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ORIGINAL ARTICLE

Does rod overhang matter? Clinical impact in adolescent idiopathic scoliosis and Scheuermann's kyphosis

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Adolescent idiopathic scoliosis (AIS) and Scheuermann's kyphosis (SK) are two common spinal deformities observed in the pediatric population.[1,2] Surgical treatment is usually recommended for patients who meet specific clinical and radiographic criteria, such as pain, progressive curvature or significant deformity affecting function or cosmesis.[3-5] The standard surgical treatment of these deformities is posterior instrumentation and fusion, which has demonstrated favorable outcomes in long term.[6,7]

In orthopedic surgery, the proper sizing and positioning of implants are essential for achieving optimal clinical outcomes. Oversized or mispositioned implants, such as excessively long screws, plates extending beyond specific margins, or improperly fitted prostheses, have been associated with irritation of surrounding soft tissues and

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ABSTRACT

Objectives: The aim of this study was to investigate the potential relationship between rod overhang (RO) and quality of life (QoL) scores, as well as implant-related irritation, in patients with adolescent idiopathic scoliosis (AIS) and Scheuermann's kyphosis (SK).

Patients and methods: Between October 2016 and December 2018, a total of 33 pediatric patients with AIS and SK who underwent posterior instrumentation were retrospectively analyzed. On radiographs, the longest RO at both the superior and inferior ends (right or left) was recorded, and patients were grouped according to whether RO exceeded 1 cm. Quality of life outcomes were assessed using the Scoliosis Research Society-22r (SRS-22r), Oswestry Disability Index (ODI), and Short Form-36 (SF-36) questionnaires, and patients were also asked about implant-end irritation.

Results: Of the patients, 10 were male and 23 were female. The mean age at the time of operation was 15.18±1.98 years, while the mean age at the latest follow-up was 23.85±1.86 years. The median follow-up was 104.08 months. The mean maximum RO was 11.3±7.8 mm superiorly and 11.1±6.2 mm inferiorly. Superior RO correlated significantly with SF-36 role-physical ($r = -0.36$, $p = 0.04$) and vitality ($r = -0.43$, $p = 0.01$) subdomains; no other significant QoL correlations were found. Implant-related irritation was reported in eight (n = 3 superior, n = 5 inferior) patients. There was no significant difference in RO between patients who did and did not report implant-related irritation (superior $p = 0.18$ *vs*. inferior $p = 0.48$). There were no significant differences in QoL scores (for superior, inferior, and either end; $p > 0.05$) or in the rate of implant-related irritation between patients with RO greater or less than 1 cm (superior $p = 0.70$; inferior and either end $p = 1.00$).

Conclusion: Our study results suggest that rod overhangs up to 3 cm may not be a clinically relevant determinant of patient-reported outcomes or implant-related irritation in AIS and SK surgery. From a clinical perspective, this may help reduce concern regarding minor distal or proximal overhang during posterior instrumentation, particularly when optimal correction and fixation require slight extension of the construct. The absence of a measurable association with QoL or irritation also supports a more flexible intraoperative decision-making approach, prioritizing deformity correction and implant stability over strict limitation of rod length within this range.

Keywords: Adolescent idiopathic scoliosis, posterior instrumentation, quality of life, rod overhang, Scheuermann's kyphosis.

subsequent pain or functional limitations.[8-10] In the context of posterior instrumentation, excessively long rods may protrude beyond the most cranial or caudal pedicle screws and cause discomfort due to soft tissue irritation. Theoretically, such overhang could lead to mechanical impingement or increased tension within the overlying paraspinal musculature and fascia, resulting in localized soft-tissue irritation or discomfort at the implant ends.

