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Phone: +90 212 217 17 00
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TURKISH JOURNAL of ORTHODONTICS

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Turkish Journal of Orthodontics (Turk J Orthod) is an international, scientific, open access periodical published in accordance with independent, unbiased, and double-blinded peer-review principles. The journal is the official publication of Turkish Orthodontic Society and it is published quarterly on March, June, September and December.

Turkish Journal of Orthodontics publishes clinical and experimental studies on on all aspects of orthodontics including craniofacial development and growth, reviews on current topics, case reports, editorial comments and letters to the editor that are prepared in accordance with the ethical guidelines. The journal's publication language is English and the Editorial Board encourages submissions from international authors.

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Editor in Chief: Derya Germeç Çakan
Address: Bağdat Cad. No: 238, Göztepe,34728 İstanbul/Turkey
Phone: +90 216 468 08 00
Fax: +90 216 468 08 00
E-mail: info@turkjorthod.org

Publisher: AVES
Address: Büyükdere Cad. 105/9 34394 Mecidiyeköy, Şişli, İstanbul, Turkey
Phone: +90 212 217 17 00
Fax: +90 212 217 22 92
E-mail: info@avesyayincilik.com
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Table 1. Limitations for each manuscript type

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|---|---|---|---|---|---|
| ORIGINAL ARTICLE | 4500 | 250 (Structured) | 30 | 6 | 7 or total of 15 images |
| REVIEW ARTICLE | 5000 | 250 | 50 | 6 | 10 or total of 20 images |
| CASE REPORT | 1000 | 200 | 15 | No tables | 10 or total of 20 images |
| LETTER TO THE EDITOR | 500 | No abstract | 5 | No tables | No media |

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Tables should be included in the main document, presented after the reference list, and they should be numbered consecutively in the order they are referred to within the main text. A descriptive title must be placed above the tables. Abbreviations used in the tables should be defined below the tables by footnotes (even if they are defined within the main text). Tables should be created using the "insert table" command of the word processing software and they should be arranged clearly to provide easy reading. Data presented in the tables should not be a repetition of the data presented within the main text but should be supporting the main text.

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Figures, graphics, and photographs should be submitted as separate files (in TIFF or JPEG format) through the submission system. The files should not be embedded in a Word document or the main document. When there are figure subunits, the subunits should not be merged to form a single image. Each subunit should be submitted separately through the submission system. Images should not be labeled (a, b, c, etc.) to indicate figure subunits. Thick and thin arrows, arrowheads, stars, asterisks, and similar marks can be used on the images to support figure legends. Like the rest of the submission, the figures too should be blind. Any information within the images that may indicate an individual or institution should be blinded. The minimum resolution of each submitted figure should be 300 DPI. To prevent delays in the evaluation process, all submitted figures should be clear in resolution and large in size (minimum dimensions: 100 × 100 mm). Figure legends should be listed at the end of the main document.

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When a drug, product, hardware, or software program is mentioned within the main text, product information, including the name of the product, the producer of the product, and city and the country of the company (including the state if in USA), should be provided in parentheses in the following format: "Discovery St PET/CT scanner (General Electric, Milwaukee, WI, USA)"

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**Book Section:** Suh KN, Keystone JS. Malaria and babesiosis. Gorbach SL, Barlett JG, Blacklow NR, editors. Infectious Diseases. Philadelphia: Lippincott Williams; 2004.p.2290-308.

**Books with a Single Author:** Sweetman SC. Martindale the Complete Drug Reference. 34th ed. London: Pharmaceutical Press; 2005.

**Editor(s) as Author:** Huizing EH, de Groot JAM, editors. Functional reconstructive nasal surgery. Stuttgart-New York: Thieme; 2003.

**Conference Proceedings:** Bengisson S. Sothemin BG. Enforcement of data protection, privacy and security in medical informatics. In: Lun KC, Degoulet P, Piemme TE, Rienhoff O, editors. MEDINFO 92. Proceedings of the 7th World Congress on Medical Informatics; 1992 Sept 6-10; Geneva, Switzerland. Amsterdam: North-Holland; 1992. pp.1561-5.

**Scientific or Technical Report:** Cusick M, Chew EY, Hoogwerf B, Agrón E, Wu L, Lindley A, et al. Early Treatment Diabetic Retinopathy Study Research Group. Risk factors for renal replacement therapy in the Early Treatment Diabetic Retinopathy Study (ETDRS), Early Treatment Diabetic Retinopathy Study Kidney Int: 2004. Report No: 26.

**Thesis:** Yılmaz B. Ankara Üniversitesindeki Öğrencilerin Beslenme Durumları, Fiziksel Aktiviteleri ve Beden Kitle İndeksleri Kan Lipidleri Arasındaki Ilişkiler. H.Ü. Sağlık Bilimleri Enstitüsü, Doktora Tezi. 2007.

**Manuscripts Accepted for Publication, Not Published Yet:** Slots J. The microflora of black stain on human primary teeth. Scand J Dent Res. 1974.

**Epub Ahead of Print Articles:** Cai L, Yeh BM, Westphalen AC, Roberts JP, Wang ZJ. Adult living donor liver imaging. Diagn Interv Radiol. 2016 Feb 24. doi: 10.5152/dir.2016.15323. [Epub ahead of print].

**Manuscripts Published in Electronic Format:** Morse SS. Factors in the emergence of infectious diseases. Emerg Infect Dis (serial online) 1995 Jan-Mar (cited 1996 June 5): 1(1): (24 screens). Available from: URL: http:/ www.cdc.gov/ncidodlEID/cid.htm.

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When submitting a revised version of a paper, the author must submit a detailed "Response to the reviewers" that states point by point how each issue raised by the reviewers has been covered and where it can be found (each reviewer's comment, followed by the author's reply and line numbers where the changes have been made) as well as an annotated copy of the main document. Revised manuscripts must be submitted within 30 days from the date of the decision letter. If the revised version of the manuscript is not submitted within the allocated time, the revision option may be canceled. If the submitting author(s) believe that additional time is required, they should request this extension before the initial 30-day period is over.

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Editor in Chief: Derya Germeç Çakan
Address: Bağdat Cad. No: 238, Göztepe,34728 İstanbul/Turkey
Phone: +90 216 468 08 00
Fax: +90 216 468 08 00
E-mail: info@turkjorthod.org

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Address: Büyükdere Cad. 105/9 34394 Mecidiyeköy, Şişli, İstanbul, Turkey
Phone: +90 212 217 17 00
Fax: +90 212 217 22 92
E-mail: info@avesyayincilik.com
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TURKISH JOURNAL of
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# Contents

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Original Article

# Evaluation of Risk Factors for Severe Apical Root Resorption in the Maxillary Incisors Following Fixed Orthodontic Treatment

Bashar Shahrure, Ahu Acar

Department of Orthodontics, Marmara University, Faculty of Dentistry, İstanbul, Turkey

Cite this article as: Shahrure B, Acar A. Evaluation of risk factors for severe apical root resorption in the maxillary incisors following fixed orthodontic treatment. *Turk J Orthod.* 2022;35(2):75-83.

Main Points

- Severe EARR is multifactorial in origin.
- Treatment duration, treatment type, alveolar bone thickness, and amount of orthodontic movement play a major role in the development of severe EARR.
- These factors should be taken into consideration when planning orthodontic treatment.

## ABSTRACT

**Objective:** The aim of this study was to retrospectively determine the prevalence of severe external root resorption in maxillary incisors during fixed orthodontic treatment and to evaluate the possible predisposing factors.

**Methods:** The treatment records of 7000 patients who had been treated between 1990 and 2019 at the Department of Orthodontics Faculty of Dentistry Marmara University were examined, and a total of 120 patients with severe root resorption in at least one of their upper incisors were identified. The following data were retrieved from the patients' records and radiographs: gender, root morphology, overjet, overbite, treatment modality (extraction, non-extraction), treatment duration, buccal and palatal alveolar bone thickness for the maxillary incisors, and amount of movement of the incisal root apices and incisal edges. These data from a group of 90 patients with severe root resorption were compared with the data from a control group of 90 patients with minimal root resorption. The Chi-square test, the Mann–Whitney *U*-test, and the independent *t*-test were used for statistical analysis.

**Results:** The prevalence of severe external root resorption was 3.23%, and the results demonstrated significant difference between the groups for the variables of treatment modality (extractions), treatment duration, thickness of the alveolar bone, and amount of incisor movement at the end of the treatment.

**Conclusion:** It can be concluded that extractions, increased treatment duration, thin alveolar bone, and excessive incisor movement represent risk factors for severe root resorption in maxillary incisors following orthodontic treatment.

**Keywords:** Orthodontics, external root resorption, maxillary incisors, root morphology, bone thickness

## INTRODUCTION

External apical root resorption (EARR) is an unwanted side effect following orthodontic treatment, as a result of induced tooth movement.[1,2] However, EARR can be avoided, and its severity and the number of affected teeth can be reduced.[3] The diagnosis of EARR is generally done by using periapical and panoramic radiographs,[4] and it is usually asymptomatic. The function and retention of the affected teeth are at risk only if severe resorption causes significant root loss.[5,6]

**Corresponding author**: Bashar Shahrure, e-mail: Basharshahrure@gmail.com


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Malmgren et al.[7] proposed a scoring system to classify the teeth, to assess EARR severity. It is a visual qualitative approach that is relatively subjective.

The root resorption classification scores, according to Malmgren et al.,[7] are as follows: score 0, absence of root resorption; score 1, irregularity in the apical root contour; score 2, resorption of up to 2 mm; score 3, resorption from 2 mm up to 1/3 of the root; and score 4, loss greater than 1/3 of the root length.

The etiology and mechanisms of action of EARR with an orthodontic origin are not fully understood; many studies have reported a multifactorial etiology involving both individual factors (age, individual susceptibility, systemic disease, genetic factors, root morphology, etc.) and other factors associated with orthodontic treatment (duration, type of appliance, extractions, magnitude of applied force, range of movement, etc.).[8,9] Studies have revealed that maxillary anterior teeth are more likely to develop severe EARR than other teeth.[10]



The aim of this retrospective study was to determine the prevalence and the predisposing factors of severe EARR in the maxillary incisors in patients treated at Marmara University, Faculty of Dentistry, Department of Orthodontics. The findings of this study will be useful for a self-assessment of the outcomes of treatments provided in our department and for the orthodontic community, and to show the extent to which we were able to maintain biological integrity of the dentition when striving for optimal orthodontic outcomes. By helping practitioners to determine potential risk factors, we will be able to plan the orthodontic treatment by taking into consideration the predisposing factors related to the development of EARR.

## METHODS

### Ethical Approval

The Ethical Committee of the Institute of Health Sciences, Marmara University approved of this retrospective study, which assessed the records of 7000 patients from the archives of Marmara University, Faculty of Dentistry, Department of Orthodontics (Protocol number: 2019-326).

### Patient Selection

The treatment files of 7000 patients who had been treated in Marmara University between 1990 and 2019 were examined, considering the following:

Inclusion criteria:

- Completed fixed orthodontic treatment with 0.018”-slot edgewise multibracket system
- Presence of pretreatment and post-treatment radiographic films (panoramic and cephalometric radiographs)
- Completed root development of the maxillary incisors before fixed orthodontic treatment
- No visible EARR in the maxillary incisors before the treatment
- Root resorption scored 4 according to Malmgren et al.[7] in one or more of the maxillary incisors following fixed orthodontic treatment

The exclusion criteria were:

- Radiographs with low quality
- Teeth that had been endodontically treated
- Incompletely developed root apex
- Mild or moderate EARR of the incisors
- Patients with missing radiographic records
- Patients with history of trauma to the incisors before the start of the treatment
- Patients treated with removable appliances
- Patients treated with a surgical approach
- Patients presented with cleft lip/palate
- Patients presented with systemic conditions like asthma, and patients with chronic use of medications affecting orthodontic tooth movement, such as bisphosphonate
- Patients presented with history of parafunctional habits

After scanning of all patients' archives, the total number of subjects with severe EARR anteriorly was found to be 120, while mild/moderate EARR was found in 3595 of the patients. Of the original sample size, 3285 subjects were excluded for the following reasons: 2316 patients with missing files, 244 patients who had been treated with removable appliances and did not go through fixed orthodontic treatment, 375 patients who had been treated by orthognathic surgical approach, and 350 patients who had presented with cleft lip/palate.

Of the patients in the study group who presented with severe EARR, a second scanning was performed for 120 patients, and 30 patients were excluded due to incomplete records, of whom 2 were patients with missing pre-orthodontic cephalometric radiographs, and 28 were patients with missing post-orthodontic cephalometric radiographs.

Once all subjects with severe EARR (score 4) were identified, a group of 90 control subjects were randomly selected among the patients identified with minimal EARR (score 1) for statistical comparisons.

Inclusion criteria for the control group:

- Completed fixed orthodontic treatment with 0.018”-slot edgewise multibracket system
- Presence of pretreatment and post-treatment radiographs (panoramic and cephalometric radiographs)
- Completed root development of the maxillary incisors before fixed orthodontic treatment
- No visible EARR in the maxillary incisors before the treatment
- Root resorption scored 1 according to Malmgren et al.[7] in the maxillary incisors following fixed orthodontic treatment

Exclusion criteria for the control group:

- Radiographs with inferior quality

- Teeth that had been endodontically treated
- Incompletely developed root apex
- Severe EARR of the incisors
- Patients with missing radiographic records
- Patients with a history of trauma to the incisors before the start of the treatment
- Patients treated with removable appliances
- Patients treated with surgical approach
- Patients presented with cleft lip/palate
- Patients presented with systemic conditions like asthma, and patients presented with chronic use of medications affecting orthodontic tooth movement, such as bisphosphonate
- Patients presented with history of parafunctional habits

The final sample consisted of a study group of 90 patients and a control group of 90 patients. The gender distribution was 44 males and 46 females in the study group and 40 males and 50 females in the control group. The mean age at the beginning of orthodontic treatment in the study and control groups was 16.69 years and 15.35 years, respectively.

**Treatment Protocol**

Patients who presented to the clinic in Marmara University, Faculty of Dentistry, Department of Orthodontics were diagnosed, examined, and treated under supervision of the specialists and professors. Treatment started with fixed appliances of 18"-slot brackets. The initial phase, alignment of the dentition, was initiated by round NiTi wires, followed by rectangular wires. The working phase followed later, ending with stainless steel wires, and elastics were used as needed.

**Data Collection**

The initial archival scanning was performed by checking and evaluating the pre-operative and post-operative panoramic radiographs of the whole sample (Figure 1), and subjects who presented with severe (score 4) EARR at the end of treatment were selected.

To determine potential predisposing factors of EARR, the following data were retrieved from the patients' files:

- Gender
- Root morphology
- Overjet
- Overbite
- Treatment modality (extraction, non-extraction)
- Treatment duration
- Labial and palatal alveolar bone thickness in the maxillary incisor region
- Amount of movement of the incisal root apices and incisal edges in both horizontal and vertical directions

**Data Assessment**

Root morphology was assessed on post-operative panoramic radiographs according to the classification proposed by Quintanilha et al.,[11] as follows: rhomboid, triangular, dilacerated, and pipette (Figure 2).

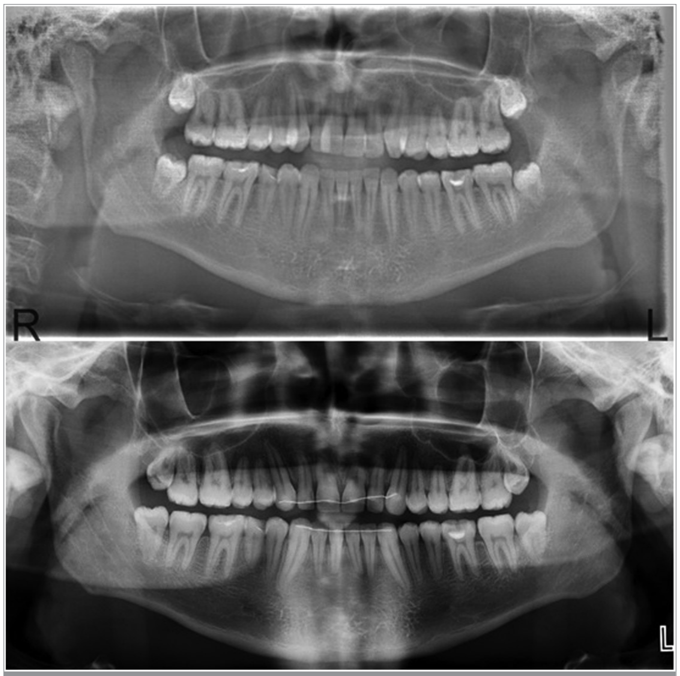


**Figure 1.** Pre-operative (above) and post-operative (below) panoramic radiographs



Overjet, overbite, buccal and palatal maxillary alveolar bone thickness, and amount of movement of the incisal root apices and incisal edges were assessed on cephalometric radiographs using cephalometric tracing software (Nemotec version 10.4.2, Software Nemotec S.L., Spain).

**Cephalometric Analysis**

Cephalometric radiographs were used to record the changes in overjet, overbite, labial and palatal maxillary alveolar bone thickness, and amount of movement of the maxillary incisors' apices and incisal edges between pre-orthodontic treatment and post-orthodontic treatment records, between the 2 groups—the anterior EARR group and the control group. Cephalometric tracing software was used to trace all cephalometric radiographs, and the radiographs were all traced by the same examiner. The cephalometric points and planes used are shown in Figure 3, and described in Table 1.

**Method of Measurement**

Evaluations on panoramic radiographs were carried out according to Malmgren's proposed method, which, despite being relatively subjective, has the advantage of not depending on the standardization of the radiograph.[12] Calibration of both pre- and post-operative cephalometric radiographs was performed as an initial step prior to recording any measurement. Cephalometric radiographs were calibrated using the length of the middle cranial base for every patient; the growth of middle cranial base is completed in early periods and at the age of 7 years, maintaining its stability in all developmental phases.[13] Two cephalometric landmarks found in the middle cranial base show high stability over the years.[13,14] These points are: the lower contours of the anterior clinoid processes intersecting the contour of the anterior wall of the sella, called as Walker's point (T, W); and the

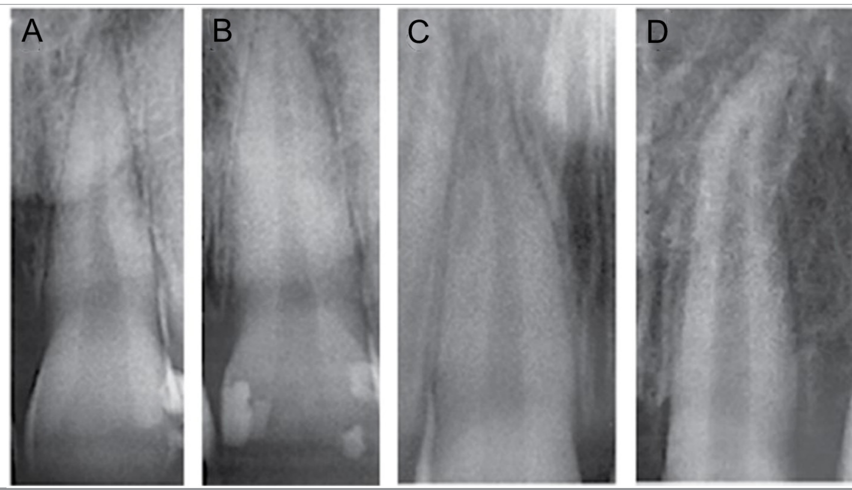


**Figure 2. A-D.** Root morphologies A, B, C, D. Triangular (A), rhomboid (B), pipette (C), and dilacerated (D) (11)

intersection point of the middle cranial fossa by the greater wing of the sphenoid bone, also called as the Wing point (w) (Figure 4).[13,15]



### Alveolar Bone Thickness

Alveolar bone thickness (width) is the sum of the width of labial (anterior), abbreviated as UA, and posterior (palatal) alveolar bone, abbreviated as UP.[16] The upper anterior bone (UA) is measured using a line drawn through the maxillary central incisor's root apex to the limit of labial cortex, and parallel to the palatal plane (ANS-PNS). The upper posterior bone (UP) is measured using a line drawn through the maxillary central incisor's root apex to the limit of palatal cortex, and parallel to the palatal plane (ANS-PNS) (Figure 3).[16] The alveolar bone thickness was measured in pre-operative cephalometric radiographs.

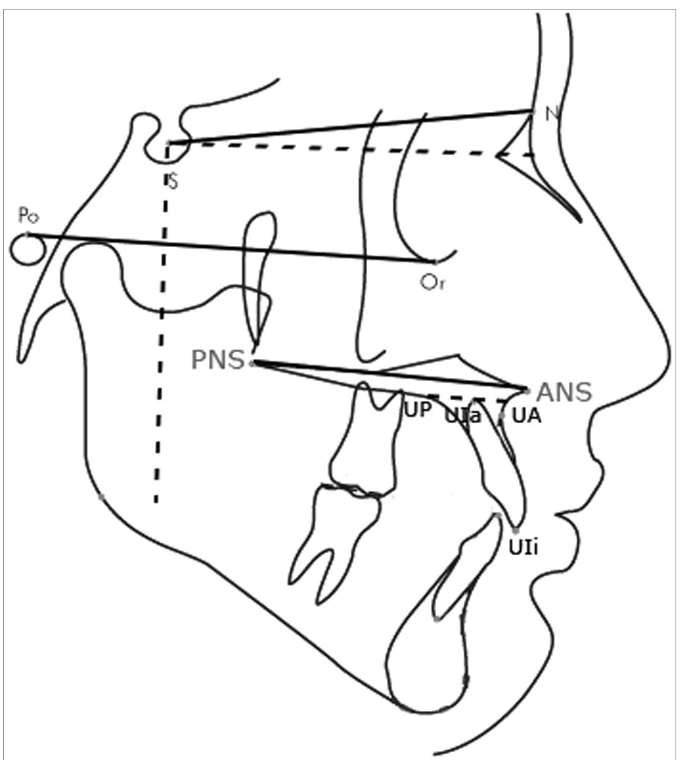


**Figure 3.** Cephalometric points and planes used

### Amount of Incisor Movement

The pre- and post-operative cephalometric radiographs were assessed in order to measure the amount of movement of the incisors. For both incisal edge and root apex, movement in vertical and horizontal directions was measured. Measurements were performed using a vertical and horizontal reference for all subjects in pre- and post-operative radiographs. The angle formed by the Frankfort Horizontal (FH) plane and the sella-nasion line was reported in literature to be 7 degrees, and for an individual, this does not vary significantly over time.[17] This angle was the base we built on to create horizontal and vertical references for linear measurements. The horizontal reference was a line parallel to the Frankfort Horizontal plane (FH). For the vertical reference, a line constructed perpendicular to the horizontal reference intersecting the sella (S) point was used. The perpendicular distances from root apex and incisal edge to horizontal and vertical references were recorded, in both pre- and post-operative radiographs (Figure 5).

**Table 1.** Cephalometric planes

| Plane | Description |
|---|---|
| SN Lines | Line crossing between sella turcica and Nasion points. |
| Palatal Plane (PP) | Plane connecting anterior nasal spine with posterior nasal spine. |
| Frankfort Horizontal Plane (FH) | Plane crossing from the Porion to the Orbitale. |
| Bone Plane | A constructed line parallel to the palatal plane passing through the apex of the root, with marking the anterior and posterior limits passing through the bone. |
| Horizontal Line | A constructed line intersecting the S point with angle of 7 degrees to SN line. |
| Vertical Line | A constructed vertical line dropped perpendicular to the horizontal line and intersecting the S point. |

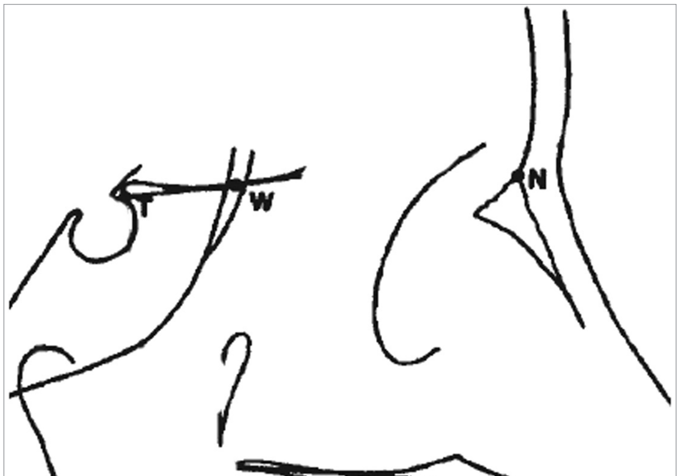


**Figure 4.** Middle cranial base points. T, Tuberculum sella, Walker's point; W, the intersection point of the middle cranial fossa by the greater wing of the sphenoid bone

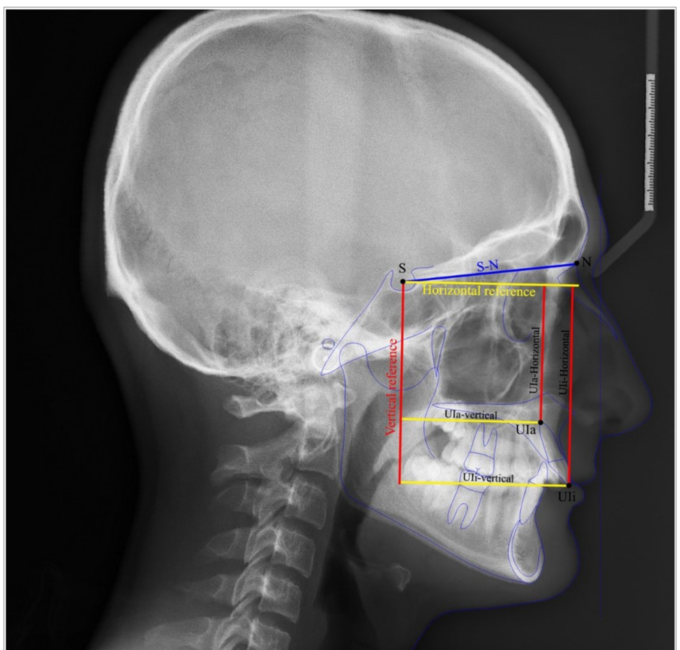


**Figure 5.** Vertical and horizontal references and distances to root apex and incisal edge

EARR causes shortening in total root and tooth length, leaving the root apex blunt and poorly visible in cephalometric radiographs. This limitation was overcome by measuring the initial tooth length in pre-operative cephalometric radiographs, and later transferring exactly the same length to the post-operative radiograph as a reference to measure from.

### Statistical Analysis

Statistical analysis was performed using the IBM SPSS Statistics software for Windows, version 26.0. A post hoc power analysis was performed, the results of which can be seen in Table 2. The Shapiro–Wilk test results for bone thickness for both control and resorption groups, in addition to vertical movement for root apex in the resorption group, indicated that *P* values were greater than .05. In other words, normality assumptions were met.

The relationship between EARR and the predisposing factors was assessed using the following statistical tests: the Chi-square test for intergroup comparison of gender, root morphology, and treatment modality; the independent samples *t*-test for alveolar bone thickness; and the Mann–Whitney *U*-test for comparison of treatment duration, overjet, overbite, and amount of tooth movement between the 2 groups.

Intra-operator reliability of the method was evaluated by repeating the EARR assessments on randomly selected 20 panoramic films after a 2-week interval. The agreement between the scores of EARR at 2 different time points was evaluated by the Kappa test, and the level of agreement was found to be substantial; the kappa coefficient was 0.643 and scoring of EARR was reliable between 2 measurements. The reliability of the measurements of overbite, overjet, buccal and palatal alveolar bone thickness in the maxillary incisor region, and amount of movement of the incisal root apices were evaluated by repeating these measurements after a 2-week interval on randomly selected 20 cephalometric films using Dahlberg's[18] formula to estimate the random error, which showed that the highest linear error was for the bone thickness (UA+UP) variable, at 0.23 mm.

## RESULTS

To calculate the prevalence of severe EARR in our study, the initial sample of 120 patients who presented with severe EARR was used. The results showed that 3.23% of total patients developed severe EARR, while 96.77% showed clinically acceptable root resorption (mild and moderate). The intergroup comparison of treatment duration showed that difference in treatment duration was statistically significant between both groups (Table 3). Intergroup comparisons of the resorption and the control groups in terms of gender, type of treatment, and root morphology showed that only the treatment type presented with premolar extractions showed statistically significant difference (Table 4). Among cephalometric measurements including overjet, overbite, and bone thickness, statistically significant difference was seen only in bone thickness between the resorption and the control groups (Table 5). For the amount and direction of tooth movement, statistically significant differences were seen in both horizontal and vertical directions at both incisal edge and root apex levels (Table 5). Moreover, the difference in the distribution of the vertical displacements among subjects showed statistical significance between the resorption and control groups (Table 6).

## DISCUSSION

The main goal of this study was to retrospectively determine the prevalence of severe EARR (score 4 according to Malmgren et al.[7]), in maxillary incisors throughout fixed orthodontic treatment and to evaluate the possible predisposing factors for EARR.

**Table 2.** Post-hoc power analysis, effect size and N needed for 0.80 power for initial age, treatment time, overjet, overbite, bone thickness, tooth movement gender, treatment type, and root morphology

| Variable | Observed Power | Effect Size | N Needed (Each Group) for 80% Power |
|---|---|---|---|
| Treatment time | 0.999 | 1.080 | 15 |
| Overjet | 0.087 | 0.084 | 2207 |
| Overbite | 0.100 | 0.098 | 1637 |
| Bone Thickness | 1.000 | 1.223 | 12 |
| Horizontal movement | | | |
| Incisal Edge | 0.999 | 0.769 | 28 |
| Root Apex | 0.810 | 0.425 | 88 |
| Vertical movement | | | |
| Incisal Edge | 0.490 | 0.290 | 188 |
| Root Apex | 0.999 | 0.741 | 30 |
| Gender | 0.086 | 0.045 | 1976 |
| Treatment type | 0.977 | 0.288 | 46 |
| Root morphology | 0.191 | 0.105 | 495 |

Calculations based on assuming alpha = 0.05.



**Table 3.** Intergroup comparison of treatment duration with Mann-Whitney U test

| | Control Group (n = 90) | | Resorption Group (n = 90) | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | *P*-value |
| Treatment time (years) | 2.48 | 0.93 | 3.7 | 1.3 | <.001 |

EARR is known as one of the most common complications following orthodontic treatment, and being irreversible, it is considered as a true limitation to obtaining an optimal orthodontic outcome.

