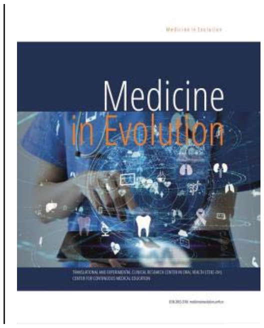
Alveolar Bone Response to Controlled Orthodontic Maxillary Incisor Vestibularization



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Abstract

1. Background/Objectives: Orthodontic proclination of retroclined maxillary incisors is frequently required for functional and esthetic correction; however, excessive movement may exceed the biological limits of the alveolar housing and compromise periodontal health. Understanding alveolar bone remodeling in response to controlled incisor vestibularization is essential for safe orthodontic planning. This study aimed to quantitatively assess alveolar bone thickness changes associated with controlled orthodontic vestibularization of retroclined maxillary incisors using standardized cephalometric and CBCT measurements, and to analyze the relationship between these changes, incisor displacement, and skeletal stability.*2. Methods*: Nineteen patients presenting with retroclined maxillary incisors underwent orthodontic treatment involving controlled incisor vestibularization. Cephalometric and CBCT-derived measurements were standardized using the SN–7° reference plane and perpendicular orientation to the incisor long axis (⊥U1). ABT was assessed at the cementoenamel junction, 3 mm, and 6 mm apical levels on both labial and lingual surfaces. Dental and skeletal parameters including U1–SN, U1–NA, L1–NB, and SN–MP were recorded pre- and post-treatment. Paired statistical comparisons were performed. 3. *3. Results:* Maxillary incisor proclination increased significantly, as demonstrated by substantial rises in U1–SN and U1–NA values. Labial alveolar bone thickness showed significant increases at mid-root and apical levels, indicating adaptive bone apposition on the tension side. In contrast, lingual ABT decreased significantly at corresponding levels, reflecting pressure-side resorption. No significant changes were observed in skeletal parameters, confirming predominantly dentoalveolar effects. Crestal bone thickness remained stable, suggesting a low periodontal risk. *4. Conclusions:* Controlled vestibularization of retroclined maxillary incisors induces predictable alveolar remodeling characterized by labial bone apposition and lingual resorption without compromising skeletal balance or crestal periodontal support. When performed within biological limits, incisor proclination appears to be a safe and effective orthodontic strategy.

Keywords: orthodontic vestibularization, alveolar bone, incisors, skeletal parameters

INTRODUCTION

Class II Division 2 malocclusion represents a relatively common dentofacial anomaly among Caucasian populations, with a reported prevalence ranging between 2.3% and 5%, according to data from the literature [1,2]. The classical classification of malocclusions proposed by Edward Angle defines Class II by a distal positioning of the mandibular first molar relative to the maxillary first molar. At the same time, Division 2 is clinically characterized by retroclination of the maxillary incisors and the presence of an increased deep overbite, features currently regarded as defining characteristics of this malocclusion type [1,2]. Although the dental manifestations are readily apparent, numerous authors have emphasized the complex and multifactorial etiology of Class II Division 2 malocclusion, suggesting the presence of an associated skeletal component [2-4]. The mandible may exhibit insufficient growth or a posterior positioning relative to the maxilla and cranial base, contributing to the sagittal discrepancy observed in these patients [4,5]. In this context, Class II Division 2 malocclusion is understood as the result of interactions among dental, skeletal, and muscular factors [1-5]. The maxillary incisors occupy a central position in the anterior region of the oral cavity and play a crucial role in both function and dentofacial aesthetics. They influence upper lip support, phonetics, masticatory efficiency, and facial profile harmony, exerting a major impact on smile perception and patient self-image [6]. Studies have shown that the primary motivation for seeking orthodontic treatment is often aesthetic in nature, with patients associating dental appearance with social integration and professional success [7,8].