Despite the widespread use of posterior instrumentation in AIS and SK, there is a lack of research investigating the potential impact of rod overhang (RO), defined as the segment of the rod that extends beyond the last pedicle screw, on patient-reported outcomes or postoperative discomfort. To date, no study has examined whether overhanging rods contribute to diminished quality of life (QoL) or implant-related irritation. In the present study, we hypothesized that increased RO length was associated with lower QoL scores and a higher rate of implant-related irritation in patients undergoing posterior spinal instrumentation for AIS or SK. We, therefore, aimed to evaluate the relationship between RO and clinical outcomes in patients with AIS and SK who underwent posterior instrumentation and to determine whether overhanging rods were associated with lower health-related QoL scores or increased reports of implant-related discomfort.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at University of Health Sciences, Metin Sabancı Baltalimanı Bone Diseases Training and Research Hospital, Department of Orthopedics and Traumatology between October 2016 and December 2018. Pediatric patients who underwent posterior instrumentation for either AIS or SK were included in the study. Exclusion criteria included revision surgery (including those with implant failure and proximal junction kyphosis) previous spinal surgery, postoperative infection and neuromuscular disease. Patients who were lost to follow-up were also excluded from the final analysis. After applying the exclusion criteria, three cases were excluded due to revision surgery for implant failure, two cases due to proximal junctional kyphosis, two cases due to previous spinal surgery, four cases due to postoperative infection, and one case due to neuromuscular disease. Finally, 41 patients who underwent posterior instrumentation between were eligible for inclusion. Of these, six patients with AIS and two patients with SK were lost to follow-up, leaving 33 patients for the final analysis. Data including demographic and clinical characteristics were retrieved from the hospital database. A written informed consent was obtained from the parents and/or legal guardians of the patients. The study protocol was approved by the University of Health Sciences, Metin Sabancı Baltalimanı Bone Diseases Training and Research Hospital Ethics Committee (Date: 14.05.2025, No: 272). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Radiological assessment

Radiological assessment included preoperative and postoperative Cobb and local kyphosis angles and overhanging rod lengths. All radiographs were calibrated using an embedded 25-mm scaling marker to ensure measurement accuracy. Cobb angles were measured using standard end-vertebra selection, and thoracic/lumbar kyphosis was measured between T5-T12 according to established protocols.[11,12] The RO lengths were determined using anteroposterior (AP) and lateral whole spine roentgenograms (Figure 1).

The RO length was defined as the distance from the most distal or proximal point of the last pedicle screw to the corresponding end of the rod. Among the AP and lateral measurements, the greater value was selected as the final RO length for each end. The greater value between AP and lateral measurements was used to represent the maximum true overhang in any plane. This approach was applied uniformly to all patients, independent of the side or location of reported irritation. For each end (proximal and distal), the longest overhang measurement, either from the right or left rod, was recorded. All radiographic measurements of RO were performed by a single experienced orthopedic surgeon to ensure consistency and minimize inter-observer variability. As measurements were obtained by a single observer following a standardized protocol, inter- and intra-observer reliability analyses were not applicable in this context. Based on the maximum RO length at the proximal and distal ends, patients were classified according to whether the overhang exceeded 1 cm at the superior end, the inferior end, or at either end. The 1-cm threshold was selected pragmatically, as the mean RO in our cohort was approximately 1.1 cm. Rounding this value to 1 cm allowed for a clinically interpretable and reproducible cut-off, facilitating comparison between groups and potential applicability in future studies.

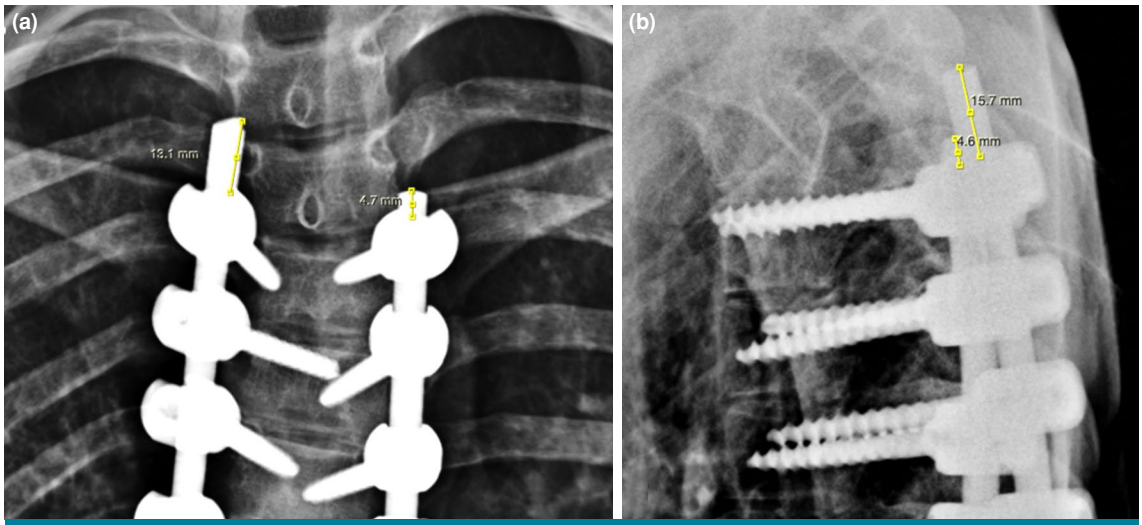

FIGURE 1. Measurement of rod overhang lengths on **(a)** anteroposterior and **(b)** lateral X-ray views.