Since the most affected teeth are known to be the maxillary incisors (Levander and Malmgren, 1988[32]), the present study aimed to focus on these teeth. The presence of at least one severely resorbed maxillary incisor was considered sufficient to categorize a patient into the resorption group. Division of the incisors into centrals and laterals for comparisons according to tooth type was not deemed necessary as there is already substantial evidence in the literature that the central incisors are more frequently affected.[19]The root morphology of the anterior teeth was a determining factor that classified the study group into 4 different subgroups according to the root shape; triangular, rhomboid, dilacerated, and pipette. The triangular root shape was the most common in the study group, while rhomboid roots were the most common in the control group. Evaluation of root morphology was done using panoramic radiographs. The main

**Table 4.** Intergroup comparison of gender, treatment modality and root morphology with Chi-Square Test

| Variable | Distribution | Control Group (n=90) | Resorption Group (n=90) | *P*-value |
|---|---|---|---|---|
| Gender | Male (n=84) | 40 (47.62%) | 44 (52.38%) | .550 |
| | Female (n=96) | 50 (52.08%) | 46 (47.92%) | |
| Treatment Modality | Without extraction (n=124) | 74 (59.68%) | 50 (40.32%) | <.001 |
| | With extraction (n=56) | 16 (28.57%) | 40 (71.43%) | |
| Root Morphology | Triangular (n=79) | 35 (44.3%) | 44 (55.7%) | .575 |
| | Rhomboid (n=69) | 38 (55%) | 31 (45%) | |
| | Pipette (n=16) | 9 (56.25%) | 7 (43.75%) | |
| | Dilacerated (n=16) | 8 (50%) | 8 (50%) | |

**Table 5.** Intergroup comparison of overjet, overbite, bone thickness, and amount of tooth movement in horizontal and vertical directions in millimeters with Independent samples T-test (*) and Mann-Whitney U test (†)

| Variable | Control Group (n = 90) | | Resorption Group (n = 90) | | |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | *P*-value |
| Overjet | 4.39 | 2.24 | 4.61 | 2.93 | .458† |
| Overbite | 2.19 | 2.01 | 1.93 | 3.17 | .350† |
| Bone Thickness | 15.06 | 1.99 | 12.54 | 2.13 | <.001* |
| Tooth Movement | | | | | |
| Horizontal Displacement | | | | | |
| Incisal Edge | 1.41 | 1.34 | 2.82 | 2.22 | <.001† |
| Root apex | 1.17 | 1.08 | 1.69 | 1.35 | .011† |
| Vertical Displacement | | | | | |
| Incisal Edge | 1.14 | 1.15 | 1.45 | 0.96 | <.001† |
| Root apex | 1.02 | 1.01 | 1.81 | 1.12 | <.001† |

**Table 6.** Distribution of subjects in terms of posterior (backward), anterior (forward), intrusion (upward) and extrusion movements (downward) in the horizontal and vertical directions

| | Control | | Resorption | | |
|---|---|---|---|---|---|
| **Horizontal Displacement** | Posterior | Anterior | Posterior | Anterior | *P*-value |
| Incisal Edge | 37 | 53 | 36 | 54 | .879 |
| Root Apex | 58 | 32 | 69 | 21 | .072 |
| **Vertical Displacement** | | | | | |
| Incisal Edge | 44 | 46 | 27 | 63 | .009 |
| Root Apex | 36 | 54 | 20 | 70 | <.001 |

limitation in this evaluation was the poor quality of radiographic films for some patients, which made the evaluation process more challenging.

The rest of the variables studied—overjet, overbite, bone thickness, and tooth movement—were measured using cephalometric radiographs. Another difficulty faced in the present study was the calibration and standardization of cephalometric radiograph dimensions and measurements. As our sample consisted of growing patients, a stable and non-changing reference was necessary to be followed. The middle cranial base was found to maintain its stability in all pubertal growth periods,[15,20] which allowed us to use it as a calibration tool. As alveolar bone width was measured on cephalometric radiographs, the limitation of unclear and poor-quality radiographic films was faced again. In a few instances, the precise location of the root apex was difficult to find.

For the assessment of tooth movement, post-treatment values were subtracted from pretreatment ones, and absolute values were used for statistical comparisons. Later on, the displacement values were classified into positive and negative values; positive results indicated backward/upward movement, while negative values indicated forward/downward movement.

In agreement with the findings of previous research, this study discovered a low prevalence of maxillary incisors that developed severe EARR (3.23%) with the loss of more than 1/3 of root length, while 96.77% showed clinically acceptable EARR classified as mild and moderate, as part of the biological tissue reaction to orthodontic treatment. Several authors have reported that a prevalence of 1-5% of severe EARR can be seen following an orthodontic treatment.[1,21,22]

The control group presented shorter treatment duration, with a mean of 2.48 years, when compared to resorption group, with a mean of 3.7 years (Table 3). Patients who underwent longer orthodontic treatment were at higher risk of developing severe EARR. Prolonged treatment time results in longer periods of stimulation of the root and development of EARR.[21] The correlation between the duration of orthodontic treatment and the incidence and severity of EARR is debatable. Some studies concluded that there is positive correlation between EARR and treatment duration,[12,26] while other studies found no significant relationship between EARR and treatment time.[24,25]

Similar to findings in numerous studies, there was no significant relationship between severe EARR and gender of the patient (Table 4).[6,12]

Treatment type may also affect the treatment duration, as they are both linked and affected simultaneously. The results showed a significant relationship between treatment type and severe EARR (Table 4). The resorption group presented 40 patients that were treated with the extraction protocol, involving mainly the upper first premolars, while just 16 patients were treated with the same treatment modality in control group. As extractions result in prolonged treatment time needed to close extraction spaces, relieve crowding, and retract anterior teeth, many authors agree with this finding, reporting that treatment type should be chosen wisely in patients accompanied by higher risk factors that could develop EARR.[6,12,21,24]

The root morphology was found to have no significant relationship with severe EARR (Table 4). This finding seems to contradict previous reports, which reported that teeth with pipette or dilacerated (irregular) root shape have a higher risk of EARR.[11,24] This finding is likely to be the result of having a high percentage of rhomboid roots in the sample, which are associated with a reduced risk of EARR.[4,6,11]

Increased overjet is usually considered to be a risk factor for root resorption because the correction may require that maxillary anterior teeth move a long distance in order to reduce the maxillary anterior protrusion.[4,26] On the other hand, there are also reports which state that there is no correlation between increased overjet and overbite and EARR.[6,27] In the present study, the mean overjet and overbite values at the beginning of orthodontic treatment did not show a statistically significant difference between the 2 groups (Table 5). It was noted that a high percentage of patients with increased overjet and overbite in the control group had treatment plans that included fewer extractions when compared to the resorption group (fixed functional appliances, intermaxillary elastics). It is also worth mentioning that some authors claim that increased overjet of more than 5 mm can be a risk factor, which is in agreement with our results, as the mean overjet was less than this value.[21]



With relatively thin alveolar bone seen in the resorption group (12.5 mm), in comparison with thicker bone in the control group (15 mm) (Table 5), the hypothesis that thin alveolar bone is a risk factor for severe EARR because teeth are being pushed against the thin cortical bone is confirmed.[6,16]

Results of the present study showed a significant relationship between the amount of tooth movement—net displacement of the root apex and incisal edge during the treatment—and severe EARR (Table 5). This finding is confirmed by many authors; the increase in the amount of tooth movement is a risk factor for EARR.[25,28] In horizontal displacement, no difference was seen between the 2 groups with respect to the number of patients with either proclination (anterior) and retraction (posterior) movements (Table 6). For the vertical displacement, statistically significant differences were seen in the distribution of subjects with extrusion (downward) and intrusion (upward) displacements in both groups. In the EARR group, greater downward movement of the incisal edge and root apex was seen compared to the control group (Table 6). This finding may seem controversial as there are many authors who have reported that intrusion is most likely to be a risk factor for EARR when compared to extrusion; intrusion of teeth causes about 4 times more EARR than extrusion.[29] Since the resorption group included a greater number of patients with extraction treatment, this finding can be justified because the extractions of premolars and retraction of the incisors during space closure result in controlled and uncontrolled tipping of the incisors, which may cause relative extrusion of these teeth.[28-31]

When interpreting the findings of the present study, we should keep in mind that it is a retrospective study which has certain limitations with regard to grouping and standardization of the subjects. Moreover, the post hoc power analysis showed that the study was underpowered for a few variables (Table 2). Also, the direction and amount of tooth movement were measured as the displacement of the incisal edges and root apices in anteroposterior and superior-inferior directions during treatment period, not as absolute tooth movement. Finally, the effect of the interactions of the parameters with each other on EARR was ignored. For this reason, the aforementioned statistical analyses were made and the data were interpreted in this regard.

## CONCLUSION

The results of the present investigation conducted on the available records of fixed orthodontic patients treated in Marmara University Faculty of Dentistry Department of Orthodontics between 1990 and 2019 showed that the prevalence of severe EARR of the upper incisors was 3.23%. Prolonged treatment duration, treatment with premolar extractions, presence of a thin alveolar bone, and excessive amounts of horizontal and vertical displacement of the teeth were identified to be risk factors for the occurrence of severe EARR. These factors should be taken into consideration when making treatment plans for future patients in order to minimize the risk of severe EARR and to optimize the treatment results. A further clinical study designed to elucidate the prognosis and longevity of these severely resorbed teeth in the long term may provide interesting and useful findings which could provide a better understanding of the outcome of this undesirable clinical phenomenon.

**Ethics Committee Approval:** Ethics committee approval was received from the Ethical Committee of Marmara University, Faculty of Dentistry, İstanbul, Turkey (approval date and number: 28.03.2019, 2019-317; protocol number: 2019-326).

**Informed Consent:** Written informed consent was obtained from all patients before starting orthodontic treatment.

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Concept - A.A.; Design - A.A.,B.S.; Supervision - A.A.; Data Collection and/or Processing - B.S.; Analysis and/or Interpretation - A.A.,B.S.; Literature Review - B.S.; Writing - B.S.; Critical Review - A.A.

**Declaration of Interests:** The authors have no conflict of interest to declare.

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Original Article

# Effects of Recent/Healed Post-Extraction Protocols on Incisor and Canine Alignment During Fixed Orthodontic Appliance Therapy

Adedayo Ayomide Olabintan[1], Olayinka Donald Otuyemi[2], Kikelomo Adebanke Kolawole[2]

[1]Department of Child Dental Health, Obafemi Awolowo University Teaching Hospitals Complex Ile-Ife, Nigeria
[2]Department of Child Dental Health, Obafemi Awolowo University Ile-Ife, Nigeria



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Main Points

- This study compared the rates of incisor and canine alignment in recent and healed extraction cases in order to determine which protocol would favor accelerated tooth movement.
- The rates of initial canine and incisor alignment were not significantly different between the recent and healed post-extraction protocols.
- The alignment rate was significantly faster in adolescents compared to adults.
- The alignment rate was not significantly different between both sexes or dental arches.

## ABSTRACT

**Objective:** The purpose of this study was to determine the effects of recent/healed post-premolar extraction protocol, gender, age, and dental arch on incisor and canine alignment during fixed orthodontic appliance therapy.

**Methods:** The study sample consisted of 50 dental arches of patients undergoing fixed orthodontic appliance therapy. The arches were randomized into an equal number of recent and healed extraction groups. The orthodontic setup was instituted within 3-7 days and 5-6 weeks following first premolar teeth extractions in the recent and healed extraction groups, respectively.

Orthodontic tooth alignment was carried out using 0.016-inch NiTi wires for 16 weeks. Study casts were made at baseline, 4, 8, 12-, and 16-week follow-up treatment. Little's Irregularity Index was used to assess orthodontic tooth alignment.

Mann–Whitney *U* test was used to compare the alignment rates between groups, and multiple linear regression was used to predict the relationship of groups and sociodemographic factors to alignment rate. The statistical significance level was set at $P < .05$.

**Results:** The mean daily incisor and canine alignment rates in the recent and healed extraction cases were 0.13 mm and 0.11 mm, respectively ($P = .332$), 0.12 mm in both males and females ($P = .827$), and 0.13 mm and 0.12 mm in the maxilla and mandible, respectively ($P = .534$). There was however a significant difference in the mean daily alignment rate between adolescents (0.15 mm) and adults (0.10 mm) ($P = .019$).

**Conclusion:** The rate of incisor and canine alignment was not affected significantly by recent/healed post-extraction protocol, gender, and dental arch. However, the rate was significantly faster in adolescents.

**Keywords:** Dental arch, incisor and canine alignment, Little's irregularity index, orthodontics, recent/healed extraction

## INTRODUCTION

The duration of fixed orthodontic appliance therapy is considered by many patients as relatively long. This discourages many potential patients from undergoing orthodontic treatment.[1] Thus, any method or intervention that leads to a reduction in the duration of orthodontic treatment is highly desirable.[1] Uribe et al.[2] reported that adolescents and adults, as well as the parents of patients, desire that orthodontic treatment be completed in the shortest possible time. A shortened treatment time reduces patients' burn-out and enables the orthodontist

**Corresponding author**: Adedayo Ayomide Olabintan, e-mail: mideday@yahoo.com


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to treat more patients and predict treatment costs more accurately.[3] Other benefits of shorter treatment time for patients include reduced risk of root resorption, caries, plaque, and calculus accumulation, as well as periodontal diseases, and enamel decalcification.[4] Excessively short treatment time however poses risks of incomplete and unstable corrections as adequate time is required for angulation and torque correction, tissue regeneration, and stability of results.[5]

During orthodontic treatment planning, premolar teeth extraction is often indicated as an adjunct to fixed orthodontic appliance therapy, to relieve crowding, flatten the curve of Spee, and correct overbite. Others include dental and skeletal Class 2 corrections and treatment stability. All these desirable treatment modalities have been reported to contribute to increased overall treatment time.[5]

Generally, tooth alignment is carried out in the first stage of fixed orthodontic appliance treatment; therefore, a proper alignment usually involves bringing malposed teeth into the arch while also specifying and controlling the anteroposterior position (inclination) of incisors, arch width posteriorly, and the dental arch form.[6] The final stage of the treatment period is required to achieve residual space closure after utilizing a part of the extraction spaces to unravel crowding or retract the anterior segment.[7]

To shorten the tooth alignment phase in fixed orthodontic appliance therapy for patients with anterior segment crowding during premolar teeth extraction, this study attempted to explore the effect of healing time on extraction sockets, among other anatomic and sociodemographic factors that may aid or assist orthodontic tooth movement. Extraction sockets have been reported to heal in overlapping stages with bone formation composed of poorly calcified osteoid at the base and periphery of the socket from the seventh day and with bone trabeculae subsequently filling two-thirds of the socket fundus by 38-day post-extraction.[8] A study by Hasler et al.[9] reported faster tooth movement in the less calcified bone of recent extraction sites compared to HE sites, as the less calcified bone resorbs faster and also due to the presence of more cells with osteoclastic potential.

The tooth alignment rate during treatment is dependent on several technical factors, including correct bracket positioning, inter-bracket span, space availability, method of ligation, and the bracket system.[10] Currently, there is a paucity of literature relating sociodemographic and anatomic factors and the impact of the healing time of extraction sockets, thus necessitating this study. The main objective of this study is, therefore, to compare the rates of incisor and canine alignment in recent and healed first premolar teeth extractions, during fixed orthodontic appliance therapy, and to relate tooth alignment rate to sociodemographic and anatomic factors in a group of Nigerians seeking orthodontic treatment.

## METHODS

### Study Design

This study was a prospective study carried out at the orthodontic clinic of a teaching hospital.

### Material

This study was approved by the Research and Ethics Committee of the teaching hospital (ERC/2016/10/10). Informed consent was obtained from every study participant. The inclusion criteria included patients 12 years and above, patients in the permanent dentition stage, and patients with an indication of bilateral maxillary and or mandibular first premolar teeth extractions to relieve moderate to severe crowding. Finally, all patients who did not require active canine retraction before alignment were also included. The exclusion criteria included patients with hypodontia, underlying periodontal diseases, history of previous extractions, or those requiring asymmetric extractions. Others were patients on non-steroidal anti-inflammatory drugs or systemic conditions that could delay wound healing.

### Methods

Consenting patients who met the inclusion criteria were recruited for this study from patients who presented at the orthodontic clinic of the teaching hospital.

The sample size was determined using the formula for calculating sample size for comparative studies.

$$N = 4o^2 \frac{(Zcrit + Zpwr)^2}{D^2}$$

where N is the sample size for the 2 groups, Ơ is the standard deviation, and D is the effect size (2.48-1.7 = 0.78).

Values for standard deviation and effect size were obtained from earlier studies by Scott et al.[6] At a power of 90%, statistical power (Zpwr) is 1.282. With a significance criterion of 95%, Zcrit is 1.960.

$$N = 4 \times 0.79^2 \frac{(1.960 + 1.282)^2}{0.78^2} = 43$$

This was then approximated to 50 dental arches (25 arches in each group) to address possible attrition.

Participants were randomly assigned to the recent extraction (RE) and healed extraction (HE) groups of 25 dental arches each, using a computer-generated randomization program on Graphpad.com (Figure 1).

For this study, the extraction protocols were adjudged "recent" and "healed" when treatment was commenced within 3-7 days and 5-6 weeks post-extraction, respectively. This was modeled according to a study by Amler[8] that showed commencement of bone formation on the seventh day and bone filling of at least two-thirds of the socket by the 38th day.

After randomization, baseline (T0) impressions for the study cast were made for each participant. First premolar teeth extractions were subsequently carried out in 2 stages by an experienced oral surgeon using extraction forceps only (Nova Instruments, Wokingham, Berkshire, UK). This was done under close monitoring by one of the researchers (A.A.O) to ensure atraumatic extraction procedures. The extractions on one side (right or left) in the maxilla and/or mandible were carried out in

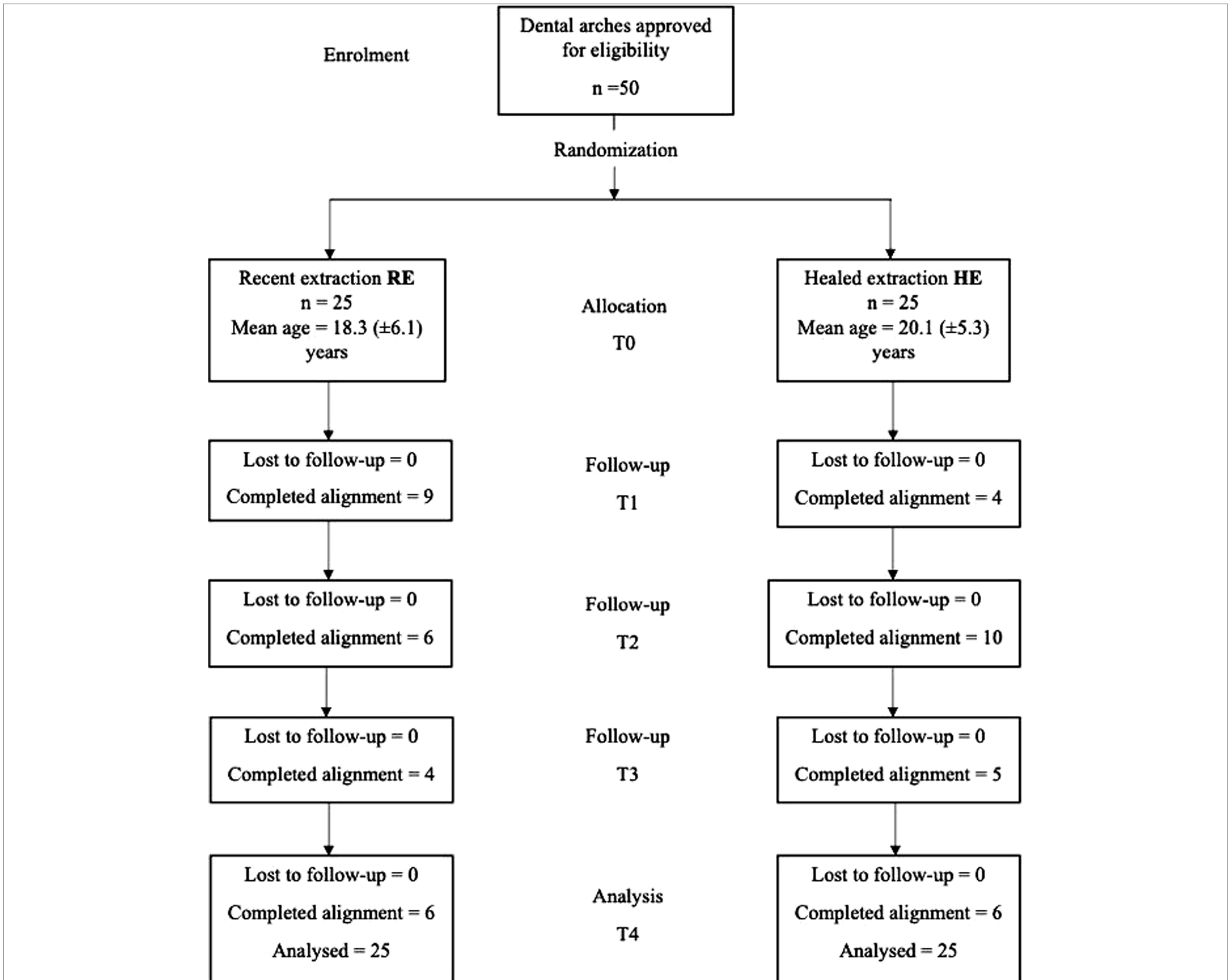


**Figure 1.** Consolidated standards of reporting trials (CONSORT) flowchart of the randomization procedure and follow-up visits



one visit, followed by extraction on the contralateral side after 3 days.

Fixed orthodontic appliance set-ups were carried out within 3-7 days after premolar teeth extractions for participants in the RE group and 5-6 weeks after the first premolar teeth extractions for the HE group.

Both groups received fixed orthodontic appliances with conventional 0.022-inch slot McLaughlin-Bennett-Trevisi (MBT) brackets. All brackets were obtained from a single manufacturer (Yahong ortho, Zhejiang, China) and were carefully positioned by one of the researchers (A.A.O.) to ensure consistency. Stainless steel (0.010 inch) lace back wire (G & H Orthodontics, Franklin, Ind, USA) was also tied lightly from canine to molar teeth in all quadrants for control of canine crown position according to MBT straight wire prescription.

Similarly, 0.016-inch NiTi archwires from another manufacturer (Orthoclassic, McMinnville, Oregon, USA) were ligated with elastic modules using the figure of eight ligation method. It was anticipated that the 0.016-inch archwires will have minimal effects on arch expansion. Bendbacks were incorporated at the end of the archwires using a ligature wire tucker to minimize the forward tipping of the incisors. The 0.016 inch round NiTi archwires were maintained throughout the first 16 weeks of the initial tooth alignment phase following the technique by Wahab et al.[11] for the 2 groups, except there was a need for replacement with another 0.016-inch NiTi wire. In addition, there was no bracket replacement in patients throughout the study period.

Alginate impressions for study casts were also made at 4 weeks (T1), 8 weeks (T2), 12 weeks (T3), and 16 weeks or less (T4) depending on the length of time required to attain the full initial tooth alignment. The irregularity index scores were determined using Little's Irregularity Index (LII).[12] Little's Irregularity Index scores were calculated from the measurements recorded with a carbon fiber composite digital caliper (Fuzhou, Fujian, China) on the study casts at the different time intervals. The rate of incisor and canine alignment was determined as the difference between the irregularity score at baseline and the final tooth alignment period (16th week or less), divided by the number of days to attain alignment. The alignment rates were compared between the RE and HE groups, dental arches, genders, and age groups.

**Statistical Analysis**

Data analysis was carried out using the Statistical Package for Social Sciences (SPSS) software package (IBM SPSS version 20; Armonk, NY, USA). Descriptive statistics were carried out for sociodemographic variables. Chi-square was used to determine the differences in categorical groupings for gender, age group, and dental arch between the RE and HE groups. The mean age difference in both groups was assessed using independent samples *t*-test. The intra-class correlation coefficient was used to determine the reliability of cast measurements for 10 randomly selected dental casts within at least 2 weeks interval. The results showed a high degree of reliability with a correlation coefficient of 0.97 and a 95% confidence interval of 0.90-0.99 for LII scores.

A normality check for data was performed using the Shapiro–Wilk test, and non-parametric tests were subsequently carried out on the skewed data. Repeated measures analysis of variance (ANOVA) was used to test for changes in LII score over time, and Bonferroni post hoc test was subsequently used for pairwise comparisons. Mann–Whitney *U* test was used to compare the alignment rates between groups, and multiple linear regression was used to test the relationship of groups and other variables to alignment rate. RE or HE group, age group, gender, and dental arch were each tested as predictors of the alignment rate while controlling for other variables. The statistical significance level was set at $P < .05$.

## RESULTS

Table 1 shows the sociodemographics of the study participants. There were more female (60%) and adult dental arches (60%) in the sample population. Similarly, the sample had more mandibular (52%) than maxillary (48%) arches. The mean ages of the RE and HE groups were 18.3 (±6.1) and 20.1 (±5.3) years, respectively, while the overall mean age was 19.18 (±5.7) years. There were, however, no statistically significant differences in age, gender, or dental arch distribution between the RE and HE groups.

**Table 1.** Distribution of study participants by age, gender, and dental arch

| Background Characteristics | RE (n = 25) | | HE (n = 25) | | | |
|---|---|---|---|---|---|---|
| | N | % | N | % | $\chi^2$ | *P* |
| Age group (years) | | | | | | |
| 12-17 | 12 | 48.0 | 8 | 32.0 | 1.333 | .248 |
| 18-32 | 13 | 52.0 | 17 | 68.0 | | |
| Gender | | | | | | |
| Male | 13 | 52.0 | 7 | 28.0 | 3.000 | .083 |
| Female | 12 | 48.0 | 18 | 72.0 | | |
| Dental arch | | | | | | |
| Maxillary arch | 10 | 40.0 | 14 | 56.0 | 1.282 | .258 |
| Mandibular arch | 15 | 60.0 | 11 | 44.0 | | |

RE, recent extraction; HE, healed extraction.

Figure 2 shows the line graph comparing the mean LII scores between the RE and HE groups, over the 16-week follow-up period. There was a steady decline in LII score, that is improvement in incisal and canine alignment over the 16-week study period. At baseline (T0), the mean LII score for the RE group was 7.76 mm and 7.79 mm for the HE group ($P = .683$). At 4 weeks (T1), the mean LII scores were further reduced to 3.58 mm and 4.14 mm for the RE and HE groups, respectively ($P = .453$). At 8 weeks (T2), it was 1.41 mm and 1.79 mm for RE and HE groups, respectively ($P = .576$). At 12 weeks (T3), it was 0.74 mm and 0.86 mm for RE and HE groups, respectively ($P = .948$). Finally, at 16 weeks (T4), the mean LII scores were 0.25 mm and 0.56 mm for RE and HE groups, respectively ($P = .630$).

A repeated measure ANOVA test was done to determine changes in LII scores at baseline and 4 weekly intervals. The results showed that there were significant changes with time, F (4, 24) = 17.22, $P < .001$ in RE and F (4, 24) = 21.61, $P < .001$ in HE groups. Table 2 shows the Bonferroni post hoc test highlighting the time intervals where significant changes occurred. There were significant reductions in the irregularity scores within the RE and HE groups between T0 and all other time intervals, T1 and all other time intervals, and T2 and T3 in the HE group. Similarly, significant differences were observed between RE and HE groups in the timelines of T0-T2 ($P = .030$) and T1-T2 ($P = .006$).

Figure 3 shows the trend of changes in LII scores across gender. The line graph shows that the male participants had a higher LII score at baseline T0 (9.4 mm) compared to the females 6.7 mm ($P = .033$). The LII scores at 4 weeks (T1) were 5.53 mm and 2.75 mm ($P = .007$), and at 8 weeks (T2), they were 2.06 mm and 1.29 mm ($P = .316$). The LII scores at 12 weeks (T3) were 1.12 mm and 0.58 mm ($P = .390$), and by the 16th week (T4), they were 0.67 mm and 0.23 mm ($P = .294$) in males and females, respectively.

Figure 4 displays the comparison of mean LII scores at the follow-up visits across age groups. The mean LII scores at baseline (T0) were 7.85 mm and 7.73 mm ($P = .976$), at 4 weeks (T1) they were 3.26 mm and 4.26 mm ($P = .221$), at 8 weeks (T2) they were 1.0 mm and 2.0 mm ($P$ = 0=.094), at 12 weeks (T3) they were 0.29 mm and 1.14 mm ($P = .057$), and at 16 weeks (T4) they were 0 and 0.67 mm ($P = .022$) in adolescents and adults, respectively. A significant difference was only observed in LII scores between adolescents and adults at the 16th week.

Figure 5 is a line graph comparing mean LII scores between mandibular and maxillary arches over the 16-week follow-up period. A steady decline in the LII scores was observed as the study progressed into the 16th week (T4). The LII scores at baseline (T0) were 8.25 mm and 7.35 mm ($P = .586$), at 4 weeks (T1) were 4.17 mm and 3.58 mm ($P = .654$), at 8 weeks (T2) were 1.85 mm and 1.37 mm ($P = .759$), at 12 weeks (T3) were 0.85 mm and 0.75 mm ($P = .726$), and at 16 weeks (T4) were 0.45 mm and 0.36 mm ($P =$

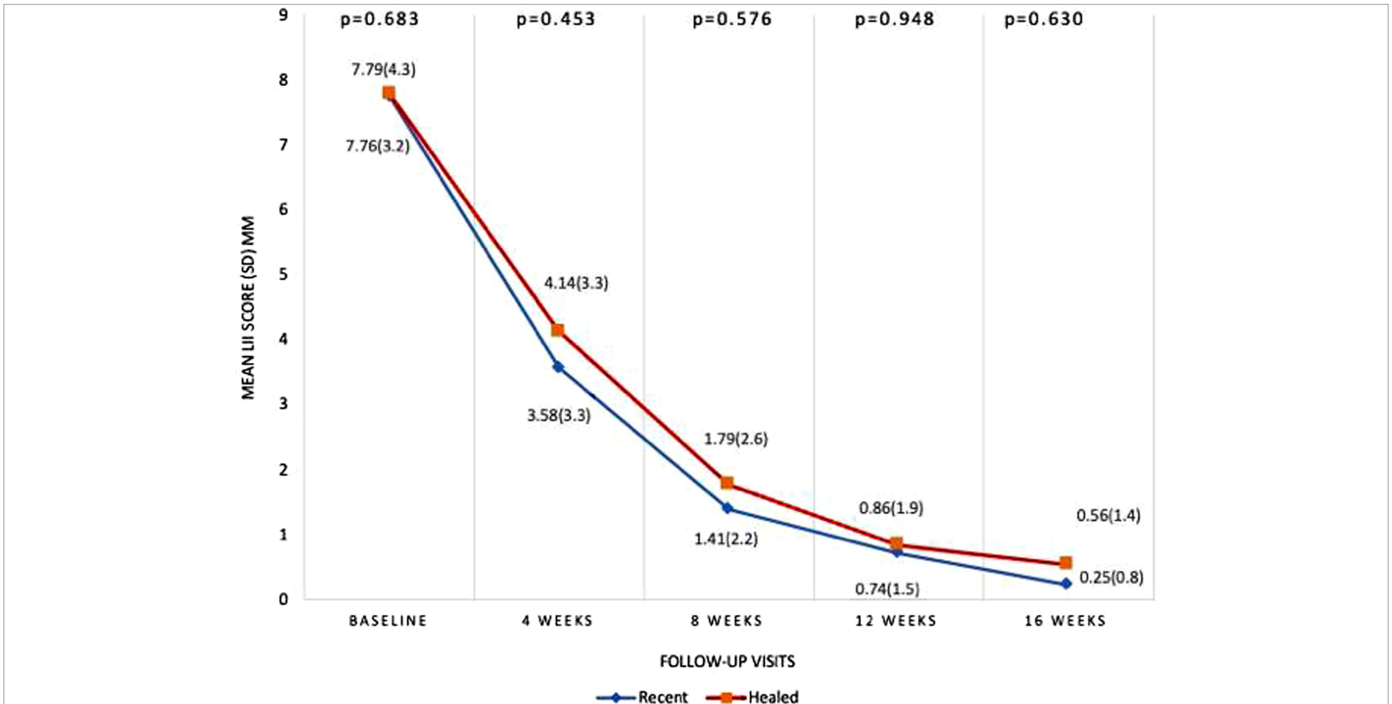


**Figure 2.** Comparison of mean irregularity scores between recent and healed extraction groups over the 16-week follow-up period



.809) in the upper and lower arches, respectively. These findings showed no significant differences in the LII scores in both dental arches at all follow-up intervals.

The RE/HE protocols, gender, age, and dental arch differences in alignment rate are shown in Table 3. The mean and median alignment rates per day in the RE group were 0.13 mm (3.9 mm per month) and 0.11 mm, respectively, while the mean and median alignment rates per day in the HE group came to 0.11 mm (3.3 mm per month) and 0.09 mm, respectively. There was however no statistically significant difference ($P = .332$).

The mean and median incisor and canine alignment rates in the males were 0.12 mm and 0.11 mm, respectively, while the mean and median alignment rates in the females were 0.12 mm and 0.10 mm, respectively. There was no statistically significant difference in the initial alignment rate between both genders ($P = .827$).

