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Preoperative Spinopelvic Alignment in Recurrent versus Nonrecurrent Lumbar Disc Herniation: A Comparative Cohort Study

Utkan Topcu[1], Zühtü Ozbek[2], Emre Ozkara[2], Ali Arslantas[2]

■ OBJECTIVE: **This study aimed to evaluate the association between preoperative spinopelvic alignment parameters and recurrent lumbar disc herniation (RLDH) and assess their value in potentially predicting recurrence following surgery.**

■ METHODS: **A retrospective cohort of 117 patients who underwent single-level lumbar discectomy between 2015 and 2018 was analyzed. The RLDH group included 62 patients who required reoperation due to recurrence, whereas the control group consisted of 55 patients with at least 24 months of recurrence-free follow-up. Preoperative standing lateral radiographs were used to measure lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt, sacral slope, and PI—LL mismatch. Intergroup comparisons were performed, followed by univariate logistic regression to identify independent associations. Receiver operating characteristic curve analysis was conducted to evaluate diagnostic performance.**

■ RESULTS: **The RLDH group showed significantly lower LL (38° vs., 53°, $P < 0.001$) and greater PI—LL mismatch (9° vs., −3°, $P < 0.001$) compared with controls. No significant differences were found in PI, pelvic tilt, or sacral slope. Logistic regression identified LL (odds ratio, 0.91; 95% confidence interval, 0.87—0.94; $P < 0.001$) and PI—LL mismatch (odds ratio, 1.09; 95% confidence interval, 1.05—1.13; $P < 0.001$) as independently associated with recurrence. Receiver operating characteristic analysis demonstrated good predictive ability for LL (area under the curve, 0.815; cutoff ≤49°) and PI—LL mismatch (area under the curve, 0.786; cutoff ≥4°).**

■ CONCLUSIONS: **Reduced LL and increased PI—LL mismatch are independently associated with RLDH and demonstrate potential predictive value for recurrence risk. These findings highlight the importance of sagittal alignment in recurrence risk assessment and support their use in preoperative planning and surgical decision-making.**

INTRODUCTION

Lumbar disc herniation (LDH) is a leading cause of radiculopathy, and surgical discectomy remains the standard treatment for patients with persistent neurological deficits or refractory pain. Despite advances in surgical techniques, recurrent lumbar disc herniation (RLDH)—defined as herniation at the same level and side following a pain-free interval of at least 6 months—continues to represent a significant source of postoperative morbidity, with reported recurrence rates ranging from 5% to 15%.[1-3] RLDH frequently necessitates reoperation and is associated with increased disability, health care utilization, and socioeconomic burden.

Multiple patient-related and surgical factors have been implicated in recurrence, including age, sex, smoking, obesity, diabetes, disc degeneration, and operative technique.[4,5] However,

Key words
- Lumbar lordosis
- PI—LL mismatch
- Recurrent lumbar disc herniation
- Sagittal balance
- Spinopelvic alignment

Abbreviations and Acronyms
CI: Confidence interval
LDH: Lumbar disc herniation
LL: Lumbar lordosis
OR: Odds ratio
PI: Pelvic incidence
PT: Pelvic tilt
RLDH: Recurrent lumbar disc herniation
ROC: Receiver operating characteristic
SS: Sacral slope

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Citation: World Neurosurg. (2026) 210:124994. http://doi.org/10.1016/j.wneu.2026.124994

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

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these variables alone do not sufficiently explain the variability in recurrence risk among patients with otherwise similar clinical profiles. Increasing attention has therefore shifted toward biomechanical and sagittal alignment parameters, which may influence spinal loading patterns, annular stress, and disc degeneration.[6-8]

Spinopelvic alignment—particularly lumbar lordosis (LL) and its relationship to pelvic morphology—plays a central role in maintaining sagittal balance and efficient upright posture. Pelvic incidence (PI), a fixed anatomical parameter, determines the ideal lumbar curvature, while pelvic tilt (PT) and sacral slope (SS) act as compensatory mechanisms to preserve alignment.[9,10] Mismatch between PI and LL (PI−LL mismatch) reflects sagittal imbalance and has been associated with abnormal load distribution across the lumbosacral junction, potentially accelerating degenerative changes and contributing to disc pathology.[11-13]

Recent studies have explored the relationship between spinopelvic alignment and lumbar disc disease, with several reporting an association between reduced LL and disc herniation or degeneration.[14-16] More recent investigations have suggested that sagittal alignment may also influence clinical decision-making and postoperative outcomes in degenerative spine conditions.[17,18] However, findings remain inconsistent, and the role of spinopelvic parameters in predicting recurrence after discectomy is not clearly established.