Within this framework, establishing an appropriate inclination of the anterior incisors represents a fundamental objective of orthodontic treatment, as their faciolingual angulation affects smile contour, anterior guidance, and the stability of Class I canine and molar relationships [9,10]. In the management of Class II Division 2 malocclusion, treatment frequently involves controlled proclination of both maxillary and mandibular incisors to reduce deep overbite and achieve functional occlusal relationships [2,4,9,10,11]. However, such movements must remain within the biological limits of the alveolar bone to prevent periodontal complications. The literature reports variable findings regarding the relationship between incisor proclination and periodontal health. Kloukos and Kobylyanskyy associated excessive proclination of the mandibular incisors with a higher incidence of periodontal problems [9,12], while Pilloni demonstrated through computed tomography that significant changes in tooth inclination may predispose to alveolar bone dehiscences and fenestrations, particularly in adult patients [13]. Conversely, Celis et al. showed that in children and adolescents, incisor proclination is not necessarily associated with gingival recession [14], although patients with severe Class II malocclusion may present an increased risk due to reduced apical base dimensions [14,15]. These conclusions are supported by the studies of Morris et al., who reported that orthodontic treatment itself does not constitute a major determinant for gingival recession and that the clinical impact of extensive maxillary expansions is generally limited [16]. Similarly, Colet et al. observed an absence of gingival recession in patients treated with the Twin Force appliance, emphasizing the importance of biomechanical control in preserving periodontal health [17].

Advances in imaging techniques have further elucidated the relationship between orthodontic tooth movement and alveolar bone remodeling. Sarikaya et al. demonstrated that incisor retraction may be associated with alveolar bone loss, particularly on the lingual surface, and highlighted the limitations of two-dimensional radiographs in detecting dehiscences [18]. Comparable findings were reported by Hong et al., who observed minor, clinically insignificant changes in labial alveolar bone thickness [19], as well as by Elnagar et al., who documented a reduction in lingual bone thickness following incisor retraction using skeletal anchorage [20]. A particularly relevant contribution to understanding alveolar remodeling in Class II Division 2 malocclusion was provided by Kang et al., who analyzed alveolar bone changes following correction of initially retroclined incisors using cone-beam computed tomography (CBCT) [21]. The authors reported that an average proclination of approximately 15° of the maxillary incisors did not result in significant changes in facial alveolar bone height, although a reduction in palatal bone height and thickness was observed. Similar results were described by Chen et al., who demonstrated through three-dimensional CBCT analyses a differential alveolar bone response depending on the surface examined and the treatment modality employed, with a potential biological advantage associated with clear aligner therapy [22].

Overall, the available evidence suggests that the relationship between incisor proclination and alveolar bone remodeling is complex and influenced by multiple variables, including the type of tooth movement, biomechanical control, patient age, and initial alveolar morphology.

Aim and objectives

This study aimed to investigate, using standardized cephalometric and CBCT analysis, the dentoalveolar changes induced by controlled vestibularization of retroclined maxillary incisors. Specifically, the study sought to quantify variations in labial and lingual alveolar bone thickness at different root levels and to evaluate their correlation with incisor inclination, positional changes, and skeletal parameters before and after orthodontic treatment.

MATERIALS AND METHODS

Study Sample and Selection Criteria

This retrospective study included 19 patients treated at the Department of Orthodontics between 2021 and 2024. The orthodontic treatments were conducted over a mean duration of approximately 18–24 months, and radiographic records were obtained at two standardized time points: before treatment initiation (T0) and immediately after completion of active orthodontic therapy (T1). The sample consisted of patients diagnosed with Class II Division 2 malocclusion presenting retroclined maxillary incisors requiring orthodontic vestibularization.

The inclusion criteria comprised the presence of permanent dentition, retroclined maxillary incisors (U1–SN < 100°), the availability of both pre-treatment and post-treatment cephalometric radiographs and CBCT scans, the absence of any previous orthodontic treatment, and good periodontal health at baseline.

The exclusion criteria included the presence of craniofacial anomalies, systemic conditions that could affect bone metabolism, periodontal disease, and incomplete radiographic records

All patients underwent comprehensive orthodontic treatment involving controlled vestibularization of the maxillary incisors using fixed appliances.

To ensure measurement reproducibility, cephalometric and CBCT analyses were performed using stable anatomical landmarks and standardized reference planes.

Cephalometric Reference Planes and Skeletal Angles

The Sella–Nasion (SN) plane, defined by the line connecting Sella (S) and Nasion (N), was used as a cranial reference due to its post-childhood stability [23]. To reduce variability related to head positioning and approximate the functional horizontal plane, measurements were oriented to SN–7°, a commonly applied correction in contemporary cephalometric studies [23,24]. Sagittal skeletal relationships were assessed using SNA, SNB, and ANB angles. SNA evaluated maxillary position relative to the cranial base (normal ≈82° ± 2°), SNB assessed mandibular position (≈80° ± 2°), and ANB classified skeletal relationships as Class I (2° ± 2°), Class II (>4°), or Class III (<0°) [24]. The stability of these parameters confirmed that observed changes were predominantly dentoalveolar rather than skeletal. Vertical facial pattern was evaluated using the SN–mandibular plane (SN–MP) angle, with higher values indicating hyperdivergent growth and lower values indicating hypodivergence, a factor known to influence anterior alveolar bone morphology.