However, there was a statistically significant difference in the alignment rate among adolescents (12-17 years) compared to adults (18-32 years). The mean and median alignment rates in the adolescents were 0.15 mm and 0.14 mm, respectively and 0.10 mm and 0.09 mm, respectively ($P = .019$) in the adults.

The mean alignment rate in the maxillary arch was 0.13 mm per day (3.9 mm per month), while the median was 0.11 mm per day. The mean mandibular alignment rate was 0.12 mm per day (3.6 mm per month) and the median was 0.09 mm per day. The

**Table 2.** Bonferroni post hoc test for pairwise comparisons of changes in irregularity scores at follow-up visits in RE and HE groups

| | RE group | | | | | HE group | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Period | Diff | *t* | *P* | 95 % CI | | Diff | *t* | *P* | 95% CI | | Intergroup *P* value |
| T0-T1 | −4.18 | −8.76 | <.001* | −5.1 | −3.2 | −3.7 | −7.8 | <.001* | −4.6 | −2.7 | .148 |
| T0-T2 | −6.36 | −13.3 | <.001* | −7.3 | −5.4 | −6.0 | −12.8 | <.001* | −6.9 | −5.1 | .031* |
| T0-T3 | −7.02 | −14.7 | <.001* | −8.0 | −6.1 | −6.9 | −14.8 | <.001* | −7.9 | −6.0 | .306 |
| T0-T4 | −7.51 | −15.7 | <.001* | −8.5 | −6.6 | −7.2 | −15.5 | <.001* | −8.2 | −6.3 | .076 |
| T1-T2 | −2.2 | −4.6 | <.001* | −3.1 | −1.2 | −2.3 | −5.0 | <.001* | −3.3 | −1.4 | .006* |
| T1-T3 | −2.8 | −6.0 | <.001* | −3.8 | −1.9 | −3.3 | −7.0 | <.001* | −4.2 | −2.4 | .097 |
| T1-T4 | −3.3 | −7.0 | <.001* | −4.3 | −2.4 | −3.6 | −7.7 | <.001* | −4.5 | −2.7 | .064 |
| T2-T3 | −0.7 | −1.4 | .165 | −1.6 | 0.3 | −0.9 | −2.0 | .049* | −1.9 | −0.004 | .161 |
| T2-T4 | −1.2 | −2.4 | .017 | −2.1 | −0.2 | −1.2 | −2.6 | .010 | −2.2 | −0.3 | .452 |
| T3-T4 | −0.5 | −1.02 | .309 | −1.4 | 0.5 | −0.3 | −0.6 | .523 | −1.2 | 0.6 | .416 |

*Statistical significance.
Diff, difference; RE, recent extraction; HE, healed extraction; T0, baseline; T1, 4 weeks; T2, 8 weeks; T3, 12 weeks; T4, 16 weeks.

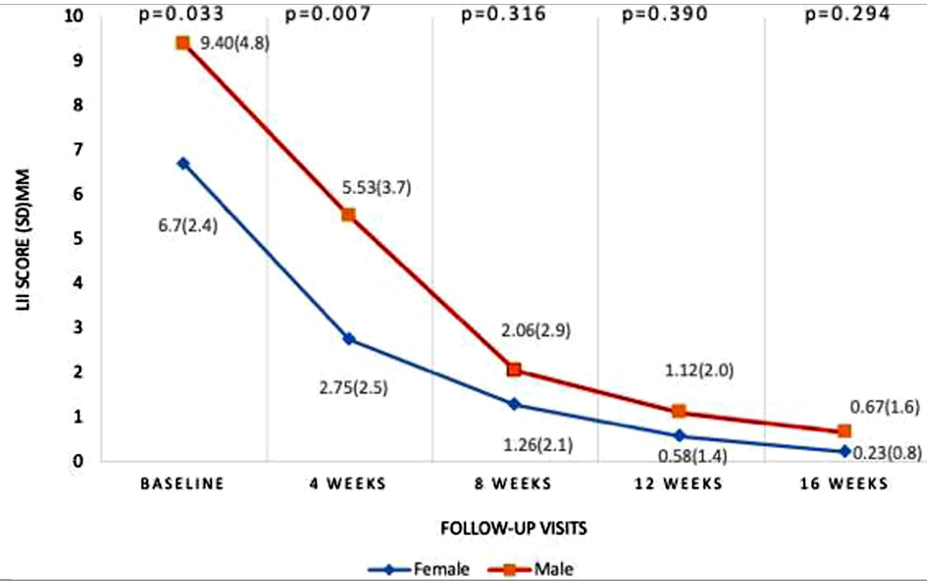


**Figure 3.** Comparison of mean irregularity scores between participants' gender over the 16-week follow-up period

difference in the maxillary and mandibular alignment rates was not statistically significant (*P* = .534).

Table 4 shows multiple linear regression of the relationship between the rate of alignment and patient group status, controlling for RE/HE protocols, age group, gender, and dental arch. There was evidence that the age group was a predictor of the alignment rate. The alignment rate per day in adolescents (<18 years) was higher by 0.004 compared with adults (≥18 years). The higher rate observed was statistically significant (*P* = .005). Recent extraction group had higher alignment rate of 0.014 mm per day compared to the HE group across the study period; however, the higher alignment rate was not significantly different (*P* = .411). Male participants had 0.010 mm less alignment rate per day compared with females. This difference was also not statistically significant (*P* = .558). The lower arch had 0.007 mm less alignment rate per day in comparison to the upper arch, and the reduction was also not significantly different (*P* = .675).

## DISCUSSION

This study compared the rates of initial tooth alignment in recent and healed first premolar extraction cases during fixed orthodontic appliance therapy and aimed at establishing a premolar



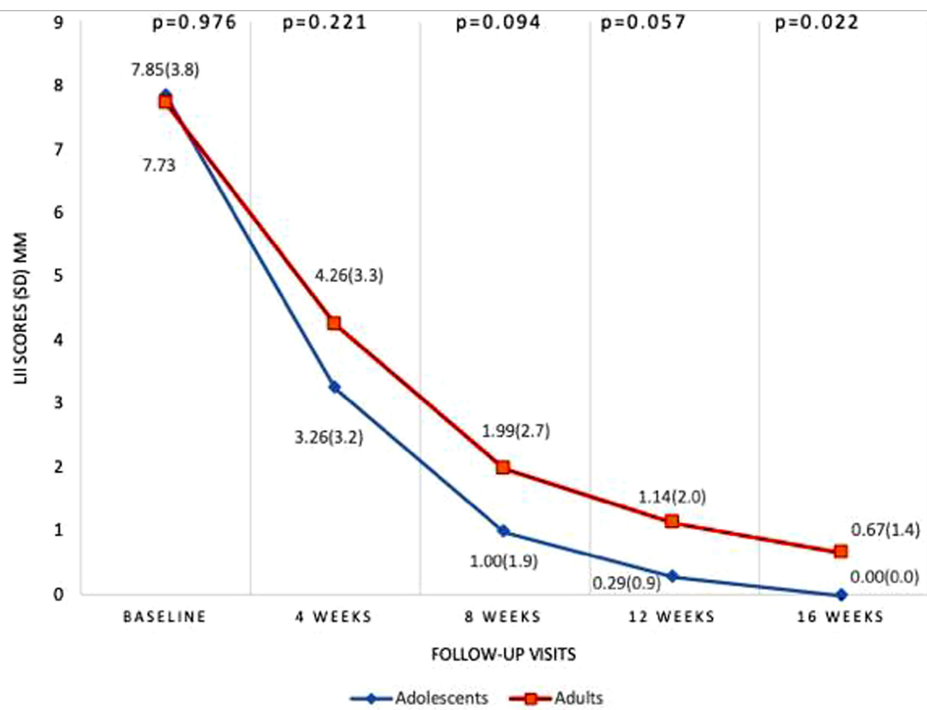


**Figure 4.** Comparison of mean irregularity scores between participants' age groups over the 16-week follow-up period

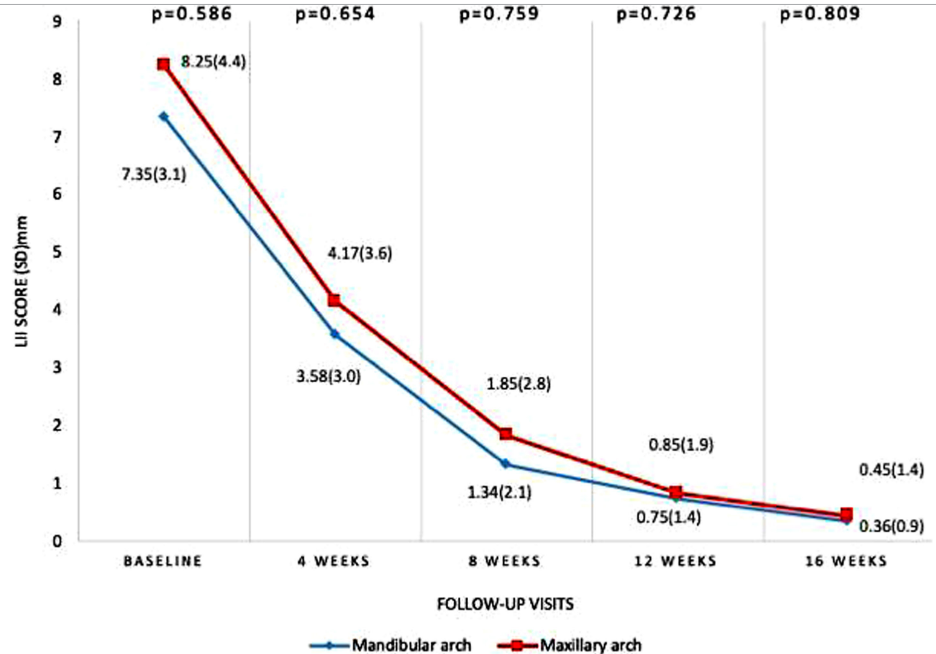


**Figure 5.** Comparison of mean irregularity scores between participants' dental arches over the 16-week follow-up period



extraction protocol among other factors that could provide faster incisor and canine alignment during fixed orthodontic appliance therapy. It is worthy of note that several adjunctive physical and surgical procedures and the use of medications have been utilized in hastening fixed orthodontic treatment time[5]; however, this study hoped to accelerate treatment without the use of any adjunctive therapy. Randomization into groups was only based on the 2 extraction protocols. To the best of our knowledge, this is the first reported study in the literature that related tooth alignment to RE and HE protocols.

The gender pattern, which tends to favor more female participants in this report, is in agreement with other previous studies that recorded a higher number of females seeking orthodontic treatment.[13] This observation may be related to greater concerns for dental appearance in the female gender than their male counterparts. Reports on orthodontic treatment needs and other epidemiologic studies have shown very limited gender differences in the incidence or severity of malocclusions. But, orthodontic treatment uptakes have substantially skewed toward the female gender.[14] Females are not only more likely to receive orthodontic treatment than their male counterparts but also perceived to need orthodontic treatment by their parents and referring dentists.[15] There are, therefore, social and cultural differences in the perception and uptake of orthodontic treatment with an obvious lower threshold for female patients.[16]

**Table 3.** Extraction protocol, gender, age, and dental arch differences in alignment rate

| | | Alignment Per Day (mm) | | | | |
|---|---|---|---|---|---|---|
| Variables | N | Mean (SD) | Median | Min | Max | Mann–Whitney *U* Test, *P* |
| Extraction protocol | | | | | | |
| RE | 25 | 0.13 (0.07) | 0.11 | 0.05 | 0.29 | .332 |
| HE | 25 | 0.11 (0.05) | 0.09 | 0.04 | 0.28 | |
| Gender | | | | | | |
| Male | 20 | 0.12 (0.07) | 0.11 | 0.05 | 0.29 | .827 |
| Female | 30 | 0.12 (0.06) | 0.10 | 0.04 | 0.29 | |
| Age group (years) | | | | | | |
| 12-17 | 20 | 0.15 (0.08) | 0.14 | 0.05 | 0.29 | .019* |
| 18-32 | 30 | 0.10 (0.03) | 0.09 | 0.04 | 0.17 | |
| Dental arch | | | | | | |
| Maxillary arch | 24 | 0.13 (0.07) | 0.11 | 0.05 | 0.29 | .534 |
| Mandibular arch | 26 | 0.12 (0.06) | 0.09 | 0.04 | 0.29 | |

*Statistical significance.
SD, standard deviation; RE, recent extraction; HE, healed extraction; Min, minimum; Max, maximum.

**Table 4.** Multiple regression analysis of the relationship between alignment rate controlling for recent and healed extraction protocols, age group, gender, and dental arch

| Variables | Coefficient | 95% CI | | Standard Error | *P* |
|---|---|---|---|---|---|
| Extraction protocol | | | | | |
| RE | 1 | | | | |
| HE | −0.014 | −0.049 | 0.020 | 0.017 | .411 |
| Age group (years) | | | | | |
| Adolescents (<18) | 1 | | | | |
| Adults (≥18) | −0.052 | −0.088 | −0.017 | 0.018 | .005* |
| Gender | | | | | |
| Female | 1 | | | | |
| Male | −0.010 | −0.046 | 0.025 | 0.018 | .558 |
| Dental arch | | | | | |
| Maxillary arch | 1 | | | | |
| Mandibular arch | −0.007 | −0.041 | 0.027 | 0.017 | .675 |
| Constant | 0.168 | 0.127 | 0.208 | 0.020 | <.001 |

*Statistical significance.
RE, recent extraction; HE, healed extraction.

The present study, though not statistically significant, showed a relatively faster rate of tooth alignment in the RE group compared to the HE group. In a related study, Hasler et al.[9] revealed a faster rate of canine retraction into RE sites. This may directly support the report that tooth movement is faster in the less calcified bone of a RE site compared to HE sites, as the less calcified bone resorbs faster.[9] The presence of more cells with osteoclastic potential is also a possible explanation for this phenomenon.[9] The tooth alignment rates recorded in our study are consistent with another reported study on the efficiency of tooth alignment.[6] The findings of the present study are however at variance with the results of an animal study by Murphey et al.[17] which reported a faster retraction into HE sites using heavy forces for canine distalization.

The rate of incisor and canine alignment in the maxillary arch was marginally higher than that of the mandible, though not significantly different. This also confirms the findings of Dudic et al.[18] that reported no difference in the rate and amount of tooth alignment, irrespective of tooth position and direction of tooth movement. However, Giannopoulou et al.[19] in a study of orthodontic tooth movement and location in the arch reported a faster rate of tooth movement in the maxilla than in the mandible. A similar observation from a study on orthodontic tooth movement in dogs concluded that tooth movement was significantly faster in the maxilla than in the mandible. This is because the maxilla is composed of relatively thin cortices and has a higher rate of bone resorption which initiates more rapid bone turnover in the mandible.[20] Higher bone turnover is linked with increased tooth movement, compared to normal or low bone turnover.[20] Increased bone density in the mandibular molar region is believed to offer more resistance to tooth movement in the mandible, compared to the maxillary molar region.[21]

The passive nature of canine retraction during tooth alignment in the present study may also be responsible for the insignificant rate of incisal and canine alignment in the maxilla compared to the mandible.

Reports on gender differences in the literature are varied; however, findings from this study are consistent with the report of Dudic et al.[18] which revealed no gender differences in tooth movement. The effects of gender on the rate of tooth movement have been studied in relation to estrogen deficiency or estrogen replacement in post-menopausal osteoporotic women. Bone formation in response to mechanical force is defective in osteoporotic women.[21] Estrogen deficiency increases bone remodeling, while tooth movement is slower in estrogen replacement.[22]

A review by Omar et al.[23] revealed that hormonal changes in pregnancy could hasten tooth movement in pregnant rats when compared to the non-pregnant rats.[23] Since the report on the rats cannot be directly extrapolated to humans, the absence of post-menopausal osteoporotic or pregnant women in our study may be responsible for the lack of gender differences in the alignment rate.

In the present study, incisor and canine alignment was significantly faster in adolescent participants when compared to adults. This aligns with the findings of Dudic et al.[18] which identified age as an important factor in tooth movement. The authors found faster tooth movement in patients whose ages were less than 16 years compared to those that were 16 years and above. Ren et al.[24] also reported faster mesiodistal tooth movement in juvenile rats compared to adult rats. A possible explanation for faster tooth movement in adolescent patients may be due to higher cellularity of periodontal ligaments exhibited in adolescents than adults.[25] The efficiency of osteoclastic activity, which is responsible for bone resorption, is an important factor that cannot be ignored and has been postulated to influence tooth movement. Ren et al.[26] found that within 2 weeks, the maximum number of osteoclasts was attained at the compression sites of the periodontal ligament in young rats. But it took 4 weeks for the same level to be attained in adult rats. Thereafter, the rate of tooth movement was found to be comparable in both young and adult rats. The authors concluded that the osteoclasts in younger rats were more efficient than those of older rats. It was, therefore, suggested that more osteoclasts are required in older rats to bring about the same rate of tooth movement observed in younger rats. Chugh et al[21] also surmised that the faster tooth movement in children compared to adults might be a result of less bone density in children.

Similarly, Ren et al.[27] reported that the significantly elevated levels of interleukin-6 and granulocyte–macrophage colony-stimulating factor in the gingival crevicular fluid and the mediator levels in juveniles are more responsive than the levels in adults. This confirms the finding that the initial tooth movement in juveniles is faster than in adults. Kawasaki et al.[28] suggested that the age-related reduction in the amount of tooth movement might be influenced by a decrease in the receptor activator of nuclear factor kappa-B ligand/osteoprotegerin ratio in gingival crevicular fluid, during the early stages of orthodontic tooth movement.[28] Observation from this study is however at variance with the conclusion of Mavreas et al.[7] who reported that age differences did not seem to play an important role in the duration of orthodontic treatment during the permanent dentition stage. This disparity might have arisen from the research methodology adopted by Mavreas et al.[7] which was mainly a systematic review of several aggregate reports, with methodological deficiencies and biased conclusions.

The results of the present report are reliable for the techniques described. In fact, the incorporation of certain procedures, surgical or physical, could have significant influences on the results. For example, the use of temporary anchorage devices which provide absolute anchorage due to their mechanical properties for space closure mechanics could have impacted the alignment rates.[29,30]

One unavoidable limitation of this study is a gap between the exact day of full alignment and the 4-weekly follow-up visits, which may not necessarily reflect the real-time tooth alignment. Also, the paucity of literature on extraction protocols and tooth alignment rate may have limited proper study comparison. Further studies on this subject are recommended to corroborate findings from the present study. Also, studies on space closure with temporary anchorage devices following this post-extraction protocols will be of great interest.



## CONCLUSION

Generally, our study showed that the rate of incisor and canine alignment was not affected significantly by RE/HE protocol, gender, or dental arch. However, incisor and canine alignment was significantly faster in adolescents when compared with adults.

**Ethics Committee Approval:** Ethics committee approval was received from the Ethics Committee of the Obafemi Awolowo University Teaching Hospitals' Complex, Ile Ife, Nigeria with protocol number ERC/2016/10/10.

**Informed Consent:** Informed consent and assent were obtained from participants.

**Peer-review:** Written informed consent was obtained from the parents of all patients.

**Author Contributions:** Concept - A.A.O, O.D.O., K.A.K.; Design - A.A.O, O.D.O., K.A.K.; Supervision - A.A.O, O.D.O., K.A.K.; Materials - A.A.O, O.D.O., K.A.K.; Data Collection and/or Processing - A.A.O, O.D.O., K.A.K.; Analysis and/or Interpretation - A.A.O, O.D.O., K.A.K.; Literature Review - A.A.O, O.D.O., K.A.K.; Writing - A.A.O, O.D.O., K.A.K.; Critical Review - A.A.O, O.D.O., K.A.K.

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Original Article

# Performance of a Convolutional Neural Network-Based Artificial Intelligence Algorithm for Automatic Cephalometric Landmark Detection

Mehmet Uğurlu

Department of Orthodontics, Eskişehir Osmangazi University, Faculty of Dentistry, Eskişehir, Turkey

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Main Points

- Artificial intelligence (AI)-based cephalometric analysis system can show clinically acceptable performance.
- As a clinical decision support system, AI-based systems can help orthodontists with diagnosis, treatment planning, and follow-up in clinical orthodontics practice.
- Automatic cephalometric analysis software will save the orthodontists time making their work easier.

## ABSTRACT

**Objective:** The aim of this study is to develop an artificial intelligence model to detect cephalometric landmark automatically enabling the automatic analysis of cephalometric radiographs which have a very important place in dental practice and is used routinely in the diagnosis and treatment of dental and skeletal disorders.

**Methods:** In this study, 1620 lateral cephalograms were obtained and 21 landmarks were included. The coordinates of all landmarks in the 1620 films were obtained to establish a labeled data set: 1360 were used as a training set, 140 as a validation set, and 180 as a testing set. A convolutional neural network-based artificial intelligence algorithm for automatic cephalometric landmark detection was developed. Mean radial error and success detection rate within the range of 2 mm, 2.5 mm, 3 mm, and 4 mm were used to evaluate the performance of the model.

**Results:** Presented artificial intelligence system (CranioCatch, Eskişehir, Turkey) could detect 21 anatomic landmarks in a lateral cephalometric radiograph. The highest success detection rate scores of 2 mm, 2.5 mm, 3 mm, and 4 mm were obtained from the sella point as 98.3, 99.4, 99.4, and 99.4, respectively. The mean radial error $\pm$ standard deviation value of the sella point was found as 0.616 $\pm$ 0.43. The lowest success detection rate scores of 2 mm, 2.5 mm, 3 mm, and 4 mm were obtained from the Gonion point as 48.3, 62.8, 73.9, and 87.2, respectively. The mean radial error $\pm$ standard deviation value of Gonion point was found as 8.304 $\pm$ 2.98.

**Conclusion:** Although the success of the automatic landmark detection using the developed artificial intelligence model was not insufficient for clinical use, artificial intelligence-based cephalometric analysis systems seem promising to cephalometric analysis which provides a basis for diagnosis, treatment planning, and following-up in clinical orthodontics practice.

**Keywords:** Anatomic landmark, lateral cephalometric radiograph, deep learning, artificial intelligence

## INTRODUCTION

Orthodontics is one of the specialties of dentistry that mainly deals with the diagnosis of malocclusion and ultimately aims to prevent and correct them. It mainly deals with the correction of defects in the craniofacial skeleton and dentoalveolar structures. Correct diagnosis and treatment planning are considered the key elements in the success of orthodontic treatment. Orthodontists must be very precise in their diagnosis and treatment planning. Orthodontic diagnosis is mainly based on the patient's dental and medical history, clinical examination, study models, and cephalometric radiographs, which are considered the most useful tool for orthodontic

**Corresponding author**: Mehmet Uğurlu, e-mail: uzm.dt.mehmetugurlu@gmail.com


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diagnosis. Cephalometric radiography is a standard diagnostic imaging technique in orthodontics.[1,2] It is the most important tool for diagnosis and treatment to detect problems in craniofacial skeletal structures and incompatibility of anatomical structures related to each other. The skeletal relationship between the cranial base and the maxilla or mandible, the relationship between the maxilla and the mandible, and the dentoalveolar relationship were quantitatively evaluated using cephalometric radiographs. They also serve to determine the growth pattern through quantitative and qualitative assessments and superimposition of serial radiographs. In addition to that, cephalometric radiographs are also required to plan an orthognathic surgery.[3-6] Identifying anatomical points on cephalometric radiographs is crucial for accurate cephalometric analysis as the initial step of the analysis. However, detecting cephalometric anatomical points is a tedious, difficult, and time-consuming process. There is a possibility of intra- and interobserver variability. It may occur due to differences in education and clinical experience. A clear projection of the craniofacial area into a 2-dimensional image is difficult because of the overlapping of complex anatomical structures and the diversity of dentofacial morphology that differs from patient to patient.[1-8]

In the last few decades, artificial intelligence (AI) technology, which is based on the principles of imitating the functioning of the human brain, lead to important developments in the field of dentistry.[9-11] Artificial intelligence has many sub-fields that are widely used in different fields, especially in biological and medical diagnostics, which includes namely machine learning (ML), artificial neural networks (ANNs), deep learning (DL), and convolutional neural networks (CNNs). Machine learning, the main sub-fields of AI, includes ANN and DL. Artificial neural network has been developed by imitating biological neural networks through computer programs that model the way the brain performs a function. The multi-layered network structure, which is formed by combining artificial neurons and connecting artificial neuron layers with mathematical operations, is called DL. The convolutional neural network is one of the popular and successful DL model for image classification. These neural networks are mathematical computational models that can truly simulate the functioning of the biological neuron. These automated technologies will come in use as powerful tools to predict diagnosis and assist clinicians in treatment planning.[9-11] These models can be trained with clinical data sets and used for a variety of diagnostic tasks in dentistry. Taking into consideration the literature, quite a number of studies are available to assess the performance of AI algorithms to solve different problems in dentistry such as tooth detection and numbering, caries and restoration detection, detection of periapical lesion and jaw pathologies, dental implant planning, impacted tooth detection, etc.[12-18] Moreover, AI-based automatic and semi-automatic system that can be an alternative to fully automatic systems with the advantages such as faster and easier point identification, although it has some disadvantages including loss of standardization, has a great potential in developing tools that will provide significant benefits to assist orthodontists in providing standardized patient care and maximizing the chances of meeting goals. Orthodontists can benefit from AI technology for better clinical decision-making. Besides, orthodontists save time using AI-based systems.[9-11]

The aim of this study is to develop an AI model for the automatic detection of cephalometric landmark that enables the automatic analysis of cephalometric radiographs which have a very important place in dental practice and are routinely used in the diagnosis and treatment of dental and skeletal disorders.

## METHODS

### Radiographic Images Data Sets

Lateral cephalometric images of patients aged between 9 and 20 years, in the mixed or permanent dentition, were obtained from the radiology archive of the Department of Orthodontics, Faculty of Dentistry, Eskişehir Osmangazi University. The cephalometric radiographs had position error, missing/unerupted, or has any developmental problem of central incisors and first molars, metal artifacts caused by orthodontic appliance, implant, etc., trauma and maxillofacial surgery were excluded from study data. Eskişehir Osmangazi University Faculty of Medicine Clinical Research Ethics Committee (approval number: August 6, 2019/14) approved the study protocol, and all procedures were followed in accordance with the Declaration of Helsinki principles. All lateral cephalometric radiographs were taken from patients sitting upright in a natural head position with Plenmeca Promax Dental Imaging Unit (Planmeca, Helsinki, Finland) following parameters 58 kVp, 4 mA, 5 sn.



### Ground Truth Labeling

As an orthodontist with 9 years of experience, M.U. labeled lateral cephalometric radiographs with CranioCatch Annotation Software (CranioCatch, Eskisehir, Turkey) for 21 different cephalometric landmarks using the point identification tool. Following cephalometric landmarks were annotated: sella (S), nasion (N), orbitale (Or), porion (Po), Mx1r, B point, pogonion (Pg), menton (Me), gnathion (Gn), gonion (Go), Md1c, Mx1c, labiale superior (Ls), labiale inferior (Li), subnasale (Sn), soft tissue pogonion (Pg′), posterior nasal spina (PNS), anterior nasal spina (ANS), articulare (Ar), A point, and Md1r (Table 1).

### Deep Learning Architecture

Feature aggregation and refinement network (FARNet) proposed by Yueyuan et al.[19] was used to model the development of cephalometric landmark detection as a CNN-based deep learning model. The feature aggregation and refinement network comprises 3 main systems including a backbone network, a multi-scale feature aggregation (MSFA), and a feature refinement (FR). The backbone network is a pre-trained architecture trained on ImageNet. The backbone network figures out a feature hierarchy of feature maps at various ranges. Feature maps were extracted from the input images with a ranging step of 2 and it works as the first down-sampling way. The MSFA module has an up-sampling and down-sampling way followed by an up-sampling way to combine the multi-range features. In each feature fusion block, features with different resolutions are combined through higher resolution-dominant coupling, where higher resolution

**Table 1.** Definition of Cephalometric Landmark

| | |
|---|---|
| 1. Sella (S) | The midpoint of sella turcica |
| 2. Nasion (N) | The extreme anterior point of the frontonasal suture/junction of frontonasal suture |
| 3. Orbitale (Or) | Inferior border of orbit |
| 4. Porion (Po) | Top of external auditory meatus |
| 5. Mx1r | The tip of the upper incisor root |
| 6. B point | The deepest point in the curvature of the mandibular alveolar process |
| 7. Pogonion (Pg) | The extreme anterior point of the chin |
| 8. Menton (Me) | The extreme inferior point of the chin |
| 9. Gnathion (Gn) | The midpoint between pogonion and menton |
| 10. Gonion (Go) | The midpoint of the mandibular angle between ramus and the mandibular corpus |
| 11. Md1c | The tip of the lower incisor |
| 12. Mx1c | The tip of the upper incisor |
| 13. Labiale superior (Ls) | Most anterior point on outline of upper lip (vermillion border) |
| 14. Labiale inferior (Li) | Most anterior point on outline of the lower lip (vermillion border) |
| 15. Subnasale (Sn) | Junction of nasal septum and upper lip in mid -sagittal plane. |
| 16. Soft tissue pogonion (Pg’) | Most anterior point on outline of ST chin. |
| 17. Posterior nasal spina (PNS) | The extreme posterior point of the maxilla |
| 18. Anterior nasal spina (ANS) | The extreme anterior point of the maxilla |
| 19. Articulare (Ar) | A point on the posterior border of the ramus at the intersection with the basilar portion of the occipital bone |
| 20. A point | The deepest point in the curvature of the maxillary alveolar process |
| 21. Md1r | The tip of the lower incisor root |



features are highlighted by retaining more channels than lower resolution ones. Feature maps obtained from the MSFA module have half resolution as the input image. In order to obtain a more accurate prediction, the FR module was used to generate feature maps with the same resolution as in the input image (Figure 1).

**Model Developing**

The model developing process was conducted on computer equipment in the Dental-AI Laboratory of Faculty of Dentistry in Eskişehir Osmangazi University that contained a Precision 3640 Tower CTO BASE workstation Intel(R) Xeon(R) W-1250P (6 core, 12 M cache, core processor frequency 4.1 GHz, Max Turbo Frequency 4.8 GHz) DDR4-2666, 64 GB DDR4 (4 X16GB) 2666 MHz UDIMM ECC memory capacity, 256 GB SSD SATA, Nvidia Quadro P620, 2 GB) and NVIDIA Tesla V100 graphics card (Dell, Texas, ABD) and 27", 1920 x 1080 pixel IPS LCD monitor (Dell, Tex, ABD). Python open-source programming language (v.3.6.1; Python Software Foundation, Wilmington, Del, USA) and Pytorch library were used for model development, and 1620 cephalometric mixed sizes images with 21 points labels were obtained. A row is determined for each point. Labels were saved in txt format as 21 points in the specified order. Images and labels resized to $1935 \times 2400$. The data sets were divided into 3 parts as training, testing, and validation:

**Training:** 1360 images and 21 points labels

**Validaton:** 140 images and 21 points labels

**Test:** 180 images and 21 points labels

The data obtained from the testing group were not reused. The training of the AI model was performed using 300 epochs with PyTorch implemented CNN-based deep learning method. The learning rate of the model was determined as 0.0001 (Figure 2).