Importantly, many prior studies have compared patients with disc herniation to asymptomatic individuals or healthy controls, which may introduce bias by conflating degenerative alignment changes with true risk factors for recurrence. A more rigorous approach is to compare patients undergoing the same surgical procedure and distinguish those who develop recurrence from those who remain recurrence-free. Recent case-control data further support the relevance of sagittal alignment in disc pathology, particularly in younger populations, highlighting the biomechanical contribution of alignment to disease development.[19,20]

In this context, we hypothesized that preoperative sagittal alignment parameters—particularly reduced LL and increased PI−LL mismatch—are not only associated with, but may also have potential predictive value for RLDH.

Therefore, the aim of this study was to compare preoperative spinopelvic parameters between patients who developed RLDH and those who did not, and to evaluate the potential predictive value of these parameters for recurrence using statistical modeling and diagnostic performance analyses.

MATERIALS AND METHODS

Study design and population

This retrospective comparative cohort study included patients who underwent single-level lumbar discectomy for LDH between January 2015 and December 2018 at a tertiary academic neurosurgical center.

Patients were divided into 2 groups.

1. Recurrent LDH (RLDH) group: Patients who developed symptomatic recurrent herniation at the same level and side after a pain-free interval of ≥6 months and subsequently required reoperation.
2. Nonrecurrent (control) group: Patients who underwent single-level discectomy during the same period and remained recurrence-free for at least 24 months of follow-up.

A total of 117 patients met the inclusion criteria, including 62 patients in the RLDH group and 55 patients in the control group. All patients had available preoperative standing lateral lumbar radiographs suitable for spinopelvic measurements.

Inclusion and exclusion criteria:

Inclusion criteria:

- Age between 18 and 80 years
- Single-level LDH confirmed by magnetic resonance imaging
- Primary posterior lumbar discectomy at L3−4, L4−5, or L5−S1
- Availability of preoperative standing lateral lumbar radiographs
- For the RLDH group: reoperation for recurrence after ≥6 months pain-free interval
- For the control group: minimum 24 months recurrence-free follow-up

Exclusion criteria:

- Multilevel disc herniation
- Prior lumbar instrumentation
- Spinal deformity (scoliosis >20°, spondylolisthesis >Grade I)
- Inadequate radiographs or missing data
- Infection, tumor, trauma, or congenital spinal pathology
- Patients with coronal malalignment or spinal deformities affecting coronal balance (including scoliosis) were excluded to ensure a homogeneous cohort focused on sagittal alignment parameters.

Radiological measurements

Preoperative standing lateral lumbar radiographs were obtained as part of the routine clinical evaluation protocol at our institution. All radiographs were acquired in a standardized upright position with patients maintaining a neutral posture. Measurements were performed digitally by 2 independent observers blinded to clinical outcomes. Each parameter was measured twice and the mean value was used for analysis. The following spinopelvic parameters were evaluated according to standard definitions:

LL: Cobb angle between the superior endplate of L1 and the superior endplate of S1

PI: Angle between the perpendicular to the sacral endplate and the line connecting the sacral midpoint to the femoral head axis

PT: Angle between the vertical and the line connecting the femoral head axis to the sacral endplate midpoint

