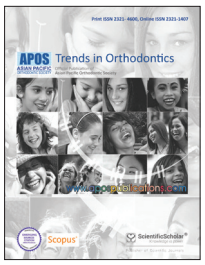
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Root length changes in the maxillary posterior segment following miniplate-anchored intrusion: A retrospective cone-beam computed tomography study

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ABSTRACT

Objectives: The objective of the study is to evaluate morphological changes and orthodontically induced root resorption (OIRR) across the maxillary posterior segment following miniplate-anchored intrusion using cone-beam computed tomography (CBCT).

Material and Methods: This retrospective observational cohort study included 19 patients treated for anterior open bite with miniplate-supported intrusion of the maxillary posterior teeth. Pre-treatment (T0) and post-treatment (T1) CBCT scans were analyzed using *in vivo* software. Root length measurements of maxillary premolars, first molars, and second molars were measured from the central fossa to the root apex. Interrater reliability was assessed using intraclass correlation coefficients > 0.76. Changes in root length between T0 and T1 were analyzed using paired *t*-tests ($\alpha = 0.05$).

Results: The greatest resorption was observed in the palatal root of the upper right first premolar (0.99 ± 0.41 mm; $p = 0.025$). Significant shortening was identified in palatal roots of the upper left second premolar (0.76 ± 0.18 mm; $p < 0.001$) and upper right second premolar (0.51 ± 0.20 mm; $p = 0.0167$). In first molars, the palatal and distobuccal roots showed the greatest resorption, reaching 0.98 ± 0.26 mm and 0.96 ± 0.21 mm, respectively ($p \leq 0.001$). Second molars demonstrated small, non-significant increases in root length (0.02–0.49 mm; $p > 0.05$), consistent with continued root development.

Conclusion: Miniplate-anchored intrusion results in limited (<1 mm) and clinically acceptable root resorption in maxillary premolars and first molars, while second molars, likely reflecting a subset with incompletely formed apices, appeared resistant to OIRR.

Keywords: Apical root shortening, Immature apex, Miniplate-anchored intrusion, Orthodontic-induced root resorption, Posterior maxillary intrusion

INTRODUCTION

Orthodontically induced root resorption (OIRR) is a well-recognized and undesirable iatrogenic effect associated with orthodontic treatment. Most commonly, OIRR presents as external apical root resorption involving irreversible loss of cementum and dentin at the root apex; however, resorptive changes may also occur across the entire root surface.[1,2] The etiology of OIRR is multifactorial in nature, arising from interactions between biological susceptibility and

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mechanical loading, and is a major clinical concern because of its unpredictable nature and potential implications for the long-term prognosis of the tooth.[1]

The development and severity of OIRR are influenced by both patient-related and treatment-related factors. Factors intrinsic to the patient, such as genetics (e.g., interleukin-1 variants affecting bone remodeling and stress concentration for longer periods on the root surface), systemic conditions, sex, and tooth type, are non-modifiable.[3-5] Treatment-related factors include force magnitude, direction, duration, and movement type.[6] Intrusion is most strongly linked to OIRR.[7,8] Among orthodontic movements of teeth, intrusion of the posterior teeth of the maxilla, especially the premolars and molars, is one of the most biomechanically demanding movements. Posterior intrusion is often used in the correction of anterior open bite, where controlled vertical movement of the posterior segment is used for counterclockwise mandibular autorotation and for correction of occlusal and facial relationships. However, intrusive mechanics concentrate orthodontic forces in the apical region of the roots, an area with limited periodontal ligament surface, which increases the susceptibility to OIRR.[7,9]

Intrusion carries a greater risk of root resorption than other orthodontic movements, such as extrusion or tipping.[10] Three-dimensional cone-beam computed tomography (CBCT)-based evaluations of posterior intrusion using temporary anchorage devices have shown measurable apical root shortening in maxillary premolars and first molars, which is usually shorter than 1 mm and is usually deemed clinically acceptable but biologically significant.[11,12] However, variations in root anatomy, force vectors, and root development stage indicate that different teeth in the posterior segment may respond heterogeneously to intrusive forces. This heterogeneous response signifies the significant value of skeletal anchorage systems, which have resulted in a substantial expansion of orthodontic intrusion possibilities. While miniscrews are widely utilized, miniplates offer superior stability, resistance to loosening, and the capacity to withstand heavier, more complex force systems, which renders them particularly advantageous for full posterior intrusion in hyperdivergent and anterior open bite patients, where absolute anchorage is essential.[13,14]

Despite the fact that miniplates facilitate intrusion with minimal reliance on patient compliance, concerns about OIRR persist. Assessments of miniplate-assisted intrusion have demonstrated limited but statistically significant root resorption in maxillary premolars and first molars.[15-17] However, the majority of current evidence is restricted to individual teeth evaluated separately, without considering the posterior segment as a biomechanical unit.