**Evaluation of the Model Performance**

The point-to-point error of each landmark was measured with the absolute distance and averaged over the all-test data set. Landmark error was measured manually and was estimated landmark position of an image respectively. Mean Radial Error (MRE) and Standart Deviation (SD) values were reported for the all landmarks. The radial error (*R*) computed as $\Delta x$ is the distance between the estimated position and the manual localized standard position in the x direction, and $\Delta y$ is the distance between the estimated position and the manual localized standard position in the y direction in the horizontal (x) and vertical (y) coordinate systems.[2]

$$R = \sqrt{\Delta x^2 + \Delta y^2}$$

MRE and SD were computed using following formula[2]:

$$MRE = \frac{\sum_{i=1}^{N} R_i}{N}$$

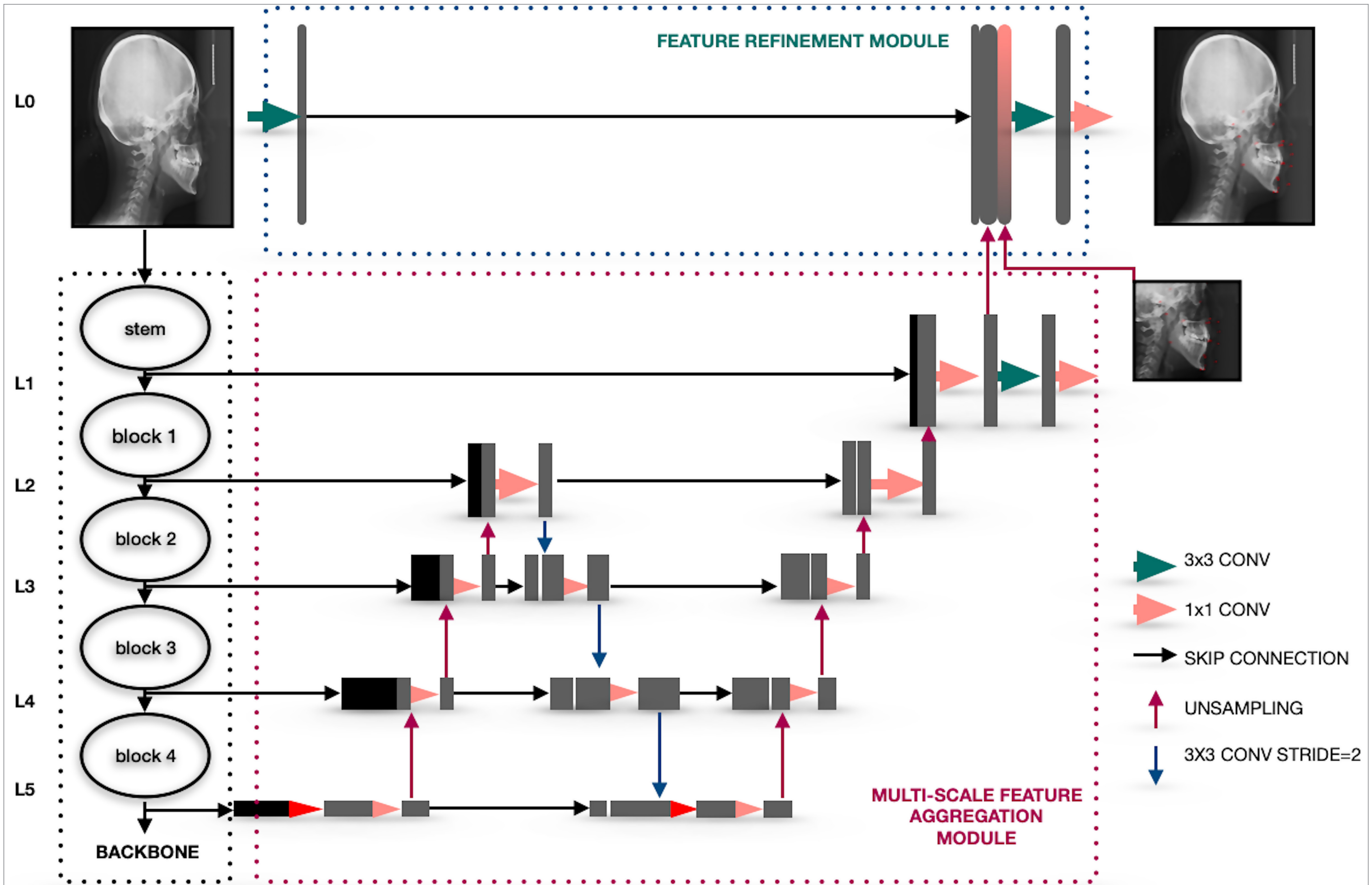


**Figure 1.** The system architecture of the CNN-based AI algorithm

$$\mathrm{SD} = \sqrt{\frac{\sum_{i=1}^{N}(R_i - MRE)^2}{\mathrm{N}-1}}$$

The successful detection rates (SDR) were measured which indicate percentages of estimated points within each precision range of 2 mm, 2.5 mm, 3 mm, and 4 mm, respectively. For each cephalometric landmark, if the distance between the automatically determined position by AI and the ground truth is no higher than a certain value *d*, automatic localization detected by AI is accepted successful, and the SDR related to the accuracy of *d* can be calculated.[2]

## RESULTS

The presented AI system (CranioCatch, Eskisehir, Turkey) could detect 21 anatomic landmarks in a lateral cephalometric radiograph (Figure 3). The highest SDR score of 2 mm, 2.5 mm, 3 mm, and 4 mm was obtained from the S point as 98.3, 99.4, 99.4, and 99.4, respectively. The MRE $\pm$ SD value of S was found as 0.616 $\pm$ 0.43. The lowest SDR score of 2 mm, 2.5 mm, 3 mm, and 4 mm were obtained from the Go point as 48.3, 62.8, 73.9, and 87.2, respectively. The MRE $\pm$ SD value of Go was found as 8.304 $\pm$ 2.98. The MRE and SDR value of each anatomic landmark obtained from test data is summarized in Table 2.

## DISCUSSION

Deep learning-based AI algorithms are using commonly medical image analysis. Cephalometric images are routinely used to evaluate the relationship between mandible and maxilla and dentoalveolar structure and detection of dental and skeletal anomalies in orthodontics practice. Although analysis of cephalometric images is so important, it is a time-consuming and strong procedure and the result of the analysis can be varying from person to person. Taking into consideration, the opinion of automatic cephalometric analysis using AI algorithms was found to be useful and so many studies were available using different methods in the literature. In this view, automatic cephalometric landmark detection challenges were organized by the International Symposium on Biomedical Imaging (ISBI) and the Institute of Electrical and Electronics Engineers which created public data set comprising the 19 cephalometric landmarks. Using this data set, different AI methods such as decision tree, random forest, Bayesian convolutional neural networks, and cascade CNNs were applied for the detection of cephalometric landmark.[20-26] A study conducted by Zeng et al.[20] proposed an original way based on cascaded CNNs for automatic cephalometric landmark detection of 19 points on ISBI 2015 challenge test 1 data set. In this study, the highest SDR score of 2 mm, 2.5 mm, 3 mm, and 4 mm were obtained from incision superius point as 95.33, 96.00, 98.00, and 100.0, respectively. The MRE $\pm$ SD value of incision superius was found as 0.96 $\pm$ 0.61. The lowest SDR score of 2 mm, 2.5 mm,

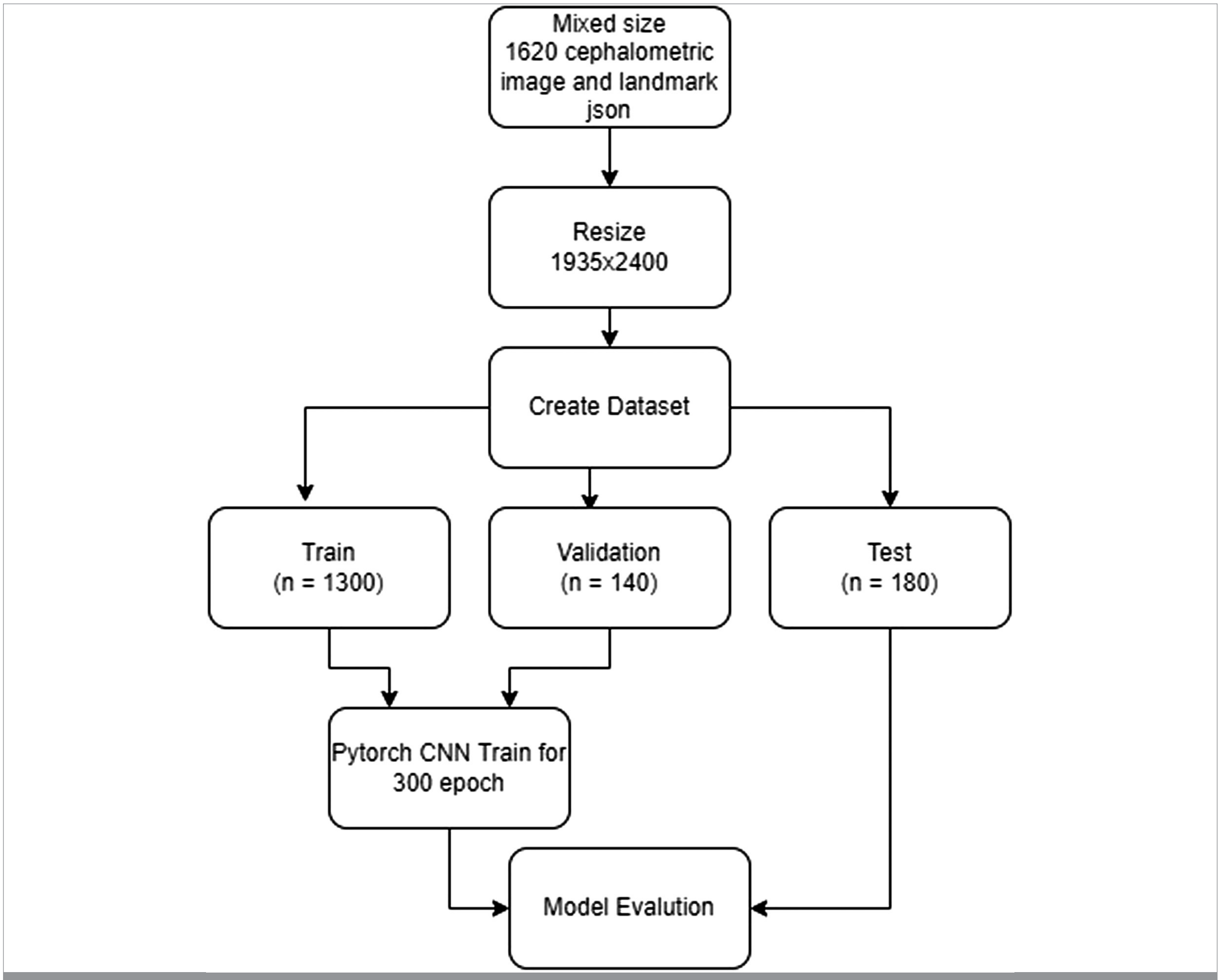


**Figure 2.** AI model pipeline of automatic landmark detection (JSON: Java Script Object Notation)

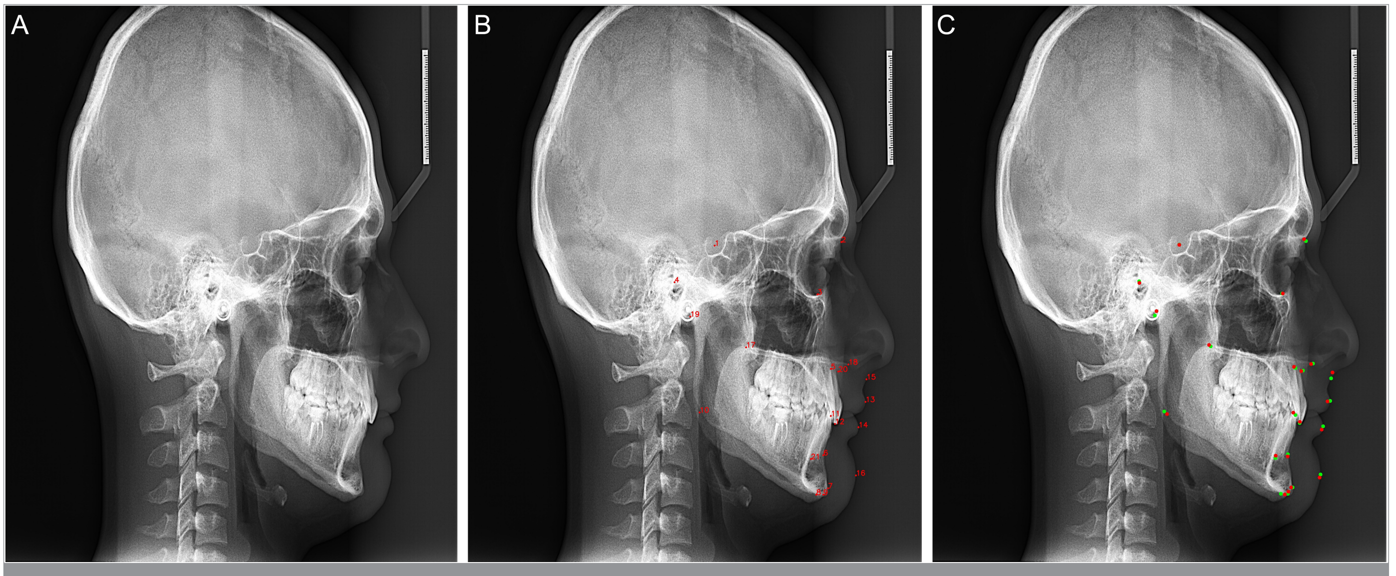


**Figure 3. A-C.** Automatic detection of cephalometric points by the AI model. (A) Original image (B) Automatic landmark detection by AI model. (C) The comparison of landmark detection by expert and AI. Red: landmark location detected by expert. Green: landmark location detected by AI

**Table 2.** The MRE and SDR value of landmarks obtained from test data

| Anatomic Landmark | 2 mm | 2.5 mm | 3 mm | 4 mm | MRE ± SD |
|---|---|---|---|---|---|
| Sella (S) | 98.3 | 99.4 | 99.4 | 99.4 | 0.616 ± 0.43 |
| Nasion (N) | 77.8 | 83.9 | 89.4 | 94.4 | 1.391 ± 1.26 |
| Orbitale (Or) | 66.1 | 73.3 | 83.3 | 92.2 | 2.070 ± 1.63 |
| Porion (Po) | 65.0 | 75.6 | 80.6 | 90.6 | 3.963 ± 1.78 |
| Mx1r | 72.2 | 82.2 | 87.8 | 93.9 | 4.870 ± 1.84 |
| B point | 66.1 | 79.4 | 85.0 | 91.1 | 3.416 ± 1.82 |
| Pogonion (Pg) | 73.9 | 80.6 | 87.2 | 93.3 | 1.579 ± 1.31 |
| Menton (Me) | 67.8 | 75.0 | 83.9 | 92.8 | 1.429 ± 1.33 |
| Gnathion (Gn) | 88.9 | 93.3 | 96.1 | 97.8 | 2.172 ± 1.13 |
| Gonion (Go) | 48.3 | 62.8 | 73.9 | 87.2 | 8.304 ± 2.98 |
| Md1c | 91.7 | 93.3 | 95.0 | 95.6 | 5.318 ± 1.62 |
| Mx1c | 94.4 | 95.0 | 95.6 | 95.6 | 1.774 ± 0.86 |
| Labiale superior (Ls) | 90.6 | 94.4 | 95.6 | 96.7 | 2.519 ± 1.10 |
| Labiale inferior (Li) | 86.7 | 89.4 | 92.2 | 95.6 | 2.110 ± 1.18 |
| Subnasale (Sn) | 90.6 | 94.4 | 96.1 | 97.2 | 2.028 ± 1.08 |
| Soft tissue pogonion (Pg′) | 53.9 | 66.1 | 70.0 | 78.9 | 4.045 ± 2.32 |
| Posterior nasal spina (PNS) | 66.1 | 78.3 | 84.4 | 90.6 | 5.780 ± 2.24 |
| Anterior nasal spina (ANS) | 78.3 | 86.1 | 90.6 | 95.6 | 4.187 ± 1.68 |
| Articulare (Ar) | 69.4 | 77.2 | 82.2 | 90.0 | 5.570 ± 2.03 |
| A point | 76.1 | 83.3 | 87.8 | 94.4 | 5.124 ± 1.67 |
| Md1r | 81.7 | 89.4 | 95.6 | 97.8 | 3.524 ± 1.41 |
| **Mean** | 76.2 | 83.5 | 88.2 | 93.4 | 3.400 ± 1.57 |

MRE, mean radial error; SD, standard deviation.

3 mm, and 4 mm were obtained from P as 54.67, 68.67, 80.67, and 94.00, respectively. The MRE ± SD value of incision superius was found as 2.02 ± 1.25. The average SDR score of 2 mm, 2,5 mm, 3 mm, and 4 mm were obtained as 81.37, 89.09, 93.79, and 97.86, respectively. The average value of MRE ± SD was found as 1.34 ± 0.92. Lee et al.[21] developed a new network for detecting cephalometric points with confidence regions using Bayesian CNNs. Their AI model was also trained with the public data set from the ISBI 2015 grand challenge in dental x-ray image analysis. The highest SDR score of 2 mm, 2.5 mm, 3 mm, and 4 mm were obtained from lower lip point as 97.33, 98.67, 98.67, and 99.33, respectively. Landmark error with SD of lower lip point was found as 1.28 ± 0.85. The lowest SDR score of 2 mm, 2,5 mm, 3 mm, and 4 mm were obtained from the A point as 52.00, 62.00, 74.00, and 87.33, respectively. The MRE with SD values of lower lip point was found as 2.07 ± 2.53. The average SDR score of 2 mm, 2,5 mm, 3 mm, and 4 mm were obtained from 82.11, 88.63, 92.28, and 95.96, respectively. Landmark error with SD of average was found as 1.53 ± 1.74. A study conducted by Bulatova et al.[22] evaluated the accuracy of cephalometric landmark detection between the You Only Look Once, Version 3 (YOLOv3) algorithm based on the CNN and the manual identification group. There were no found statistical differences between manual identification and AI groups for 11 out of 16 points. Significant differences (>2 mm) were found for points of U1 apex, L1 apex, Basion, Go, and Or. They concluded that AI may increase the efficiency of the cephalometric point identification in routine clinical practice. Kim et al.[7] investigated the accuracy of automated detection of cephalometric points using the cascade CNNs on lateral cephalograms obtained from multi-centers in South Korea. A total of 3150 lateral cephalograms were used for training. For external validation, 100 lateral cephalograms were used as the data set. The mean identification error for each point was found to be between 0.46 ± 0.37 mm for the maxillary incisor crown tip and 2.09 ± 1.91 mm for the distal root tip of the mandibular first molar.

Taking literature into consideration, many cephalometric points including A point, Ar, Go, Pg′, and Or were detected difficult, and these points present higher errors or lower SDR values than other points. In the present study, Go point had the lowest value of SDR as 48.3, 62.8, 73.9, and 87.2 for 2 mm, 2.5 mm, 3 mm, and 4 mm, respectively. The points of Pg′, PNS, Me, Or, B, Ar, and Po had SDR values also lower than 70.0 for 2 mm. The SDR score of 2 mm, 2.5 mm, 3 mm, and 4 mm obtained from A point was found as 76.1, 83.3, 87.8, and 94.4, respectively. The MRE ± SD value of a point was found as 5.124 ± 1.67. Although the success of the model was not clinically acceptable in automatic landmark detection, the success of the system seems promising and open to improvement (developable and upgradeable). The present study has many limitations such as including images obtained from only 1 center and the same exposure parameters, making of the labeling by an orthodontist, no testing of external data set, and limited numbers of cephalometric landmarks for cephalometric analysis. The results obtained are promising in terms of localizing the cephalometric landmarks.

## CONCLUSION

Convolutional neural network-based AI algorithms show promising success for medical image evaluations. Although the success of the automatic landmark detection developed using the AI model was not insufficient for clinical use, AI-based cephalometric analysis systems seem promising to cephalometric analysis which provides a basis for diagnosis, treatment planning, and following-up in clinical orthodontics practice.

**Ethics Committee Approval:** Eskişehir Osmangazi University Faculty of Medicine Clinical Research Ethics Committee (approval number: 06.08.2019/14) was approved the study protocol and all procedures were followed Declaration of Helsinki principles.

**Informed Consent:** Verbal informed consent was obtained from all participants who participated in this study.

**Peer-review:** Externally peer-reviewed.

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Original Article

# Cephalometric Variables Prediction from Lateral Photographs Between Different Skeletal Patterns Using Regression Artificial Neural Networks

Saif Mauwafak Ali[1], Hayder Fadhil Saloom[1], Mohammed Ali Tawfeeq[2]

[1]Department of Orthodontic, University of Baghdad, Baghdad, Iraq
[2]Department of Computer Engineering, University of Mustansiriyah, Baghdad, Iraq

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Main Points

- These neural network models represented a new clinical implication to measure orthodontic lines and angles through lateral photographs avoiding the risk of cephalometric radiation.
- The neural network models' determination success was 0.99 for the training-test set ratio: 70-30%.
- A high level of accuracy was achieved as a result of a high correlation between the output and the target measurements of the networks.

## ABSTRACT

**Objective:** This study aimed to design an artificial neural network for the prediction of cephalometric variables via a lateral photograph in skeletal Class I, II, and III patterns.

**Methods:** A total of 94 patients were recruited for this prospective study, with an age range of 15-20 years (41 boys and 53 girls) seeking orthodontic treatment. According to cephalometric analysis, using AutoCAD 21.0, they were allocated into three groups. Thirty with skeletal Class I (14 boys and 16 girls), 34 with skeletal Class II (14 boys and 20 girls), and 30 with skeletal Class III malocclusion (13 boys and 17 girls) according to SNA, SNB, and ANB angles measured from cephalometric radiographs. The study includes (1) finding the correlation of the skeletal measurements between lateral profile photographs and cephalometric radiographs for the recruited patients and (2) designing a specific artificial neural networks for the assessment of skeletal factors via lateral photographs, these artificial neural networks are trained and tested with the total of 94 standard lateral cephalograms.

**Results:** This novel Network provided models of regression that can forecast the cephalometric variables through analogous photographic measurements with excellent predictive power R = 0.99 and limited estimation error for each malocclusion (Class I, II, and III).

**Conclusion:** This study suggests that artificial intelligence would be useful as an accurate method in orthodontics for the prediction of cephalometric variables and its performance was achieved by several factors such as proper selection of the input data, preferable generalization, and organization.

**Keywords:** Artificial neural networks, cephalograms, artificial intelligence

## INTRODUCTION

Globally, digital technology is becoming constantly one of the most important procedures in the clinical activities, and, thus, orthodontic digital revolution has been added more and more by orthodontists in their clinical practice. In orthodontics, successful treatment outcomes depend on accurate diagnosis through crucial diagnostic tools, which involves the development of a comprehensive database of patient's information; the data is obtained from case history, clinical examination, and other diagnostic aids such as study casts, radiographs, and photographs.[1]

**Corresponding author**: Saif Mauwafak Ali, e-mail: Saifmowafak777@gmail.com


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An important part of diagnosis is to evaluate the skeletal factors via the records. Although cephalometric is the standard for identifying skeletal and dental craniofacial morphology in clinical practice, it might not be practical for large and repeated studies of epidemiology.[2]

Additionally, certain limitations to cephalometric radiographs are mentioned, for example, for patients exposed to a certain amount of radiation; a special source of radiation and a head holder are required to produce accurate images. For these reasons, it would be valuable to have a simple, safe, low-cost technology technique for assessing craniofacial morphology. Therefore standardized facial photography might be a useful tool for characterizing craniofacial anatomy since some aspects of facial appearance are related to the morphology of underlying hard tissues.[3]

Historically, facial photographs have been crucial parts of both pretreatment and posttreatment orthodontic records. Many orthodontic texts emphasized the use of orthodontic diagnosis and treatment planning. Graber (1946) reported that the photograph assumes even greater importance when dentists do not have equipment for taking cephalograms,[4] therefore photographs can be considered as an essential diagnostic tool.[5] From a lateral view, facial height and depth, the position of upper and lower lips, and the mandibular angle are the main factors that characterize facial patterns.[6] Additionally, photographic analysis is an economical technique and safe method since the patient does not expose to potentially harmful radiation, it can be easily used to assess the head and face postures and compare those existing relationships among different craniofacial structures.[7]



Currently, many methods of multiple-factor analysis are applicable in medicine, and among these artificial neural network (ANN) model analysis is very commonly used. Several studies have been done recently about artificial intelligence and bioinformatics.[1,8] One way is machine learning using a neural network system.[9]

In a true sense, ANNs are clustering of the primitive artificial neurons in a simple way, and this clustering is composed of multiple layers connected to one another. As shown in Figure 1, the first (input) layer consists of neurons that receive input from the external surrounding. The output layer consists of neurons that communicate the output of the model to the external environment. Between these input and output layers, there are usually a number of hidden layers; however, Figure 1 is just a simple architecture with only one intermediate (hidden layer). When the input layer receives the signal, its neurons produce output and this becomes an input to the other layers of the model. The process continues until a certain condition is fulfilled or until the output layer is invoked and fires its output to the external surrounding.[10]

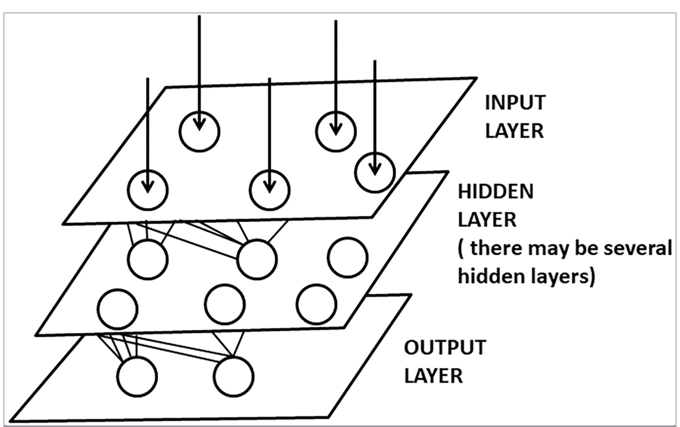


**Figure 1.** The structure of an artificial neural network (25)

Previously, in orthodontics, the use of ANN was recommended for the extraction[11]; the prediction of change in lip curvature[12]; and the prediction of arch form.[13] They found that ANN model analyses were more accurate as compared to the conventional ones. To our knowledge, no studies have employed the ANN for the prediction of skeletal parameters for full orthodontic diagnosis using lateral photographs. Thus this study aimed to make a new artificial intelligence decision-making model for the diagnosis of skeletal factors only through photographs using neural network machine learning between different skeletal malocclusion.

## METHODS

A total of 94 patients were recruited for this prospective study, with an age range of 15-20 years (43 boys and 51 girls) seeking orthodontic treatment. According to cephalometric analysis, using AutoCAD 21.0, they were divided into 3 groups. Thirty with skeletal Class I (14 boys and 16 girls, ANB angle 2°-4°), 34 with skeletal Class II (14 boys and 20 girls, ANB angle >4°), and 30 with skeletal Class III malocclusion (13 boys and 17 girls, ANB angle <2º), according to SNA, SNB, and ANB angles from cephalometric radiographs.

This study was conducted in the Al-Shaab specialized dental center in Baghdad. This study was approved by the Human Research Ethics Committee of College of Dentistry/Baghdad University (Iraq), (Approval No:168/2019). All subjects were given consent information sheets for inclusion before participation.

Inclusion criteria were patients with age range 15-20 years, no previous orthodontic or surgical treatment, all permanent teeth erupted up to the second molar included, no craniofacial trauma, and no congenital anomalies. Exclusion criteria were patients who were not fit for orthodontic treatment (i.e., poor oral hygiene and multiple caries), patients with systemic diseases or pregnant patients, and patients who were not within the age range. Standardized right profile photographs were taken for participants in the natural head position (NHP), the teeth in centric occlusion, and the lips at rest position. Eyeglasses, earrings, and necklaces were removed. Ensure that the patient's forehead was clearly visible and the hair piled high on the head. Red indicators dots were placed on anatomic landmarks (N', A', B', Pog', Mn', Go', Tr, Or') obtained by palpation (Figure 2).

In order to obtain the NHP, a 75 × 30 cm mirror was hung on a tripod, which can be adjusted vertically according to the height

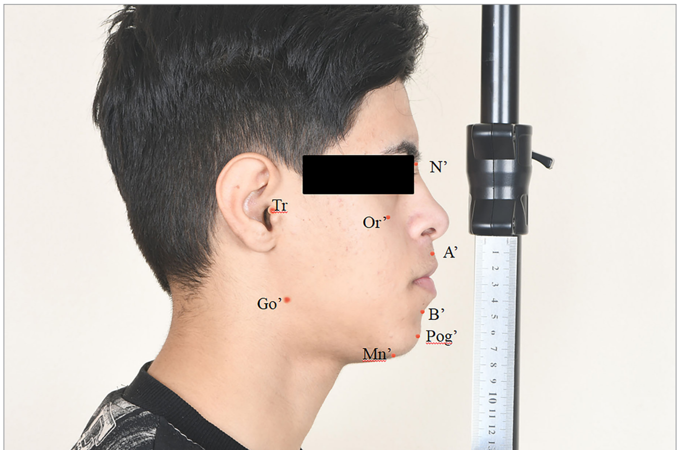


**Figure 2.** Red indicators dots were placed on anatomic landmarks

of the patients. Patients were asked to stand in a relaxed position and to look at the reflection of their eyes in the mirror that is located 120 cm from the patient. The patient asked to bite on fox bite to record the occlusal plane by pointing two red dots on the cheek of the patient parallel to the plane of fox bite. Then, a straight line was easily drawn by connecting these two dots by AutoCAD software. A protractor was used to record the NHP angle by placing it on the tip of the nose and the soft tissue pogonion.[14]

Digital lateral cephalometric radiographs were taken with Sirona Orthophos XG (Dentsply company, NY, USA). Cephalometric radiographs were taken in the NHP with centric occlusion and rest position of the lips. In order to register the true vertical line, the nose rode was placed in front of the patient, in the midsagittal plane, and the scale of the nose rode allowed later measurements at life size (1 : 1). Natural head position angle was checked by a modified protractor, it was placed on the tip of the nose and the soft-tissue pogonion to check if the same position achieved during the photographic record had also been obtained during the radiographic record.[14]

Both digital photographic and radiographic records were analyzed with AutoCAD (21.0) (codename nautilus) software for Windows. A specific analysis was customized using the landmarks defined for the purpose of this study (Figure 2). Traditional cephalometric angular and linear measurements included;

(A) Sagittal assessment: (1) Wits measurements indicate maxillomandibular linear discrepancy; (2) ANB angle indicates maxillomandibular angular discrepancy; (3) FNP angle indicates facial angle; (4) N.ANS.Pog; and (5) N.ANS.B angles indicate angles of facial convexity.

(B) Vertical assessment: (6) Ar.Go.Me angle indicates gonial angle; (7) FMA angle indicates Frankfurt to mandibular plane angle; (8) OPA angle indicates Frankfurt to occlusal plane angle; (9) AFH indicates anterior facial height (N-Me); (10) LAFH indicates lower anterior facial (ANS-Me) height; and (11) LPFH indicates lower posterior facial height (Ar-Go) (15) and analogous photographic ones were used for sagittal and vertical assessment which include (1) Wits' measurement indicates soft-tissue maxillomandibular linear discrepancy; (2) A'N'B'angle indicates soft tissue maxillomandibular angular discrepancy; (3) FNP'angle indicates soft-tissue facial angle; (4) N'.Sn.Pog'; (5) N'.Sn.B' angles indicate soft tissue angles of facial convexity for sagittal assessment; (6) Tr.Go'.Me' angle indicates soft tissue gonial angle; (7) FMA' angle indicates soft tissue Frankfort to mandibular plane angle; (8) OPA' angle indicates soft tissue Frankfort to occlusal plane angle; (9) AFH' indicates soft tissue anterior facial height (N'-Me'); (10) LAFH' indicates soft tissue lower anterior facial height (Sn-Me'); and (11) PFH' indicates lower posterior facial height (Tr-Go').[15] All the measurements were calculated once the landmarks were properly identified on each record; these were previously scaled to life size. Inter- and intra-examiner calibrations were performed on a sample of 27 subjects (15 boys and 12 girls) for computerized analysis of facial morphology through radiographs and photographs.