SS: Angle between the sacral endplate and the horizontal plane

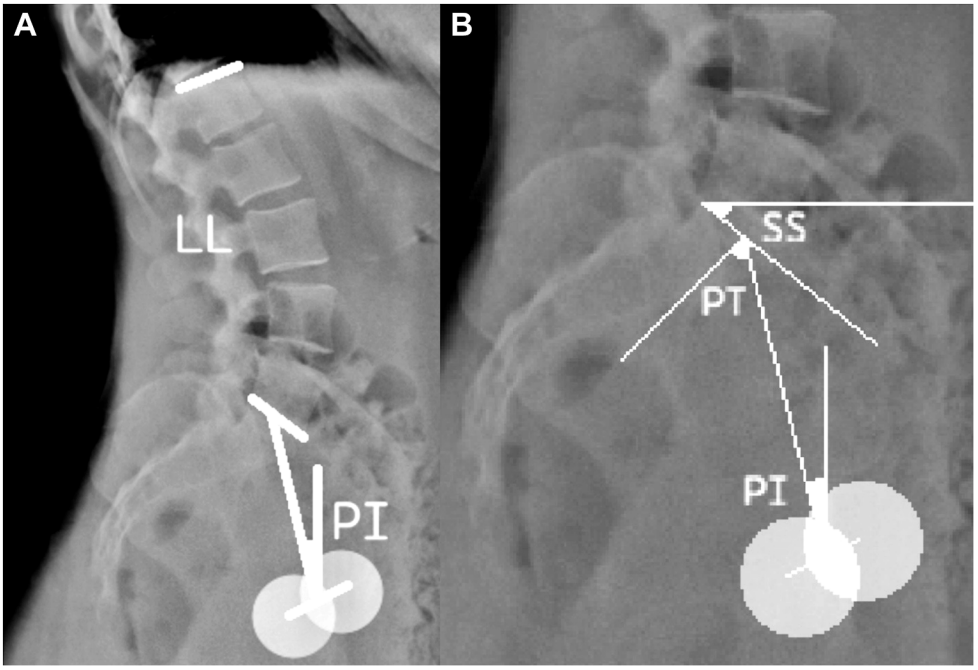


Figure 1. Measurement of spinopelvic parameters on standing lateral lumbar radiographs. (**A**) Schematic illustration demonstrating lumbar lordosis (LL), pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS). (**B**) Representative standing lateral lumbar radiograph showing measurement of the same parameters. LL was measured between the superior endplates of L1 and S1. PI was defined as the angle between the perpendicular to the sacral endplate and the line connecting the sacral midpoint to the femoral head axis. PT was defined as the angle between the vertical and the line connecting the femoral head axis to the sacral midpoint, and SS as the angle between the sacral endplate and the horizontal plane.

The PI—LL mismatch was calculated as the numerical difference between PI and LL. The measurement technique is illustrated in Figure 1. Interobserver reliability was assessed using the intraclass correlation coefficient.

Clinical variables

Demographic and clinical data were obtained from electronic medical records and included: age, sex, body mass index, smoking status, and operated level. All procedures were performed using standard microsurgical discectomy techniques.

Statistical analysis

Statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Normality of data distribution was assessed using the Shapiro—Wilk test. Continuous variables were compared using independent samples *t*-test or Mann—Whitney *U* test as appropriate. Categorical variables were analyzed using the $\chi 2$ test. To evaluate the independent association between spinopelvic parameters and recurrence, univariate logistic regression analysis was performed. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. Given the relatively homogeneous cohort and the limited number of clinically relevant variables, multivariable modeling was not performed to avoid potential overfitting. Additionally, receiver operating characteristic (ROC) analysis was conducted to assess the predictive performance of significant parameters and to determine optimal cut-off values using the Youden index. Statistical significance was defined as $P < 0.05$.

Ethical considerations

The study protocol was approved by the Institutional Clinical Research Ethics Committee (approval no: 33/2019, June 25, 2019). All procedures were conducted in accordance with the Declaration of Helsinki and its later amendments. Written informed consent was obtained from all participants.

RESULTS

Demographic and clinical characteristics

A total of 117 patients were included, comprising 62 patients with RLDH and 55 patients who remained recurrence-free after primary discectomy. There were no statistically significant differences between the groups in terms of age (47 ± 11 vs., 44 ± 14 years, $P = 0.162$), body mass index (26 ± 3 vs., 26 ± 3 kg/m^2, $P = 0.846$), or smoking status (63% vs., 46%, $P = 0.088$). Sex distribution showed a borderline difference (female: 42% vs., 62%, $P = 0.050$). Overall, the 2 groups were comparable with respect to baseline demographic and clinical characteristics, suggesting that

Table 1. Demographic and Clinical Characteristics of Patients with and without Recurrent Lumbar Disc Herniation

Variable	RLDH (n = 62)	Control (n = 55)	*P* Value
Age (years)	47 ± 11	44 ± 14	0.162
Sex (female, %)	42%	62%	0.050
BMI (kg/m^2)	26 ± 3	26 ± 3	0.846
Smoking, n (%)	39 (63%)	25 (46%)	0.088

Data are presented as mean ± SD or n (%).
BMI, body mass index; RLDH, recurrent lumbar disc herniation; SD, standard deviation.

differences observed in radiological parameters are less likely to be confounded by these variables (Table 1).