Despite the expanding amount of literature on orthodontic intrusion and OIRR, evidence is currently fragmented. Most studies assessed individual teeth (premolars or first molars) without assessing the collective response of the entire maxillary posterior segment subjected to the same intrusive force system. In addition, little attention has been paid to differences in resorptive response between teeth with fully developed apices and immature or developing roots. Emerging evidence indicates that teeth with incomplete root formation may have a lower susceptibility to orthodontic-induced root resorption than teeth with mature roots.[1,5,11] However, detailed segment level that account for root developmental stage in the context of miniplate-anchored intrusions are missing. Addressing this gap is vital to the refinement of risk assessment and optimizing treatment planning and clinical decision-making with regard to posterior intrusion indications.

To address this gap, the study aimed to assess morphological changes and the root resorption pattern across the maxillary posterior segment following miniplate-anchored intrusion using three-dimensional CBCT analysis, with attention to variation in response that may relate to differences in root developmental stage across the posterior segment.

MATERIAL AND METHODS

Study design

This study was designed as a retrospective observational cohort study evaluating morphological changes and OIRR across the maxillary posterior segment following miniplate-anchored intrusion. All analyses were performed on a single cohort of patients derived from a previously treated clinical population, ensuring consistency in treatment mechanics, imaging protocols, and outcome assessment.

Study sample

The sample consisted of 19 subjects treated for anterior open bite using miniplate-supported intrusion of the maxillary posterior teeth. The mean interval between T0 and T1 CBCT scans, corresponding to the duration of active intrusion loading, was approximately 7 months (range 4.5–8.5 months). All included patients had both pre-treatment (T0) and post-treatment (T1) CBCT scans of diagnostic quality available for analysis. Only patients in whom miniplates were used specifically for posterior intrusion were included. Patients treated with miniplates for alternative purposes, such as distalization, were excluded.

Miniplate placement protocol

Miniplates were inserted bilaterally at the infrazygomatic crest in all patients through a small incision positioned between the first and second maxillary molars. The insertion site and plate position were consistent for all patients and for

both sides. Two titanium miniplates (KLS Martin, Tuttlingen, Germany) were placed per patient, one on each side. These were secured using self-drilling screws with a diameter of 1.5–2.0 mm and a length of 5–7 mm. Two to three fixation screws were used per plate.

Imaging and measurement protocol

CBCT scans were obtained at two time points: Before initiation of orthodontic treatment (T0) and after completion of posterior intrusion (T1). All measurements were performed using *in vivo* software (*in vivo* 6; Anatomage, San Jose, CA), which allows standardized three-dimensional visualization and linear measurement across sagittal, axial, and coronal planes.

Root length measurements were performed for maxillary premolars, first molars, and second molars. For each tooth, linear measurements were recorded from a standardized occlusal reference point to the apex of each root. The central fossa was selected as the occlusal reference point, and measurements were taken from the central fossa to the root apex for each corresponding root (palatal, mesiobuccal, and distobuccal where applicable) [Figure 1]. The central fossa was chosen as the reference point due to its anatomical stability and minimal susceptibility to occlusal wear over time, in contrast to cuspal tips, which may undergo attrition between T0 and T1 and introduce measurement error. Root apices were identified as the most apical point of each root and confirmed through multiplanar assessment to ensure accuracy. Linear measurements at T0 and T1 were compared to evaluate changes in root length indicative of OIRR or continued root development.