All the data of the skeletal measurements that were calculated by AutoCad software in millimeter values had arranged in the excel program (Microsoft Office 2020) in the form of tables. The first table for Class I malocclusion, the second table for Class II malocclusion, and the third for Class III malocclusion, each table included 22 variables, 11 variables for the cephalometric radiographs, and 11 variables for the lateral photographs.

In ANN programing, all the data of skeletal measurements had been copied into the MATLAB program (R2020a vs. 9.8.0/2020) from Microsoft Excel. The first neural network was for the Class I malocclusion measurements and the second and the third neural networks were for Class II and III malocclusion measurements respectively. The data were randomly allocated into 70% of data for training (Ptrian = 0.7) and 30% for testing, Feedforward backpropagation was used for these networks and the learning functions were Bayesian Regularization for all. These networks were trained by entering the 11 variables (angular and linear measurements) for the lateral photographs as input values for the network while the output values were the 11 variables (angular and linear measurements) for the cephalometric radiographs. The percentage of training data was 70% of the total data selected randomly and the percentage for testing the network was 30% of the total data (testing new data that was never trained).

**Statistical Analysis**

Shapiro-Wilk test for data distribution showed a non-significant difference ($P > .05$) thus data were considered normally distributed. Data were subjected to statistical analysis using the Statistical Package for the Social Sciences, version 16.0 (SPSS Inc, Chicago, Ill, USA). Descriptive statistics were performed for each photographic and cephalometric variable for the skeletal measurements networks. Sexual dimorphism was evaluated by independent sample *t*-test. Intraclass correlation coefficients (ICCs) were estimated from repeated photographic measurements and analysis of cephalometric and photographic variables to evaluate the repeatability and reproducibility of the method. Cephalometric measurements were compared with analogous photographic variables to assess Pearson correlation coefficients. Linear regression analyses were made after designing the networks for all networks between the targets (dependent variable to be estimated) and actual outputs of cephalometric variables (independent variable). Levels of $P < .05$ were considered statistically significant.

## RESULTS

The ICC to evaluate the reliabilities of the photographic technique and the analysis of the skeletal measurements on cephalometric and lateral photos demonstrated excellent reliability with values ranged between 0.85 and 0.90.

The independent sample *t*-test showed no significant difference between male and female subjects except for the anterior and posterior facial height which were greater in males than females for all skeletal malocclusions in the cephalometric and facial photographs (Tables 1 and 2).

Highly significant correlations ($P \leq .001$, $r > 0.79$) were found for most sagittal and vertical diagnostic variables with higher vertical than sagittal measurements using the Pearson correlation coefficient.



Linear regression analysis was estimated for 70% of the collected data (skeletal Class I, II, III malocclusion) after designing the neural network. It showed very high coefficients of correlations between cephalometric radiographic variables of the actual output and the target during the training process (Figure 3) (R = 0.999 during training part, R = 0.999 during testing part of training process, R = 0.999 as a whole). The best training performance which means the least mean square error during training process was 0.20 337 at epoch 135 for Class I malocclusion, 0.35 917 at epoch 78, 0.43 499 at epoch 111 for Class II and III malocclusion respectively (Figure 4).

Following testing process, linear regression analysis was estimated for the other 30% of the collected data after designing the neural network. It showed very high correlation coefficients between cephalometric radiographic variables of the output and the actual target (Figure 5) ($R = 0.9991$, $R = 0.9998$, and $R = 0.9987$ for skeletal Class I, II, and III, respectively).

## DISCUSSION

The cephalometric analysis creates the current gold standard for diagnosing different skeletal patterns in the clinical practice of orthodontists. However, the photographic assessment is a tremendous diagnosis tool for studies of epidemiology since there is no potentially harmful radiation and it is a cost-effective technique.[5,16]

The standardized technique of facial photography has several advantages for using as an alternative practical technique for the diagnosis of craniofacial morphology. It is easier to take measurements without skin pressure-related errors since the subjects do not move and the interaction period is potentially shorter with the subject. Furthermore, longitudinal studies are applicable since measurements can be performed repeatedly, and storing of the data is permanent.[3,17] Conversely, facial photographic technique has some drawbacks. The objects near the camera appear larger than those away from it due to distortion from the distance between the lens and the subject.[3]

Since most landmarks obtained from lateral photographs in the current study are at the midline, the effect of distortion is minimum because this effect is critical at the landmarks that are located in different planes of space.[18] Moreover, most variables used in the current study were angular which partially overcomes the problem of magnification.

Another source of error concerns is head posture, it must be the same during the recording protocol of radiographs and photographs. The landmarks' location is greatly affected even by a slight deviation of the NHP and this causes changes in the results of the measurements.[1] Additionally, mentalis muscle constriction due to jaw opening may increase the estimate of error.[19]

One of the most important aspects of anthropometry studies is the reliability of measurement, which is the ability to obtain the same measurement consistently over sequential measures.[20] In the current study, most photographic measurements were performed based on palpation of anatomic points. It is important to find the reliability in positioning the red dots without the interference of other source of error therefore a reproducibility test was conducted. Accurate establishment of landmarks is crucial to ensure standardized photography protocol. Results of this study showed that method reproducibility was satisfactory.

Although the sample in this study had different skeletal patterns (Class I, II, and III malocclusions) generally, most cephalometric measurements showed no significant gender differences which explain the identical distribution into male and female subgroups. However, differences were found only for facial height anteriorly and posteriorly (AFH, LAFH, PFH) for photographs and cephalometric radiographs which were significantly higher in male subjects. This came in agreement with many studies which reported sexual dimorphism in most parameters of the chin, nasal, and labial areas. Ferrario et al.[21] in 1993 mentioned that male faces show, on average, greater prominences of these areas as well as greater heights and lengths. Bishara et al.[22] (1995) and Fernandez-Riveiro et al.[23] (2009) had also reported significantly larger values for AFH, LAFH, and PFH in male subjects, which agrees with the findings of this study.

Highly significant correlations were found for most sagittal and vertical diagnostic variables. However, the highest coefficients were found between vertical variables as compared with sagittal variables. These findings agreed with the results of Gomes and coworkers in 2013.[15]

Good correlation coefficient was reported in this study between analogous photographic and cephalometric ANB angles ($r = 0.79$, $r = 0.79$, $r = 0.84$ in Class I, II, and III malocclusions, respectively). These results agreed with the results of Staudt and Kiliaridis[19] in 2009 who mentioned that a predictable description of the underlying sagittal jaw relationship can be obtained from

**Table 1.** Gender difference for Cephalometric radiographic Measurements

| **Measurements** | **Male subjects n = 14** | | | | **Female subjects n = 16** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Class I** | **Mean** | **SD** | **Min** | **Max** | **Mean** | **SD** | **Min** | **Max** | ***t*-test** | ***P*** | **Significance** |
| Sagittal assessment | | | | | | | | | | | |
| Wits | 0.50 | 0.41 | −0.27 | 0.91 | 0.42 | 0.32 | −0.05 | 0.94 | 0.619 | .541 | NS |
| ANB | 3.33 | 0.65 | 2.00 | 4.00 | 3.50 | 0.89 | 2.00 | 5.00 | −0.545 | .590 | NS |
| FNB | 87.92 | 1.88 | 85.00 | 91.00 | 89.44 | 3.01 | 83.00 | 95.00 | −1.536 | .137 | NS |
| N-ANS-Pog | 167.25 | 4.25 | 161.00 | 174.00 | 164.88 | 6.70 | 153.00 | 173.00 | 1.074 | .293 | NS |
| N-ANS-B | 164.83 | 4.71 | 157.00 | 171.00 | 161.81 | 6.99 | 150.00 | 172.00 | 1.291 | .208 | NS |
| Vertical assessment | | | | | | | | | | | |
| Ar-Go-Me | 130.50 | 8.02 | 123.00 | 146.00 | 129.63 | 6.38 | 120.00 | 142.00 | 0.322 | .750 | NS |
| FMA | 28.17 | 6.90 | 20.00 | 41.00 | 26.69 | 6.18 | 17.00 | 37.00 | 0.596 | .556 | NS |
| OPA | 9.42 | 3.37 | 4.00 | 15.00 | 9.88 | 4.03 | 4.00 | 17.00 | −0.319 | .752 | NS |
| LAFH | 16.49 | 0.78 | 15.66 | 18.28 | 15.29 | 0.85 | 14.07 | 16.83 | 3.816 | .001 | **S** |
| AFH | 9.79 | 0.90 | 8.81 | 12.12 | 8.71 | 0.73 | 7.18 | 9.74 | 3.504 | .002 | **S** |
| LPFH | 6.47 | 0.81 | 4.86 | 7.73 | 5.58 | 0.55 | 4.65 | 6.66 | 3.491 | .002 | **S** |
| **Measurements** | **Male subjects n = 14** | | | | **Female subjects n = 20** | | | | | | |
| **Class II** | **Mean** | **SD** | **Min** | **Max** | **Mean** | **SD** | **Min** | **Max** | ***t*-test** | ***P*** | **Significance** |
| Sagittal assessment | | | | | | | | | | | |
| Wits | 1.14 | 0.58 | 0.43 | 2.56 | 1.10 | 0.43 | 0.37 | 2.03 | 0.275 | .785 | NS |
| ANB | 7.29 | 2.20 | 5.00 | 12.00 | 7.16 | 1.49 | 5.00 | 10.00 | 0.212 | .833 | NS |
| FNB | 87.43 | 3.27 | 81.00 | 93.00 | 87.28 | 2.56 | 83.00 | 92.00 | 0.157 | .876 | NS |
| N-ANS-Pog | 160.21 | 6.53 | 147.00 | 169.00 | 160.52 | 4.80 | 153.00 | 171.00 | −0.167 | .868 | NS |
| N-ANS-B | 156.57 | 7.65 | 140.00 | 168.00 | 157.56 | 5.15 | 150.00 | 170.00 | −0.482 | .633 | NS |
| Vertical assessment | | | | | | | | | | | |
| Ar-Go-Me | 128.43 | 10.12 | 114.00 | 146.00 | 128.40 | 6.66 | 116.00 | 143.00 | 0.011 | .992 | NS |
| FMA | 25.71 | 10.10 | 12.00 | 44.00 | 27.88 | 5.21 | 21.00 | 42.00 | −0.887 | .381 | NS |
| OPA | 9.21 | 3.77 | 3.00 | 17.00 | 11.12 | 3.14 | 6.00 | 19.00 | −1.692 | .099 | NS |
| LAFH | 16.02 | 1.20 | 14.06 | 17.69 | 15.08 | 0.83 | 13.65 | 16.86 | 2.876 | .007 | S |
| AFH | 9.29 | 1.29 | 7.57 | 11.37 | 8.52 | 0.61 | 7.23 | 9.79 | 2.528 | .016 | S |
| LPFH | 6.24 | 0.54 | 5.35 | 7.28 | 5.61 | 0.57 | 4.75 | 6.84 | 3.401 | .002 | S |
| **Measurements** | **Male subjects n = 13** | | | | **Female subjects n = 17** | | | | | | |
| **Class III** | **Mean** | **SD** | **Min** | **Max** | **Mean** | **SD** | **Min** | **Max** | ***t*-test** | ***P*** | **Significance** |
| Sagittal assessment | | | | | | | | | | | |
| Wits | 0.00 | 0.37 | −0.68 | 0.66 | 0.03 | 0.39 | −0.68 | 0.66 | 0.354 | .726 | NS |
| ANB | 0.15 | 1.43 | −5.00 | 1.00 | −0.23 | 1.88 | −5.00 | 1.00 | −1.393 | .176 | NS |
| FNB | 91.12 | 3.54 | 84.00 | 97.00 | 91.23 | 3.83 | 84.00 | 96.00 | 0.163 | .872 | NS |
| N-ANS-Pog | 171.08 | 5.64 | 157.00 | 180.00 | 170.15 | 6.50 | 157.00 | 179.00 | −0.829 | .415 | NS |
| N-ANS-B | 169.19 | 5.78 | 154.00 | 179.00 | 168.69 | 6.66 | 154.00 | 179.00 | −0.434 | .668 | NS |
| Vertical assessment | | | | | | | | | | | |
| Ar-Go-Me | 130.54 | 7.96 | 119.00 | 155.00 | 131.15 | 9.84 | 119.00 | 155.00 | 0.387 | .702 | NS |
| FMA | 25.19 | 6.78 | 16.00 | 45.00 | 25.69 | 7.92 | 16.00 | 45.00 | 0.369 | .715 | NS |
| OPA | 9.81 | 4.41 | 1.00 | 19.00 | 8.31 | 4.29 | 1.00 | 16.00 | −1.812 | .082 | NS |
| LAFH | 15.86 | 1.47 | 13.99 | 19.34 | 16.71 | 1.51 | 14.86 | 19.34 | 3.600 | .001 | S |
| AFH | 9.01 | 1.22 | 7.14 | 11.76 | 9.65 | 1.18 | 8.26 | 11.76 | 3.098 | .005 | S |
| LPFH | 6.35 | 0.74 | 4.89 | 7.75 | 6.81 | 0.62 | 6.02 | 7.75 | 4.079 | .001 | S |

***Wits** measurements indicates maxillomandibular linear discrepancy; **ANB angle** indicates maxillomandibular angular discrepancy; **FNP angle** indicates facial angle; **N-ANS-Pog** and **N-ANS-B angles** indicate angles of facial convexity. **Ar-Go-Me angle** indicates gonial angle; **FMA angle** indicates Frankfurt to mandibular plane angle; **OPA angle** indicates Frankfurt to occlusal plane angle; **AFH** indicates anterior facial height **(N-Me)**; **LAFH** indicates lower anterior facial **(ANS-Me)** height; and **LPFH** indicates lower posterior facial height **(Ar-Go)**; SD, standard deviation; Min, minimum; Max, maximum.

**Table 2.** Gender difference for lateral photographic measurements

| Measurements | Male subjects n = 14 | | | | Female subjects n = 16 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Class I** | **Mean** | **SD** | **Min** | **Max** | **Mean** | **SD** | **Min** | **Max** | ***t*-test** | ***P*** | **Significance** |
| Sagittal assessment | | | | | | | | | | | |
| Wits | 0.68 | 0.22 | 0.34 | 1.11 | 0.65 | 0.18 | 0.33 | 1.00 | 0.458 | .651 | NS |
| ANB | 6.75 | 1.66 | 3.00 | 8.00 | 6.88 | 1.63 | 4.00 | 9.00 | −0.199 | .843 | NS |
| FNB | 88.42 | 2.68 | 84.00 | 93.00 | 89.25 | 2.65 | 83.00 | 92.00 | −0.820 | .419 | NS |
| N-ANS-Pog | 162.50 | 4.54 | 153.00 | 169.00 | 162.81 | 5.28 | 153.00 | 172.00 | −0.164 | .871 | NS |
| N-ANS-B | 160.75 | 4.37 | 156.00 | 168.00 | 159.81 | 5.66 | 150.00 | 171.00 | 0.476 | .638 | NS |
| Vertical assessment | | | | | | | | | | | |
| Ar-Go-Me | 130.08 | 8.32 | 121.00 | 146.00 | 128.63 | 6.24 | 119.00 | 143.00 | 0.531 | .600 | NS |
| FMA | 28.42 | 7.06 | 22.00 | 43.00 | 25.63 | 6.08 | 16.00 | 35.00 | 1.123 | .272 | NS |
| OPA | 9.67 | 3.03 | 5.00 | 15.00 | 9.81 | 4.02 | 4.00 | 17.00 | −0.105 | .917 | NS |
| LAFH | 13.00 | 0.62 | 12.23 | 14.49 | 12.14 | 0.55 | 11.26 | 13.25 | 3.886 | .001 | S |
| AFH | 7.31 | 0.73 | 6.57 | 9.28 | 6.43 | 0.46 | 5.53 | 7.23 | 3.943 | .001 | S |
| LPFH | 5.51 | 0.60 | 4.30 | 6.16 | 4.85 | 0.49 | 4.02 | 6.00 | 3.195 | .004 | S |
| **Measurements** | **Male subjects n = 14** | | | | **Female subjects n = 20** | | | | | | |
| **Class II** | **Mean** | **SD** | **Min** | **Max** | **Mean** | **SD** | **Min** | **Max** | ***t*-test** | ***P*** | **Significance** |
| Sagittal assessment | | | | | | | | | | | |
| Wits | 1.30 | 0.51 | 0.69 | 2.55 | 1.10 | 0.38 | 0.52 | 2.03 | 1.360 | .182 | NS |
| ANB | 10.14 | 1.75 | 7.00 | 13.00 | 9.68 | 1.57 | 7.00 | 13.00 | 0.847 | .402 | NS |
| FNB | 86.86 | 3.63 | 81.00 | 93.00 | 87.40 | 2.27 | 83.00 | 92.00 | −0.575 | .569 | NS |
| N-ANS-Pog | 156.07 | 5.27 | 147.00 | 162.00 | 157.48 | 4.15 | 151.00 | 164.00 | −0.922 | .363 | NS |
| N-ANS-B | 152.86 | 6.02 | 140.00 | 164.00 | 154.68 | 4.22 | 148.00 | 163.00 | −1.108 | .275 | NS |
| Vertical assessment | | | | | | | | | | | |
| Ar-Go-Me | 128.21 | 9.61 | 117.00 | 146.00 | 128.28 | 6.73 | 116.00 | 140.00 | −0.025 | .980 | NS |
| FMA | 25.43 | 9.24 | 12.00 | 40.00 | 27.28 | 5.37 | 17.00 | 41.00 | −0.795 | .432 | NS |
| OPA | 9.21 | 3.93 | 3.00 | 17.00 | 11.32 | 3.35 | 6.00 | 19.00 | −1.770 | .085 | NS |
| LAFH | 12.69 | 0.78 | 11.28 | 13.95 | 11.98 | 0.63 | 10.93 | 13.47 | 3.094 | .004 | S |
| AFH | 6.82 | 0.67 | 5.60 | 7.86 | 6.38 | 0.45 | 5.42 | 7.26 | 2.452 | .019 | S |
| LPFH | 5.53 | 0.43 | 4.89 | 6.16 | 4.90 | 0.59 | 3.75 | 6.00 | 3.502 | .001 | S |
| **Measurements** | **Male subjects n = 13** | | | | **Female subjects n =17** | | | | | | |
| **Class III** | **Mean** | **SD** | **Min** | **Max** | **Mean** | **SD** | **Min** | **Max** | ***t*-test** | ***P*** | **Significance** |
| Sagittal assessment | | | | | | | | | | | |
| Wits | 0.46 | 0.36 | −0.27 | 1.08 | 0.48 | 0.38 | −0.21 | 1.08 | 0.212 | .834 | NS |
| ANB | 4.46 | 1.82 | −1.00 | 7.00 | 4.77 | 1.88 | 1.00 | 7.00 | 0.859 | .399 | NS |
| FNB | 90.58 | 3.57 | 84.00 | 96.00 | 90.69 | 4.07 | 84.00 | 96.00 | 0.162 | .873 | NS |
| N-ANS-Pog | 168.38 | 5.50 | 157.00 | 179.00 | 167.85 | 6.12 | 157.00 | 179.00 | −0.492 | .627 | NS |
| N-ANS-B | 165.19 | 5.17 | 154.00 | 179.00 | 165.08 | 5.50 | 154.00 | 179.00 | −0.112 | .912 | NS |
| Vertical assessment | | | | | | | | | | | |
| Ar-Go-Me | 129.88 | 7.96 | 119.00 | 156.00 | 130.92 | 9.88 | 119.00 | 156.00 | 0.657 | .517 | NS |
| FMA | 25.04 | 6.43 | 16.00 | 42.00 | 25.38 | 7.15 | 16.00 | 42.00 | 0.269 | .790 | NS |
| OPA | 10.08 | 4.49 | 1.00 | 18.00 | 8.38 | 4.50 | 1.00 | 17.00 | −2.040 | .052 | NS |
| LAFH | 12.76 | 1.27 | 10.94 | 15.99 | 13.57 | 1.28 | 12.03 | 15.99 | 4.201 | .000 | S |
| AFH | 6.92 | 0.96 | 5.45 | 9.27 | 7.53 | 0.88 | 6.48 | 9.27 | 4.120 | .000 | S |
| LPFH | 5.50 | 0.70 | 4.22 | 6.99 | 5.93 | 0.56 | 5.01 | 6.99 | 3.980 | .001 | S |

**Wits'** measurement indicates soft-tissue maxillomandibular linear discrepancy; **A'N'B'angle** indicates soft tissue maxillomandibular angular discrepancy; **FNP'angle** indicates soft-tissue facial angle; **N'-Sn-Pog'**and **N'-Sn-B' angles** indicate soft tissue angles of facial convexity for) **Tr-Go'-Me' angle** indicates soft tissue gonial angle; **FMA' angle** indicates soft tissue Frankfurt to mandibular plane angle; **OPA' angel** indicates soft tissue Frankfurt to occlusal plane angle; **AFH'** indicates soft tissue anterior facial height **(N'-Me')**; **LAFH'** indicates soft tissue lower anterior facial height **(Sn-Me')**; and **PFH'** indicates lower posterior facial height **(Tr-Go')**; SD, standard deviation; Min, minimum; Max, maximum.

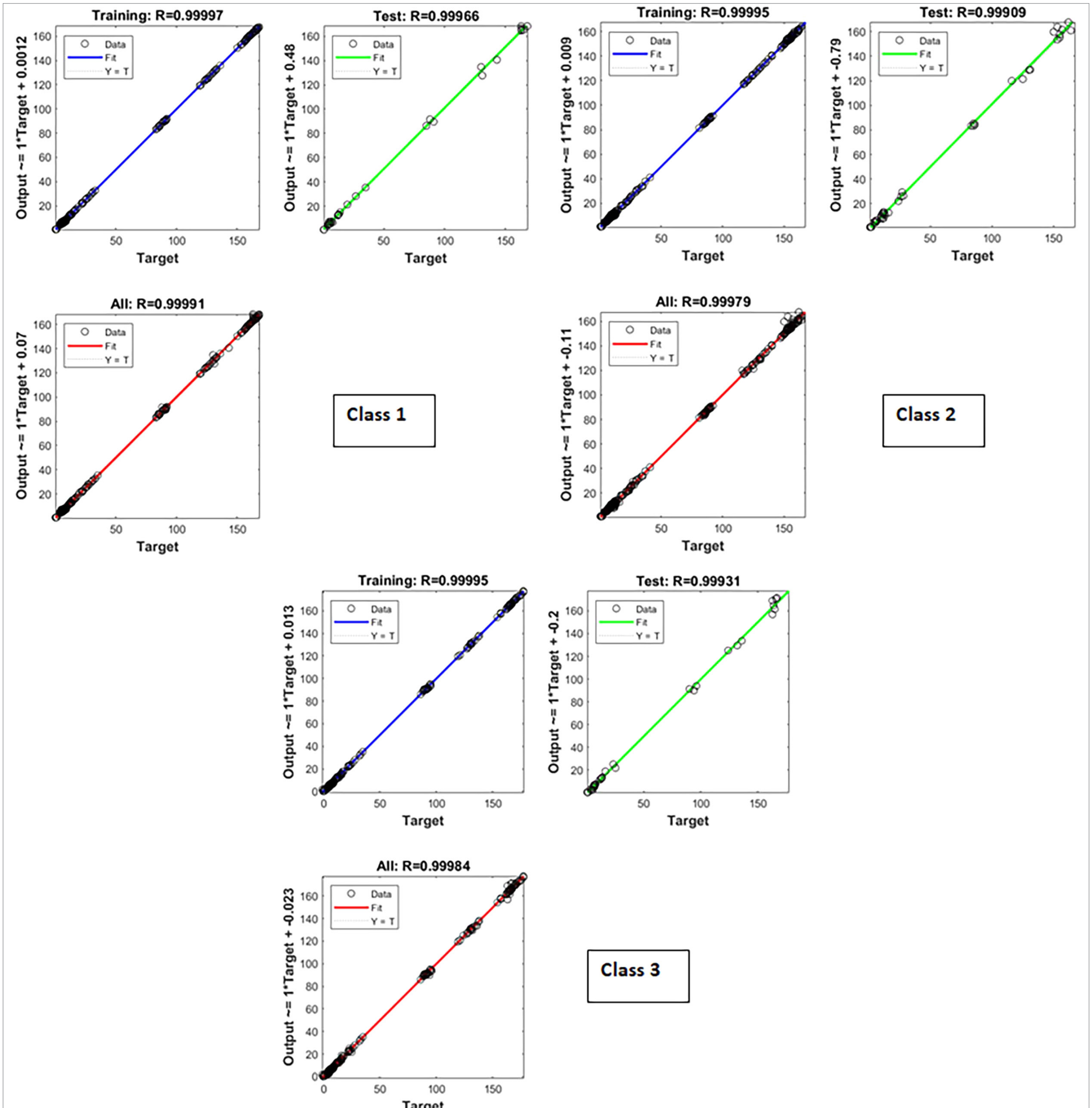


**Figure 3.** Scatterplots illustrating linear regression results between the cephalometric radiographic variables of the target and the actual output between different skeletal patterns during the training process



several soft tissue measurements ($r$ = 0.80), on the other hand, Bittner and Pancherz[6] in 1990 reported moderate correlations regarding these variables ($r$ = 0.63) and this may related to the different in thickness of soft tissue in different age groups.

Regarding Wits variable, the findings of this study showed that ($r$ = 0.80, $r$ = 0.86, $r$ = 0.77 in Class I, II, III malocclusions, respectively) and this agreed with the results of previous studies,[15,16] which showed that Wits measurements of the soft tissue was significantly correlated to the conventional Wits ($r$ = 0.77, $r$ = 0.73) and this may related to the accurate determination of the occlusal plane by using fox bite.

On the other hand, FNB, N-ANS-Pog, and N-ANS-B variables showed a good correlation and their values between 0.75 and 0.85, and this may be related to the standardized position of the head for cephalometric and lateral photograph procedures.

Excellent correlation was found for vertical angular variables (0.90-0.95) this agreed with the results of previous studies.[6,24]

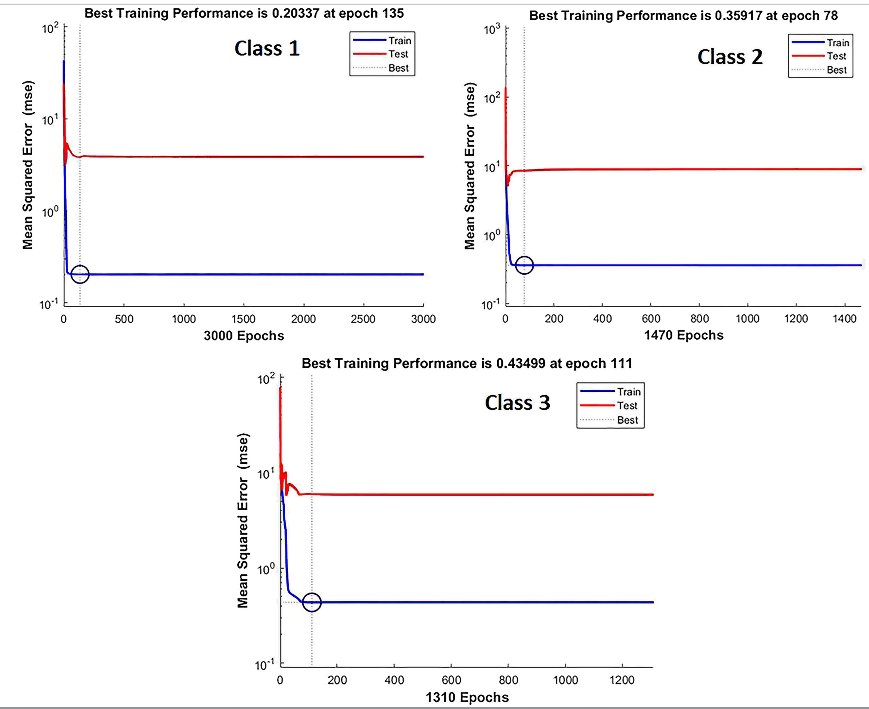




**Figure 4.** Best training performance for the network between the cephalometric radiographic variables of the target and the actual output for different skeletal patterns after designing the neural network during the training process

Other studies showed that the values of correlation ranged from 0.80 to 0.85.[15] Such difference might be related to individual variations in the inclination of the intracranial SN line.[25]

On comparing the vertical linear cephalometric and photographic variables for different skeletal malocclusion subjects, the results of this study showed that AFH, LAFH, and PFH have a good relationship with analogous photographic measurements. The comparison of these parameters was in conjunction with other studies.[15,24] This may be related to the low effect of magnification since these landmarks are located in midsagittal plane.

It cannot depend on the only photograph to represent the true measurement of cephalometric radiographs. A powerful prediction is essential to achieve a good correlation between cephalometric and photographic variables which can be obtained using ANNs.

Artificial neural networks represent great tools to match real targets by learning examples. These neural networks are able to find suitable information among initial data and establish a system for decision-making and results prediction. Such networks are made up of layers of neurons, typically an input layer, hidden or intermediate layers (one or more), and an output layer. These layers are fully connected to each other's. These layers are connected by synapses associated with numerical weightings. Repeated adjustments of these weightings are crucial steps for feed-forward back propagation networks until there is little difference between the real targets and the actual outputs in a training environment.[26]

No study regarding cephalometric variables predictions from lateral photographs between different skeletal patterns using ANNs was found in the literature review. Therefore, comparisons with similar studies in the literature are difficult to make. However, the present study showed another important application of ANNs in dentistry.

To verify the fitness of the model and to minimize overfitting, the samples were randomly divided into 70% of data for learning (PTrian = 0.7) and 30% for testing from the beginning in this study. In addition, the learning set was divided into the training set and the testing set and all set to make a generalized model. This has been described by Chang and Kim.[27]

A high degree of correlation between the real target and the actual output (R = 0.99) for each malocclusion was observed during the training and testing processes (Figures 3 and 5). The best training performance which means the least mean square error during the training process was 0.20 337 at epoch 135 for class I malocclusion, 0.35 917 at epoch 78, 0.43 499 at epoch 111 for class II and III malocclusion respectively (Figure 4), this makes this method very accurate for prediction of cephalometric variables as compared with other conventional methods.

This study provides models of regression that can estimate the cephalometric variables through analogous photographic measurements with a limited estimate error and a satisfactory predictive power. Further studies are recommended to evaluate the accuracy of such models.