Spinopelvic parameters

Preoperative LL was significantly lower in the RLDH group compared with the control group (38 ± 11° vs., 53 ± 14°, P < 0.001). The mean difference of approximately 15° indicates a substantial reduction in sagittal curvature among patients who developed recurrence. In contrast, no significant differences were observed in other spinopelvic parameters, including PI (47 ± 10° vs., 49 ± 12°, P = 0.218), PT (14 ± 7° vs., 14 ± 9°, P = 0.610), and SS (33 ± 10° vs., 35 ± 10°, P = 0.402). These findings suggest that while pelvic morphology and compensatory parameters remain similar between groups, local sagittal alignment—particularly LL—differs significantly in patients who develop recurrence (Table 2).

PI–LL mismatch

The PI–LL mismatch was significantly higher in the RLDH group compared with controls (9 ± 11° vs., −3 ± 14°, P < 0.001), reflecting a relative mismatch between pelvic morphology and lumbar curvature. This shift from a negative or balanced PI–LL relationship in the control group to a positive mismatch in the RLDH group indicates a transition toward sagittal imbalance. The magnitude of this difference further supports the role of altered spinopelvic alignment in the pathophysiology of recurrent disc herniation (Table 2, Figure 2).

Table 2. Comparison of Preoperative Spinopelvic Parameters Between Patients with and without Recurrent Lumbar Disc Herniation

Parameter	RLDH (n = 62)	Control (n = 55)	*P* Value
Lumbar lordosis (°)	38 ± 11	53 ± 14	<0.001*
PI–LL mismatch (°)	9 ± 11	−3 ± 14	<0.001*
Pelvic incidence (°)	47 ± 10	49 ± 12	0.218
Pelvic tilt (°)	14 ± 7	14 ± 9	0.610
Sacral slope (°)	33 ± 10	35 ± 10	0.402

LL, lumbar lordosis; PI, pelvic incidence; PT, elvic tilt; RLDH, recurrent lumbar disc herniation; SS, sacral slope. Statistically significant (*P* < 0.05).
*Data are presented as mean ± SD.

Logistic regression analysis

Univariate logistic regression analysis demonstrated that both LL and PI–LL mismatch were significantly associated with RLDH. Lower LL was associated with an increased risk of recurrence (OR 0.91, 95% CI 0.87–0.94, P < 0.001), indicating that each 1° increase in LL was associated with an approximate 9% reduction in recurrence risk. Conversely, higher PI–LL mismatch was associated with an increased risk of recurrence (OR 1.09, 95% CI 1.05–1.13, P < 0.001), suggesting that each 1° increase in mismatch corresponded to a 9% increase in recurrence risk (Table 3).

ROC analysis

ROC analysis demonstrated good discriminative ability for both parameters. LL yielded an area under the curve of 0.815, indicating strong predictive performance. The optimal cut-off value was ≤49°, with a sensitivity of 86% and specificity of 69%. Similarly, PI–LL mismatch showed an area under the curve of 0.786, with an optimal cut-off value of ≥4°, yielding a sensitivity of 76% and specificity of 78%. These findings suggest that both LL and PI–LL mismatch may serve as clinically useful thresholds for identifying patients at increased risk of recurrence (Table 4).

Additional analyses

No significant association was found between the operated level and recurrence (P > 0.05). Interobserver reliability for all radiographic measurements was excellent (intraclass correlation coefficient = 0.92), indicating high reproducibility of the measurement technique.

DISCUSSION

RLDH remains a persistent clinical challenge despite advances in surgical techniques and perioperative care. Reported recurrence rates range between 5% and 15%, and the mechanisms underlying recurrence remain incompletely understood.[1-3] While biological factors such as annular healing capacity and progressive degeneration are well established, increasing attention has been directed toward biomechanical factors, particularly sagittal spinopelvic alignment.

