.201	-0.148	-0.016
	p	0.186	0.493	0.130	0.268	0.906

*: Correlation is significant at the 0.05 level, **: Correlation is significant at the 0.01 level, Spearman's rho

structural body characteristics of the athletes indirectly affect the success of sports. We found a significant relationship between sailing time, low-back asymmetry and lumbar lordosis. Also, we demonstrated that shoulder asymmetry is correlated with weekly training hours, scapular asymmetry, and low-back asymmetry. It is important to note that shoulder asymmetry positively correlated with calf fat percentage.

SFT measurements are widely used as practical and non-invasive field methods for estimating body composition; however, they do not provide the same level of accuracy as advanced imaging techniques such as magnetic resonance imaging or dual-energy X-ray absorptiometry. It is known that subscapular, abdomen, triceps and thigh regions SFTs' are suitable parameters for assessing the body composition and measurements taken from these regions were found reliable[13,21].

Palomino-Martín et al.[21] conducted a study with 180 sailors from 42 international teams participating and found that the skin on the thigh was the thickest. This was followed by the lower leg and triceps. When skin folds are evaluated individually, only the skin folds on the triceps, thigh and anterior thigh seem to be of greater importance for performance[21]. Additionally, they found that the profile of the top optimistic competitors tended to be meso-ectomorphic, and better athletic performance was associated with a reduction in adipose tissue overall. On the contrary, our results showed that the thickest SFT measurement was in the abdomen, followed by the lower leg and triceps, respectively. This may be a consequence of sailors participating in international championships being the most professional in their countries, and therefore, they have been performing this sport for the longest time. On the other hand, in our study, sailors performing this sport for more than five years constituted only 19% of all participants.

In our study, over half of the sailors exhibited a mesomorphic body type, and the majority had mild shoulder and scapula asymmetry along with foot deformities. Interestingly, our findings contrast with previous studies that reported associations between scoliosis and pelvic asymmetry, leg length discrepancies, and musculoskeletal disorders[22]. Notably, successful Optimist sailors tended to exhibit a meso-ectomorphic body profile, emphasizing the potential performance benefits of reduced adipose tissue[21]. This may be attributed to their extensive experience, as 81% of participants in our study had been engaged in the sport for less than five years.

Another result that we obtained with this study is the prevalence of ATR measurement of ⩾5° was 8.6% of sailors, which was assessed by scoliometer, surpassing the prevalence in the normal age-matched population[22]. Additionally, we found correlations between training hours and shoulder asymmetry, lumbar lordosis in those combining swimming with sailing, and lumbar asymmetry in basketball players. Similarly, Becker[8] found a significant prevalence of structural scoliosis (6.9%) in teenagers engaging in competitive swimming programs. The increased frequency of scoliosis was attributed to a coexisting muscular imbalance, which is typically considered a causal factor in scoliosis development. This imbalance was believed to result from repetitive swimming exertion and subsequent potential vertebral adaptation[8].

The observed postural asymmetries may reflect sport-specific adaptations related to repetitive asymmetric loading rather than structural scoliosis itself. Therefore, the findings should not be interpreted as evidence of a causal relationship between sailing participation and IS development.

Study Limitations

This study has several limitations. First, the absence of a control group consisting of non-athlete adolescents limits direct comparison regarding the prevalence of trunk asymmetry findings. Second, the cross-sectional design does not permit causal interpretation of the observed associations. Third, the sample size was relatively small, and no a priori power analysis was performed because the study was designed as an exploratory

pilot investigation. Additionally, scoliosis assessment relied on scoliometer-based ATR measurements without radiographic confirmation. Since scoliometer evaluation is a screening method rather than a diagnostic tool, the findings should be interpreted as trunk asymmetry or ATR positivity rather than confirmed scoliosis. Inter- and intra-rater reliability analyses were also not conducted. Furthermore, radiographic spinopelvic parameters such as Cobb angle, sagittal vertical axis, pelvic incidence, and pelvic tilt were not evaluated because the study was designed as a non-radiographic screening investigation in asymptomatic athletes.

CONCLUSION

The present study demonstrated a considerable frequency of trunk asymmetry findings and postural alterations among young Optimist and Laser sailors. Repetitive asymmetric loading during sailing may be associated with postural adaptations in adolescent athletes. However, due to the cross-sectional design, absence of a control group, and lack of radiographic confirmation, no conclusions regarding causality or scoliosis risk can be drawn. Future prospective controlled studies including radiographic assessment are needed to better understand the relationship between sailing and IS.

Ethics

Ethics Committee Approval: The Ethics Committee of the University of Health Sciences Türkiye, Bakırköy Dr. Sadi Konuk Training and Research Hospital approved the design and protocol of the study in agreement with the principles of the Declaration of Helsinki and ethical standards for human experimentation (approval no: 2019-11-02, date: 10.06.2019).
Informed Consent: All participants and their parents were informed about the study. Signed informed consent was obtained from parents.

Footnotes

Authorship Contributions

Concept: A.M.T., F.Y.A., A.B., Ç.Ç., Design: A.M.T., F.Y.A., Y.S.Ö., Ç.Ç., Data Collection or Processing: A.M.T., F.Y.A., A.B., Y.S.Ö., Analysis or Interpretation: Y.S.Ö., Ç.Ç., Literature Search: A.M.T., A.B., Y.S.Ö., Writing: A.M.T., F.Y.A., Ç.Ç.
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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ORIGINAL ARTICLE

J Turk Spinal Surg 2026;37(3):116-122

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DOI: 10.4274/jtss.galenos.2026.58661

PLANTAR CUTANEOUS SENSATION AND POSTURAL CONTROL IN NSCLBP: A CASE-CONTROL STUDY

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ABSTRACT

Objective: Postural control deficits and reduced physical performance are well documented in non-specific chronic low back pain (NSCLBP); however, it remains uncertain whether impairment of plantar cutaneous sensation contributes meaningfully to these disturbances. This study, therefore, aimed to investigate the association between plantar sensory function, postural balance, and functional performance in patients with NSCLBP relative to healthy controls.

Materials and Methods: A cross-sectional case-control design was employed, and data were collected at a single center. The sample comprised 30 individuals diagnosed with NSCLBP and 30 age- and sex-matched healthy volunteers. Plantar light touch-pressure (Semmes-Weinstein monofilaments), vibration (128 Hz diapason), and two-point discrimination (esthesiometer) thresholds were measured at standardized plantar regions. Static balance (one-leg stance test with eyes-open and eyes-closed), dynamic balance (Y balance test in the anterior, posteromedial, and posterolateral directions), and physical performance [timed up and go test (TUG)] were assessed. Pain (10-point visual analog scale), disability (Oswestry disability index), and depression (Beck depression inventory) were recorded. Between-group comparisons and correlations between plantar sensation measures and balance and functional outcomes were analyzed.

Results: Compared with healthy controls, NSCLBP patients demonstrated poorer plantar sensory function, reduced static and dynamic balance performance, and longer TUG durations (all $p<0.05$). In the NSCLBP group, plantar sensory measures were significantly correlated with postural balance and physical performance on the dominant side ($p<0.05$).

Conclusion: Decreased plantar cutaneous sensation was significantly associated with impaired postural balance and functional performance in NSCLBP. Plantar sensory testing may therefore represent an additional clinical parameter in the evaluation of these patients and help guide individualized conservative rehabilitation strategies.

Keywords: Non-specific chronic low back pain, plantar foot sensation, postural balance, physical performance, Y balance test

INTRODUCTION

Dynamic and static balance of the spinal column are maintained through complex interactions between proprioceptive input and the musculoligamentous system[1,2]. From a functional perspective, body stability during quiet stance and voluntary movement is a key criterion of balance and is essential for efficient gait and daily activities[3]. Plantar cutaneous mechanoreceptors provide critical contact with the environment, particularly during weight-bearing and locomotor tasks such as walking[4]. Perception of alterations in light touch, pressure, and vibration via these mechanoreceptors contributes to the fine regulation of postural balance[5,6]. Accordingly, decreased plantar foot sensation may adversely affect locomotor stability[5-8]. Meyer et al.[6] demonstrated that proprioceptive deficits caused by reduced plantar sensation can impair postural control and deteriorate balance even in healthy individuals.

Insufficient proprioceptive information arising from the lumbopelvic and lower-limb region has been proposed as one of the mechanisms underlying altered trunk muscle activation and difficulties in postural control and repositioning of the body in patients with non-specific chronic low back pain (NSCLBP)[9]. Reduced physical capacity and curtailed daily activity participation consistently co-occur with postural instability in chronic low back pain, a pattern corroborated by clinical evidence from several independent studies[1,2,10].

Despite this body of evidence, the specific contribution of plantar foot sensation to postural balance and physical performance in NSCLBP has not been systematically characterized. To address this gap, the present study was designed to examine

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Received: 07.04.2026 **Accepted:** 25.05.2026 **Publication Date:** 06.07.2026
Cite this article as: Erdoğanoğlu Y, Mimir B, Çal MA, Kahraman S. Plantar cutaneous sensation and postural control in NSCLBP: a case-control study. J Turk Spinal Surg. 2026;37(3):116-122

the interrelationships among plantar sensory function, static and dynamic postural control, and functional performance, contrasting NSCLBP patients with age- and sex-matched healthy individuals. The central hypothesis held that NSCLBP patients would exhibit concurrent impairments spanning plantar cutaneous sensitivity, static and dynamic postural stability, and physical performance each dimension more compromised than in matched healthy controls.