The system constructed in this study showed high performance, however, some limitations should be mentioned. First, a large amount of data and good informatics skills were required during the training phase.[28] Secondly, frequent updating is required for models since they might change over time. Another relevant

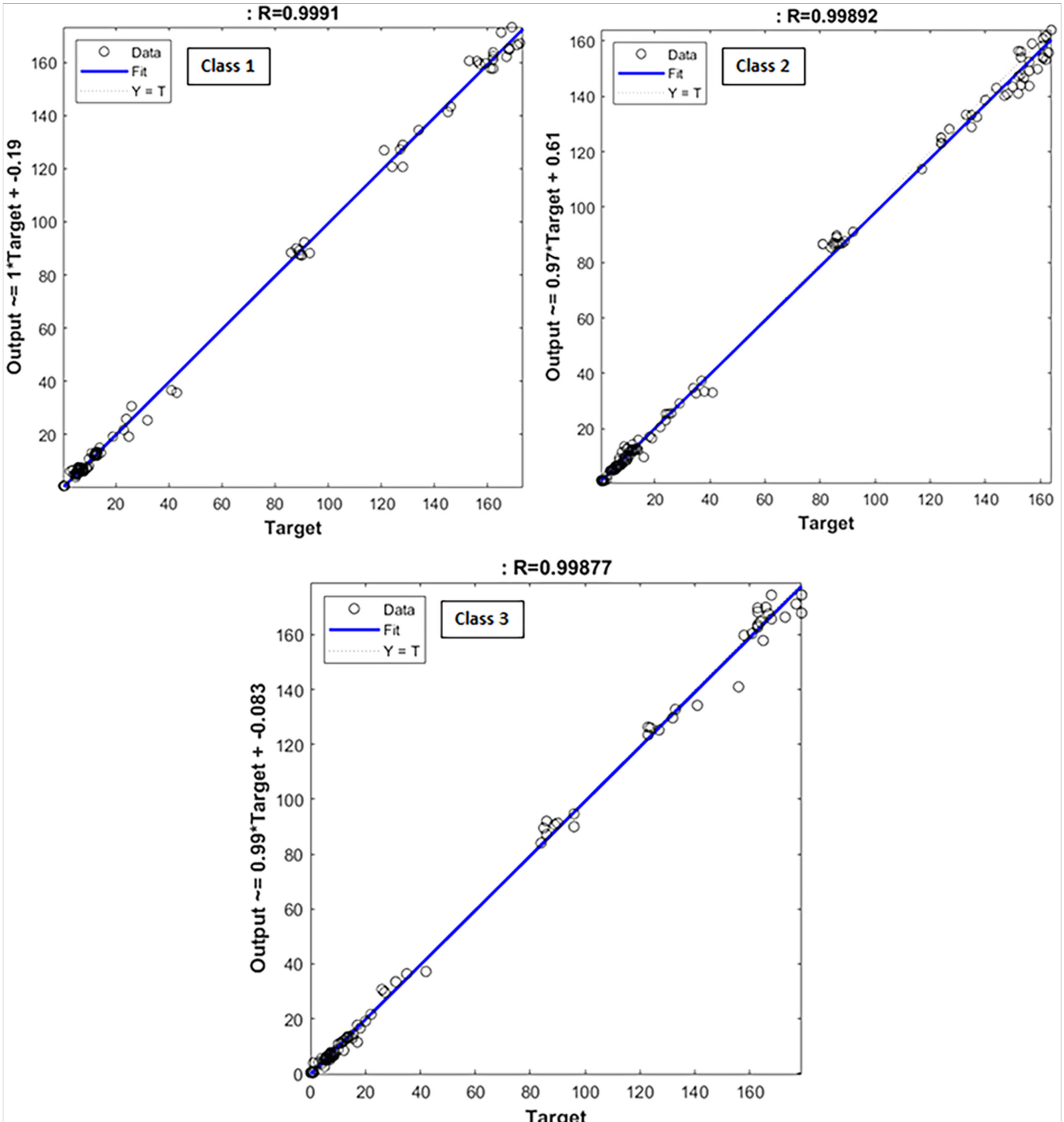


**Figure 5.** Scatterplot illustrating linear regression result between the cephalometric radiographic variables of the target and the actual output for different skeletal patterns after designing the neural network during the testing process



problem in their training is occurred when the algorithm is excessively custom-made to the training sample and it is called overfitting. Hence, it makes almost perfect predictions on it, but at the price of generalization, therefore its performance decreases on other populations. This issue can be solved by stopping the training when the error on the test set is at a minimum or subtle modifications to the training set.[29]

During the training, patterns that are not useful in real-life clinical practice might develop due to large amounts of low-quality data used and thus limiting the potential of classifiers.[27] Generating models separately for each skeletal pattern may limit the generalizability of the model, although there were successful results in all skeletal patterns, there may be a limitation to applying the test only to each skeletal pattern trained.

**Table 3.** Correlation Coefficients Between Cephalometric Radiographs and Photographic Variables

| **Measurement Parameters of Class I** | | **All subjects n = 30** | | **Male subjects n = 14** | | **Female subjects n = 16** | |
|---|---|---|---|---|---|---|---|
| **Cephalometric radiographs** | **Photographs** | **Correlation coefficient** | ***p*** | **Correlation coefficient** | ***p*** | **Correlation coefficient** | ***p*** |
| Sagittal assessment | | | | | | | |
| Wits | Wits' | 0.80 | 0.001 | 0.78 | 0.002 | 0.74 | 0.003 |
| ANB | A'N'B' | 0.79 | 0.001 | 0.78 | 0.002 | 0.75 | 0.004 |
| FNB | FNB' | 0.80 | 0.001 | 0.84 | 0.001 | 0.81 | 0.001 |
| N-ANS-Pog | N'-SN-Pog' | 0.77 | 0.001 | 0.83 | 0.001 | 0.85 | 0.001 |
| N-ANS-B | N'-Sn-B' | 0.87 | 0.001 | 0.71 | 0.010 | 0.84 | 0.001 |
| Vertical assessment | | | | | | | |
| Ar-Go-Me | Tr-Go'-Me' | 0.94 | 0.001 | 0.91 | 0.001 | 0.93 | 0.001 |
| FMA | FMA' | 0.95 | 0.001 | 0.95 | 0.001 | 0.92 | 0.001 |
| OPA | OPA' | 0.96 | 0.001 | 0.95 | 0.001 | 0.95 | 0.001 |
| LAFH | LAFH' | 0.94 | 0.001 | 0.87 | 0.001 | 0.93 | 0.001 |
| AFH | AFH' | 0.94 | 0.001 | 0.92 | 0.001 | 0.93 | 0.001 |
| LPFH | LPFH' | 0.92 | 0.001 | 0.91 | 0.001 | 0.87 | 0.001 |
| **Measurement parameters of Class II** | | **All subjects n = 34** | | **Male subjects n = 14** | | **Female subjects n = 20** | |
| **Cephalometric radiographs** | **Photographs** | **Correlation coefficient** | ***p*** | **Correlation coefficient** | ***p*** | **Correlation coefficient** | ***p*** |
| Sagittal assessment | | | | | | | |
| Wits | Wits' | 0.86 | 0.001 | 0.87 | 0.001 | 0.77 | 0.001 |
| ANB | A'N'B' | 0.79 | 0.001 | 0.77 | 0.001 | 0.73 | 0.001 |
| FNB | FNB' | 0.86 | 0.001 | 0.85 | 0.001 | 0.85 | 0.001 |
| N-ANS-Pog | N'-SN-Pog' | 0.79 | 0.001 | 0.79 | 0.001 | 0.79 | 0.001 |
| N-ANS-B | N'-Sn-B' | 0.79 | 0.001 | 0.81 | 0.001 | 0.76 | 0.001 |
| Vertical assessment | | | | | | | |
| Ar-Go-Me | Tr-Go'-Me' | 0.93 | 0.001 | 0.94 | 0.001 | 0.93 | 0.001 |
| FMA | FMA' | 0.93 | 0.001 | 0.92 | 0.001 | 0.91 | 0.001 |
| OPA | OPA' | 0.91 | 0.001 | 0.91 | 0.001 | 0.90 | 0.001 |
| LAFH | LAFH' | 0.91 | 0.001 | 0.89 | 0.001 | 0.90 | 0.001 |
| AFH | AFH' | 0.87 | 0.001 | 0.89 | 0.001 | 0.82 | 0.001 |
| LPFH | LPFH' | 0.89 | 0.001 | 0.84 | 0.003 | 0.90 | 0.001 |
| **Measurement parameters of Class III** | | **All subjects n = 30** | | **Male subjects n = 13** | | **Female subjects n = 17** | |
| **Cephalometric radiographs** | **Photographs** | **Correlation coefficient** | ***p*** | **Correlation coefficient** | ***p*** | **Correlation coefficient** | ***p*** |
| Sagittal assessment | | | | | | | |
| Wits | Wits' | 0.77 | 0.001 | 0.82 | 0.001 | 0.79 | 0.006 |
| ANB | A'N'B' | 0.85 | 0.001 | 0.86 | 0.001 | 0.87 | 0.003 |
| FNB | FNB' | 0.92 | 0.001 | 0.98 | 0.001 | 0.85 | 0.001 |
| N-ANS-Pog | N'-SN-Pog' | 0.84 | 0.001 | 0.84 | 0.001 | 0.84 | 0.001 |
| N-ANS-B | N'-Sn-B' | 0.74 | 0.001 | 0.74 | 0.004 | 0.75 | 0.003 |
| Vertical assessment | | | | | | | |
| Ar-Go-Me | Tr-Go'-Me' | 0.94 | 0.001 | 0.92 | 0.001 | 0.93 | 0.001 |
| FMA | FMA' | 0.91 | 0.001 | 0.91 | 0.001 | 0.93 | 0.001 |
| OPA | OPA' | 0.92 | 0.001 | 0.93 | 0.001 | 0.91 | 0.001 |
| LAFH | LAFH' | 0.96 | 0.001 | 0.95 | 0.001 | 0.92 | 0.001 |
| AFH | AFH' | 0.95 | 0.001 | 0.94 | 0.001 | 0.93 | 0.001 |
| LPFH | LPFH' | 0.89 | 0.001 | 0.88 | 0.002 | 0.86 | 0.001 |

***Wits** measurements indicates maxillomandibular linear discrepancy; **ANB angle** indicates maxillomandibular angular discrepancy; **FNP angle** indicates facial angle; **N-ANS-Pog** and **N-ANS-B** angles indicate angles of facial convexity. Ar.Go.Me angle indicates gonial angle; **FMA angle** indicates Frankfurt to mandibular plane angle; **OPA angle** indicates Frankfurt to occlusal plane angle; **AFH** indicates anterior facial height (N-Me); **LAFH** indicates lower anterior facial **(ANS-Me)** height; and **LPFH** indicates lower posterior facial height (Ar-Go).

**Wits**', linear discrepancy of the soft tissue between maxilla and mandible; **A'N'B'**, angular discrepancy of the soft tissue between maxilla and mandible; **FNP'**, the soft-tissue facial angle; **N'-Sn-Pog'**; **N'-Sn-B'**, the soft tissue angles of the facial convexity. **Tr-Go'-Me'**, the soft tissue gonial angle; **FMA'**, soft tissue angle between Frankfurt and mandibular planes; **OPA'**, soft tissue angle between Frankfurt and occlusal planes; **AFH' (N'-Me')**, soft tissue anterior facial height; LAFH' (Sn-Me'), soft tissue lower anterior height of the face; **LPFH' (Tr-Go')**, lower posterior height of the face for the soft tissue; SD, standard deviation; Min, minimum; Max, maximum.

Despite these limitations, the results of the present study confirmed that ANNs are able to predict cephalometric variables to a clinically excellent level.

## CONCLUSION

As a result of designing models for the prediction of cephalometric variables via lateral photographs between different skeletal patterns with neural network machine learning, the results of this study suggest that ANNs could be a new and alternative approach for the cephalometric radiographs for measuring angular and linear variables.

In the near future, the increasing use of ANNs in orthodontic daily practice will probably continue. After adequate validation, these could potentially facilitate daily workflow, patient satisfaction, and correct interpretation of findings, leading to accurate safe method to improve patient outcomes without any radiation risk.

**Ethics Committee Approval:** This study was approved by the Human Research Ethics Committee of College of Dentistry/Baghdad University (Iraq), (Approval No:168/2019).

**Informed Consent:** Written informed consent was obtained from the patients who agreed to take part in the study.

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Concept - S.M.A., H.F.S., M.A.T.; Design - S.M.A., H.F.S., M.A.T.; Supervision - H.F.S., M.A.T.; Materials - S.M.A.; Data Collection and/or Processing - S.M.A.; Analysis and/or Interpretation - S.M.A.; Literature Review - S.M.A.; Writing - S.M.A.; Critical Review - H.F.S., M.A.T.

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Original Article

# In Vivo Comparison of the Efficiency of En-Masse Retraction Using Temporary Anchorage Devices With and Without Orthodontic Appliances on the Posterior Teeth

Sanjam Oswal[1], Sonali V. Deshmukh[1], Sanket S. Agarkar[2], Sachin Durkar[1], Chaitra Mastud[1], Jayesh S. Rahalkar[1]

[1]Department of Orthodontics and Dentofacial Orthopaedics, Dr. D.Y. Patil Vidyapeeth, Pimpri, Pune, Maharashtra, India
[2]Private Practice, Pune, Maharashtra, India

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Main Points

- This study aimed to compare the effectiveness of en-masse retraction of maxillary anterior teeth with and without orthodontic appliances on the posterior teeth using mini-implants.
- Among the various factors evaluated, a greater amount of retraction is achieved at a faster rate when the posterior teeth are not included during retraction.
- A greater amount of bodily movement is achieved when the posterior teeth are not included during retraction.
- This newer approach to en-masse retraction using mini-implants will provide efficiency in treating bimaxillary protrusion cases with a good Class I molar relationship and optimal intercuspation of posterior teeth.

## ABSTRACT

**Objective:** To compare the effectiveness of en-masse retraction of maxillary anterior teeth using temporary anchorage devices with and without orthodontic appliances on the posterior teeth.

**Methods:** In the study, 20 participants (18.25 ± 4.07 years) meeting the inclusion criteria were randomly divided into 2 groups using the sequentially numbered opaque sealed envelopes method. In group I (control group, n = 10), en-masse retraction was carried out with conventional high hooks soldered to the retraction wire and posterior teeth were included. In group II (experimental group, n = 10), the en-masse retraction was carried out without an orthodontic appliance on posterior teeth and a modified retraction wire was incorporated. In both groups, mini-implants were placed bilaterally between the maxillary second premolar and maxillary first molar, and a retraction force of 6 ounces (180 g) was applied using power chains. Lateral cephalograms and study models were taken before retraction and 4 months after retraction. All statistical analyses were performed with Statistical Package for the Social Sciences software with a statistically significant level of 5%. We used unpaired *t*-tests for the comparison, and the error of the method was assessed using intraclass correlation coefficients and the Bland–Altman method.

**Results:** The maxillary incisor apex retraction, change in maxillary incisor in the vertical plane, and its inclination showed statistically significant differences ($P < .05$). The rate of retraction was significantly greater in the experimental group when evaluated clinically and in the study models ($P < .05$).

**Conclusion:** The rate/amount of retraction evaluated clinically and in the study models was significantly faster/greater when the posterior teeth were not included during anterior retraction. Also, a greater amount of bodily retraction of anterior teeth was achieved.

**Keywords:** En-masse retraction, mini-implants, without posterior dental anchorage

## INTRODUCTION

Malocclusions characterized by bimaxillary protrusion are commonly encountered in orthodontic practice all over the world. Treatment protocol followed for such cases often involves extraction of all the primary bicuspids,

**Corresponding author**: Sanjam Oswal, e-mail: sanjamoswal@gmail.com


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shadowed by the closure of spaces by retracting the anterior teeth. This enhances patients' esthetic by correcting the malocclusion and in turn improving the soft tissue profile. However, the extraction of bicuspids requires an increase in anchorage reinforcement.[1]

Orthodontic anchorage has always been an integral aspect of treatment planning and execution, and several appliances have been designed to fulfill the anchorage demands. These involve transpalatal arches, the Nance buttons, and extraoral traction using headgears in addition to the posterior anchor teeth. It is also advocated to use light, continuous forces for retraction to eliminate possible side effects.[2,3] However, these appliances possess a few disadvantages such as complex designs, increased patient compliance, and extensive wire bending.[4] Recently, titanium alloy mini-screws have been suggested as a source of absolute anchorage due to their various advantages.[3,5]

In the majority of the clinical cases with a bimaxillary protrusion, it is seen that the patient has a good Class I molar relationship and acquires optimal intercuspation of teeth in the posterior segments. But involving the posterior teeth during orthodontic treatment disturbs the pre-existing ideal occlusion, requiring further orthodontic treatment.[3]

Few authors have efficiently carried out en-masse retraction using mini-implants without bonding the posterior teeth and have named it biocreative therapy.[3,4,6-10] This therapy provides more simplified orthodontic biomechanics and aids in reducing orthodontic visit time. In their protocol, they have carried out en-masse retraction without bonding the posterior teeth and achieved significant and favorable results making the overall orthodontic experience easy and comfortable for the patients.

Therefore, our study aimed to evaluate and compare the efficiency of en-masse retraction of maxillary anterior teeth using temporary anchorage devices (TADs) with and without orthodontic appliances on the posterior teeth. The null hypothesis was that there is no difference in the rate of retraction, amount of retraction, and the type of tooth movement in both the treatment modalities.

## METHODS

This study was reviewed and approved by the Research and Recognition Committee and the Ethics Committee (ethical approval No -DYPDCH/IEC/1262/19/18) of Dr. D. Y. Patil Vidyapeeth, Pune University.

The inclusion criteria involved participants with skeletal Class I malocclusion, Angles Class I bimaxillary protrusion requiring absolute or high anchorage, participants requiring extraction of both the maxillary first premolars, and participants with good periodontal health and oral hygiene. Participants with any known systemic diseases, with a history of previous orthodontic treatment, and with extracted or missing teeth in the maxillary arch except the third molars were excluded. After evaluating the pre-treatment diagnostic records, all participants who met the inclusion criteria were selected and written consent was obtained for the same.

Sample size of 10 participants per group was calculated using convenience sampling technique and the formula used was: {N = [(z1-a - zb)s/d] 2 = [(1.96+0.84) 0.7/0.5] = 15}

A total of 20 participants (5 males and 15 females) with a mean age of 18.25 $\pm$ 4.07 years who met the inclusion criteria were selected and randomly allocated by using sequentially numbered opaque sealed envelopes method into the following groups:



Group I (G-I, control group): En-masse retraction of maxillary anterior teeth using TADs with the orthodontic appliance on posterior teeth (n = 10, mean age = 19.0 $\pm$ 4.2 years, 1 male and 9 females) (Figure 1A).

Group II (G-II, experimental group): En-masse retraction of maxillary anterior teeth using TADs without orthodontic appliance on posterior teeth (n = 10, mean age = 17.5 $\pm$ 4.0 years, 4 males and 6 females) (Figure 1B).

All participants were strapped up with 0.018″ MBT prescription (Gemini series, 3M-UNITEK, USA). In G-I, Dentos™ SH1615-08 mini-implants, and in G-II, Dentos™ TH1817-08 mini-implants were placed bilaterally.

Initial leveling and alignment were carried out using 0.014″, 0.016″, and 0.016 $\times$ 0.022″ NiTi wires. The retraction of the anterior teeth was carried out on 0.017 $\times$ 0.025″ SS wire in both the groups using power chains, and a force of 6 ounces (180 g) was applied using a Dontrix gauge.

In G-I, conventional crimpable hooks were positioned between the lateral incisor and canine bilaterally. The hooks were placed as closely as possible in the line with the center of resistance of maxillary anterior dentition and parallel to the occlusal plane (Figure 2).

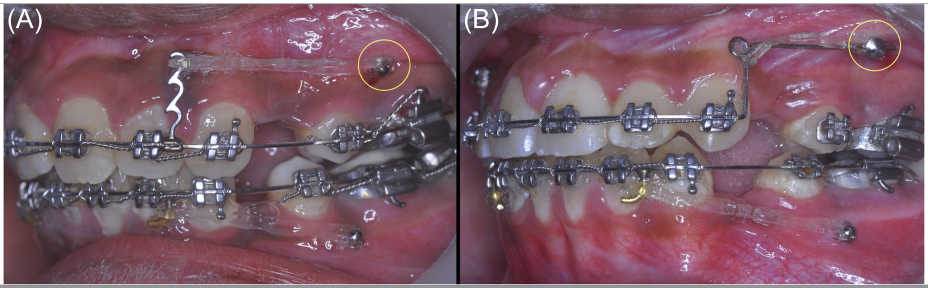


**Figure 1. A, B.** Retraction design in G-I, control group (A) and retraction design in G-II, experimental group (B). G-I, group I; G-II, group II

In G-II, the retraction wire was modified in its shape to exclude the posterior teeth and a step-up bend was given distal to the canine in line with the TADs and passing through the head of the TADs and the center of resistance of maxillary anterior dentition (Figure 3).

In both the groups, TADs were positioned between the maxillary first molar and maxillary second bicuspid bilaterally in line with the center of resistance of maxillary anterior dentition to achieve bodily retraction of the anterior dentition.

To achieve this, all lateral cephalograms were traced by the first author (S.O.), and a vector diagram was drawn to locate the exact height at which the implant would be placed. The center of resistance of the 6 maxillary anterior teeth group was determined at 13.5 mm superior and 14.0 mm distal to the incisal edge of the maxillary central incisor.[11]

In all of the participants, mini-implants were placed by the same examiner (S.O.). We did not experience any implant failures, that is, loosening of implants, inflammation at the implant site, or fracture of the implant during mini-implant placement during the 4 months of our experimental study.

Lateral cephalograms and study models (SM) were taken for each participant before retraction (pre-retraction) and 4 months after the start of retraction (post-retraction). Also, the retraction space was clinically evaluated using Vernier calipers intraorally every 3 weeks.

The measurements on pre- and post-retraction lateral cephalogram are shown in Figure 4.

Evaluation of the retraction space was carried out as follows:

1. Clinical evaluation




**Figure 2. A-H.** Pre-retraction (A–D) and post-retraction (E–H) intraoral photographs of G-I (control group). G-I, group I

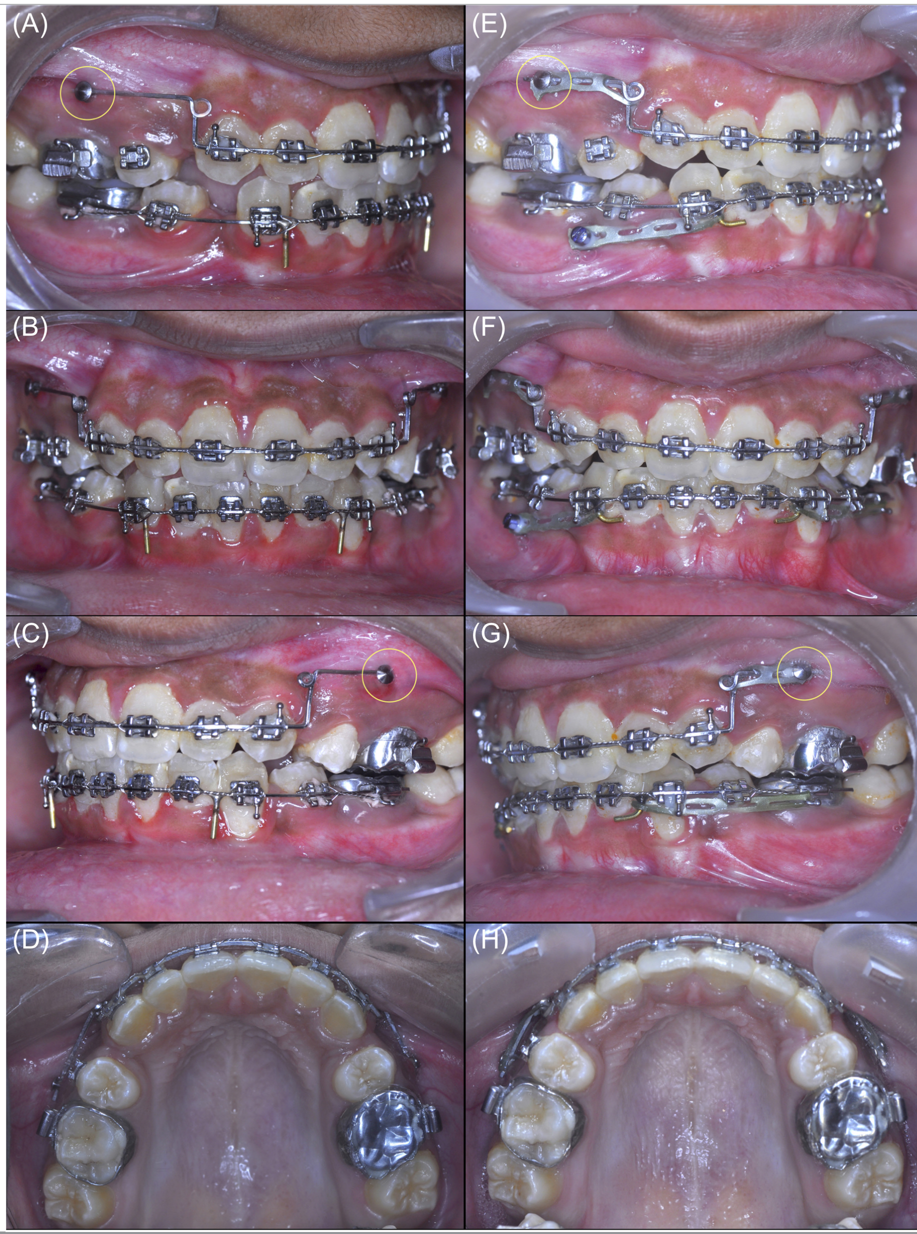


**Figure 3. A-H.** Pre-retraction (A–D) and post-retraction (E–H) intraoral photographs of G-II (experimental group). G-II, group II



The rate of retraction was evaluated clinically using Vernier calipers at a 3-week interval on both the right and left sides in both groups by the same author (S.O.). These measurements were recorded intraorally from the distal-most point on the maxillary canine to the mesial-most point on the maxillary second premolar.

Each measurement was repeated 3 times, and the mean of the 3 readings was used for statistical analysis.

2. On study models

Pre-retraction (T0) and 4 months from the start of retraction (T1), SM were obtained by the first author (S.O.).

On each initial maxillary cast, an acrylic palatal jig was made with a reference wire (0.021 × 0.025″ SS) fixed in the acrylic. One arm was extended to the mesial pit of maxillary first molar and the other arm to the distal surface of the canine bilaterally as reference landmarks as shown in Figure 5.[13]

Each measurement was repeated 3 times, and the mean of the 3 readings was used for statistical analysis.

### Statistical Analysis

All statistical analyses were performed with Statistical Package for the Social Sciences for Windows, Version 19; SPSS Inc. Chicago, Ill, USA. The mean and standard deviation for each cephalometric variable were determined. We used parametric statistical tests (unpaired *t*-tests) to determine the differences between the 2 groups. Power analysis showed that a sample size of at least 10 subjects per group would give an 80% probability of detecting a real difference between the groups at a statistically significant level of 5%. A confidence level larger than 5% was considered statistically insignificant.

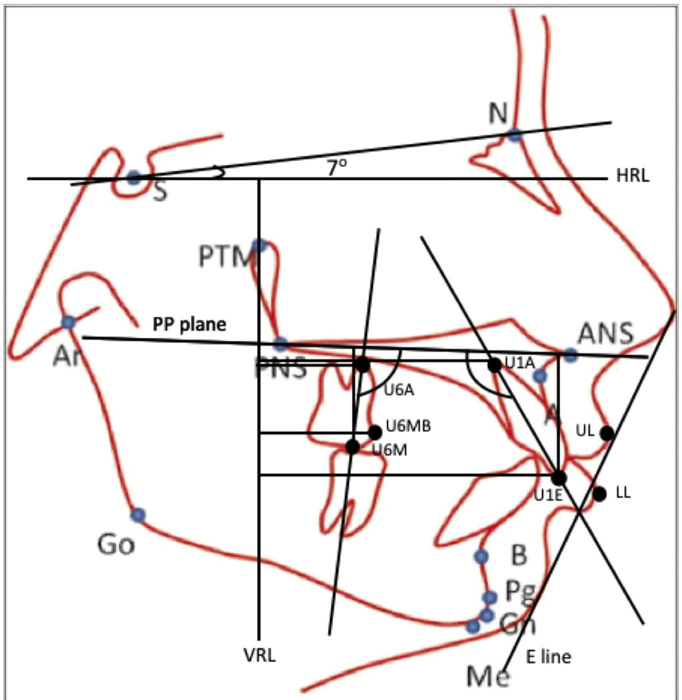


**Figure 4.** Cephalometric parameters evaluated on lateral cephalogram. HRL, horizontal reference line; VRL, vertical reference line; U6M, maxillary first molar crown; U6A, maxillary first molar apex; U1E, maxillary incisor edge; U1A, maxillary incisor apex; ANS, anterior nasal spine; PNS, posterior nasal spine; PP, palatal plane; U6MB, mesiobuccal cusp tip of maxillary first molar; UL, highest point on upper lip; LL, highest point on lower lip

All cephalometric measurements were performed by the first author (S.O.). The same examiner repeated all the cephalometric measurements at a 4-week interval. The error of the method for all variables was assessed using intraclass correlation coefficients and the Bland–Altman method.[14,15]

## RESULTS

The intraoperator agreement for the variables was excellent, with intraclass correlation coefficients ranging from 0.83 to 0.98. The greatest limits of agreement were seen in the linear measurement value of the variable U6M–VRL (mm), which were −4.41 and 4.71.

The mean age of the participants included in G-I (19.00 ± 4.22) and G-II (17.50 ± 4.01) did not show any statistically significant difference.

Table 1 depicts the intergroup comparison of the means of all cephalometric parameters. We found a statistically significant difference in the following parameters: U1A–VRL (mm, $P = .002$), U1–PP (mm, $P = .019$), and U1–PP (degrees, $P = .031$), whereas no statistically significant difference was found in the following parameters: U1E–VRL (mm), U6M–VRL (mm), U6A–VRL (mm), U6MB–PP (mm), UM–PP (degrees), UL–E-line (mm), and LL–E-line (mm).

When evaluating the rate of retraction clinically, the mean retraction score in G-I was 0.56 ± 0.08 mm/month and 0.52 ± 0.05 mm/month, and in G-II, it was 1.15 ± 0.312 mm/month and 0.94 ± 0.19 mm/month on right and left side, respectively. The mean difference in both the groups was −0.58 ($t = -5.72$, $P < .001$) and −0.41 ($t = -6.55$, $P < .001$) on right and left sides, respectively, and both were found to be statistically significant. (Table 2)

Similarly, when evaluating the rate of retraction on SM, the mean retraction score in G-I was −1.85 ± 0.24 mm and −1.90 ± 0.21 mm, and in G-II, it was −3.80 ± 1.22 mm and −3.40 ± 1.04 mm on right and left sides, respectively. The mean difference in both the groups was 1.95 ($t = 4.92$, $P < .001$) and 1.50 ($t = 4.43$, $P < .001$) on right and left sides, respectively, and both were found to be statistically significant (Table 3).

## DISCUSSION

Our study aimed to evaluate and compare the efficiency of en-masse retraction of maxillary anterior teeth using TADs with and without orthodontic appliances on the posterior teeth. The null hypothesis was proven to be wrong.