Dental Cephalometric Measurements

The maxillary central incisor (U1) was analyzed due to its key role in aesthetics and occlusal function [25]. Axial inclination was assessed using the U1–SN angle (normal ≈102° ± 5.5°), where reduced values indicated retroclination and increased values indicated proclination. This parameter served as both an inclusion criterion and the primary indicator of treatment-induced decompensation. Incisor position and torque were further evaluated using U1–NA angular and linear measurements. Increases in U1–NA (°) and U1–NA (mm) reflected labial movement of the incisor and allowed differentiation between tipping and bodily movement [25]. Mandibular incisor position was monitored using the linear measurement L1–NB (mm), a classical Steiner parameter used to assess dental compensation during orthodontic treatment [26].

Alveolar Bone Thickness Assessment

Alveolar bone thickness (ABT) was evaluated to determine the biological limits of incisor proclination and the risk of periodontal complications such as dehiscence, fenestration, and attachment loss [13]. ABT was defined as the distance between the root surface and the cortical plate of the alveolar bone and was measured on both labial and palatal/lingual surfaces. Measurements were obtained at three standardized levels: at the cementoenamel junction (CEJ), 3 mm apical to the CEJ, and 6 mm apical to the CEJ, corresponding to crestal, mid-root, and apical regions, respectively. This protocol enabled site-specific evaluation of alveolar remodeling [27].

Reference Systems for ABT Measurement

ABT measurements were performed using two perpendicular reference orientations:

(1) perpendicular to the SN–7° plane to ensure cranial standardization and interindividual comparability, and

(2) perpendicular to the long axis of the maxillary incisor (⊥U1) to reflect biologically relevant root–bone relationships. The combined approach minimized orientation bias and enhanced measurement validity.

Examiner Reliability

Intra-examiner reliability was assessed using the intraclass correlation coefficient (ICC) to ensure measurement consistency and reduce systematic error.

RESULTS

Intra-examiner reliability analysis demonstrated excellent measurement reproducibility, with intraclass correlation coefficients (ICCs) ranging from 0.89 to 0.96, indicating high consistency of repeated cephalometric and CBCT measurements. A total of 19 patients met the inclusion criteria and were analyzed in this study. The sample consisted of 10 male patients (mean age: 14.3 years) and 9 female patients (mean age: 15.2 years).

The initial descriptive cephalometric values indicated a predominantly skeletal Class I pattern, with retroclined maxillary incisors, in accordance with the selection criteria. The mean values and standard deviations for the main pre-treatment skeletal and dental parameters were as follows:

- SNA: 79.48° ± 4.48
- SNB: 77.08° ± 3.51
- ANB: 2.39° ± 2.19
- U1–SN: 92.03° ± 2.74
- U1–NA: 12.56° ± 5.85
- U1–NA (mm): 1.97 ± 2.44
- L1–NB (mm): 1.35 ± 1.96
- SN–MP: 32.87° ± 6.83

Table 1. Cephalometric and alveolar bone thickness measurements before and after orthodontic treatment (N= 19)