Quality of health and implant irritation

Patient-reported QoL measures included the Scoliosis Research Society-22r (SRS-22r), Oswestry Disability Index (ODI), and Short Form-36 (SF-36) scores.[13-15] All questionnaires were administered in person in a supervised setting to minimize missing items and ensure complete responses. The SRS-22r and ODI scores were recorded preoperatively and at the latest postoperative follow-up, while SF-36 scores were collected only at the latest follow-up. The SF-36 outcome parameters were calculated as described in the literature.[15] Quality of life questionnaires were administered by a single orthopedic surgeon to ensure consistency in data collection. In addition, implant-related irritation was evaluated at the latest follow-up by asking each patient a standardized Yes/No question regarding the presence of any discomfort or irritation localized to the superior or inferior ends of the implant.

Statistical analysis

Statistical analysis was performed using IBM SPSS for Windows version 26.0 software (IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Shapiro-Wilk test. Continuous data were presented in mean ± standard deviation (SD) for normally distributed variables and as median and interquartile range (IQR) for non-normally distributed variables. Categorical data were presented in number and frequency. For comparisons, non-normally distributed continuous variables were analyzed using either the Mann-Whitney U test or Wilcoxon signed-rank test, while normally distributed variables were analyzed using either the independent samples t-test or the paired samples t-test, as appropriate. Categorical variables were compared using the chi-square test or Fisher exact test. Correlations between variables were assessed using Spearman's rank correlation coefficient due to non-normal distribution of the data. The strength and direction of correlations were expressed using Spearman's ϱ (rho) values. A p value of < 0.05 was considered statistically significant.

RESULTS

In this study, only patients with complete pre- and postoperative SRS-22r and ODI data, as well as complete SF-36 data at the latest follow-up, were included in the analysis; therefore, no missing data were present in the patient-reported outcome measures. Of a total of 33 patients included, 27 had AIS and six had SK. Of the patients, 10 were male and 23 were female. The mean age at the time of operation was 15.18±1.98 (range, 12 to 18) years, while the mean age at the latest follow-up was 23.85±1.86 (range, 21 to 27) years. The median follow-up was 104.08 (range, 78.77 to 107.97) months.

All patients had significant reduction in Cobb angles after surgery (preoperative 50.64±14.54 *vs.* postoperative 13.79±12.26, $p < 0.01$). All SK patients had significant reduction in the local kyphosis angle after surgery (preoperative 74.25±15.51 *vs.* postoperative 44.33±9.77, $p < 0.01$).

The mean RO length was 10.03±7.83 mm for the superior left, 7.34±5.40 mm for the superior right, 9.30±6.54 mm for the inferior left, and 8.48±6.18 mm for the inferior right. Considering the greater value for each end, the mean maximum RO was measured as 11.31±7.76 mm at the superior end and 11.13±6.20 mm at the inferior end, ranging from 1.80 to 30.12 mm.

Fifteen patients had a superior RO longer than 1 cm (n = 12 in AIS and n = 3 in SK group, $p = 1$), while 19 patients had an inferior RO longer than 1 cm (n = 14 in AIS and n = 5 in SK group, $p = 0.21$).