We found that there was a greater amount of incisor crown retraction in G-II (5.50 ± 1.78 mm) when compared to G-I (4.80 ±



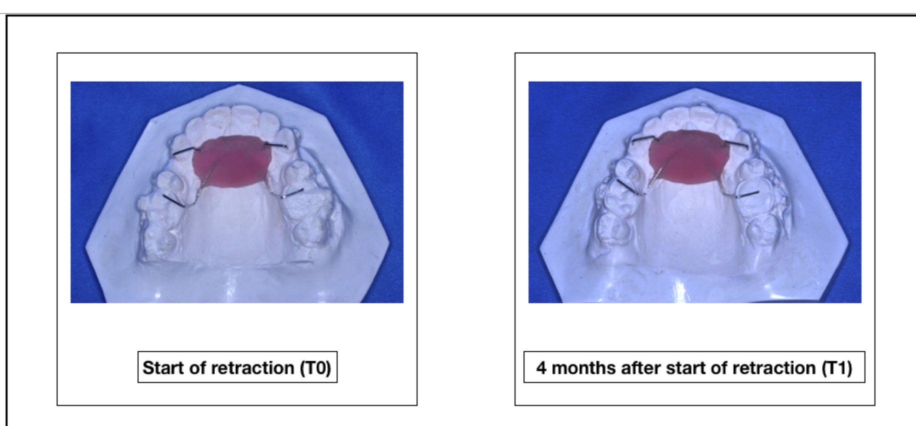


**Figure 5.** Palatal jig to evaluate retraction

**Table 1.** Intergroup comparison of the means of all cephalometric parameters using unpaired *t*-Tests

| Parameters | Group | Mean Pre-Retraction | Standard Deviation | Mean Post-Retraction | Standard Deviation | Difference | Standard Deviation | *P* |
|---|---|---|---|---|---|---|---|---|
| U1E–VRL (mm) | G-I | 52.0 | 4.83 | 47.2 | 3.97 | 4.80 | 2.04 | .425 |
| | G-II | 55.2 | 4.84 | 49.7 | 4.49 | 5.50 | 1.78 | |
| U1A–VRL (mm) | G-I | 44.3 | 4.76 | 42.5 | 3.91 | 1.80 | 1.32 | **.002** |
| | G-II | 44.3 | 4.45 | 40.1 | 3.65 | 4.20 | 1.69 | |
| U6M–VRL (mm) | G-I | 26.5 | 3.56 | 26.4 | 3.34 | 0.10 | .57 | .660 |
| | G-II | 29.4 | 2.79 | 29.2 | 2.78 | 0.20 | .42 | |
| U6A–VRL (mm) | G-I | 25.5 | 2.41 | 25.7 | 2.26 | −0.20 | .79 | .279 |
| | G-II | 26.9 | 2.60 | 26.8 | 2.65 | 0.10 | .32 | |
| U6MB–PP (mm) | G-I | 21.8 | 1.87 | 22.0 | 2.05 | −0.20 | .42 | .151 |
| | G-II | 21.7 | 1.82 | 21.6 | 1.81 | 0.10 | .32 | |
| U1–PP (mm) | G-I | 27 | 3.85 | 27.2 | 3.03 | −0.20 | 0.79 | **.019** |
| | G-II | 26.3 | 3.40 | 25.4 | 2.36 | 0.90 | 1.10 | |
| U6–PP (degrees) | G- I | 99 | 4.76 | 96.2 | 5.67 | 2.80 | 1.55 | .749 |
| | G-II | 94.2 | 4.70 | 91.8 | 2.57 | 2.40 | 3.57 | |
| U1–PP (degrees) | G-I | 114.7 | 5.22 | 108.8 | 3.95 | 5.90 | 1.10 | **.031** |
| | G-II | 119.4 | 7.35 | 111.5 | 7.12 | 7.90 | 2.47 | |
| UL–E line (mm) | G-I | 0.15 | 1.65 | -0.62 | 1.40 | 0.77 | 0.89 | .369 |
| | G-II | −0.25 | 1.58 | -1.35 | 1.95 | 1.10 | 0.70 | |
| LL–E line (mm) | G-I | 3.5 | 1.77 | 1.3 | 1.15 | 2.20 | 1.14 | .379 |
| | G-II | 2.9 | 4.09 | 1.2 | 3.29 | 1.70 | 1.34 | |

Bold font indicates a significant change ($P < .05$).

2.05 mm). This finding did not show any statistically significant difference but, however, may prove to be clinically significant. On the contrary, there was an extensively greater amount of incisor apex retraction in G-II (4.20 ± 1.69 mm) when compared to G-I (1.80 ± 1.32 mm) suggesting a more bodily movement of 4.2 mm when the posterior teeth were not included. Monga et al.[12] in their study found that the maxillary incisor crown and apex were retracted by 5.47 ± 1.65 mm and 2.47 ± 2.07 mm, respectively. Al-Sibaie and Hajeer[16] in their RCT found that the maxillary incisor crown and apex were significantly retracted by 5.92 mm and 4.56 mm, respectively and intruded (1.53 mm and 1.16 mm), which are similar to the results achieved in our study. Seven millimeters of translatory movement was achieved by Park and Kwon,[17] whereas Yao et al.[18] in their study found a greater amount of translatory movement in the mini-implant group. Upadhyay et al.[19] in their study have reported only 1 mm of bodily movement.

The maxillary molar crown in G-II and G-I moved distally by 0.20 ± 0.42 mm and 0.10 ± 0.57 mm, respectively, with no statistically significant difference. Upadhyay et al.[1] in their study found that the maxillary first molars in the implant group intruded by 0.22 ± 0.65 mm and were distalized by 0.78 ± 1.35 mm, and Al-Sibaie and Hajeer[16] found that the maxillary molars were significantly distalized by 0.89 mm after en-masse retraction with mini-implants. These findings are similar to the results achieved in our study. However, several studies have demonstrated the mesial advancement of maxillary molars despite the use of mini-implants to conserve anchorage.[18,20,21] Kim et al.[20] and Monga et al.[12] in their studies found that the maxillary molars were mesialized by 0.74 ± 1.01 mm and 1.27 ± 0.82 mm and extruded by 0.72 ± 0.91 mm and 0.20 ± 1.10 mm, respectively.

A statistically significant difference was seen in the maxillary central incisor when evaluated in the vertical plane. In

**Table 2.** Intergroup comparison of clinical space evaluation using unpaired *t*-Tests

| Side | Group | Mean | Standard Deviation | *P* |
|---|---|---|---|---|
| Right side (mm/month) | G-I | 0.56 | 0.09 | **<.001** |
| | G-II | 1.15 | 0.31 | |
| Left side (mm/month) | G-I | 0.53 | 0.053 | **<.001** |
| | G-II | 0.94 | 0.19 | |

Bold font indicates a significant change ($P < .05$).

**Table 3.** Intergroup comparison of space evaluated on study models using unpaired *t*-Tests

| Side | Group | Mean | Standard Deviation | *P* |
|---|---|---|---|---|
| Right side | G-I | −1.85 | 0.24 | **<.001** |
| | G-II | −3.80 | 1.23 | |
| Left side | G-I | −1.90 | 0.21 | **<.001** |
| | G-II | −3.40 | 1.05 | |

Bold font indicates a significant change ($P < .05$).

G-II, the maxillary central incisor intruded significantly by 0.90 ± 1.101 mm, whereas in G-I, it extruded by 0.20 ± 0.79 mm. Monga et al.[12] in their study found that the maxillary incisor was intruded by 2.43 ± 1.31 mm. This is a crucial finding observed in our study suggesting that simultaneous retraction and intrusion can be achieved by omitting the need to include the posterior teeth.

We also evaluated the changes in the upper and lower lip to Rickett's E-line and found that there was no statistically significant difference observed among both groups. Drobocky and Smith[22] have concluded that 95% of the cases with all 4 first bicuspid extraction had a reduction in lip protrusion to the E-line. Kusnoto et al.[23] in their study concluded that the upper lip is retracted by 0.4 mm and the lower lip is retracted by 0.6 mm with every millimetric retraction of the lower incisor tip. Talass et al.[24] in their study have shown lower lip retraction and escalation in lower lip length and nasolabial angle when the maxillary anterior segment is retracted. Roos[25] in his study has concluded that the shape and the position of the lower lip are dependent on the lower incisor position.



The mean extraction space available clinically on right and left side was 5.8 ± 1.14 mm and 6.1 ± 1.91 mm in G-I, whereas the mean extraction space available clinically on the right and left side was 6.1 ± 1.19 mm and 5.5 ± 1.43 mm in G-II. The difference in the mean extraction space available on both sides in both the groups necessitated calculating the rate of retraction on either side differently. The mean rate of retraction found in our study was 0.54 mm/month and 1.04 mm/month in G-I and G-II, respectively. Thiruvenkatachari et al.[26] have reported the rate of canine retraction using the mini-implant as 0.93 mm/month, and Davis et al.[27] in their study have reported the rate of canine retraction using mini-implants as 0.95 mm/month. The rate of retraction evaluated clinically in our study was significantly greater in G-II on both the right and left sides when compared to G-I. With our findings, we can conclude that the rate of retraction evaluated clinically in G-II was more than 2 times faster on the right side and more than 1.5 times faster on the left side when compared to G-I.

Similarly, we calculated the amount of retraction on the right and left sides separately in both the groups on SM. With our findings, we can conclude that the amount of retraction evaluated on SM in G-II was more than 2 times greater on the right side and more than 1.5 times greater on the left side when compared to G-I. This may be because of the difference in the available space on the right and left sides and/or excessive masticatory forces exerted on the right buccal occlusion.

Nienkemper et al.[28] have reported the movement of mini-implants in the direction of the applied force. We considered the mini-implants to have a stabilized position and continued with the same retraction force and direction of the force vector. Another limitation of our study was the variation in the mini-implant height. The aim was to insert the mini-implants in line with the center of resistance. But due to biological limitations, it was not possible to place the mini-implants beyond a certain level in a few of the participants. The design used in the experimental group is technique sensitive and may lead to differing results between different operators and the results achieved in this study.

In our study, when the posterior teeth were not included during retraction, we found that the maxillary incisor apex and crown retracted and intruded at a significantly faster rate with a greater amount of retraction suggesting more of a bodily movement. The upper lip retraction was clinically significant and the maxillary molar crown tipped distally and intruded. Whereas, when the posterior teeth were included, the amount of maxillary incisor apex retraction was significantly less suggesting controlled tipping. The maxillary molar crown was distalized, and there was extrusion seen with the maxillary incisor and molars.

## CONCLUSION

The null hypothesis was proven to be wrong, and the following conclusions can be drawn from our study:

- The rate of retraction and amount of retraction was more than 2 times faster/greater on the right side and more than 1.5 times faster/greater on the left side when the posterior teeth were not included.
- The type of movement achieved when the posterior teeth were not included during retraction was more bodily movement (4.2 mm) and when the posterior teeth were included it was more of a tipping movement.
- From the results of this study, it can be concluded that mini-implant-supported en-masse retraction of anterior teeth proves to be more efficient when the posterior teeth are not included during retraction.

**Ethics Committee Approval:** Ethical committee approval was received from the Research and Recognition Committee and the Ethics Committee of Dr. D. Y. Patil Vidyapeeth, Pune University (Ethical approval No -DYPDCH/IEC/1262/19/18).

**Informed Consent:** Written consent was obtained from all the participants included in the study.

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Concept - S.O., S.S.A.; Design - J.S.R., S.V.D.; Data Collection and/or Processing - S.O.; Analysis and/or Interpretation - S.O., S.V.D., S.S.A., J.S.R.; Writing - S.D., C.M.; Critical Review - S.V.D., S.S.A., J.S.R.

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**Declaration of Interests:** The authors have no conflict of interest to declare.

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Original Article

# Evaluation of Palatal Bone Thickness and Its Relationship with Palatal Vault Depth for Mini-Implant Insertion Using Cone Beam Computed Tomography Images

Gholinia Faegheh[1], Negar Khosravifard[2], Dina Maleki[3], Sahar Khaje Hosseini[1]

[1]Department of Orthodontics, School of Dentistry, Guilan University of Medical Sciences, Rasht, Iran
[2]Department of Oral and Maxillofacial Radiology, School of Dentistry, Guilan University of Medical Sciences, Rasht, Iran
[3]Student Research Committee, School of Dentistry, Guilan University of Medical Sciences, Rasht, Iran



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Main Points

- The thickness of the palatal bone significantly decreases from anterior to posterior and also from midsagittal to lateral in patients with deep or normal palates.
- At the midsagittal, the normal palate was significantly thicker than the deep palate.
- No significant relation was found between gender and the prevalence of deep and normal palate.
- The thickness of the palatal bone was significantly more in males than females in patients with deep or normal palates.

## ABSTRACT

**Objective:** The purpose of this study was to measure the thickness of the palatal bone using cone beam computed tomography images for placement of mini-screws and their relationship with palatal vault depth.

**Methods:** This study was performed on 150 maxillary cone beam computed tomography images, 50% (n = 75) had deep palate and 50% (n = 75) had normal palate and 27.3% (n = 41) were male and 72.7% (n =109) were female. Coronal sections with a thickness of 1 mm were prepared at distances of 4 mm, 8 mm, 12 mm, 16 mm, 20 mm, and 24 mm from the posterior wall of the incisive foramen. Then, in each section, in the midsagittal line and at distances of 2 mm, 4 mm, 6 mm, 8 mm, and 10 mm from that to the lateral sides, the bone thickness was measured. The Korkhaus index was used to identify the patients with a high palatal vault.

**Results:** The results showed that at the posterior sections in the midsagittal and parasagittal area, a significant difference ($P < .05$) was observed between deep and normal palate, and in these points, the bone thickness in the normal palate was greater. Also, in the section of 4 mm and 8 mm, a significant difference was observed between males and females in most of these points, and those were greater in males than females.

**Conclusion:** The maximum thickness of the palatal bone was observed first along the midsagittal line and then the paramedian and in the anterior section. Patients with deep palate had less palatal bone thickness in the posterior sections.

**Keywords:** Cone beam computed tomography, mini-screw, mini-implant, palatal bone thickness, palatal depth

## INTRODUCTION

In many cases, orthodontic treatment requires maximum anchorage to achieve the best results and reduce side effects; therefore, we need further extra or intraoral anchorage. The success of extraoral appliances depends on patient cooperation. For this reason, the use of intraoral anchorage devices, such as mini-screws without the need for patient cooperation, is increasingly noteworthy.[1-2]

**Corresponding author**: Sahar Khaje Hosseini, E-mail: saharkhajehosseini@ymail.com


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Hourfar et al.[3] stated in their study that a correlation might be found between the availability of bone and palatal morphology. Later, it was stated that the palatal morphology and the available bone at the mini-screw insertion site in the hard palate are important factors in its primary stability and overall success, and if this primary stability is not achieved during placement, the mini-screw may fail during orthodontic treatment.[3-6] Care should be taken when inserting the mini-screws to prevent penetration into the nasal cavity and incisive canal. The selection of long mini-screws increases the risk of penetration into the nasal cavity and subsequent problems. If the mini-screws is too short, the depth of penetration into the bone may not be sufficient to achieve initial stability; therefore, the clinician must recognize the midpalate and paramedian palate topography.[7-10] Computer guides can help to safely insert mini-screws; however, determining the safe mini-screw insertion site through cone beam computed tomography assessments can be helpful.[11]

Most of the patients with high palatal vault require skeletal expansion, so using mini-screws in the palatal area during orthodontic treatment is helpful. However, the results of studies are inconsistent about favorable site of mini-screw placement. Baumgaertel et al.[12] evaluated the bone depth and thickness to determine successful mini-screw placement sites. They concluded that bone depth and cortical bone thickness of the palate were most favorable around first and second premolars to place mini-screw. While, Uday et al.[13] evaluated bone around the first premolar, second premolar, first molar, and second molar at maxillary buccal and palatal sides and mandibular buccal sides to determine safe sites for mini-screw. The results indicated that adult mandibular buccal cortical bone to be the thickest and safest. On the other hand, not many studies have evaluated the safest site for mini-screw placement in patients with a high palatal vault. This study measured the palatal bone thickness in 60 points of the palate using CBCT to determine the most suitable area to place the temporary anchorage device (TAD) and also evaluated its relationship with the palatal vault depth and gender because diagnosing the factors related to the palatal bone thickness can help clinicians to identify cases with insufficient bone thickness and design the anchorage control method accordingly.

## METHODS

This retrospective analytical study was performed on 150 maxillary CBCT images consisting of 2 groups of the normal and deep palate. This study was performed after receiving approval from ethical committee of Guilan University of Medical Sciences (IR.GUMS.REC.1399.057). To determine the sample size, a formula for estimating an average in a community has been used. Considering the statistical power of 80%, error level of 0.05, standard deviation of 3.09 and d = 1, the minimum sample size was calculated to be 74.86 which was considered as 75:

$$n=\frac{\left(z_{1-\frac{\alpha}{2}}+z_{1-\beta}\right)^2(\sigma^2)}{(d)^2}=\frac{(1.96+0.84)^2(3.09)^2}{1^2}=74.86\cong 75$$

Inclusion criteria covered all patients over the age of 15 years old who have been referred to the Guilan University, Faculty of Dentistry, Department of Radiology. Exclusion criteria included the history of trauma or surgery in the study area, the presence of impacted teeth in the palate, a systemic disease affecting bone quality or quantity, pathological defects or craniofacial deformities in the maxilla and palatal area, and the presence of palatal torus. The presence of rotation or tilting in the patient's head was also examined.

Cone beam computed tomography images of all cases were taken by NewTom VGI (NewTom, Verona, Italy) with 90 kVp, 6 mA, 0.2 voxel size, and standard zoom mode. The images were then retrieved by NewTom (NNT) viewer software (NewTom, Verona, Italy).

First, the location of the incisive foramen was determined using the axial view, and then coronal sections with a thickness of 1 mm were prepared at a distance of 4 mm, 8 mm, 12 mm, 16 mm, 20 mm, and 24 mm from the posterior wall of the incisive foramen (Figure 1). Then, in each point, in the midsagittal area and at intervals of 2 mm, 4 mm, 6 mm, 8 mm, and 10 mm from that, points were identified on both sides laterally. Finally, in the designated areas, the bone thickness was measured in millimeter, which included the distance between the outer cortical layer of the nasal floor and the outer cortical layer of the oral hard palate (Figure 2).



Measurements were performed on both right and left sides of the midpalate, and their averages were used. The Korkhaus index was used to identify cases with the deep palate:[14]

$$\frac{\text{Palatal height}\times 100}{\text{Posterior arch width}}$$

Posterior arch width is in the section of the first molars at the level of the occlusal plane and is measured as a distance from the midpoint connecting the fissures of the first molars of 2 sides. Palatal height is measured in the midsagittal plane and as a vertical distance between that horizontal line to the palatal surface. The average of this ratio is 42%. Values above this indicate a deep palate (Figure 3).

In this study, we used archival images of patients who were referred to the Guilan University, Faculty of Dentistry, Department of Oral and Maxillofacial Radiology for reasons such as implant surgery, impacted teeth, etc. None of the patients underwent radiation for this study.

### Statistical Analysis

Kolmogorov–Smirnov (KS) test was used to evaluate the normality of the groups. Independent *t*-test and Statistical Package for Social Sciences (SPSS) software (IBM Corp, Armonk, NY, USA) version 24 were used for the statistical examination of the relationship and comparison of groups if the relevant assumptions were made, otherwise Mann–Whitney *U* test was used. The significance level in all tests was considered to be $P = .05$.


**Figure 1.** Reconstructed coronal cross-sections from the posterior wall of the incisive foramen



For 10 samples, measurements were repeated randomly with an interval of 2 weeks and the inter-observer agreement was evaluated by interclass correlation (ICC) calculation (ICC = 96%).

## RESULTS

In this study, 50% (n = 75) of the subjects had deep palate and 50% (n = 75) had normal palate. Also, 27.3% (n = 41) were male and 72.7% (n = 109) were female. Findings indicated 56.1% (n = 23) in men and 47.7% (n = 52) in women had deep palate. The 2 groups of deep and normal palate were homogeneous in terms of gender (*P* = .360).

Tables 1 and 2 show the mean and standard deviation of palatal bone thickness measurements at the distances of 4 mm, 8 mm, 12 mm, 16 mm, 20 mm, and 24 mm of posterior wall of the incisive canal and at the distance of 2 mm, 4 mm, 6 mm, 8 mm,

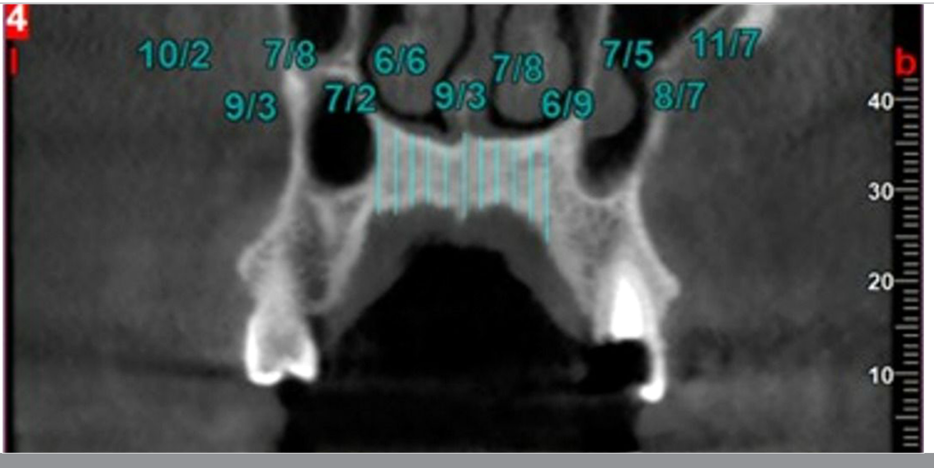


**Figure 2.** A sample of measurement in 1 section

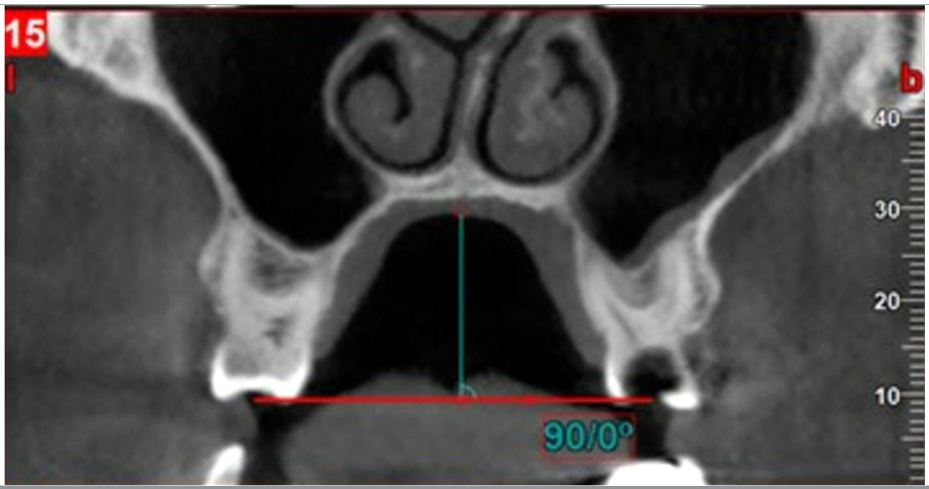


**Figure 3.** A sample of palatal height measurement

10 mm from the midsagittal line to the lateral sides in the normal and deep palate, respectively.

Table 3 shows a comparison of bone thickness sizes in the deep and normal palate. At the sections of 20 mm and 24 mm, a significant difference was observed in paramedian 1 (MD1), MD2, and midsagittal, and the normal palate thickness was greater in all 6 points.

Table 4 shows a comparison of bone thickness measurements by gender. Based on the obtained results in the 4 mm distance, a significant difference was observed between males and females in all the studied areas and in all cases. It was observed that the thickness was greater in men than in women. In the sections of 8 mm in MD2, MD3, MD4, and midsagittal, a significant difference was observed. In all mentioned points, the thickness was greater in men than in women (Figure 4, 5).



## DISCUSSION

One of the disadvantages of using the palatal area is the relative inadequacy of palatal bone thickness and its great variety in patients. Therefore, caution should be taken when inserting mini-screws because the selection of long mini-screws increases

**Table 1.** The measurements of palatal bone thickness in the normal palate

| | Palatal Bone Thickness | | | | | |
|---|---|---|---|---|---|---|
| Sections | MD5 Mean ± SD | MD4 Mean ± SD | MD3 Mean ± SD | MD2 Mean ± SD | MD1 Mean ± SD | MM Mean ± SD |
| 4 | 17.10 ± 3.45 | 8.0 ± 3.04 | 6.82 ± 2.69 | 6.57 ± 2.46 | 6.81 ± 2.11 | 8.95 ± 1.92 |
| 8 | 6.23 ± 2.43 | 4.42 ± 2.0 | 3.71 ± 1.73 | 4.07 ± 1.62 | 5.51 ± 1.67 | 7.64 ± 1.77 |
| 12 | 4.64 ± 1.80 | 3.13 ± 1.47 | 2.71 ± 1.20 | 3.31 ± 1.35 | 4.60 ± 1.55 | 7.22 ± 1.71 |
| 16 | 3.61 ± 1.47 | 2.40 ± 1.10 | 2.30 ± 1.01 | 3.01 ± 1.29 | 4.56 ± 1.60 | 7.39 ± 1.86 |
| 20 | 2.85 ± 1.30 | 2.0 ± 0.83 | 2.11 ± 0.89 | 2.95 ± 1.27 | 4.47 ± 1.73 | 7.74 ± 1.99 |
| 24 | 2.08 ± 0.77 | 1.79 ± 0.81 | 1.91 ± 0.75 | 2.47 ± 1.1 | 4.46 ± 1.55 | 7.68 ± 1.76 |

MD, mediolateral points at 10-mm, 8-mm, 6-mm, 4-mm, and 2-mm distances from the midsagittal line to the lateral; MM, midsagittal points.

**Table 2.** The measurements of palatal bone in the deep palate

| | Palatal Bone Thickness | | | | | |
|---|---|---|---|---|---|---|
| Sections | MD5 Mean ± SD | MD4 Mean ± SD | MD3 Mean ± SD | MD2 Mean ± SD | MD1 Mean ± SD | MM Mean ± SD |
| 4 | 10.23 ± 3.82 | 7.82 ± 3.16 | 6.48 ± 2.7 | 6.19 ± 2.28 | 6.35 ± 2.08 | 8.74 ± 2.07 |
| 8 | 6.15 ± 2.67 | 4.44 ± 2.05 | 3.60 ± 1.54 | 3.81 ± 1.38 | 4.92 ± 1.50 | 7.47 ± 1.72 |
| 12 | 4.38 ± 2.09 | 3.08 ± 1.52 | 2.59 ± 1.05 | 2.98 ± 1.09 | 4.32 ± 1.36 | 7.07 ± 1.75 |
| 16 | 3.57 ± 1.84 | 2.46 ± 1.24 | 2.15 ± 0.89 | 2.72 ± 1.06 | 4.13 ± 1.28 | 7.0 ± 1.64 |
| 20 | 2.88 ± 1.40 | 1.90 ± 0.91 | 1.86 ± 0.72 | 2.57 ± 0.90 | 4.22 ± 1.27 | 6.98 ± 1.57 |
| 24 | 2.19 ± 1.00 | 1.67 ± 0.70 | 1.71 ± 0.57 | 2.29 ± 0.80 | 4.03 ± 1.23 | 7.05 ± 1.54 |

MD, mediolateral points at 10-mm, 8-mm, 6-mm, 4-mm, and 2-mm distances from the midsagittal line to the lateral; MM, midsagittal points.

**Table 3.** The comparison of palatal bone thickness measurements in the deep and normal palate

| Sections | MD5 *P* | MD4 *P* | MD3 *P* | MD2 *P* | MD1 *P* | MM *P* |
|---|---|---|---|---|---|---|
| 4 | .925 | .735 | .435 | .331 | .425 | 0.520 |
| 8 | .855 | .965 | .695 | .305 | .384 | 0.570 |
| 12 | .429 | .832 | .542 | .104 | .247 | 0.609 |
| 16 | .889 | .771 | .365 | .139 | .074 | 0.174 |
| 20 | .907 | .507 | .056 | .039* | .038* | 0.010* |
| 24 | .429 | .332 | .061 | .006* | .009* | 0.022* |

*Statistically significant at $P < .05$.

the risk of penetration into the nasal cavity and incisive canal, and the limited palate height results in the production of short palatal mini-implants. If the mini-screws are selected too short, the depth of penetration into the bone may not be sufficient to achieve initial stability, therefore clinicians should know midpalate and paramedian palate topography.[15-17] Determining the patient's palatal bone thickness can help the clinician prevent possible problems by determining the exact location and the size of the TAD. Also, this kind of information can help to design prefabricated devices for palatal expanders.



According to our study, when a mini-screw is needed in the palatal region, the most suitable area in terms of bone thickness to select the appropriate length of the screw is along the midsagittal line, 4 mm posterior to the incisive canal, paramedian areas, and the alveolar bone adjacent to the teeth. Along the midsagittal line, due to the presence of the nasal crest, suitable bone thickness is provided, even though insertion of the mini-screw in the non-bony sutures should be avoided due to the potential of affecting growth. In contrast to this study, Suteerapongpun et al.[17] reported that the midsagittal bone thickness increased in posterior areas compared to anterior areas. Also, at the sections of 3 mm and 6 mm laterally from the posterior wall of the incisive canal, an increasing trend had been reported, which could be due to selecting shorter distances in their measurement method. The risk of penetration into the canal increases as the thickness of the bone around the incisive canal decreases. The findings of Kang[16] correspond to our data in that the bone thickness decreases from the anterior to the posterior and from the midsagittal to the lateral. In another study, Ryu et al.[18] reported

**Table 4.** The comparison of palatal bone thickness between men and women

| Sections | MD5 *P* | MD4 *P* | MD3 *P* | MD2 *P* | MD1 *P* | MM *P* |
|---|---|---|---|---|---|---|
| 4 | .026* | .008* | .004* | .010* | .003* | .002* |
| 8 | .0164* | .047* | .021* | .041* | .061* | .039* |
| 12 | .356 | .229 | .173 | .334 | .347 | .399 |
| 16 | .632 | .623 | .767 | .662 | .422 | .730 |
| 20 | .689 | .644 | .684 | .543 | .218 | .131 |
| 24 | .120 | .875 | .866 | .266 | .057 | .056 |

*Statistically significant at $P < .05$.

that the thickness of the palatal bone decreases from anterior to posterior in the paramedian regions while increases posteriorly in the midline. Inconsistencies between studies may be due to differences in bone thickness between individuals, differences in measurement methods, racial differences, and anatomy of the palate.[18]

The results of the current study showed that, for the insertion of the mini-screw in the anterior region of the palate, the safest location is the paramedian areas at sections of 4 mm and then 8 mm posterior to the incisive canal. In the middle and posterior areas (12 mm and more), screw insertion of more than 2 mm from the midsagittal line should be avoided. King et al.[15] showed sufficient bone thickness for a 3 mm height implant in adolescents in the palatal paramedian region at a distance of 4 mm posteriorly and 3 mm laterally to the incisive foramen. In another study, Baumgaertel[12] used 30 dry skulls to assess bone thickness in the coronal sections and used dental contacts as a landmark to measure sections in the anterior–posterior dimension. He reported that bone thickness in the anterior is greatest and gradually decreases posteriorly. Also, in each coronal section, the greatest thickness was related to the parasagittal areas. When inserting the mini-screw in the anterior areas, we must consider the potential for damage to the incisive canal. Though the incisive foramen is located almost at the site of the incisive papilla, the canal extends upward and backward to about the level of the premolars (with differences in different individuals). To stay away from this sensitive area, parasagittal placement is recommended because the canal is located in the midsagittal plane.[12]

Comparing the average bone thickness between patients with deep and normal palate, the insignificant difference was observed from the sections 4-16 mm, but at 20 mm and 24 mm sections in midsagittal and parasagittal points (MD1 and MD2), the bone thickness was greater in patients with normal palate than in the deep palate. This shows the increased risk of mini-screw failure in these areas. Since the deep palate is a feature of long face patients, the difference between the 2 groups of deep and normal palate could be related to the function of the masticatory muscles, the bite force, and soft tissue function that can affect skeletal morphology. In the study by Ozdemir et al.[19] it was found that the thickness of the alveolar maxillary and mandibular cortical bone was less than that of the low-angle cases, and this could lead to a higher risk of mini-screw loss in these patients. No studies were found about the relationship between the depth of the palate and the thickness of the palatal bone. Moon et al.[20] examined the relationship between vertical skeletal patterns and the success of mini-implants. They found that patients with a high Frankfort-mandibular angle and a low upper gonial angle had a lower odds ratio than the other facial patterns and concluded that the longer facial pattern is associated with the failure of mini-implants.