Parameter	Pre-treatment Mean ± SD	Post-treatment Mean ± SD	Change (Δ)
Alveolar bone thickness — labial (SN–7°)			
CEJ level (a)	0.60 ± 0.49 mm	0.32 ± 0.36 mm	−0.28
3 mm apical (b)	1.11 ± 0.36 mm	1.42 ± 0.58 mm	+0.31
6 mm apical (c)	1.19 ± 0.47 mm	2.02 ± 1.39 mm	+0.83
Alveolar bone thickness — lingual (SN–7°)			
CEJ level (a)	0.52 ± 0.70 mm	0.51 ± 0.86 mm	−0.01
3 mm apical (b)	3.07 ± 1.03 mm	2.66 ± 1.11 mm	−0.41
6 mm apical (c)	5.37 ± 1.26 mm	4.15 ± 1.71 mm	−1.22
Alveolar bone thickness — labial (⊥U1)			
CEJ level (a)	0.63 ± 0.53 mm	0.38 ± 0.41 mm	−0.25
3 mm apical (b)	1.10 ± 0.36 mm	1.28 ± 0.56 mm	+0.18
6 mm apical (c)	1.13 ± 0.49 mm	1.70 ± 1.19 mm	+0.57
Alveolar bone thickness — lingual (⊥U1)			
CEJ level (a)	0.49 ± 0.62 mm	0.26 ± 0.49 mm	−0.23
3 mm apical (b)	2.75 ± 0.83 mm	1.94 ± 0.72 mm	−0.81
6 mm apical (c)	4.85 ± 0.96 mm	3.19 ± 1.31 mm	−1.66
Dental and skeletal parameters			
U1–SN (°)	92.03 ± 2.74	102.09 ± 8.63	+10.06
U1–NA (°)	12.56 ± 5.85	22.16 ± 7.66	+9.60
U1–NA (mm)	1.97 ± 2.44	3.88 ± 2.78	+1.91
L1–NB (mm)	1.35 ± 1.96	4.25 ± 2.78	+2.90
SN–MP (°)	32.87 ± 6.83	31.82 ± 8.11	−1.05

Orthodontic treatment induced significant dentoalveolar changes, characterized by a marked increase in the angulation and protrusion of the maxillary incisors. This was evidenced by increases in U1–SN (from 92.03° ± 2.74 to 102.09° ± 8.63) and U1–NA values, as well as by a linear advancement of the incisors from 1.97 ± 2.44 mm to 3.88 ± 2.78 mm. Labial alveolar bone thickness demonstrated adaptive remodeling, with a slight reduction at the crestal level and a significant increase at the mid-root and apical levels, suggesting localized bone apposition in response to tooth movement. In contrast, lingual alveolar bone thickness decreased significantly across all measured levels, particularly at the mid-root and apical regions, reflecting root displacement toward the palatal cortical plate and pressure-side bone resorption. Skeletal parameters remained stable throughout treatment, with no statistically significant changes observed in SNA, SNB, or ANB angles, confirming the absence of major skeletal modifications. Vertical skeletal relationships were also preserved, as indicated by minimal variation in the SN–MP angle.

Collectively, these findings confirm that the orthodontic corrections achieved were predominantly dentoalveolar in nature and occurred within the physiological limits of alveolar bone remodeling, without compromising skeletal harmony. Correlation analysis indicated a positive association between the degree of maxillary incisor proclination (U1–SN, U1–NA) and increases in labial alveolar bone thickness at mid-root and apical levels, while a negative correlation was observed with lingual bone thickness reduction, reflecting the biological pattern of tension-side apposition and pressure-side resorption.

DISCUSSIONS

The primary aim of this study was to evaluate changes in labial and lingual alveolar bone thickness associated with the vestibularization of retroclined maxillary incisors using lateral cephalometric analysis. A secondary objective was to correlate these changes with dental movements and skeletal stability to determine whether orthodontic tooth movement remained within the biological limits of the alveolar housing.

The results allow an integrated dentoalveolar interpretation and provide clinically relevant orthodontic and periodontal insights, consistent with biomechanical and biological principles described in the literature.

One of the most important findings was the significant increase in U1–SN and U1–NA values, both angularly and linearly. These changes indicate substantial proclination and labial displacement of the maxillary incisors, confirming the effectiveness of orthodontic treatment in correcting initial retroclination.

The mean increase in U1–SN of approximately 8–10° and in U1–NA of around 7–9° falls within the limits reported by Lanteri et al., who described such values as compatible with controlled dental decompensation without inducing skeletal or periodontal instability [28]. Moreover, the significant increase in U1–NA (mm) confirms true anterior bodily movement rather than mere torque alteration. Clinically, these modifications are essential for correcting dental inclination, achieving functional occlusion, and improving anterior facial aesthetics. Skeletal parameters (SNA, SNB, and ANB) did not show statistically significant changes throughout treatment. This is particularly relevant, as it confirms that the observed modifications were predominantly dentoalveolar rather than the result of orthopedic or growth-related skeletal changes. The stability of the ANB angle indicates preservation of sagittal maxillomandibular relationships, supporting the concept that incisor proclination was achieved without compromising facial skeletal balance. The literature emphasizes that alveolar changes should always be interpreted within the context of skeletal stability to avoid misattributing biological remodeling to dental movement alone [29].