Given the limited number of SK cases (n = 6) and the overall sample size (n = 33), subgroup comparisons between AIS and SK, as well as between

TABLE I

Spearman correlation coefficients (ρ) and p-values for the association between superior and inferior maximum rod overhang lengths and quality of life scores

	Superior max overhang	Superior max overhang	Inferior max overhang	Inferior max overhang
	ρ	*p*	ρ	*p*
SRS-22r	0.10	0.58	0.19	0.30
ODI	0.01	0.95	–0.18	0.31
SF-36				
PF	–0.08	0.65	0.07	0.69
RP	**–0.36**	**0.04**	–0.22	0.21
BP	0.21	0.25	–0.15	0.40
GH	0.10	0.58	0.09	0.61
VT	**–0.43**	**0.01**	–0.24	0.18
SF	–0.18	0.33	–0.10	0.57
RE	–0.14	0.44	–0.11	0.56
MH	0.05	0.77	0.13	0.48

SRS-22r: Scoliosis Research Society 22 revised; ODI, Oswestry Disability Index; SF-36, Short Form-36; PF, physical functioning; RP, role physical; BP, bodily pain; GH, general health; VT, vitality; SF, social functioning; RE, role emotional; MH, mental health. Only the SF-36 Role Physical and Vitality subdomains showed statistically significant inverse correlations with superior overhang length; however, these were not considered clinically relevant.

TABLE II

Postoperative quality-of-life scores according to the presence of rod overhang > 1 cm at the superior, inferior, and either end of the construct

	Either end, no rod overhang > 1 cm (n = 7)		Either end, rod overhang > 1 cm (n = 26)		Superior, no rod overhang > 1 cm (n = 18)		Superior, rod overhang > 1 cm (n = 15)		Inferior, no rod overhang > 1 cm (n = 14)		Inferior, rod overhang > 1 cm (n = 19)	
	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR
SRS-22r	4.10	0.60	4.20	0.50	4.15	0.55	4.20	0.30	4.20	0.50	4.20	0.50
ODI	4.00	12.00	4.00	5.00	4.00	9.00	4.00	0.00	4.00	6.00	4.00	8.00
SF-36												
PF	90	10	100	10	100	10	90	10	90	10	100	10
RP	100	0	100	0	100	0	100	10	100	0	100	0
BP	100	55	90	30	100	15	90	30	95	15	90	30
GH	80	0	80	4	80	4	80	4	80	1	80	4
VT	70	20	77.5	10	75	12.5	70	10	70	12.5	80	10
SF	80	37	80	17.5	80	26.25	80	10	80	30	80	15
RE	100	0	100	10	100	10	100	0	100	0	100	10
MH	75	30	77.5	22.5	75	22.5	80	30	75	30	75	20

IQR, interquartile range; SRS-22r: Scoliosis Research Society 22 revised; ODI, Oswestry Disability Index; SF-36, Short Form-36; PF, physical functioning; RP, role physical; BP, bodily pain; GH, general health; VT, vitality; SF, social functioning; RE, role emotional; MH, mental health. Across all comparisons and overhang locations, no statistically significant differences were observed between patients with and without > 1 cm rod overhang in any quality-of-life domain. (all $p > 0.05$).

TABLE III
Association between rod overhang greater than 1 cm and implant-related irritation at the superior, inferior, and either end

	No Irritation	Irritation	Total	
Overhang group	n	n	n	*p*
Superior > 1 cm				
No	13	5	18	0.70
Yes	12	3	15	
Inferior > 1 cm				
No	11	3	14	1.00
Yes	14	5	19	
Either end > 1 cm				
No	5	2	7	1.00
Yes	20	6	26	

Frequencies (counts) are shown for patients reporting irritation versus no irritation. No significant associations were observed for any overhang location (all $p > 0.05$).

RO > 1 cm and < 1 cm groups, are underpowered and should be interpreted with caution.

Both the median SRS-22r and ODI scores demonstrated statistically significant improvement from preoperative to postoperative assessments, with SRS-22r increasing from 4.00 (0.55) to 4.20 (0.50) ($p = 0.03$) and ODI decreasing from 8.00 (5.50) to 4.00 (8.00) ($p < 0.01$).

The correlation coefficients between RO length and QoL scores are shown on the Table I. Only significant correlations between RO length and QoL scores were between superior RO length and role-physical and vitality subdomains of SF-36 (r = –0.36, $p = 0.04$ and r = –0.43, $p = 0.01$, respectively). No other significant correlations were identified between RO lengths and QoL scores (Table I).