MATERIALS AND METHODS

Study Design and Ethical Approval

All assessments were carried out at a single clinical site Üsküdar University (İstanbul, Türkiye) within the framework of a cross-sectional case-control design. The study protocol was reviewed and approved by the Local Ethics Committee of Üsküdar University (approval no: 61351342-/2019-461, date: 24.10.2019), with all procedures carried out in full accordance with the ethical standards set forth in the Declaration of Helsinki. Written informed consent was secured from every participant following comprehensive disclosure of the study protocol and procedures, as required prior to formal enrolment.

Participants

Thirty NSCLBP patients and 30 age- and sex-matched healthy controls were recruited for participation in this study. Patients had a history of low back pain exceeding 3 months. All participants were between 18-50 years of age.

Exclusion criteria included previous spinal surgery; spinal disorders (such as vertebral fracture, spinal stenosis, spondylolisthesis, inflammatory or neoplastic disease); neurological and musculoskeletal pathologies; comorbidities that might affect sensory or motor function (diabetes, neuropathies, respiratory disorders, cardiovascular problems); and physical difficulties such as visual or hearing impairments that could affect test performance. In addition, patients with obesity [body mass index (BMI)>30] were not included in the study. Healthy controls had no history of chronic low back pain or spinal disorders and met the same exclusion criteria.

Sample Size Calculation

To achieve a minimum statistical power of 80%, an a priori power analysis determined that at least 29 participants per group would be required[11]. This estimate was derived using SPSS Sample Power 3.0 (IBM Corporation, Armonk, NY), with an expected correlation coefficient of r=0.50 and a type I error rate set at α=0.05. To compensate for potential dropouts, 30 NSCLBP patients and 30 healthy controls were included.

Evaluation Tests

All assessments were performed in a standardized sequence during a single session. Pain intensity was recorded first, followed by plantar sensory testing, static balance assessment, dynamic balance assessment, functional mobility testing, and questionnaire-based disability and depression evaluations.

Pain

Current low back pain intensity was quantified on a 10-point visual analog scale (VAS), anchored at 0 (no pain) and 10 (worst imaginable pain), with each participant self-reporting their perceived pain level at the time of assessment[12].

Plantar Foot Sensation

Light Touch-pressure

Plantar light touch-pressure thresholds were evaluated at four anatomically standardized sites-the first, third, and fifth metatarsal heads, and the heel midpoint-using the Semmes-Weinstein monofilament (SWM) test (North Coast Medical, San Jose, CA, USA). At each site, two calibrated monofilaments (2.83 and 6.65) were applied perpendicularly for 1-1.5 seconds per contact, with three applications per filament. Once participants correctly perceived two out of three stimuli, the monofilament number was recorded. If there was no sensation during trials with the first thin monofilament, then a second thicker one was used[13].

Vibration Sensation

Vibratory perception was evaluated at two anatomically distinct foot landmarks-the first metatarsal head and medial malleolus-using a 128 Hz tuning fork (Elcon Medical Instruments, Germany). Participants were asked to report vibration sensation from initial contact until disappearance at the measurement site. The duration of perceived vibration was timed with a digital chronometer across three consecutive trials; the mean of these measurements was retained as the outcome variable and expressed in seconds[14].

Two-point Discrimination

Using a calibrated aesthesiometer (Baseline, White Plains, USA), spatial tactile acuity was assessed at the trans-metatarsal and heel sites via a descending-threshold protocol in which caliper separation was reduced stepwise from maximum until the participant reported loss of dual-point perception. The threshold was defined as the minimum interpoint distance yielding a consistent two-point response. The correct response of two out of three trials was recorded as the result in millimeters[15].

Postural Control

Static Balance

To characterize static postural stability across both limbs, the one-leg standing balance test was administered bilaterally, yielding independent scores for the dominant and non-dominant extremities. Test instructions were explained to participants, who then performed the test barefoot on a flat surface.

Initial trials were performed with eyes-open. Participants assumed a unilateral stance-hands on hips, gaze locked onto a wall-mounted fixation point at eye level-prior to the examiner initiating the timing sequence. After three repetitions of the test, average times were recorded with a chronometer in seconds.

To evaluate balance under more challenging conditions, the same procedure was then repeated with eyes-closed. For the eyes-closed condition, participants closed their eyes after achieving a stable one-leg stance position, and three trials were again performed for each limb. Regardless of visual condition (eyes-open and eyes-closed), timing was discontinued when participants either achieved uninterrupted single-limb stance for the full 30-second maximum or lost balance, defined as any contralateral foot contact with the supporting surface[16].

Dynamic Balance

The Y balance test-a well-validated measure of dynamic postural control derived from the star excursion balance test-was used to assess reach performance in three directions: anterior, posteromedial, and posterolateral. Maintaining single-leg stance on the central platform, each participant maximally extended the contralateral limb toward each target direction. Following six familiarization trials per direction, three test trials were recorded with 30-second inter-trial rest intervals; the mean of these three values (in centimeters) served as the directional outcome score. To control for limb length variation, lower extremity length was determined as the linear distance from the anterior superior iliac spine to the medial malleolus, and each directional reach distance was normalized accordingly: normalized reach (%)=(reach distance/limb length)×100[17].

Physical Performance

The timed up and go (TUG) test served as the primary measure of functional mobility. From a standardized seated position, each participant executed a complete sit-to-stand-to-walk-to-return-to-sit sequence over a 3-meter course; chronometer-recorded completion times were averaged across three trials to yield the outcome score[18].

Functional Assessment

Pain-related functional disability was quantified via the Turkish-validated Oswestry disability index (ODI), a self-report measure encompassing pain intensity and its perceived impact on activities of daily living[19]. Each participant read through the questionnaire independently and recorded their responses without investigator prompting.

Psychological Assessment

Psychological status was indexed using the Turkish-validated Beck depression inventory (BDI)[20]. A 21-item self-report questionnaire sensitive to the severity of depressive symptoms over the prior week, the BDI was completed independently by each participant; scores were recorded and incorporated into both descriptive and inferential analyses.

Statistical Analysis

All analyses were performed in IBM SPSS (version 22.0). Continuous data are presented as mean ± standard deviation. Three distinct analytical approaches were employed: paired-sample t-tests to detect dominant-non-dominant asymmetries in plantar sensory thresholds within the NSCLBP group; independent-samples t-tests to compare sensory, postural, and functional performance outcomes between patients and healthy controls; and Pearson correlation analyses to quantify associations between plantar foot sensation and balance and mobility variables in the patient group. Statistical significance was set at $p<0.05$ for all comparisons.

RESULTS

The two groups were well-matched at baseline: mean age approximated 37 years in each cohort, sex composition was identical (20 women and 10 men per group), and no significant between-group differences were detected for age or standing height. Body weight, however, was significantly elevated in the NSCLBP group relative to controls (73.67±12.64 kg vs. 65.40±10.13 kg, $p=0.050$). Within the patient group, mean VAS and ODI scores of 6.03±1.80 and 52.80±19.87, respectively, reflected moderate-to-severe pain intensity and substantial pain-related functional limitation. Depressive symptom burden was markedly higher in patients than in controls, as evidenced by a nearly fivefold difference in mean BDI scores (28.60±11.11 vs. 6.20±6.32, $p<0.001$). Medication usage was approximately 83% in the NSCLBP group. The demographic and clinical characteristics of the participants are presented in Table 1.

Within the NSCLBP cohort, plantar sensory thresholds for light touch-pressure, vibration, and two-point discrimination did not differ significantly between the dominant and non-dominant limbs (all within-group $p>0.05$). By contrast, comparisons with healthy controls revealed a consistently inferior level of plantar sensory performance in the NSCLBP group. Specifically, NSCLBP patients demonstrated higher SWM values, shorter vibration perception times, and larger two-point discrimination distances than healthy controls across all tested plantar regions. Relative to healthy controls, individuals with NSCLBP demonstrated inferior postural and functional performance, characterized by reduced one-leg stance duration, diminished Y balance reach distances in the anterior, posteromedial, and posterolateral directions, and prolonged TUG times (all between-group $p<0.05$). Detailed findings are presented in Table 2.

In the NSCLBP group, dominant-side plantar sensory measures were significantly associated with postural balance and physical performance. Higher SWM values and larger two-point discrimination distances were generally associated with shorter one-leg stance times, lower Y balance reach values, and longer TUG durations, whereas longer vibration perception times were associated with better balance and mobility outcomes. Collectively, the results indicate that diminished plantar sensory function is closely associated with decrements in static and dynamic balance as well as functional mobility among patients with NSCLBP. Detailed correlation coefficients for these relationships are reported in Table 3.