The primary aim of this study was not only to investigate the association between preoperative spinopelvic parameters and recurrence, but also to explore their potential value in identifying patients at risk for RLDH. The present findings demonstrate that both reduced LL and increased PI–LL mismatch is significantly associated with recurrence and may have potential predictive value. Patients who developed recurrence exhibited significantly lower LL and higher PI–LL mismatch compared with controls, and both parameters remained significant in logistic regression analysis. The observed difference in LL between groups (approximately 15°) is not only statistically significant but also clinically meaningful, suggesting a substantial alteration in sagittal alignment in patients who develop recurrence.

Previous studies examining the role of spinopelvic alignment in lumbar disc disease have yielded heterogeneous results. Early investigations reported that decreased LL and altered sagittal

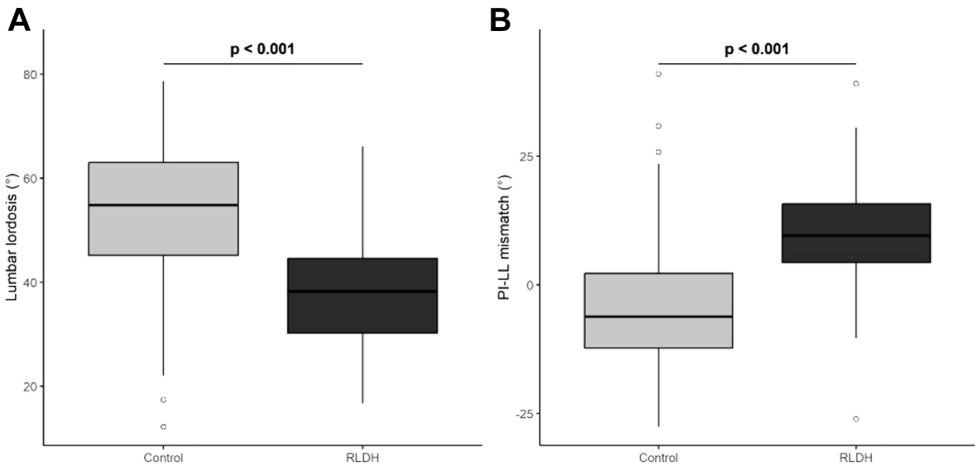


Figure 2. Comparison of lumbar lordosis (LL) and pelvic incidence (PI)—LL mismatch between patients with recurrent lumbar disc herniation (RLDH) and controls. Boxplots demonstrate significantly lower LL and higher PI—LL mismatch in the RLDH group. Boxes represent interquartile ranges, horizontal lines indicate medians, and whiskers show data distribution. Statistical significance is indicated above each comparison.

profiles are associated with lumbar disc degeneration and herniation,[14-16] whereas others failed to demonstrate a consistent relationship with clinical outcomes.[3-5] These discrepancies may be partly explained by methodological differences, particularly the use of asymptomatic or healthy control groups, which may confound degenerative alignment changes with true risk factors.

In contrast, the present study compares patients undergoing the same surgical procedure and distinguishes those who develop recurrence from those who remain recurrence-free. This design allows for a more accurate assessment of spinopelvic alignment as a preoperative factor that may contribute to recurrence risk, rather than a secondary consequence of degenerative disease.

Recent literature further supports the clinical relevance of sagittal alignment. Cabrera et al., demonstrated that spinopelvic parameters are increasingly incorporated into surgical decision-making in degenerative lumbar conditions.[17] Similarly, Tartara et al., emphasized the importance of PI—LL mismatch in postoperative outcomes and alignment restoration.[18] Biomechanical and radiological studies have also shown that sagittal alignment influences spinal loading patterns and disc degeneration.[8,11-13] In addition, recent case-control studies suggest that sagittal alignment may influence the occurrence and distribution of LDH.[19,20]