Among the 33 patients, eight (24.2%) reported implant-related irritation, including three patients with irritation localized to the superior end of the implant and five to the inferior end. There were no significant differences in QoL scores (Table II) or implant-related irritation (Table III) between patients with RO greater or less than 1 cm whether at the superior end, inferior end, or either end. There was no significant difference in the mean maximum RO lengths between patients who reported implant-related irritation and those who did not, with superior overhang measuring 7.48±4.60 mm *vs.* 12.54±8.22 mm ($p = 0.18$) and inferior overhang measuring 9.35±3.46 mm *vs.* 11.70±6.81 mm ($p = 0.48$). Irritation was reported in 10% of males (1/10) and 30.4% of females (7/23). There was no significant association between gender and implant-related irritation ($p = 0.38$).

DISCUSSION

In the present study, we evaluated the relationship between RO and clinical outcomes in patients with AIS and SK who underwent posterior instrumentation. Our study results showed that the RO length, averaging approximately 1.1 cm, was not inversely correlated with patient-reported QoL scores for overhangs up to 3 cm. Although statistically significant weak inverse correlations were observed between superior RO length and the Vitality and Role Physical subdomains of the SF-36, these findings were interpreted as not clinically relevant. Furthermore, in this cohort, patients who reported implant-related irritation did not have significantly longer RO compared to those who did not report irritation. Additionally, there were no significant differences in QoL scores or implant-related irritation between patients with RO of 0-1 cm and those with overhangs of 1-3 cm. Taken together, these findings suggest that RO averaging around 1.1 cm may be considered clinically acceptable within the range observed in this cohort (up to 3 cm).

While implant overhang has been associated with complications in various orthopedic procedures, including total knee arthroplasty (TKA), volar plating of distal radius fractures, and proximal humerus fracture fixation, its relevance in posterior spinal instrumentation for AIS and SK remains underexplored. For instance,

femoral component overhang of ≥ 3 mm has been reported in 57% of TKA cases and has been linked to soft tissue irritation and poorer clinical outcomes.[8] In the management of distal radius fractures, excessively long distal screws have been shown to cause extensor tendon complications, including tenosynovitis and rupture of the extensor pollicis longus (EPL), often necessitating hardware removal.[16] Similarly, improper plate positioning in proximal humerus fractures can result in subacromial impingement and an increased risk of implant failure.[10] In spine surgery, prominent implants can act as a source of mechanical back pain due to local irritation or soft tissue impingement.[17,18] In symptomatic cohorts with healed thoracolumbar fractures, pain and functional limitations have been linked to local hardware-related factors, with subsequent improvement in patient-reported outcome measures (PROMs) after implants were removed.[19,20] In AIS, focal tenderness over prominent implants has been identified as a discrete pain source, and targeted removal of the symptomatic hardware has resolved symptoms, reinforcing the clinical relevance of prominence-driven irritation in this population.[21] Taken together, implant removal may be considered to alleviate symptoms; however, this intervention carries its own risks, including infection, neurovascular injury, and potential loss of spinal alignment.[18] As such, careful evaluation of implant positioning and prominence is essential to minimize the need for secondary procedures. To the best of our knowledge, this is the first study to investigate the clinical impact of RO in posterior spinal instrumentation.

Quantifiable implant-related parameters can meaningfully influence postoperative outcomes, as demonstrated in recent work showing that specific rod curvature measurements were associated with superior recovery following lumbar fusion.[22] Such findings highlight the broader value of establishing measurable, clinically relevant intraoperative parameters to guide implant configuration, reinforcing the importance of better defining how much RO can be considered acceptable in deformity surgery. Notably, in patients with AIS and SK, RO averaging approximately 1 cm and up to 3 cm, whether at the proximal or distal ends, were not associated with increased implant-related irritation or decreased QoL scores. These findings suggest that minor/moderate RO may be clinically acceptable in the context of posterior spinal instrumentation.

Beyond clinical outcomes, implant malpositioning also represents a notable medicolegal concern in orthopedic practice. An analysis of orthopedic malpractice claims reported that spine procedures accounted for 15% of all claims but 28% of total payouts, with the highest median defense costs among subspecialties.[23] Another review of 68 medicolegal cases involving misplaced screws identified lumbar pedicle screws as the most frequent source of litigation, with average payouts exceeding $1.2 million.[24] These findings emphasize that accurate implant positioning is essential not only for patient safety, but also for minimizing medicolegal exposure. In our cohort, the average RO was 1.1 cm (max 3 cm), and within this range, RO length was not associated with poorer QoL scores or increased implant-related irritation. These findings apply only to RO values up to 3 cm, and larger overhangs were not represented in this series. While further research is required to evaluate the safety of greater RO values, the present results may serve as an initial, evidence-based reference for medicolegal considerations regarding implant positioning.