Table 1. Demographic, clinical, and self-reported outcome characteristics of the NSCLBP and healthy control groups

	NSCLBP (n=30) Mean ± SD	Healthy controls (n=30) Mean ± SD	p-value
Sex [female/male, n (%)]	20 F/10 M (67%/33%)	20 F/10 M (67%/33%)	-
Age (years)	37.17±10.21	37.69±10.90	0.844
Height (cm)	169.73±10.26	170.00±8.03	0.609
Weight (kg)	73.67±12.64	65.40±10.13	0.050
VAS	6.03±1.80	-	-
Medication use (%)	83.3	-	-
BDI	28.60±11.11	6.20±6.32	p<0.001*
ODI	52.80±19.87	2.87±7.11	p<0.001*

Independent-samples t-test, *: p<0.05, NSCLBP: Non-specific chronic low back pain, SD: Standard deviation, VAS: Visual analog scale, BDI: Beck depression inventory, ODI: Oswestry disability index

Table 2. Between-group comparison of plantar sensory thresholds, static and dynamic balance, and functional mobility in NSCLBP patients and healthy controls, with within-patient dominant–non-dominant comparisons

Evaluation criteria	NSCLBP patients (n=30) dominant Mean ± SD	NSCLBP patients (n=30) non-dominant Mean ± SD	Healthy controls (n=30) dominant Mean ± SD	Healthy controls (n=30) non-dominant Mean ± SD	p-value	p-value (within)
Light touch sensation (SWM units)						
1st metatarsal head	3.96±0.41	3.88±0.48	3.20±0.38	3.29±0.58	p<0.05	0.222
3rd metatarsal head	4.08±0.57	4.05±0.45	3.14±0.35	3.13±0.37	p<0.05	0.764
5th metatarsal head	4.07±0.44	4.14±0.37	3.30±0.37	3.40±0.35	p<0.05	0.284
Heel midpoint	4.36±0.41	4.33±0.45	3.54±0.36	3.52±0.32	p<0.05	0.535
Vibration sensation (s)						
1st metatarsal head	9.31±2.70	9.43±2.87	13.22±3.08	14.91±4.04	p<0.05	0.687
Medial malleolus	8.94±2.35	8.94±2.35	12.43±2.45	12.88±3.17	p<0.05	0.994
Two-point discrimination (cm)						
Trans-metatarsal	2.36±0.67	2.37±0.70	1.61±0.43	1.60±0.38	p<0.05	0.937
Heel midpoint	2.06±0.62	2.21±0.57	1.72±0.39	1.65±0.37	p<0.05	0.247
Static balance (s)						
Eyes-open	15.86±5.88	16.28±6.68	28.24±4.42	27.26±4.21	p<0.05	0.565
Eyes-closed	6.11±3.53	6.25±3.88	15.91±3.49	14.74±3.81	p<0.05	0.721
Y balance test (cm)						
Anterior	67.76±12.59	66.84±12.38	82.43±8.07	82.62±6.97	p<0.05	0.181
Posteromedial	55.10±12.11	56.30±14.16	77.13±7.68	76.23±7.15	p<0.05	0.307
Posterolateral	66.50±11.04	65.53±11.35	82.88±6.82	84.01±7.28	p<0.05	0.392
TUG (s)	7.59 ±1.24	-	4.19±1.05	-	p<0.05	-

Between-group p-values were calculated using the independent-samples t-test. Within-group p-values were calculated using the paired-samples t-test for dominant versus non-dominant side comparisons in the NSCLBP group. Higher SWM values and larger two-point discrimination distances indicate poorer plantar sensory function; shorter vibration perception times indicate reduced vibration sensation; lower static balance and Y balance values and higher TUG values indicate worse performance. NSCLBP: Non-specific chronic low back pain, SWM: Semmes-Weinstein monofilament, TUG: Timed up and go

Table 3. Correlations of dominant-side plantar sensory measures with static balance, dynamic balance, and functional mobility in patients with NSCLBP

	Static balance (eyes-open)	Y balance anterior (A)	Y balance posterolateral (PL)	Y balance posteromedial (PM)	TUG
Light touch sensation					
1st metatarsal head	r=−0.748** p<0.001	r=−0.391** p=0.002	r=−0.496** p<0.001	r=−0.576** p<0.001	r=0.697** p<0.001
3rd metatarsal head	r=−0.633** p<0.001	r=−0.316* p=0.014	r=−0.456** p<0.001	r=−0.561** p<0.001	r=0.571** p<0.001
5th metatarsal head	r=−0.631** p<0.001	r=−0.574** p<0.001	r=−0.446** p<0.001	r=−0.594** p<0.001	r=0.689** p<0.001
Heel midpoint	r=−0.696** p<0.001	r=−0.478** p<0.001	r=−0.600** p<0.001	r=−0.696** p<0.001	r=0.770** p<0.001
Vibration sensation					
1st metatarsal head	r=0.608** p<0.001	r=0.437** p<0.001	r=0.523** p<0.001	r=0.487** p<0.001	r=−0.556** p<0.001
Medial malleolus	r=0.672** p<0.001	r=0.487** p<0.001	r=0.577** p<0.001	r=0.541** p<0.001	r=−0.583** p<0.001
Two-point discrimination					
Trans-metatarsal	r=−0.723** p<0.001	r=−0.257* p=0.047	r=−0.416** p=0.001	r=−0.482** p=0.001	r=0.660** p<0.001
Heel midpoint	r=−0.328* p=0.010	r=−0.080 p=0.542	r=−0.151 p=0.249	r=−0.273* p=0.035	r=0.344* p=0.007

Pearson correlation analysis, *: p<0.05, **: p<0.01, NSCLBP: Non-specific chronic low back pain, SWM: Semmes-Weinstein monofilament, TUG: Timed up and go, Y balance sub-directions; A: Anterior, PL: Posterolateral, PM: Posteromedial, Higher SWM values indicate reduced light touch sensitivity; higher TUG values indicate worse functional mobility; higher static balance and Y balance values indicate better performance

DISCUSSION

This study examined the relationship between plantar foot sensation, postural balance, and physical performance in patients with NSCLBP without neurological or musculoskeletal comorbidities. Compared with age- and sex-matched healthy individuals, patients with NSCLBP exhibited significant deficits in plantar light touch, vibration, and two-point discrimination, together with impaired static and dynamic balance and poorer functional performance. Collectively, these findings indicate that reduced plantar sensation is associated with impaired postural control in NSCLBP and may represent one of several factors linked to limitations in locomotor performance and body repositioning.

Altered central and peripheral sensorimotor function may reduce the ability to appropriately receive, integrate, and respond to sensory stimuli[21]. In this context, plantar cutaneous afferents provide continuous information regarding contact pressure, load distribution, and subtle shifts in the base of support during standing and gait. When perception from these mechanoreceptors is delayed or diminished, the timing and accuracy of postural readjustments may be reduced, thereby compromising rapid balance responses[22-24]. Previous studies have shown that postural control is adversely affected both in individuals with neuropathy-related loss of plantar sensation and in healthy subjects in whom plantar input was experimentally reduced[4,5]. Plantar sensitivity also decreases with aging[25]. Ito et al.[26] further reported that static balance with eyes-closed and the stereotypic ankle-hip strategy deteriorate in elderly patients with low back pain when proprioceptive signals from the gastrocnemius muscle are disturbed. Conversely, dynamic balance has been shown to improve after brief periods of plantar cutaneous stimulation in healthy subjects, and stimulation of plantar mechanoreceptors may facilitate postural control[27,28]. Taken together, these observations suggest that plantar sensory input may contribute to the proprioceptive weighting process required for stable stance and coordinated postural strategies. Consistent with this body of evidence, we found reduced plantar foot sensation in patients with NSCLBP, and this finding was associated with poorer postural control in our cohort.

Postural control deficits in NSCLBP have previously been reported, particularly during challenging or constrained tasks[29,30]. Static and dynamic balance have also been identified as important factors related to the presence and persistence of chronic low back pain[31,32]. Our findings are in agreement with these reports, as the NSCLBP group in the present study showed significantly reduced one-leg stance performance and lower Y balance test reach distances in the anterior, posterolateral, and posteromedial directions under both eyes-open and eyes-closed conditions. In this respect, our results are broadly consistent with the balance deficits described by Tsigkanos et al.[29] and with the view that altered postural control is a

clinically relevant feature of chronic low back pain[29-32]. In contrast, Hemmati et al.[33] suggested that postural balance may not be impaired in relatively young NSCLBP patients with mild pain scores. That discrepancy may partly reflect differences in patient characteristics, since their cohort had a mean age of 24 years and a mean pain intensity of 4 on the VAS, whereas our cohort had a mean age of approximately 37 years and a mean pain score of approximately 6. Tsigkanos et al.[29] also reported that age and BMI significantly influence dynamic balance. Accordingly, we excluded participants with BMI greater than 30 kg/m^2 or age over 50 years to reduce the potential confounding effect of these factors. Nevertheless, body weight remained significantly higher in the NSCLBP group, and this difference should be considered when interpreting the between-group balance and functional performance findings. Although obesity was excluded, the observed weight difference may still have influenced postural control and mobility outcomes to some extent.

Individuals with chronic low back pain generally report lower levels of physical activity and functional capacity than healthy peers[34,35]. Concomitant impairments in static and dynamic balance are also associated with poorer performance in functional tasks[6,36]. In addition, decreased plantar foot sensation can negatively affect physical performance in chronic conditions even in the absence of overt neuropathy[37]. In agreement with this literature, patients with NSCLBP in our cohort had significantly worse TUG performance and higher disability scores than healthy controls. Thus, our findings are broadly consistent with prior reports showing reduced functional capacity and altered postural control in chronic low back pain[34-36], while also extending these observations by demonstrating that such impairments coexist with measurable deficits in plantar cutaneous sensation. However, habitual physical activity level was not directly assessed in the present study; therefore, its potential contribution to the observed between-group differences in balance, mobility, and plantar sensory performance cannot be excluded. We also found higher depressive symptom scores in the NSCLBP group, which is in keeping with previous reports that psychological burden frequently accompanies chronic low back pain[38].

From a rehabilitation perspective, these findings suggest that plantar sensory assessment may complement conventional pain- and disability-oriented evaluation in patients with NSCLBP. Interventions targeting sensorimotor function, such as progressive balance training, proprioceptive single-leg stance and reach exercises, and plantar sensory stimulation strategies, may be considered as part of individualized conservative rehabilitation programs, although their specific effects in this population should be confirmed in prospective interventional studies[27,28,30,35].