Examiner calibration and reliability

The CBCT scans were anonymized, and the T0 and T1 images for each patient were presented to the examiners in a randomized order. This meant that the examiners were blinded to the time point during the measurement process. Before full data collection, examiner calibration was performed to ensure measurement reliability. Two independent examiners evaluated a subset of five randomly selected CBCT scans, measuring all predefined landmarks and root lengths according to the study protocol. Interrater reliability was assessed using the intraclass correlation coefficient (ICC). An ICC value >0.76 was considered indicative of excellent agreement.[18] All measured ICC values exceeded this threshold, confirming high consistency and reliability between examiners. Following calibration, the full dataset was measured according to the standardized protocol.

Statistical analysis

All data were anonymized before statistical analysis. Root length measurements were summarized using means and standard deviations. Changes in root length between T0 and T1 were evaluated using paired *t*-tests, as the same teeth were measured at both time points. Differences in means with corresponding 95% confidence intervals were calculated to quantify the magnitude of change. A $p < 0.05$ was considered statistically significant. All statistical analyses were performed using SAS software version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

Segmental comparison of root resorption patterns

Morphological changes in root length were evaluated across the maxillary posterior segment using paired comparisons between pre-treatment (T0) and post-treatment (T1) CBCT measurements. Results are presented by tooth type to illustrate the progression of root resorption patterns from anterior to posterior.

Premolars

Maxillary premolars demonstrated statistically significant root resorption in nearly all evaluated roots following miniplate-anchored intrusion. Significant reductions in root length were observed in both first and second premolars, predominantly affecting the palatal roots.

The greatest amount of resorption among premolars was observed in the palatal root of the upper right first premolar (UR4), with a mean reduction of 0.99 mm between T0 and T1 [Table 1]. Significant resorption was also noted in the palatal roots of the upper right second premolar (0.51 mm), upper

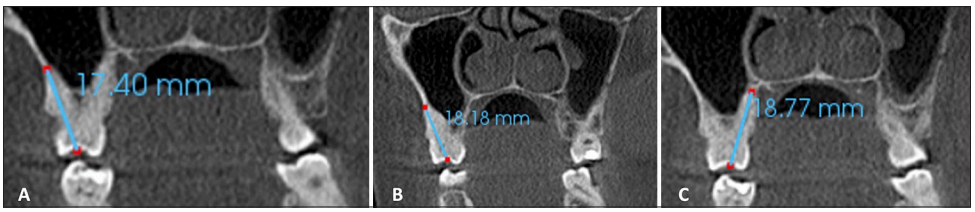


Figure 1: Three-dimensional cone-beam computed tomography images showing measurement of root length from central fossa to the root apex for each root of the maxillary first molar (A) Distobuccal root, (B) Mesiobuccal root, and (C) Palatal root.

Table 1: Comparison of morphological changes of maxillary premolars before and after orthodontic intrusion.

Tooth[a]	Measurement[b]	Mean (SD)			*p*-value
		Time 0	Time 1	Difference (mm)	
UR5	FP	17.96 (1.95)	17.45 (1.77)	−0.51 (0.20)	0.0167
UR4	FP	17.34 (2.05)	16.35 (1.92)	−0.99 (0.41)	0.025
UR4	FB	17.26 (1.9)	16.92 (1.76)	−0.34 (0.23)	0.152
UL5	FP	18.08 (1.94)	17.31 (1.94)	−0.76 (0.18)	<0.001
UL4	FP	17.6 (1.64)	16.56 (1.86)	−0.47 (0.14)	0.004
UL4	FB	17.69 (1.36)	17.03 (1.45)	−0.66 (0.25)	0.018

[a]UR5: Upper right second premolar, UR4: Upper right first premolar, UL5: Upper left second premolar, UL4: Upper left first premolar. [b]FP: Central fossa to apex of palatal root, FB: Central fossa to apex of buccal root. SD: Standard deviation. $p < 0.05$ was considered statistically significant.

left first premolar (0.47 mm), and upper left second premolar (0.76 mm). In addition, the buccal root of the upper left first premolar exhibited significant shortening (0.66 mm).

In contrast, the buccal root of the upper right first premolar did not demonstrate a statistically significant change in root length (mean change: 0.34 mm; $p > 0.05$), representing the only premolar root without significant resorption. Overall, premolar intrusion with miniplate anchorage was associated with measurable and statistically significant root resorption in the majority of roots, with palatal roots being the most affected.