Quality assessment in surgery enhances care delivery and outcomes, and it plays a key role in evaluating the effectiveness of surgical interventions. Patient-reported outcome measures, both generic and disease-specific, provide a comprehensive understanding of a patient's health by capturing aspects such as QoL, functional status, and pain levels.[25] In spinal surgery research, QoL questionnaires are commonly relied upon to assess treatment outcomes. Among the most frequently used QoL instruments are pain scales, the SRS-22r, the ODI, and SF-36.[26,27] For both adolescent AIS and SK, the SRS questionnaires, ODI, and SF-36 are well-established tools for evaluating surgical outcomes.[28,29] This rationale guided our choice of these instruments to assess the potential impact of RO on patients' QoL. Our results demonstrate that RO with an average length of approximately 1.1 cm do not negatively affect patient-reported QoL scores, suggesting that overhang of this extent does not compromise outcomes in this population.

A notable strength of this study is its focus on a previously unexplored aspect of spinal deformity surgery: the clinical relevance of RO in patients with AIS and SK. To the best of our knowledge, this is the first study to evaluate the relationship between RO, patient-reported QoL outcomes, using validated tools such as the SRS-22r, ODI, and SF-36, and implant-related irritation. The study benefits

from a relatively long mean follow-up duration of over eight years, allowing for the assessment of long-term outcomes.

Nonetheless, this study has several limitations that should be acknowledged. The relatively small sample size may reduce the statistical power and limit the generalizability of the findings, particularly for subgroup analyses (AIS *vs.* SK and RO > 1 cm *vs.* < 1 cm) given the limited number of SK cases. Additionally, the restricted cohort size made it not feasible to perform multivariate analyses, which would be necessary to account for potential confounding factors that may also influence postoperative QoL scores. Furthermore, the range of RO lengths in our cohort was narrow, with a maximum overhang of approximately 3 cm. As a result, the conclusions primarily apply to minor RO and may not be generalizable to more pronounced cases. Studies with larger sample sizes and a broader range of overhang lengths may help refine the upper limit of what is considered clinically and potentially legally acceptable. In particular, multicenter studies are warranted to validate these findings and to establish more accurate thresholds for clinically acceptable RO. Such collaborative efforts would also enable the application of advanced statistical methods, such as the receiver operating characteristic (ROC) curve analysis or predictive modeling approaches, that are more appropriate to define precise cut-off values.

In conclusion, our study results showed that ROs averaging approximately 1.1 cm, and extending up to a maximum of 3 cm, were not associated with decreased QoL scores or increased implant-related irritation. Patients who reported irritation did not have significantly longer RO than those who did not, and no significant differences in outcomes were observed between those with RO of 0-1 cm and 1-3 cm. These findings suggest that rod overhangs up to 3 cm may not be a clinically relevant determinant of patient-reported outcomes or implant-related irritation in AIS and SK surgery. From a clinical perspective, this may help reduce concern regarding minor distal or proximal overhang during posterior instrumentation, particularly when optimal correction and fixation require slight extension of the construct. The absence of a measurable association with QoL or irritation also supports a more flexible intraoperative decision-making approach, prioritizing deformity correction and implant stability over strict limitation of rod length within this range. However, caution remains necessary when extrapolating these results to larger overhangs, which were not represented in the current cohort. Further multi-center, prospective studies with broader variability in rod overhang are needed to better define potential threshold effects and to confirm these observations in larger populations.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: D.K.: Contributed to the idea/concept, design, control/supervision, and critical review of the manuscript; U.Y.: Contributed to the design, control/supervision, data collection and/or processing, analysis and/or interpretation, literature review, writing of the article, and references and funding-related sections; B.K.: Contributed to data collection and/or processing. All authors read and approved the final version of the manuscript.

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AI Disclosure: The authors declare that artificial intelligence (AI) tools were not used, or were used solely for language editing, and had no role in data analysis, interpretation, or the formulation of conclusions. All scientific content, data interpretation, and conclusions are the sole responsibility of the authors. The authors further confirm that AI tools were not used to generate, fabricate, or 'hallucinate' references, and that all references have been carefully verified for accuracy.

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