Study Limitations

Some limitations of this study should be acknowledged. First, exclusion of peripheral neuropathy and other relevant neurological conditions was based on clinical history and neurological examination, whereas electrophysiological confirmation was not systematically performed. Therefore, subclinical peripheral neuropathy cannot be completely excluded. Likewise, additional radiological investigations were not systematically available beyond routine clinical evaluation; thus, subclinical structural pathology also cannot be entirely ruled out. The same limitation applies to the healthy control group, and more extensive testing in asymptomatic volunteers would raise ethical and practical concerns. Second, the sample size was relatively small and the study was conducted at a single center, which limits the broader generalizability of our findings. Accordingly, these results should be interpreted primarily as data from a specific clinical setting and should be confirmed in larger multicenter cohorts. In addition, habitual physical activity level was not assessed. Because physical activity may influence plantar sensory function, postural balance, and physical performance, its potential confounding effect cannot be excluded. Third, we focused specifically on plantar cutaneous sensation and did not evaluate other components of sensorimotor control such as lower-limb muscle strength or joint position sense. Future studies including radiologically confirmed NSCLBP subgroups, larger and more diverse samples, and interventional designs targeting plantar mechanoreceptor stimulation and balance training are warranted to clarify the direction and clinical significance of these associations.

CONCLUSION

Patients with NSCLBP showed impaired plantar sensation, poorer balance, and reduced physical performance compared with healthy controls. Plantar sensory measures were also significantly associated with balance and functional mobility in the NSCLBP group. These findings support an association between plantar sensory dysfunction and impaired postural control in NSCLBP. Further prospective studies are required to clarify the direction and clinical implications of this relationship.

Ethics

Ethics Committee Approval: The study protocol was reviewed and approved by the Local Ethics Committee of Üsküdar University (approval no: 61351342-/2019-461, date: 24.10.2019).

Informed Consent: Written informed consent was secured from every participant following comprehensive disclosure of the study protocol and procedures, as required prior to formal enrolment.

Footnotes

Authorship Contributions

Surgical and Medical Practises: Y.E., B.M., Concept: Y.E., B.M., S.K., Design: Y.E., B.M., S.K., Data Collection or Processing: Y.E., B.M., Analysis or Interpretation: Y.E., B.M., M.A.Ç., Literature Search: Y.E., B.M., M.A.Ç., S.K., Writing: Y.E., B.M., M.A.Ç., S.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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ORIGINAL ARTICLE

J Turk Spinal Surg 2026;37(3):123-129

123

DOI: 10.4274/jtss.galenos.2026.50570

MORPHOMETRIC ANALYSIS OF DRY HUMAN ATLAS AND AXIS VERTEBRAE: ANATOMICAL CONSIDERATIONS FOR C1-C2 SCREW PLACEMENT

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ABSTRACT

Objective: This study aimed to evaluate the morphometric characteristics of dry human atlas (C1) and axis (C2) vertebrae and to assess their potential relevance for safe C1-C2 screw placement.

Materials and Methods: This descriptive osteometric and anatomical study included 35 dry human C1 vertebrae and 25 dry human C2 vertebrae. All measurements were performed directly on dry bones using a digital caliper with 0.01 mm precision. Right- and left-sided parameters were measured separately. Continuous variables were expressed as mean ± standard deviation and minimum-maximum values. Right-left comparisons were performed using paired-samples t-tests, with $p<0.05$ considered statistically significant.

Results: In C1, significant side-to-side differences were observed in the outer and inner distances of the vertebral artery groove, in the horizontal thickness of the lateral mass, and in the diameter of the vertebral foramen. The outer distance of the vertebral artery groove and the lateral mass horizontal thickness were significantly greater on the right side, whereas the inner distance of the vertebral artery groove and the vertebral foramen diameter were significantly greater on the left side. In C2, significant differences were found only in the anteroposterior diameter of the vertebral canal and in lamina length, both of which were greater on the right side. No significant bilateral differences were observed in most of the remaining C1 and C2 parameters.

Conclusion: Dry human C1 and C2 vertebrae exhibited measurable bilateral morphometric variations, particularly in parameters related to the C1 vertebral artery groove and in C2 lamina length. These findings may contribute to anatomical knowledge relevant to craniovertebral junction surgery and support individualized, side-specific preoperative evaluation before screw fixation.

Keywords: Atlas vertebra, axis, craniovertebral junction, morphometry, bone screws

INTRODUCTION

The craniovertebral junction is a complex anatomical region formed by the occiput, atlas (C1), and axis (C2), and it has a critical role in supporting the skull while allowing flexion, extension, and axial rotation of the head[1]. Surgical procedures in this region are technically demanding because C1 and C2 are closely related to the spinal cord, nerve roots, venous plexus, and vertebral artery[2].

Posterior C1-C2 stabilization is widely used for atlantoaxial instability caused by trauma, congenital anomalies, inflammatory disease, degenerative disorders, and other craniovertebral junction pathologies[3]. Although modern screw fixation techniques provide strong biomechanical stability, inaccurate screw placement may result in serious neurovascular complications, particularly vertebral artery injury or spinal canal violation[4].

The C1 has a unique ring-shaped structure without a vertebral body, and its posterior arch, lateral masses, superior and inferior articular facets, transverse foramina, and vertebral artery groove are important landmarks during screw fixation[5]. Previous cadaveric and radiological studies have emphasized that morphometric knowledge of the C1 posterior arch and lateral mass is essential for determining the feasibility, entry point, trajectory, and safe length of C1 screw placement[6]. Tan et al.[4] evaluated screw fixation through the posterior arch and lateral mass of the C1 and showed that morphometric evaluation is necessary for assessing the feasibility of this technique. Similarly, cadaveric studies on atlantal lateral mass screws demonstrated that screw depth and trajectory vary according to the entry point and individual vertebral morphology[7].

The vertebral artery groove of the C1 is another clinically important structure because anatomical variations in this region may increase the risk of vascular injury during posterior

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Received: 10.05.2026 **Accepted:** 07.06.2026 **Publication Date:** 06.07.2026
Cite this article as: Yay MÖ, Akdoğan I, Çalık MY, Akıllı S. Morphometric analysis of dry human atlas and axis vertebrae: anatomical considerations for C1-C2 screw placement. J Turk Spinal Surg. 2026;37(3):123-129

exposure and screw insertion[8]. Morphometric studies of the C1 have reported clinically relevant measurements such as total C1 width, intertransverse foraminal distances, vertebral foramen dimensions, and vertebral artery groove thickness, all of which may guide safer surgical planning around C1[5]. Recent studies focusing on the lateral mass of the C1 have also shown that measurements such as inferior articular facet dimensions, screw length, horizontal thickness, vertical height, and screw trajectory angle may provide practical information for craniovertebral junction surgery[1].

The C2 is also surgically important because its dens, pedicles, pars interarticularis, laminae, vertebral canal, and articular facets are directly related to different fixation techniques[9]. C2 pedicle, pars, and laminar screw fixation require detailed anatomical knowledge because narrow pedicles, small laminar dimensions, or asymmetric bony structures may limit screw placement and increase the risk of cortical breach[10]. Morphometric studies of C2 have shown that pedicle width, pedicle height, laminar length, laminar thickness, vertebral canal dimensions, and dens measurements are important parameters for selecting the appropriate screw type and trajectory[11]. Computed tomography (CT)-based and dry bone studies also suggest that C2 morphometric parameters may vary between populations, making population-specific anatomical data valuable for surgical planning[12].

Although several studies have separately evaluated the morphometry of the C1 or C2, studies assessing C1 and C2 together on dry human bones remain limited[13]. Combined evaluation of C1 and C2 may provide a more comprehensive anatomical basis for craniovertebral junction surgery because stabilization procedures often involve both vertebrae[3]. Therefore, the present study aimed to perform a detailed morphometric analysis of dry human C1 and C2 vertebrae and to evaluate the potential implications of these measurements for safe C1-C2 screw placement.

MATERIALS AND METHODS

Study Design and Specimens

This study was designed as a descriptive osteometric anatomical study. A total of 35 dry human C1 vertebrae and 25 dry human C2 vertebrae were evaluated. All specimens were obtained from the anatomy laboratory collection. Only intact adult dry vertebrae with preserved anatomical landmarks were included in the study. Vertebrae with fractures, deformities, marked erosion, structural damage, or incomplete anatomical parts that could affect morphometric measurements were excluded. Representative dry human C1 and C2 vertebrae included in the study are shown in Figure 1. The anatomical figures were used to demonstrate the principal landmarks and the representative measurement approach. Because the morphometric parameters were obtained from different surfaces and orientations of the vertebrae, all measurement lines and abbreviations were not displayed on a single figure in order to avoid overcrowding and preserve visual clarity.

Ethical Statement

The study protocol was approved by the Aydın Adnan Menderes University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee (approval no: 2026/145, date: 05.05.2026). Informed consent was not required because the study was conducted on anonymized dry human vertebral specimens obtained from an anatomy laboratory collection and did not involve living participants or identifiable personal data.