First molars

Maxillary first molars exhibited significant root resorption in almost all evaluated roots following intrusion. Both right and left first molars showed a consistent pattern of apical shortening, with the palatal and distobuccal roots demonstrating the greatest magnitude of resorption. For the right maxillary first molar, statistically significant reductions in root length were observed in all three roots. The palatal root showed a mean decrease of 0.98 mm, while the distobuccal root demonstrated a reduction of 0.96 mm [Figure 2A]. The mesiobuccal root also exhibited significant resorption, although to a lesser extent (0.53 mm) [Table 2].

For the left maxillary first molar, significant resorption was observed in the palatal root (0.47 mm) [Figure 2B] and distobuccal root (0.75 mm) [Figure 2C]. The mesiobuccal root of the left first molar did not demonstrate a statistically significant change in root length (mean change: 0.03 mm; $p > 0.05$) [Figure 2D]. Across both sides, the palatal and distobuccal roots were consistently the most affected, indicating a non-uniform distribution of resorptive changes among the roots of maxillary first molars.

Second molars

In contrast to premolars and first molars, maxillary second molars did not demonstrate OIRR following miniplate-anchored intrusion. Instead, all measured roots showed an increase in root length from T0 to T1 [Table 3].

For the right maxillary second molar, mean increases in root length were observed in the palatal (0.08 mm), mesiobuccal (0.02 mm), and distobuccal (0.09 mm) roots. Similarly, the left maxillary second molar demonstrated increases in root length across all roots, with mean changes of 0.32 mm (palatal), 0.49 mm (mesiobuccal), and 0.31 mm (distobuccal) [Figure 3A and B].

None of these changes reached statistical significance ($p > 0.05$ for all comparisons). These findings are consistent with continued root development rather than resorptive change and are attributed to the presence of immature or incompletely formed apices at the pre-treatment time point.

DISCUSSION

The present study shows the non-uniform distribution of OIRR in the maxillary posterior segment after miniplate-anchored intrusion. Resorptive changes were more marked in premolars and first molars, showing a definite predilection for specific roots, especially the palatal and distobuccal roots in second molars with no evidence of resorption noted.

The asymmetric resorption pattern with more changes on the right side and palatal and distobuccal roots may be explained by biomechanical and anatomical factors. Force vectors created by miniplate-supported intrusion are not distributed evenly among all roots. Palatal roots, by virtue of their length, morphologic characteristics, and proximity to the applied intrusive force, are probably subjected to greater stress concentrations. Similarly, distobuccal roots will have an increased compressive force depending upon the direction of force application and the spatial relationship between the miniplate and the posterior teeth. These results are consistent with the findings of previous reports stating that root resorption depends on the direction of tooth movement, force distribution, and proximity of roots to anchorage units.[1,7,11]