From a biomechanical perspective, reduced LL shifts the center of gravity anteriorly, increasing shear and compressive forces at the lumbosacral junction. This altered mechanical environment may impair annular healing following discectomy and predispose the operated segment to reherniation. In contrast, PI is a fixed anatomical parameter and does not directly reflect functional alignment. The absence of significant differences in PI, PT, and SS in the present study supports the concept that functional sagittal alignment—particularly LL and PI—LL mismatch—may be more relevant to recurrence risk than pelvic morphology alone.[9,10]

Importantly, ROC analysis in the present study demonstrated good discriminative performance for both LL and PI—LL mismatch, suggesting that these parameters may have practical value in identifying patients at increased risk of recurrence. The identified cut-off values (LL $\leq 49^\circ$ and PI—LL $\geq 4^\circ$) may provide a potential framework for clinical risk stratification, although further validation is required. These thresholds may be particularly useful in preoperative clinical decision-making, allowing surgeons to identify patients who may benefit from closer follow-up or alignment-aware treatment strategies.

The clinical implications of these findings are noteworthy. Preoperative assessment of sagittal alignment may help identify patients at higher risk for recurrence. In such cases, alignment-aware strategies—including preservation of posterior stabilizing structures, careful surgical technique, and targeted rehabilitation—may be considered. These findings also suggest that sagittal alignment

Table 3. Univariate Logistic Regression Analysis of Factors Associated with Recurrent Lumbar Disc Herniation

Variable	Odds Ratio (Per 1° Increase)	95% CI	*P* Value
Lumbar lordosis	0.91	0.87—0.94	<0.001
PI—LL mismatch	1.09	1.05—1.13	<0.001

CI, confidence interval; LL, lumbar lordosis; OR, odds ratio; PI, pelvic incidence.

Table 4. Receiver Operating Characteristic Analysis of Lumbar Lordosis and Pelvic Incidence—Lumbar Lordosis Mismatch for Predicting Recurrence

Parameter	AUC	Cut-off	Sensitivity	Specificity
Lumbar lordosis	0.815	≤49°	86%	69%
PI—LL mismatch	0.786	≥4°	76%	78%

AUC, area under the curve; LL, lumbar lordosis; PI, pelvic incidence.

parameters could be integrated into preoperative evaluation alongside conventional clinical and radiological factors.

This study has several limitations. Its retrospective design introduces potential selection bias, and radiological evaluation was limited to standing lateral lumbar radiographs without full-spine or dynamic assessment. Additional variables such as disc degeneration grade, annular defect size, occupational load, and postoperative rehabilitation were not analyzed and may influence outcomes. Furthermore, although univariate logistic regression demonstrated strong associations, multivariable modeling may further refine predictive accuracy. Coronal alignment parameters were not evaluated in this study, as the study cohort was intentionally restricted to patients without coronal deformity to allow a more focused assessment of sagittal spinopelvic mechanics. Therefore, the findings of this study may not be generalizable to patients with combined sagittal and coronal imbalance, which represent a distinct degenerative subgroup.

Despite these limitations, the present study provides evidence that sagittal alignment particularly LL and PI—LL mismatch is associated with and may contribute to the recurrence risk. These findings support the inclusion of spinopelvic assessment in preoperative evaluation and highlight its potential role in improving risk stratification.

CONCLUSIONS

Reduced preoperative LL and increased PI—LL mismatch is independently associated with RLDH and may have predictive value for recurrence risk. These findings highlight the importance of sagittal alignment in the pathophysiology of recurrence and suggest that preoperative spinopelvic assessment may contribute to improved risk stratification and surgical planning. Further prospective studies with multivariable analysis are warranted to validate these findings and clarify the role of sagittal alignment in preventing recurrence.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Utkan Topcu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Writing — original draft. **Zühtü Ozbek:** Supervision, Writing — original draft, Writing — review & editing. **Emre Ozkara:** Methodology, Supervision, Writing — original draft, Writing — review & editing. **Ali Arslantas:** Supervision, Writing — review & editing.

ACKNOWLEDGMENTS

The authors thank the radiology department staff for their assistance with imaging assessments.

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Ethics Approval: The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Eskisehir Osmangazi University Clinical Research Ethics Committee (Approval No: 33/2019, June 25, 2019).Conflict of interest statement: The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received 3 April 2026; accepted 12 April 2026

Citation: World Neurosurg. (2026) 210:124994. http://doi.org/10.1016/j.wneu.2026.124994

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

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