Measurement Technique

All morphometric measurements were performed directly on dry bones using a digital caliper with 0.01 mm precision, as demonstrated in Figure 2. Measurements were recorded in millimeters. Right- and left-sided structures were measured

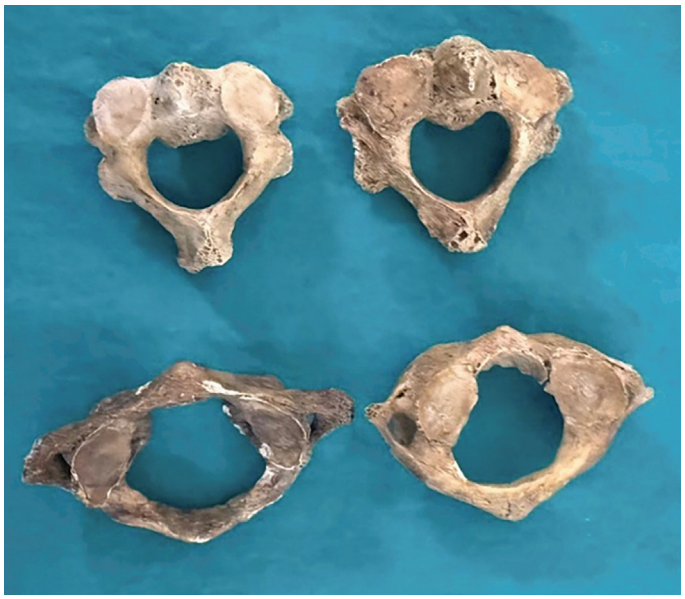

Figure 1. Representative dry human C1 and C2 vertebrae included in the study. C1: Atlas, C2: Axis

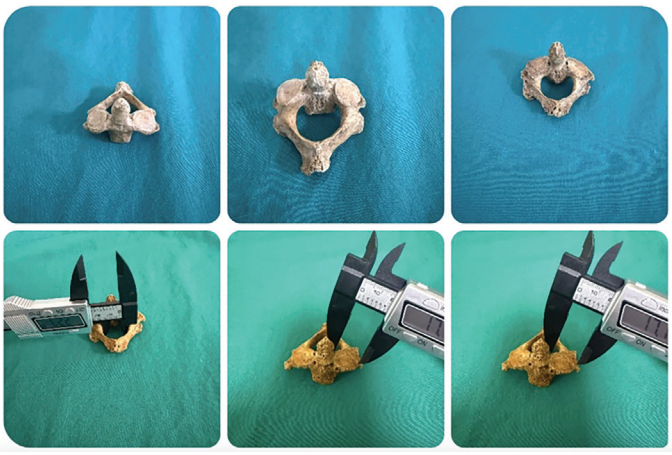

Figure 2. Measurement of C2 morphometric parameters using a digital caliper. C2: Axis

separately. Each measurement was performed twice, and the mean value was used for statistical analysis. The same anatomical landmarks were used consistently throughout the study to minimize measurement variability.

Representative photographs of the dry C1 and C2 vertebrae and the measurement technique were obtained. The images showing the use of the digital caliper were used to demonstrate the measurement method.

C1 Measurements

For the C1 vertebra, all measurements were obtained bilaterally where applicable using predefined anatomical landmarks. The main anatomical landmarks used for C1 morphometric measurements are illustrated in Figure 3. Vertebral canal length (VCL) represented the anteroposterior VCL, whereas vertebral canal width (VCW) represented the maximum transverse VCW. Outer distance of the vertebral artery groove (VAG-OD) and inner distance of the vertebral artery groove (VAG-ID) represented the VAG-OD and VAG-ID, respectively. Inferior articular facet length (IAF-L) and inferior articular facet width (IAF-W) represented the maximum IAF-L and IAF-W. Distance from the posterior arch to the anterior facet border (PA-AFB) represented the PA-AFB of the inferior articular facet. Horizontal thickness of the lateral mass (LM-HT) and vertical height of the lateral mass (LM-VH) represented the LM-HT and LM-VH, respectively. Superior articular facet anteroposterior length (SAF-APL) and superior articular facet width (SAF-W) represented the SAF-APL and SAF-W. Total C1 width (ATW) represented the maximum total transverse ATW, and vertebral foramen diameter (VF-D) represented the VF-D.

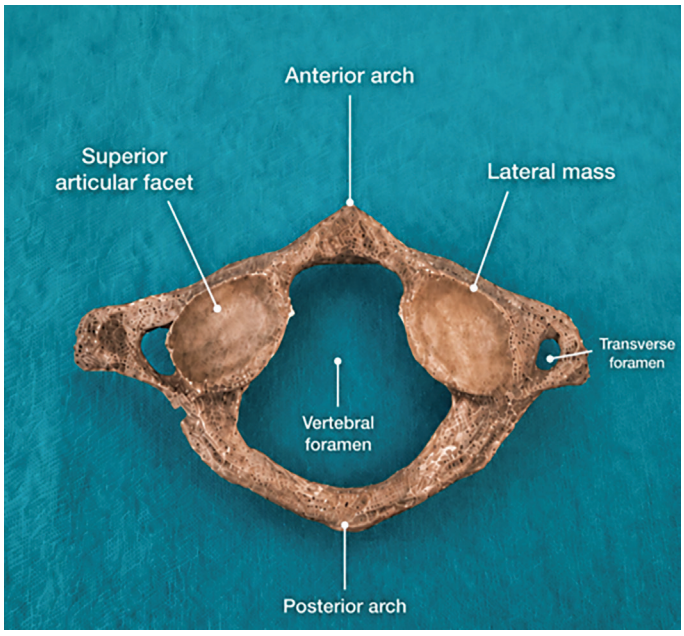

Figure 3. Representative dry atlas vertebra showing the anatomical landmarks used for morphometric measurements

C2 Measurements

For the C2 vertebra, all measurements were obtained bilaterally where applicable using predefined anatomical landmarks. Vertebral body anteroposterior diameter (VB-APD) represented the anteroposterior diameter of the vertebral body, vertebral body transverse diameter (VB-TD) represented the transverse diameter of the vertebral body, and vertebral body height (VB-H) represented the height of the vertebral body. Dens height (D-H), dens anteroposterior diameter (D-APD), and dens transverse diameter (D-TD) represented D-H, D-APD, and D-TD, respectively. Pedicle length (P-L), pedicle width (P-W), and pedicle height (P-H) represented P-L, P-W, and P-H, respectively. Lateral mass height (LM-H) and width (LM-W) represented LM-H and LM-W. Vertebral canal anteroposterior diameter (VC-APD) and vertebral canal transverse diameter (VC-TD) represented the VC-APD and VC-TD. Lamina length (LAM-L), Lamina thickness (LAM-T), and lamina height (LAM-H) represented LAM-L, LAM-T, and LAM-H, respectively. Superior articular facet diameter (SAF-D) and inferior articular facet diameter (IAF-D) represented the SAF-D and IAF-D.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics for Mac, version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation and minimum-maximum values. Right- and left-sided measurements were compared using the paired-samples t-test. A p-value of <0.05 was considered statistically significant. For midline or non-lateralized parameters, the same value was entered in both the right- and left-sided columns to maintain a consistent tabular format. Because these parameters do not represent true bilateral measurements, statistical comparison was not applicable. Accordingly, no test statistic was calculated for parameters with identical right- and left-sided values. This approach is consistent with the result tables already prepared for C1 and C2.

RESULTS

The right- and left-sided C1 morphometric measurements are summarized in Table 1. VAG-OD was significantly greater on the right side than on the left side (18.30±2.72 mm vs. 15.54±2.33 mm, $p<0.001$). In contrast, VAG-ID was significantly greater on the left side (7.44±1.48 mm vs. 8.53±2.16 mm, $p=0.006$). LM-HT was also significantly greater on the right side (12.74±1.43 mm vs. 11.68±2.16 mm, $p=0.023$), whereas VF-D was significantly greater on the left side (6.63±0.95 mm vs. 7.44±0.95 mm, $p<0.001$). No significant side-to-side differences were observed for IAF-L, IAF-W, LM-VH, SAF-APL, and SAF-W. For VCL, VCW, PA-AFB, and ATW, statistical comparison could not be performed because the right and left measurements were identical.

The right- and left-sided C2 morphometric measurements are summarized in Table 2. Significant side-to-side differences were observed only in VC-APD and LAM-L. VC-APD was significantly

Table 1. Comparison of C1 measurements between right and left sides

Parameter	Right side	Left side	p-value
VCL	30.57±2.20 (26.80-36.70)	30.57±2.20 (26.80-36.70)	-
VCW	28.03±1.84 (24.50-31.50)	28.03±1.84 (24.50-31.50)	-
VAG-OD	18.30±2.72 (10.80-24.00)	15.54±2.33 (9.40-19.90)	<0.001
VAG-ID	7.44±1.48 (4.10-10.30)	8.53±2.16 (6.70-18.90)	0.006
IAF-L	17.45±1.36 (14.00-20.30)	17.64±0.96 (15.80-19.80)	0.543
IAF-W	14.38±1.40 (11.60-16.90)	13.96±1.06 (11.20-16.00)	0.114
PA-AFB	24.32±1.80 (21.10-27.60)	24.32±1.80 (21.10-27.60)	-
LM-HT	12.74±1.43 (9.60-15.50)	11.68±2.16 (7.50-20.50)	0.023
LM-VH	18.58±2.29 (12.20-22.60)	18.49±1.60 (15.20-22.50)	0.786
SAF-APL	21.77±3.42 (9.30-29.20)	21.98±1.62 (18.80-24.40)	0.684
SAF-W	10.40±1.52 (7.60-15.60)	9.93±1.70 (7.30-15.60)	0.153
ATW	71.30±6.45 (56.80-80.50)	71.30±6.45 (56.80-80.50)	-
VF-D	6.63±0.95 (4.70-8.80)	7.44±0.95 (5.70-9.50)	<0.001