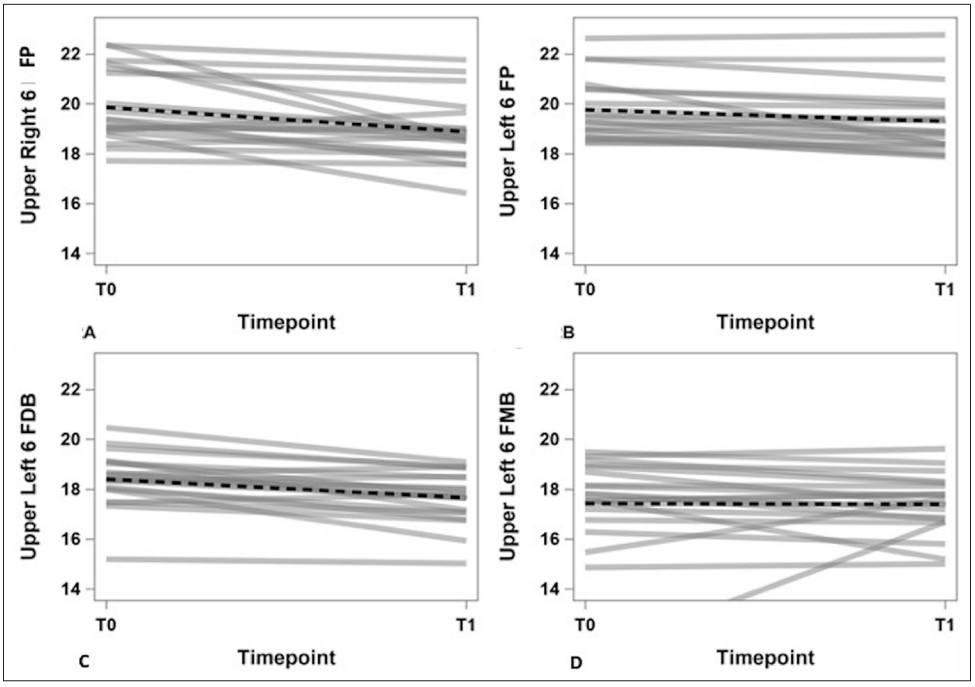


Figure 2: Individual and mean changes in root length of the maxillary first molars following miniplate-anchored intrusion from pretreatment (T0) to post-treatment (T1). Gray lines represent individual patient measurements, and the dashed black line represents the mean change in root length. (A) Upper right first molar palatal root (UR6 FP), (B) upper left first molar palatal root (UL6 FP), (C) upper left first molar distobuccal root (UL6 FDB), and (D) upper left first molar mesiobuccal root (UL6 FMB).

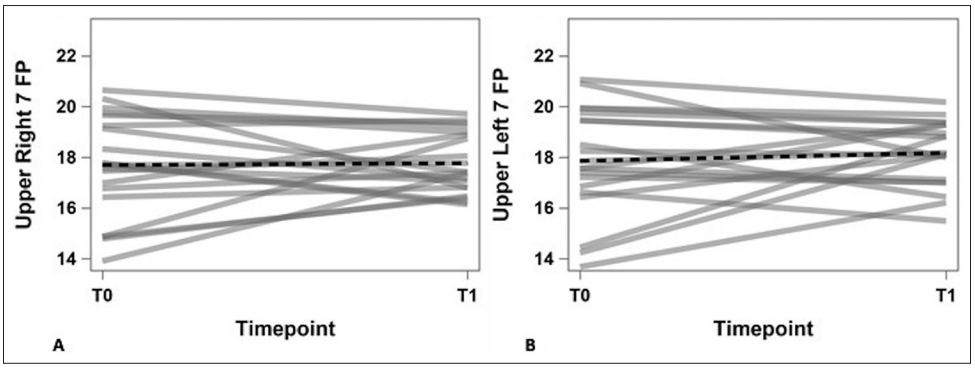


Figure 3: Individual and mean changes in root length of the maxillary second molars following miniplate-anchored intrusion from pretreatment (T0) to post-treatment (T1). Gray lines represent individual patient measurements, and the dashed black line represents the mean change in root length. (A) Upper right second molar palatal root (UR7 FP) and (B) upper left second molar palatal root (UL7 FP).

The observed right-left asymmetry may further demonstrate subtle differences in the magnitude of the forces, positioning of the plate, or individual anatomical differences, all of which could have an effect on localized stress within the periodontal ligament and root surface. One of the clinical aspects of this study that seems to be most important is the difference in the biological response of teeth with mature roots (premolars and first molars) versus teeth with immature or developing roots (second molars). While significant OIRR was noticed in premolars and first molars, maxillary second molars showed an increase in the root length from T0 to T1 without statistical evidence of resorption. This finding is a strong argument in support of the idea that teeth with incomplete root development are less prone to orthodontically induced apical root resorption. Continued root elongation observed in second molars is probably a result of continued physiological

Table 2: Comparison of morphological changes of maxillary molars before and after orthodontic intrusion.

Tooth[a]	Measurement[b]	Mean (SD)			*p*-value
		Time 0	Time 1	Difference (mm)	
UR6	FP	19.86 (1.46)	18.88 (1.34)	−0.98 (0.26)	0.001
UR6	FMB	17.95 (1.17)	17.42 (1.34)	−0.53 (0.16)	0.004
UR6	FDB	18.39 (1.11)	17.42 (1.29)	−0.96 (0.21)	<0.001
UL6	FP	19.76 (1.26)	19.3 (1.35)	−0.47 (0.14)	0.004
UL6	FMB	17.42 (1.94)	17.4 (1.22)	−0.03 (0.36)	0.945
UL6	FDB	18.4 (1.13)	17.65 (1.07)	−0.75 (0.15)	<0.001

[a]UR6: Upper right first molar, UL6: Upper left first molar. [b]FP: Central fossa to apex of palatal root, FMB: Central fossa to apex of mesio-buccal root, FDB: Central fossa to apex of disto-buccal root, SD: standard deviation. $p < 0.05$ was considered statistically significant.