A key outcome of this study was the significant increase in labial alveolar bone thickness, particularly at mid-root and apical levels (b and c), measured both relative to the SN–7° plane and perpendicular to the incisor long axis. These findings support the concept of adaptive bone remodeling, extensively described by Kalina et al., whereby alveolar bone responds favorably to controlled orthodontic forces through apposition on the tension side. The increase in labial bone thickness suggests that incisor vestibularization occurred within an alveolar envelope capable of biological adaptation [30]. Importantly, no significant changes were observed at the CEJ level, a region considered critical from a periodontal perspective. This suggests that treatment did not increase the risk of gingival recession, a conclusion consistent with the findings of Verdecchia et al., who reported that apical bone changes are more frequent and biologically safer than coronal alterations [31].

In contrast, lingual alveolar bone thickness decreased significantly at mid-root and apical levels, particularly when measurements were taken perpendicular to the incisor long axis. This observation aligns with biomechanical principles of orthodontic tooth movement, whereby root displacement toward the palatal cortical plate induces bone resorption on the pressure side. The literature confirms that lingual bone reduction is an expected response during incisor proclination, provided that movement remains within biological limits and does not result in direct root–cortical contact. The values obtained in this study suggest controlled remodeling rather than pathological bone loss [13]. A notable methodological strength of this study is the use of two reference orientations for ABT measurement: SN–7° and perpendicular to the incisor long axis (⊥U1). The differences observed between these methods support recent literature emphasizing that tooth-axis–oriented measurements provide a more realistic assessment of root–bone relationships. The fact that the most pronounced and statistically significant changes were detected using ⊥U1 reinforces the biological validity of this approach and justifies its inclusion in alveolar bone assessment protocols. The significant increase in L1–NB (mm) reflects mandibular incisor protrusion, suggesting a global dental compensation mechanism. Clinically, this demonstrates that treatment was not confined to the maxillary arch but involved coordinated alignment of both arches.

Orthodontic studies highlight the importance of evaluating mandibular incisor response during maxillary decompensation to ensure occlusal stability and a harmonious facial profile. From a periodontal standpoint, the findings are encouraging. The absence of significant labial bone reduction at the CEJ suggests a low risk of post-treatment gingival recession. This is particularly relevant, as recession is frequently associated with excessive labial movement of incisors within thin alveolar envelopes. Bucur et al. demonstrated that tooth position plays a more critical role in recession development than gingival biotype [32]. The present results suggest that incisor positioning remained within safe biological limits. Study limitations include the use of two-dimensional cephalometric analysis, which does not allow full three-dimensional evaluation of the alveolar housing, the relatively small sample size, and the absence of direct clinical periodontal assessment. Nevertheless, the standardized methodology and rigorous comparative analysis enhance the validity of the findings.

Overall, this study demonstrates that controlled vestibularization of retroclined maxillary incisors can be performed safely within biological limits when closely monitored through alveolar bone assessment. The integration of dental, alveolar, and skeletal parameters provides a valuable predictive model for individualized orthodontic treatment planning.

CONCLUSIONS

This study demonstrates that orthodontic vestibularization of retroclined maxillary incisors produces significant dentoalveolar changes while preserving skeletal stability and periodontal safety. The observed increase in labial alveolar bone thickness at mid-root and apical levels confirms the capacity of the alveolar process for adaptive remodeling in response to controlled orthodontic forces. Conversely, the reduction in lingual alveolar bone thickness reflects expected pressure-side resorption associated with anterior tooth movement, without evidence of pathological bone loss or breach of biological limits. The stability of crestal bone thickness further supports the periodontal safety of the treatment protocol applied.

The absence of significant skeletal changes emphasizes that the observed effects were primarily dental and alveolar in nature. The use of dual reference orientations for ABT measurement enhanced the biological validity of the analysis and highlighted the clinical relevance of tooth-axis–based assessment. Overall, these findings support the concept that carefully planned and biologically guided incisor proclination can be safely achieved within the alveolar envelope. Integrating cephalometric, alveolar, and skeletal parameters offers a reliable framework for individualized orthodontic treatment planning and risk assessment.

Future research incorporating three-dimensional imaging and larger sample sizes is recommended to further refine predictive models of alveolar remodeling and periodontal response.

Conflicts of Interest

The authors declare no conflict of interest.

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