Values are presented in millimeters as mean ± standard deviation (minimum-maximum). Right- and left-sided measurements were compared using the paired-samples t-test. A p-value of <0.05 was considered statistically significant. Parameters with identical right- and left-sided values represent midline or non-lateralized measurements; therefore, statistical comparison was not applicable for these variables. C1: Atlas, VCL: Vertebral canal length, VCW: Vertebral canal width, VAG-OD: Outer distance of the vertebral artery groove, VAG-ID: Inner distance of the vertebral artery groove, IAF-L: Inferior articular facet length, IAF-W: Inferior articular facet width, PA-AFB: Distance from the posterior arch to the anterior facet border, LM-HT: Horizontal thickness of the lateral mass, LM-VH: Vertical height of the lateral mass, SAF-APL: Superior articular facet anteroposterior length, SAF-W: Superior articular facet width, ATW: Total atlas width, VF-D, Vertebral foramen diameter

Table 2. Comparison of C2 measurements between right and left sides

Parameter	Right side	Left side	p-value
VB-APD	15.26±1.57 (13.10-18.70)	15.26±1.57 (13.10-18.70)	-
VB-TD	22.06±1.33 (19.00-24.20)	22.06±1.33 (19.00-24.20)	-
VB-H	19.86±1.92 (16.30-24.00)	19.86±1.92 (16.30-24.00)	-
D-H	16.05±2.07 (13.20-20.30)	16.05±2.07 (13.20-20.30)	-
D-APD	10.59±1.05 (8.90-12.60)	10.59±1.05 (8.90-12.60)	-
D-TD	9.86±1.02 (8.30-11.90)	9.86±1.02 (8.30-11.90)	-
P-L	27.27±1.78 (24.00-30.50)	27.46±2.42 (23.10-34.20)	0.631
P-W	8.18±1.14 (5.80-9.80)	8.30±1.16 (6.30-10.80)	0.675
P-H	8.27±1.21 (6.30-10.30)	8.52±1.24 (5.80-10.60)	0.387
LM-H	13.11±1.77 (9.90-16.70)	13.48±1.26 (11.10-16.60)	0.435
LM-W	10.95±1.41 (8.60-14.80)	10.97±1.80 (7.60-16.70)	0.955
VC-APD	5.80±0.93 (4.40-9.10)	5.24±0.81 (3.70-6.90)	0.025
VC-TD	5.44±0.63 (4.20-6.50)	5.59±1.10 (3.40-7.60)	0.533
LAM-L	21.20±2.15 (15.90-25.60)	20.02±2.25 (16.80-25.50)	0.027
LAM-T	6.18±1.33 (3.70-9.80)	6.04±1.15 (3.70-9.40)	0.461
LAM-H	11.40±1.79 (6.10-15.70)	11.22±1.47 (8.80-14.90)	0.341
SAF-D	17.32±1.66 (13.70-19.90)	17.61±1.45 (14.30-20.00)	0.456
IAF-D	11.01±1.38 (8.70-14.10)	11.48±1.50 (9.10-14.60)	0.143

Values are presented in millimeters as mean±standard deviation (minimum-maximum). Right- and left-sided measurements were compared using the paired-samples t-test. A p-value of <0.05 was considered statistically significant. Parameters with identical right- and left-sided values represent midline or non-lateralized measurements; therefore, statistical comparison was not applicable for these variables. C2: Axis, VB-APD: Vertebral body anteroposterior diameter, VB-TD: Vertebral body transverse diameter, VB-H: Vertebral body height, D-H: Dens height, D-APD: Dens anteroposterior diameter, D-TD: Dens transverse diameter, P-L: Pedicle length, P-W: Pedicle width, P-H: Pedicle height, LM-H: Lateral mass height, LM-W: Lateral mass width, VC-APD: Vertebral canal anteroposterior diameter, VC-TD: Vertebral canal transverse diameter, LAM-L: Lamina length, LAM-T: Lamina thickness, LAM-H: Lamina height, SAF-D: Superior articular facet diameter, IAF-D: Inferior articular facet diameter

greater on the right side than on the left side (5.80±0.93 mm vs. 5.24±0.81 mm, p=0.025). Similarly, LAM-L was significantly greater on the right side (21.20±2.15 mm vs. 20.02±2.25 mm, p=0.027). No significant differences were found for P-L, P-W, P-H, LM-H, LM-W, VC-TD, LAM-T, LAM-H, SAF-D, or IAF-D. For VB-APD, VB-TD, VB-H, D-H, D-APD, and D-TD, statistical comparison could not be performed because the right and left measurements were identical.

DISCUSSION

The present study evaluated the morphometric characteristics of dry human C1 and C2 vertebrae and demonstrated measurable side-to-side variations in selected C1 and C2 parameters. The main C1 findings were significant asymmetry in VAG-OD, VAG-ID, LM-HT, and VF-D, whereas the main C2 findings were significant right-sided predominance in VC-APD and LAM-L. These findings support the concept that even in apparently intact dry vertebrae, C1 and C2 morphology may show relevant bilateral differences that should be considered during craniovertebral junction surgery.

C1 lateral mass and vertebral artery-related measurements are particularly important because posterior C1-C2 fixation is performed in close proximity to the vertebral artery, venous plexus, C2 nerve root, and spinal canal. Saba et al.[1] emphasized that the C1 lateral mass is a key structure for screw fixation and that its morphometric dimensions can guide screw length, diameter, and trajectory planning in craniovertebral junction surgery. In the present study, VAG-OD was significantly greater on the right side than on the left side, while VAG-ID and VF-D were significantly greater on the left side. This asymmetric pattern suggests that vertebral artery groove-related anatomy and vertebral foramen dimensions may vary between sides, which may be surgically relevant during posterior exposure and instrumentation of C1. The close relationship between the vertebral artery and the posterior arch/lateral mass region of C1 has also been highlighted by Periyasamy et al.[13], who described the vertebral artery groove as an important landmark after the artery exits the transverse foramen.

Although these side-to-side differences reached statistical significance, their clinical interpretation should be made cautiously. The absolute differences observed in several parameters were relatively small, and therefore they may not necessarily indicate a direct contraindication for screw placement. However, even small asymmetries in vertebral artery groove-related measurements, lateral mass dimensions, or laminar length may become relevant in borderline anatomical conditions, particularly when selecting the screw entry point, screw diameter, trajectory, and safe screw length. Therefore, the present findings should not be interpreted as replacing patient-specific preoperative CT evaluation, but rather as supporting the need for individualized and side-specific assessment before C1-C2 instrumentation.

The inferior articular facet measurements in the present study were generally comparable with those reported by Saba et al.[1]. In their study, the length of the inferior articular facet was 17.93±0.76 mm on the right side and 18.01±0.75 mm on the left side, while the width was 14.88±0.85 mm and 14.86±0.79 mm, respectively[1]. In the present study, the corresponding values were 17.45±1.36 mm and 17.64±0.96 mm for IAF-L, and 14.38±1.40 mm and 13.96±1.06 mm for IAF-W. These similarities indicate that the articular facet dimensions of the present sample are broadly consistent with previous dry C1 data. However, LM-HT was lower in the present study than in Saba et al.[1], who reported horizontal lateral mass thickness values of 15.91±1.73 mm on the right and 15.83±1.56 mm on the left. This difference may be related to population characteristics, sample size, or subtle differences in the exact anatomical landmarks used for measurement.

The PA-AFB measurement in the present study was 24.32±1.80 mm on both sides, which was slightly higher than the values reported by Saba et al.[1]. Saba et al.[1] reported the distance from the posterior arch of the C1 to the anterior margin of the inferior articular facet as 22.87±0.60 mm on the right side and 22.79±0.61 mm on the left side. Because this parameter is related to the potential screw path in posterior C1 lateral mass fixation, even small differences may be clinically relevant. Saba et al.[1] also noted that reported screw length recommendations vary across previous studies, supporting the need for individualized surgical planning rather than using a single universal value.

For C2, the present study found that most parameters did not show significant side-to-side differences, except for VC-APD and LAM-L. The right-sided LAM-L was significantly greater than the left-sided value, suggesting a degree of laminar asymmetry. This finding is partially consistent with Gosavi and Swamy[9], who reported that C2 lamina length, thickness, and height were greater on the right side than on the left side and that these differences were statistically significant. In the present study, only lamina length reached statistical significance, whereas LAM-T and LAM-H were not significantly different. This discrepancy may reflect differences in sample size, population structure, or measurement technique.

The body and dens measurements of C2 in the present study were broadly close to those reported by Gosavi and Swamy[9]. In their dry bone study, the mean anteroposterior diameter of the C2 body was 14.77±1.73 mm, the dens height was 14.86±1.54 mm, and the average transverse diameter of the dens was 9.28 mm[9]. In the present study, VB-APD was 15.26±1.57 mm, D-H was 16.05±2.07 mm, and D-TD was 9.86±1.02 mm. These findings suggest that the core morphometric dimensions of the C2 in the present sample are generally within the range of previous dry bone studies. However, VB-TD in the present study was higher than that reported by Gosavi and Swamy[9], which may again be explained by anatomical variability or differences in measurement level. From a surgical perspective,

the statistically significant difference in lamina length may be relevant mainly for C2 translaminar screw planning, where laminar length and thickness influence screw trajectory and the available bony corridor. Nevertheless, the magnitude of this difference should be interpreted together with other morphometric parameters and individual CT anatomy rather than as an isolated determinant of screw feasibility.