Table 3: Comparison of morphological changes of maxillary second molars before and after orthodontic intrusion.

Tooth[a]	Measurement[b]	Mean (SD)			*p*-value
		Time 0	Time 1	Difference (mm)	
UR7	FP	17.70 (2.05)	17.77 (1.22)	0.08 (0.42)	0.855
UR7	FMB	16.8 (1.68)	16.82 (1.14)	0.02 (0.43)	0.963
UR7	FDB	16.92 (1.67)	17.01 (1.33)	0.09 (0.49)	0.854
UL7	FP	17.86 (2.17)	18.17 (1.31)	0.32 (0.44)	0.483
UL7	FMB	16.87 (1.93)	17.36 (0.99)	0.49 (0.43)	0.272
UL7	FDB	17.05 (1.96)	17.36 (1.19)	0.31 (0.49)	0.530

[a]UR7: Upper right second molar, UL7: Upper left second molar. [b]FP: Central fossa to apex of palatal root, FMB: Central fossa to apex of mesio-buccal root, FDB: Central fossa to apex of disto-buccal root. SD: Standard deviation. $p < 0.05$ was considered statistically significant.

root formation and not a true lack of the influence of orthodontic forces. It has been quantitatively shown that immature teeth have a significantly lower risk of apical root resorption than fully developed teeth, a difference attributed to higher cellular activity, higher reparative capacity, and a wider apical foramen, which may allow better dissipation of mechanical stress.[12]

The present findings are consistent with this biological model and indicate that root maturity is an important deciding factor of resorptive risk during intrusive mechanics. From a clinical point of view, this brings the issue of the significance of taking into account the dental developmental stage when planning posterior intrusion, especially in younger patients where second molars may still be undergoing root formation.

Another strength of this study is the use of CBCT imaging for the evaluation of morphological root changes. Conventional two-dimensional imaging modalities, including panoramic radiographs, are limited, by their very nature, by distortion, magnification errors, and superimposition of anatomical structures that may mask subtle resorptive changes or cause inaccurate measurements.[17,19,20] CBCT enabled standardization of a three-dimensional view of root anatomy and accuracy in identifying apical landmarks in different planes to improve the accuracy of linear measurements of root length.[21] This methodological advantage is especially important when evaluating small variations in root length, such as those observed in orthodontically induced resorption, and adds to the validity of the present findings compared with previous studies that were only conducted using two-dimensional imaging.[20-22]

Despite the strengths, the study has a few limitations. The sample size of nineteen patients, while sufficient to detect meaningful differences in the primary outcomes, is modest. A larger cohort would provide greater confidence in the generalizability of the results. However, the use of a well defined single cohort design ensured methodological consistency across all measurements and helped minimize confounding variability.

Although CBCT offers a better spatial resolution than two-dimensional imaging, the volumetric analysis of root resorption was not possible because of imaging artifacts, including beam hardening, scatter, and noise that are inherent to CBCT imaging. These limitations required the use of linear measurements as opposed to actual volumetric measurements. While linear measurements are well accepted and of clinical interest, they can underestimate localized or irregular resorptive defects.[22] Future research using larger sample sizes, more standardized force magnitudes, and

advanced techniques of volumetric analysis of the response are warranted to further elucidate segment-level and root-specific responses to miniplate-anchored intrusion.

CONCLUSION

Miniplate-anchored intrusion results in limited (<1 mm) and clinically acceptable root resorption in maxillary premolars and first molars with mature apices. In contrast, maxillary second molars with immature roots do not exhibit OIRR and may continue physiologic root development. During posterior intrusion, clinicians should closely monitor palatal and distobuccal roots, which appear most susceptible to resorptive changes.

Ethical approval: The research/study was approved by the Institutional Review Board at Georgia School of Orthodontics, number IRB No.12049, dated April 04, 2024.
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Use of artificial intelligence (AI)-assisted technology for manuscript preparation: The authors confirm that there was no use of Artificial Intelligence (AI)-Assisted Technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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