Periyasamy et al.[13] compared dry C1 and C2 bones with CT scan images and reported that several measurements differed significantly between the two methods. Their findings are important because they suggest that dry bone measurements and radiological measurements may not always be directly interchangeable. In the present study, all measurements were performed directly on dry bones, which provides precise osseous morphometry but does not account for soft tissue, cartilage, degenerative changes in living subjects, or radiological reconstruction factors. Therefore, the results may be most useful as anatomical reference data rather than as a substitute for patient-specific preoperative CT evaluation.

Thejeshwari et al.[14] also emphasized the value of descriptive morphometric data of the C1 for neurosurgeons and orthopedic surgeons operating near the vertebral artery and nerve roots. Their study reported a mean C1 total width of 71.34 mm, which is very close to the ATW value of 71.30±6.45 mm in the present study[14]. This similarity supports the reliability of the present C1 width measurements. However, differences were observed in articular facet-related measurements between the present study and some previous reports, which may be due to regional anatomical variation, dry bone preservation status, and differences in landmark definitions.

The clinical relevance of the present study lies in its combined assessment of C1 and C2, because craniovertebral junction stabilization frequently requires instrumentation of both vertebrae. Morphometric evaluation of C1 is useful for lateral mass screw planning, whereas C2 measurements are important for pedicle, pars, and laminar screw placement. The significant asymmetries observed in C1 vertebral artery groove-related measurements and C2 lamina length support the need for side-specific assessment before instrumentation. These findings reinforce the importance of careful preoperative imaging and individualized screw trajectory planning.

Study Limitations

This study has some limitations. First, it was performed on dry bones, so demographic data such as age and sex were unavailable. Second, the sample size was modest, particularly for C2. Third, radiological correlation was not performed, and therefore the applicability of these measurements to CT-based surgical planning could not be directly tested. Finally, some measurements in previous studies were defined differently, which limits direct numerical comparison across studies. In addition, multiple morphometric parameters were statistically compared, and no adjustment for multiple comparisons was applied. Therefore, statistically significant findings should be interpreted cautiously, particularly for parameters with relatively small absolute side-to-side differences.

CONCLUSION

In conclusion, the present study provides morphometric data on dry human C1 and C2 vertebrae and demonstrates significant side-to-side differences in selected parameters. At the C1 level, VAG-OD, VAG-ID, LM-HT, and VF-D showed significant asymmetry, while at the C2 level, VC-APD and LAM-L differed significantly between sides. These results may contribute to anatomical knowledge relevant to craniovertebral junction surgery and support the need for individualized, side-specific evaluation before C1-C2 screw placement.

Ethics

Ethics Committee Approval: The study protocol was approved by the Aydın Adnan Menderes University Faculty of Medicine Non-Interventional Clinical Research Ethics Committee (approval no: 2026/145, date: 05.05.2026).

Informed Consent: Informed consent was not required because the study was conducted on anonymized dry human vertebral specimens obtained from an anatomy laboratory collection and did not involve living participants or identifiable personal data.

Footnotes

Authorship Contributions

Surgical and Medical Practises: M.Ö.Y., I.A., M.Y.Ç., S.A., Concept: M.Ö.Y., Design: M.Ö.Y., I.A., Data Collection or Processing: M.Ö.Y., I.A., M.Y.Ç., S.A., Analysis or Interpretation: M.Ö.Y., I.A., M.Y.Ç., S.A., Literature Search: M.Ö.Y., Writing: M.Ö.Y., I.A.

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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TECHNICAL NOTE

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J Turk Spinal Surg 2026;37(3):130-133

DOI: 10.4274/jtss.galenos.2026.92485

GEOMETRY-INDEPENDENT REMOVAL OF PEDICLE SCREWS WITH DIFFERENT HEAD DESIGNS: CLINICAL APPLICATION OF THE Z-ROD TECHNIQUE

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ABSTRACT

Pedicle screw removal during revision spinal surgery may become technically difficult because of stripped screw heads, incompatible drivers, or unavailable manufacturer-specific instrumentation. Existing extraction methods often depend on implant design and may increase operative time, costs, and risk of complications.

To describe the Z-rod technique, a geometry-independent pedicle screw removal method, and to evaluate its clinical feasibility, safety, and effectiveness. A retrospective, single-center study was conducted involving patients who underwent revision spinal surgery between 2020 and 2025. Patients in whom conventional screwdrivers failed to remove pedicle screws and who subsequently underwent removal using the Z-rod technique were included. The technique involves bending a standard spinal rod into a Z shape, rigidly fixing it to the tulip head with the existing set screw, and applying controlled rotational torque through a long lever arm. Demographic data, surgical indications, technical success, and complications were evaluated. A total of 83 pedicle screws in 24 patients (mean age: 42.1±16.7 years) were successfully removed using the Z-rod technique after failure of standard driver systems. Adequate mechanical stability and controlled torque transmission were achieved in all cases. No implant fractures, neurological deficits, vascular injuries, or additional bone and soft tissue injuries were observed. The technique was successfully applied across different implant manufacturers and screw-head geometries without requiring dedicated extraction systems.

The Z-rod technique is a simple, universal, and cost-effective method for pedicle screw removal that eliminates dependence on screw-head geometry and manufacturer-specific instrumentation. It may represent a practical alternative in revision spinal surgery when conventional removal methods fail.

Keywords: Spine, pedicle screws, reoperation, methods

INTRODUCTION

The pedicle screw systems are widely used to achieve segmental stabilization and to enhance fusion rates in the thoracic and lumbar spine[1]. Currently, these systems are manufactured by different companies and vary considerably in terms of internal drive-head geometry. Internal hex, Torx-like star-shaped, hexagonal, and various modified designs are commonly encountered in clinical practice.

Parallel to the increasing number of spinal fusion procedures, the number of patients requiring implant revision or removal has also steadily increased[2-6]. The pedicle screw removal may be necessary because of infection, implant failure, pseudoarthrosis, persistent pain, soft tissue irritation, or planned revision surgery[7]. Traditionally, pedicle screws are removed using manufacturer-specific screwdriver tips and instrumentation sets precisely matched to the internal geometry of the screw-head. However, in revision settings, conventional removal methods may fail because of stripped or deformed screw heads, driver incompatibility, unavailable instrumentation sets, or breakage of the screwdriver tip within the screw-head. Although dedicated extraction/removal sets may be used in such cases, these systems are not universally available as they may create additional cost, and perpetuate dependency on the implant manufacturer. Furthermore, difficulty during implant removal may prolong operative time and increase the risks of infection, blood loss, and iatrogenic soft tissue injury.

Spinal rods are one of the principal components of vertebral instrumentation systems and provide rigid segmental stability by connecting pedicle screws. In present study, we describe a geometry-independent screw removal method created by bending a standard spinal rod into a Z configuration and

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Received: 19.05.2026 **Accepted:** 15.06.2026 **Publication Date:** 06.07.2026
Cite this article as: Koç A, Uysal A, Güler ÜÖ, Kaya M, Sağlam F, Çınar BM. Geometry-independent removal of pedicle screws with different head designs: clinical application of the Z-rod technique. J Turk Spinal Surg. 2026;37(3):130-133

utilizing the rod-screw connection principle. The aim of this study was to evaluate the feasibility and clinical outcomes of the Z-rod technique, which functions independently of the internal drive-head geometry while using readily available spinal rod material.

MATERIALS AND METHODS

Patients who underwent revision spinal surgery between 2020 and 2025 were retrospectively reviewed. This was a single-center study designed to evaluate the effectiveness and safety of the Z-rod technique for pedicle screw removal. Patients in whom the Z-rod technique was used because pedicle screws could not be removed with conventional screwdriver systems were included.

Inclusion Criteria

1. Patients who had previously undergone posterior spinal instrumentation in the thoracic, lumbar, or thoracolumbar region for trauma, degenerative disease, deformity, or tumor, and subsequently required revision surgery.
2. Patients aged 12-89 years.
3. Cases in which technical difficulty was encountered during screw removal with standard driver systems, necessitating use of the Z-rod technique.

Exclusion Criteria

1. Patients whose pedicle screws were loose enough to be manually removed without any driver.
2. Screws fractured at the shaft, with dissociated tulip components, or with structural deformation preventing rod fixation using the set screw.

Surgical Technique

The Z-rod technique is a mechanical extraction method. The principal steps are as follows:

1. A standard metal rod (titanium or cobalt-chromium alloy) of appropriate diameter for the pedicle screw system is bent into a Z shape using a rod bender (Figure 1).
2. The short arm of the rod, approximately 15 mm in length; is inserted into the tulip head of the pedicle screw to be removed. This arm should be kept as short as possible to minimize soft tissue injury during extraction.
3. Using the existing set screw (nut), the rod is rigidly fixed to the screw-head, thereby establishing a mechanical connection. This allows torque to be transmitted directly to the screw shaft without reliance on the internal drive-head geometry.
4. The long arm of the rod, approximately 105 mm in length, is used as a lever-arm, and controlled rotational force is applied.
5. The pedicle screw is extracted from the bone using the generated high torque (Figure 2).

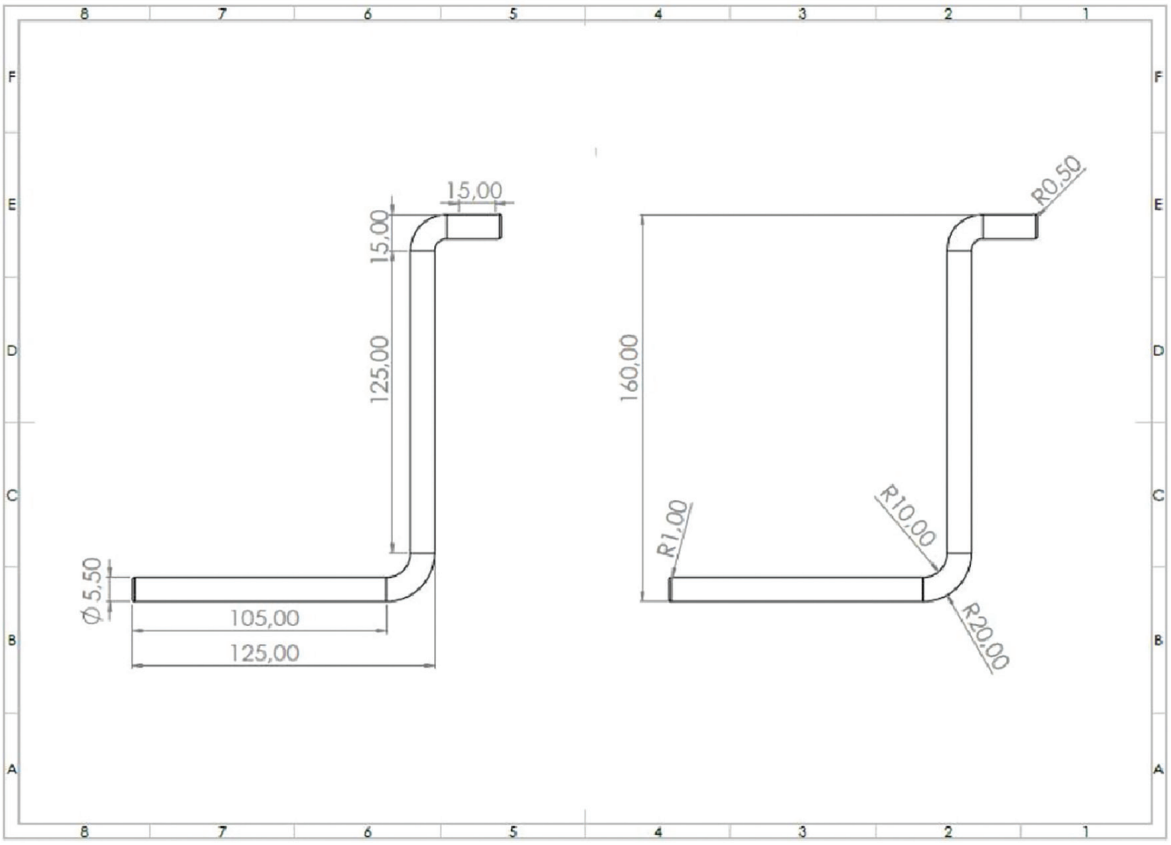

Figure 1. Technical drawing of the hand tool

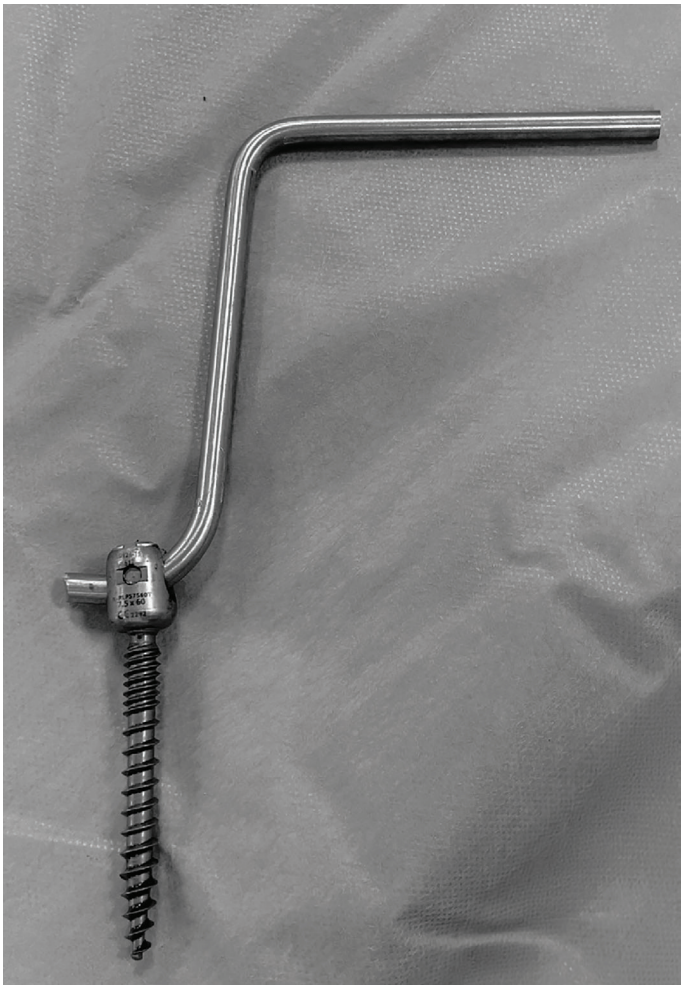

Figure 2. A screw removed via a Z-rod

RESULTS

Using this novel technique, pedicle screws that could not be removed with standard screwdriver systems were successfully extracted during a five-year period of clinical application. A total of 83 pedicle screws from 24 patients (mean age: 42.1±16.7 years) scheduled for implant removal for various indications were successfully removed using the Z-rod technique after failure of conventional driver systems due to screw-head incompatibility or inadequate torque transmission. In all cases, sufficient mechanical stability and controlled torque transfer were achieved during screw removal. No implant fracture occurred in any patient. No complications such as neurological deficit, vascular injury, or additional damage to surrounding bone or soft tissues were observed intraoperatively or during the early postoperative period. No manufacturer-specific removal/extraction sets were required during the procedures, eliminating the need for additional equipment procurement. This avoided unnecessary prolongation of surgery and prevented extra financial burden. The technique was found to be effective in pedicle screw systems from different manufacturers and with variable internal drive-head geometries, demonstrating that it can be applied independently of implant design.

DISCUSSION

Removal of pedicle screws can be technically challenging, particularly in systems using tulip-head polyaxial pedicle screws. Damage to the internal drive-head geometry, driver incompatibility, unknown implant brands, or lack of access to manufacturer-specific instrumentation may render conventional removal methods ineffective. This may prolong surgical time, requires additional bone resection, and increase the risk of complications.

Several alternative techniques have been described in the literature to address this problem. Kose et al.[8] described the U-rod technique, based on rotating a rod-screw complex counter clockwise using a rod bent into a U shape and inserted into the tulip head. Although practical since it does not require a dedicated extraction tool, the rod must be grasped and rotated using a rod holder. Unlike the Z-rod technique, this method does not incorporate a lever-arm principle and may require greater manual force for extraction. More recently, Zhang et al.[9] reported an alternative method in which a rod segment is cut to an appropriate length, reinserted into the tulip head, and tightened with the nut, thereby functionally converting the polyaxial screw into a monoaxial rod-screw construct. Although this technique may reduce operative time and intraoperative blood loss, its applicability may be limited when the screw rotates during tightening of the short rod segment or when counter-torque instruments are unavailable.

The Z-rod technique described in this study offers a mechanical solution aimed at eliminating dependency on implant-system type or screw-head geometry during removal of polyaxial pedicle screws. The technique can be performed without modifying the existing implant-system or requiring special extraction devices. The long lever-arm of the rod-screw construct enables controlled torque generation, facilitating screw extraction. The principal advantages observed with this method include:

1. Successful removal of stripped, damaged, or driver-incompatible pedicle screws.
2. Elimination of dependence on manufacturer-specific screwdrivers or extraction sets.
3. Applicability using standard instruments commonly available in most hospitals.
4. Easier extraction through generation of high and controlled torque.
5. Potential reduction in surgical time, cost, and complication risk.

Accordingly, the Z-rod technique may offer simpler applicability and greater implant-system independence compared with previously described U-rod and rod-reuse techniques.

Study Limitations

This study has several limitations. The sample size was relatively small, and no comparative control group was included. Although the primary aim was to introduce a new technique and the current results were satisfactory, larger comparative studies are required to establish stronger evidence. In addition, objective torque measurements were not performed. Future biomechanical studies are warranted to quantify the mechanical capacity of the technique. Nevertheless, the 100% clinical success rate supports its practical applicability.

CONCLUSION

The Z-rod technique is a simple, universal, and cost-effective method that eliminates dependence on internal screw-head geometry and manufacturer-specific systems during pedicle screw removal. It may serve as a practical alternative in revision surgery, particularly when pedicle screws cannot be removed using standard driver systems.

Ethics

Ethics Committee Approval: Ethics committee approval was not required for this study.
Informed Consent: Retrospective study.

Footnotes

Authorship Contributions

Surgical and Medical Practises: A.K., Concept: A.U., Design: A.K., Data Collection or Processing: Ü.Ö.G., Analysis or Interpretation: M.K., Literature Search: Ü.Ö.G., F.S., Writing: A.U., B.M.Ç.
Conflict of Interest: No conflict of interest was declared by the authors.

One of the authors of this article (Ü.Ö.G.) is a member of the Editorial Board of this journal. He had no involvement in the peer-review process or editorial decision regarding this manuscript. The peer-review process and editorial decision were handled independently by another editor.
Financial Disclosure: The authors declared that this study received no financial support.

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