Examining the data from men and women and comparing the means showed that the greatest bone thickness is related to the midsagittal line and gradually decreases to the middle regions of the palate (MD3) and then gradually increases to the margins of the palate (MD4 and MD5). This increase is less in

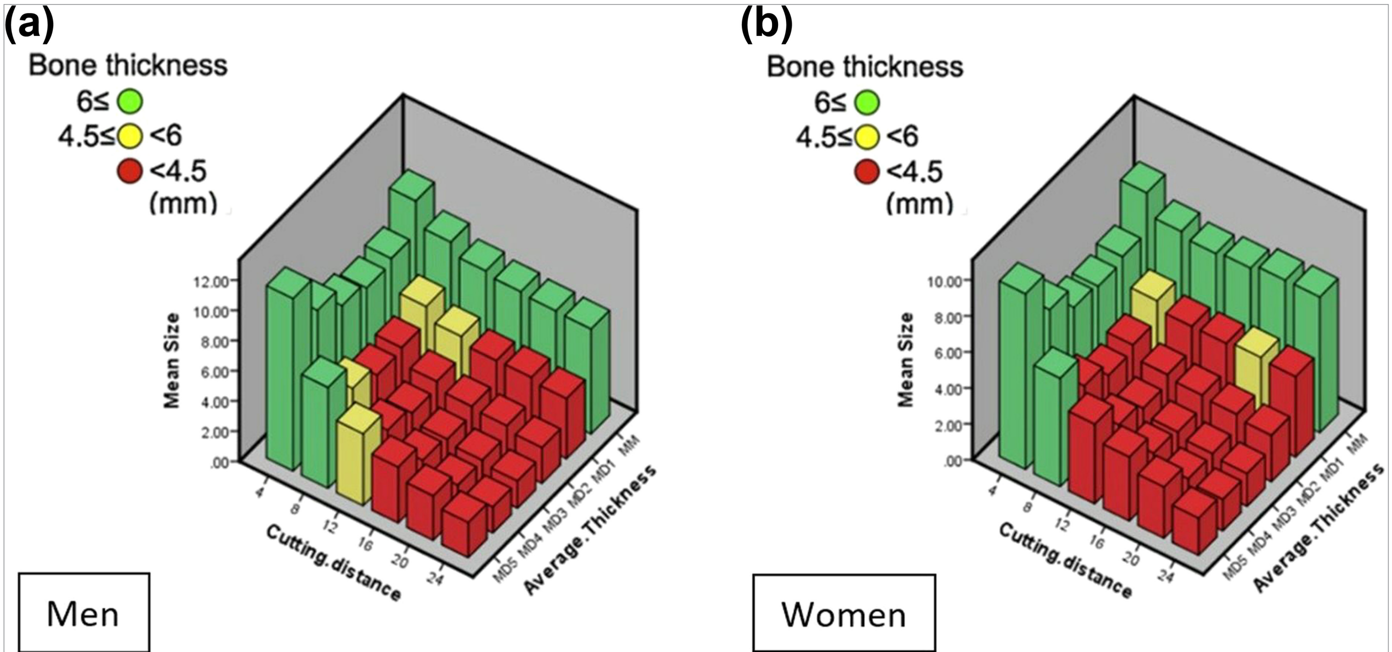


**Figure 4. a, b.** Thickness graph in men (a) and women (b)



the 20 mm and 24 mm sections. Also, the thickness decreases in all parts, by moving from the anterior to the posterior palate, which is more frequently observed in women. Also, by comparing males and females, it was found that the difference of palatal bone thicknesses in all points of the section of 4 mm and also in MM, MD2, MD3, MD4 points of a section of 8 mm is more in male than that in the female. So, in the anterior regions of the palate in the men, 1 mm longer mini-screws can be used. This finding was similar to Holm et al[1] who reported that, on average, bone thickness in men was 1.2 mm greater than in women. This finding was not in accordance with the study of Wang et al.[21] showing an insignificant difference between men and women.

One of the limitations of the current study was finding patients with deep palate. To overcome the limitation, patients from a wide age range were included in the study.

## CONCLUSION

The maximum thickness of the palatal bone was observed first along the midsagittal line and then the paramedian (MD1) and

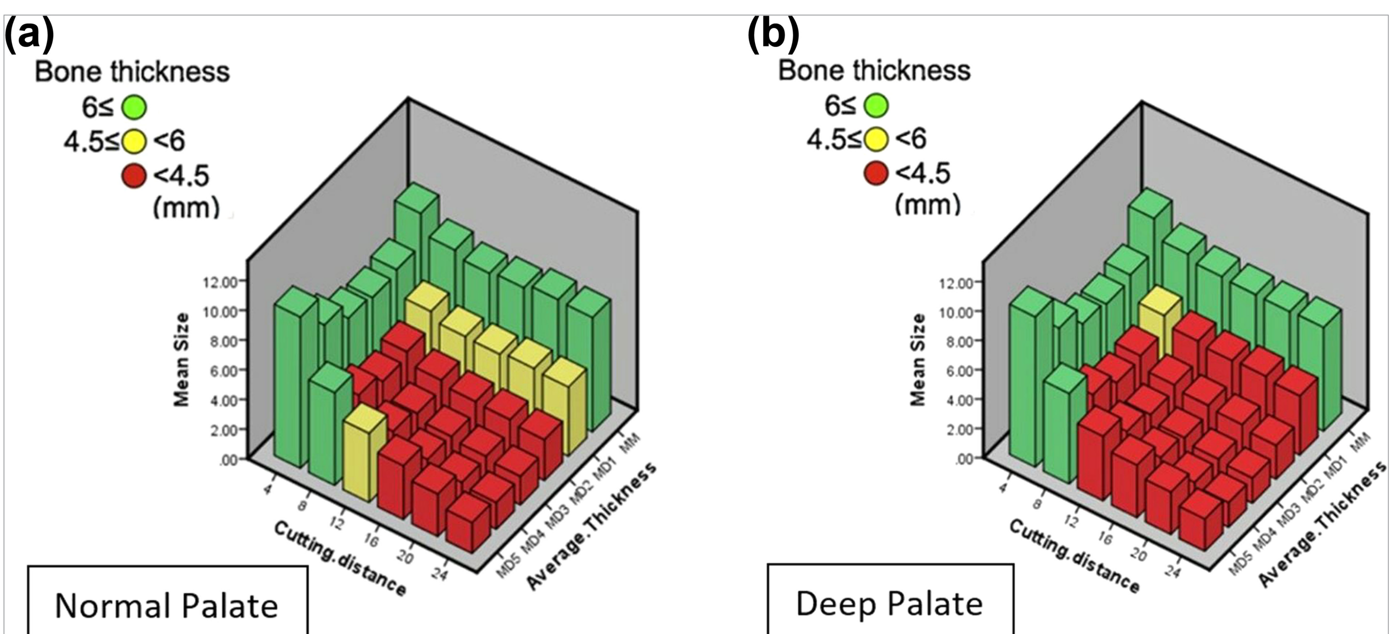


**Figure 5. a, b.** Thickness graph in normal (a) and deep palate (b)

anterior (4 mm distance) areas; these points could be safe areas for selecting the suitable length of the mini-screw. The thickness of the palatal bone decreases from anterior to posterior and also from midsagittal to lateral.

Patients with a deep palate at the posterior area (20 mm and 24 mm) in the midsagittal and parasagittal points had less bone thickness. Men at the sections of 4 mm and 8 mm had more bone thickness than women. When the mini-screw is to be used in the paramedian areas, it is recommended not to be inserted in the posterior areas or to use a screw with a shorter length.

There is a vast variation in the thickness of the palatal bone, and it is recommended to carefully evaluate the desired location in each patient to reduce the risk of failure of the mini-screws. This information can help clinicians to choose the best TAD location.

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Original Article

# The Association of ACTN3 Rs1815739 Polymorphism with Various Malocclusion Phenotype

Hussain Nihad Izaddin Alalim[1], Başak Funda Eken[2], Korkut Ulucan[2], Fulya Özdemir[1]

[1]Department of Orthodontics, Marmara University, Faculty of Dentistry, İstanbul, Turkey
[2]Department of Medical Biology and Genetics, Marmara University, Faculty of Dentistry, İstanbul, Turkey

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Main Points

- A relationship is present with some traits of the face and alpha-actinin-3 (ACTN3) rs1815739 polymorphism.
- This relationship is present in the sagittal position of the maxilla and inclination of the maxillary incisors.
- The prognathic maxilla was related to RR genotype.
- The retrognatic maxilla was found to be related to RX and XX genotypes.
- Subjects having normal incisor angulation in the maxilla had no RX genotype but had RR and XX.

## ABSTRACT

**Objective:** A functional polymorphism on the 16th exon of the alpha-actinin-3 gene has an effect on the protein structure and cellular signaling and therefore on muscle contraction. In this study, we aimed to analyze the alpha-actinin-3 rs1815739 polymorphism in 3-dimensional malocclusions and different craniofacial skeletal patterns.

**Methods:** Forty-nine volunteering subjects enrolled for the study. Genotyping of alpha-actinin-3 rs1815739 polymorphism was performed using real-time polymerase chain reaction. Pre-orthodontic cephalometric radiographs were traced using NemoTech cephalometric tracing software. IBM SPSS Statistics for Windows was utilized to carry out statistical analysis. $P < .05$ was considered to be statistically significant.

**Results:** The respective numbers and the percentages of alpha-actinin-3 rs1815739 polymorphisms for RR, RX, and XX genotypes were 39 (79.6%), 4 (8.2%), and 6 (12.2%), respectively. Twenty-one patients had low angle vertical patterns and 17 patients had Class I and the same number of the patients had Class III facial patterns. But none of these had statistically significant difference in terms of alpha-actinin-3 rs1815739 polymorphism and in vertical or sagittal facial patterns, and mandibular incisor inclination. When we examined the maxillary anteroposterior position, we found a significant difference between rs1815739 polymorphisms ($P < .05$). Also, we detected a significant difference between rs1815739 polymorphism and maxillary incisor inclination ($P < .05$).

**Conclusion:** Maxillary incisor inclination and maxillary anteroposterior position are associated with alpha-actinin-3 rs1815739 polymorphism in a Turkish cohort.

**Keywords:** ACTN3, facial pattern, malocclusion, polymorphism

## INTRODUCTION

Malocclusion is a complex trait in both its phenotypic expression and its genetic etiology, and several genes are associated with the phenotype. Dental and skeletal malocclusions, especially bone, teeth, skeletal muscles, and other soft tissues, are affected by transcription and growth factors combined and additional environmental factors. Our knowledge of the etiology of many of the resulting malocclusion is very limited. The effect of muscle tissues on the bone structure of the face and therefore malocclusions has been a subject that has been included in textbooks for years.[1] In studies conducted in the last decade, it has been shown that facial muscles are quite effective on facial morphology.[2,3] Therefore, gene variants related to muscle composition and activity have also

**Corresponding author**: Fulya Özdemir, e-mail: fulya.ozdemir@marmara.edu.tr

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been studied and have been associated with different craniofacial skeletal phenotypes.[4] Alpha-actinin-3 (*ACTN3*) is one of these genes. Proteins expressed by these genes are closely related to muscle function. The presence of *ACTN3* was found to be associated with strong and rapid contraction in type II muscle fibers.[5] The rs1815739 polymorphism (R577X) of the *ACTN3* gene has been associated with Class II deep-bite malocclusion[6] and sagittal and vertical craniofacial skeletal pattern.[7]

Actinins are actin-binding proteins and have important functions in muscle contraction. In humans, there are 4 different types of actin, and each type of actin is encoded by specific genes.[8] The product of the *ACTN3* gene, ACTN3 protein, is localized in the Z lines of the sarcomers and is responsible for binding the actins more closely to the Z line.[9] The result of the variation in codon coding for amino acid 577 of exon 16 of *ACTN3* (R577X; dbSNP rs1815739) leads to a change of arginine amino acid (R) to a stop codon (X). This transformation results in shorter protein formation than normal form.[10]



In addition, *ACTN3* interacts with the signal protein calcineurin to influence fiber-type ratios during growth, causing changes in muscle function.[11] Alpha-actinin-3 binds to the calsarcin family of signal proteins on the Z disc and binds to calcineurin to activate specific gene expression pathways of the muscle fiber type that determine muscle fiber types and size.[12,13]

The aim of our study is to investigate the potential relationship between 3-dimensional malocclusion phenotypes and *ACTN3* gene that may play a role in craniofacial development. For this purpose, the *ACTN3* rs1815739 polymorphism, which is expressed in muscle cells and is related to muscle structure by having important functions in providing appropriate muscle movements, is examined in adults with malocclusions to determine its clinical effect in a Turkish population.

## METHODS

### The Participants

Forty-nine (18 male and 31 female) orthodontic patients, who have applied to the Department of Orthodontics at Marmara University between January and October 2019 and have agreed to be a part of this project, participated in this study. The study protocol was in agreement with the Helsinki Declaration 2 (2015) guidelines and approved by Usküdar University Non-Interventional Ethics Committee (61351342/2019-575). The volunteers participating in the study were given detailed information about the analyses and outputs before the study, and their consent forms were obtained.

The following inclusion and exclusion criteria were followed to include or discard patients who were not in line with the purpose of this study. Inclusion criteria were being older than 18 years, being in permanent dentition, having no previous orthodontic treatment, and having available pre-orthodontic records. Exclusion criteria were having a history of orthodontic or orthognathic treatment, an aesthetic/plastic operation or trauma in the facial area, having any hereditary genetic disease in its self and in their first-degree relatives, having uncontrolled medical systemic disease or diseases, cleft lip and palate and having lost more than 1 permanent tooth.

Pre-orthodontic cephalometric radiographs were used in this study to evaluate the sagittal and vertical malocclusion of the patients. All cephalometric radiographs were traced using NemoTech Cephalometric tracing software (Version 10.4.2, Madrid, Spain) by a single examiner (HA).

## CEPHALOMETRIC MEASUREMENTS USED IN THIS STUDY

### Vertical

1. Sum of inner angles: the collective sum of the saddle angle, articulare angle, and the gonial angle
2. Gonion–Menton–SN: the angle between the anterior cranial base and the plane passing through the gonion and menton points
3. ANS-Me/N-Me: the ratio of anterior facial height to lower anterior facial height
4. Jarabak ratio: the ratio of posterior facial height to anterior facial height
5. FMA: the angle between the Frankfort horizontal plane and the mandibular plane
6. Maxillary height: The angle between the nasion, center of face, and A point

### Sagittal

1. SNA: the angle between the S-N and the N-A plane
2. SNB: the angle between the S-N and the N-B plane
3. ANB: the angle between the N-A and the N-B plane that determines the sagittal relationship between maxilla and mandible
4. Wits: a measure of jaw relationships in an anteroposterior plane, by drawing perpendiculars from A and B points on the occlusal plane
5. N per A: distance between A point from a line drawn perpendicular from nasion with respect to the Frankfort horizontal plane

### Dental

1. UI-SN: the angle between the axis of maxillary central incisor and the SN plane
2. IMPA: the angle between the axis of the lower central incisors and the mandibular plane
3. LI-UI angle: the inter-incisal angle, the angle between the axis of maxillary and mandibular incisors
4. UI-OP angle: the angle between the axis of upper incisor and occlusal plane
5. LI-OP angle: the angle between the axis of lower incisors and occlusal plane

For the assessment of vertical discrepancy, cephalometric radiographs were used to categorize the patient into normal, high and low angle vertical pattern. The analyses that were used are total inner angle, GoMe-SN, Jarabak, ANSMe/NMe, Frankfort mandibular plane angle, and Maxillary height. Since there are many variations in these analyses, all of the measurements were used to categorize the patient into 1 of the 3 vertical patterns in order to come up with a more accurate diagnosis for the patients.

ANB and Wits analyses were utilized to classify the patients into Class I, Class II, and Class III relationship. SNA, maxillary depth, and nasion perpendicular A were utilized to categorize the patients into normal, prognathic, and retrognathic maxillary position groups, and the overall maxillary position of the patients were decided by considering all 3 analysis.

Incisor SN angle and maxillary incisor-occlusal plane angle were utilized to determine maxillary incisor inclination and categorized them into normal, proclined, and retroclined incisor inclination groups. Similarly, incisor-mandibular plane angle and incisor-occlusal plane angles were utilized to determine mandibular incisor inclination and categorizing patients into normal, proclined, and retroclined incisor inclination groups.

## *ACTN3* RS1815739 GENOTYPING

### DNA Isolation

Oral epithelium cells were collected by DNA collection swabs from the volunteers who participated in the study, and DNA isolation was completed by using PureLink DNA isolation kit (Invitrogen, Van Allen Way Carlsbad, Calif, USA). Briefly, 20 µL proteinase K was vortexed by adding 10 µL of RNAase to 200 µL of DNA isolation. After 2 minutes at room temperature, 200 µL of binding buffer was added and homogenized with stirring. After incubation for 10 minutes in a 55°C water bath, 200 µL of ethanol was added and vortexed for 5 seconds. It was taken to the filtered tube and centrifuged at 10 000 g for 1 minute. The supernatant was discarded and 500 µL of washing buffer was added to the pellet and centrifuged at 10 000g for 1.15 seconds. Later, 80 µL of elution buffer was added and incubated and centrifuged at maximum speed for 1 minute. The DNA samples obtained were stored at −20°C until the analysis of the respective gene regions was completed. An average of 20 ng of DNA was isolated from each sample, and the isolated DNAs were evaluated according to the OD260/280 spectrophotometric ratio. The DNA samples obtained were stored at −20°C until the analysis of the relevant gene regions was completed.

### Genotyping of *ACTN3* rs1815739

Genotyping of *ACTN3* rs1815739 polymorphism was performed from the isolated DNA by using 7500 Fast Real-Time PCR System (Applied Biosystem, Foster City, Calif, USA). Taqman Genotyping Assays (Applied Biosystems) genotyping kit was used for allelic determination.

### Statistical Analysis

IBM SPSS-Statistical Product and Service Solutions (Statistics for Windows, Version 19.0., Armonk, NY, IBM Corp.) was used to conduct statistical analysis. Descriptive analyses were presented using means, standard deviations, median, and minimum and maximum values for continuous data, and frequencies and percentages for categorical data. The variables investigated using Kolmogorov–Smirnov test to determine whether or not they were normally distributed. The Fisher's exact test was used to compare the proportions of the groups. Since the variables were not normally distributed, Kruskal–Wallis test was used to compare medians of the groups. A 5% type I error level was used to infer a statistical significance.



## RESULTS

### Vertical Facial Pattern

There was no statistically significant relationship between ACTN3 rs1815739 polymorphism and vertical pattern $P > .05$ (Table 1).

When the overall vertical pattern was analyzed, the low angle group had 21 patients, normal group had 9 patients, and the high angle group had 19 patients. In the low angle group, 18

**Table 1.** Genotype and Percentage Distribution of ACTN3 rs1815739 Polymorphism in Vertical Pattern Groups

| | | | Genotype | | | | |
|---|---|---|---|---|---|---|---|
| | | | XX | RX | RR | Total | *P* |
| Overall vertical pattern | Low | Patients | $1_a$ | $2_a$ | $18_a$ | 21 | **.560** |
| | | Percentage | 4.8 | 9.5 | 85.7 | 100.0 | |
| | | Percentage within all patients | 16.7 | 50.0 | 46.2 | 42.9% | |
| | Normal | Patients | $2_a$ | $0_a$ | $7_a$ | 9 | |
| | | Percentage | 22.2 | 0.0 | 77.8 | 100.0 | |
| | | Percentage within all patients | 33.3 | 0.0 | 17.9 | 18.4 | |
| | High | Patients | $3_a$ | $2_a$ | $14_a$ | 19 | |
| | | Percentage | 15.8 | 10.5 | 73.7 | 100.0 | |
| | | Percentage within all patients | 50.0 | 50.0 | 35.9 | 38.8 | |
| Total | | Patients | 6 | 4 | 39 | 49 | |
| | | Percentage | 12.2 | 8.2 | 79.6 | 100.0 | |
| | | Percentage within all patients | 100.0 | 100.0 | 100.0 | 100.0 | |

*P* < .05 indicates statistically significant difference. Same subscript numbers indicate statistically insignificant relationships among genotype groups.

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**Table 2.** Genotype and Percentage Distribution of ACTN3 rs1815739 Polymorphism in Sagittal Pattern Groups

| | | | Genotypes | | | | |
|---|---|---|---|---|---|---|---|
| | | | XX | RX | RR | Total | *P* |
| Maxillary Position | Normal | Patients | $1_a$ | $0_a$ | $16_a$ | 17 | **.044*** |
| | | Percentage | 5.9 | 0.0 | 94.1 | 100.0 | |
| | | Percentage within all patients | 16.7 | 0.0 | 41.0 | 34.7 | |
| | Prognathic | Patients | $0_a$ | $0_a$ | $9_a$ | 9 | |
| | | Percentage | 0.0 | 0.0 | 100.0 | 100.0 | |
| | | Percentage within all patients | 0.0 | 0.0 | 23.1 | 18.4 | |
| | Retrognathic | Patients | $5_{a,b}$ | $4_b$ | $14_a$ | 23 | |
| | | Percentage | 21.7 | 17.4 | 60.9 | 100.0 | |
| | | Percentage within all patients | 83.3 | 100.0 | 35.9 | 46.9 | |
| Total | | Patients | 6 | 4 | 39 | 49 | |
| | | Percentage | 12.2 | 8.2 | 79.6 | 100.0 | |
| | | Percentage within all patients | 100.0 | 100.0 | 100.0 | 100.0 | |

*$P < .05$ indicates statistically significant difference. Same subscript numbers indicate statistically insignificant relationships among genotype groups.



patients had RR, 2 had RX, and 1 had XX genotype. In high vertical group, 14 had RR, 2 had RX, and 3 had XX genotype. In normal vertical group of patients, 7 had RR and 2 had XX. No RX genotype was detected in the normal group.

In XX genotype, 50% consisted of high-angle patients, 33.3% normal vertical, and 16.7% low-angle patients. Low- and high-angle groups shared RR genotype each 50%. RR genotype was seen 46.2% in low angles, 17.9% in normal vertical, and 35.9% in high angles.

**Sagittal Facial Pattern**

In the sagittal plane, 17, 15, and 17 patients had Class I, Class II, and Class III malocclusion, respectively. There was no statistically significant relationship between ACTN3 rs1815739 polymorphism and sagittal pattern using ANB or Wits appraisal $P > .05$.

**Maxillary Anteroposterior Position**

There was a statistically significant relationship between *ACTN3* rs1815739 polymorphism and overall maxillary sagittal position $P < .05$ (Table 2). The people who had retrognathic maxilla had significant proportional difference between XX and RX, and between XX and RR. In the prognathic maxilla group, all the patients had RR genotype and 23% of all RR genotype was expressed in these 9 prognathic patients. In the normal maxillary sagittal position group, RR genotype percentage was 94.1% and 100% of RX and 83.3% of XX were represented by 4 and 5 patients out of total 23 retrognathic patients, respectively.

**Maxillary Incisor Inclination**

There was a statistically significant frequency distribution difference between *ACTN3* rs1815739 polymorphism and incisor inclination using I-SN ($P < .05$) (Table 3). The subjects who had normal incisor angle had statistically significant proportional difference

**Table 3.** Genotype and Percentage Distribution of ACTN3 rs1815739 Polymorphism in Maxillary Incisor Inclination Groups

| | | | Genotype | | | | |
|---|---|---|---|---|---|---|---|
| | | | XX | RX | RR | Total | *P* |
| **I-SN** | Normal incisor angle | Patients | $4_a$ | $0_{a,b}$ | $5_b$ | 9 | **.024*** |
| | | Percentage | 44.4 | 0.0 | 55.6 | 100.0 | |
| | | Percentage within all patients | 66.7 | 0.0 | 12.8 | 18.4 | |
| | Proclined Upper Incisor | Patients | $1_a$ | $3_a$ | $24_a$ | 28 | |
| | | Percentage | 3.6 | 10.7 | 85.7 | 100.0 | |
| | | Percentage within all patients | 16.7 | 75.0 | 61.5 | 57.1 | |
| | Retroclined upper incisor | Patients | $1_a$ | $1_a$ | $10_a$ | 12 | |
| | | Percentage | 8.3 | 8.3 | 83.3 | 100.0 | |
| | | Percentage within all patients | 16.7 | 25.0 | 25.6 | 24.5 | |
| Total | | Patients | 6 | 4 | 39 | 49 | |
| | | Percentage | 12.2 | 8.2 | 79.6 | 100.0 | |
| | | Percentage within all patients | 100.0 | 100.0 | 100.0 | 100.0 | |

*$P < .05$ indicates the statistically significant difference.

between RX and XX ($P < .05$) and between RX and RR ($P < .05$). In the normal incisor angle group, we detected no RX genotype. Also, 66.7% had XX and 12.8% had RR genotype in this group, presenting in 4 and 5 subjects, respectively. In the proclined group, 85.7% and in the retroclined group, 83.3% of subjects had genotype RR, presenting in 24 and 10 subjects, respectively.

On the other hand, there was no statistically significant frequency distribution difference between *ACTN3* rs1815739 polymorphism and incisor inclination when UI-OP measurement was used ($P > .05$).

**Mandibular Incisor Inclination**

There was no statistically significant frequency distribution difference between *ACTN3* rs1815739 polymorphism and incisor inclination using IMPA or LI-OP ($P > .05$). In volunteers with normal incisor angle, all of them had RR genotype RR.

## DISCUSSION

Identifying the cause and early detection of malocclusion is valuable in the effective treatment, management of malocclusions, as well as public health planning. Many researchers have pointed out to date the relationship of facial bones and facial muscles. Therefore, the aim of the present research was to investigate the impact of *ACTN3* rs1815739 polymorphism, which has an effect on the muscle performance and on the configuration of the facial bones.

In order to describe the configuration of facial pattern, cephalometric radiographs were utilized because they are inexpensive and powerful tools, readily available in the patient files, and give information about both the vertical and sagittal relationship of the facial bones. Well-established diagnostic angular measurements in orthodontics were selected to determine the skeletal malocclusion and the facial type in the present study.

Wolff's[14] law points out that the internal structure and the shape of the bone is closely related to function and defines a relationship between bone shape and muscle function. Following this rule, one of the most established concepts in orthodontics is that there is an effect of facial muscles on the facial skeleton and malocclusion.[2,3,15,16]

In previous research, it was shown that facial morphology was related to the fiber type of masticatory muscles.[17,18] The relationship of fiber type and genetic variations were revealed by other researchers.[4,19,20]

In the present study, when the overall vertical pattern was analyzed, there was no statistically significant relationship of *ACTN3* rs1815739 polymorphism and vertical facial pattern. Also, 50% of XX genotype consisted of high-angle patients, 33.3% normal vertical, and 16.7% were low-angle patients, which showed tendency of XX genotype to have a higher frequency of high-angle vertical pattern supporting the findings of Cunha et al.[21] who have stated that the XX genotype is associated with dolichofacial phenotype. It was stated in the recent literature that *ACTN3* rs1815739 polymorphism resulted in a lack of *ACTN3* protein expression.

The loss of this protein has been shown to lead to smaller type II fiber diameters in masseter muscles and an increased expression of ENPP1, a negative regulator of mineralization, which was related to a small-sized mandible and reduced bone mass in the mandible.[22,23,24] This condition was found to be similar to Class II openbite morphology in humans. Cunha et al.[21] have also studied *ACTN3* rs678397and rs1815739 and have concluded that polymorphisms in *ACTN3* were found to be associated with sagittal and vertical craniofacial skeletal patterns, and this could vary according to the patient's ethnicity. In our study, as 2-dimensional measurements were carried out, mandibular bone volume analysis could not be performed.

For the sagittal facial pattern, there was no statistically significant relationship between *ACTN3* rs1815739 polymorphism results and sagittal relation using ANB or Wits. Also, 35.9% and 48.7% of RR genotype consisted of Class III patients. Recent studies reported the association of XX genotype which was found with higher frequency of Class II patients.[6,21] Zebrick et al.[6] has studied *ACTN3* rs678397 which is a cytosine to thymine transition in the intronic region of *ACTN3*.



**Rs678397 and rs1815739**

Even though there was no relationship between *ACTN3* rs1815739 polymorphism and sagittal classification, there was a statistically significant relationship between *ACTN3* rs1815739 polymorphism results and overall maxillary sagittal position in our study. It was found that the prognathic maxilla group was only associated with RR genotype. For incisor inclination, there was a statistically significant relationship between *ACTN3* rs1815739 polymorphism and incisor inclination in the I-SN parameter ($P < .05$). The subjects who had normal incisor inclination had significant proportion difference between RX and XX and between RX and RR. It showed an association of XX genotype with normal incisor inclination phenotype and RR genotype with proclined upper incisor inclination phenotype. A master's thesis in 2018 has stated that the genotype for polymorphisms rs678397 and rs1815739 was associated with both weak lips and a skeletal Class II phenotype, with a protrusive maxilla, and that genotype and soft tissue were significantly associated with skeletal phenotype. There was a significant association between the position of the maxilla and the strength of the labial musculature, and associations were found between markers in gene *ACTN3* and skeletal measures.[25] The findings of this study, especially about lip weakness, may explain why maxilla was prognathic and upper incisors were proclined in patients with rs1815739 polymorphism in the present study.

***ACTN3* rs1815739 Polymorphism**

There are some limitations in our study. Although the study investigated a relatively large number of patients, the study protocol separated participants into subgroups for comparisons. This resulted in a limitation of the study for the statistical comparisons. Future studies should include larger subject numbers to further understand the relationship of genetic variants with facial phenotype.

This study used conventional lateral cephalograms to determine morphologic differences in the pattern of craniofacial skeletal patterns. These imaging modalities are routinely utilized in radiographic evaluation of dental patients. Although cone beam computed tomography is more precise, for this study, routine and already available records were evaluated. Future studies may use 3D evaluations of the dentofacial complex to unfold relations of genetics and morphology of the face.

## CONCLUSION

There was no statistically significant frequency distribution difference between *ACTN3* rs1815739 polymorphism and facial pattern except:

1. Overall maxillary position measured by SNA, maxillary depth, and nasion perpendicular A:
   - (a) The prognathic maxilla was related to RR genotype.
   - (b) The retrognatic maxilla was found to be related to RX and XX genotypes
2. Maxillary incisor inclination measured by I-SN:
   - (a) In the normal incisor angle group, there was no RX genotype.
   - (b) In the proclined group, 85.7% and in the retroclined group, 83.3% of subjects had genotype RR.
   - (c) Both proclined (85.7%) and retroclined (83.3%) groups were dominized by RR genotype.



**Ethics Committee Approval:** Ethics committee approval was received from the Non-Interventional Ethics Committee of Üsküdar University (61351342/2019-575).

**Informed Consent:** Informed consent was obtained from the participants.

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Original Article

# Mechanical Vibration and Chewing Gum Methods in Orthodontic Pain Relief

Fatih Çelebi

Department of Orthodontics, Faculty of Dentistry, Tokat Gaziosmanpaşa University, Tokat, Turkey

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Main Points

- The effects of mechanical vibration and chewing gum on orthodontic pain caused by initial archwire were evaluated.
- Individual variations such as gender, amount of crowding, and pressure pain threshold of the participants were taken into account while forming the groups.
- The results suggest that both chewing gum and mechanical vibration have no pain-relief effect on orthodontic pain.



## ABSTRACT

**Objective:** The aim of this study was to investigate the pain relief effects of chewing gum and mechanical vibration methods on orthodontic pain caused by the initial archwire.

**Methods:** In this study, 57 patients, having a 3-6 mm maxillary dental crowding and non-extraction treatment modality were included. The pressure pain thresholds of the subjects were measured. Patients were distributed equally by sex and randomly allocated into 3 groups: mechanical vibration, chewing gum, and control. The fixed orthodontic treatment was started in the upper jaw only. In the first and second groups, mechanical vibration was applied and sugar-free gum was chewed, respectively. The third group was used as the control. The pain perceptions were measured using the Visual Analog Scale. Kruskal–Wallis and Friedman tests were used for statistical analysis.

**Results:** The groups were similar at the beginning of the study in terms of age and algometer scores ($P = .138$ and $P = .155$, respectively). Statistical significant differences in the Visual Analog Scale scores among the groups could not be detected at any time point. The highest pain scores were detected at the 24$^{th}$ hour of treatment in all 3 groups. There was no statistically significant difference in the highest pain level among the groups ($P = .279$).

**Conclusion:** Although the average pain values were perceived as lower, particularly in the mechanical vibration group, the temporary displacement of the teeth has no clinically significant pain relief effect on orthodontic pain.

**Keywords:** Algometer, chewing gum, orthodontics, pain, vibration

## INTRODUCTION

Pain is a side effect that occurs at an extremely high rate during fixed orthodontic treatments, resulting in complaints from patients. Although the rate varies according to the studies, many researchers have reported that 80-95% of orthodontic patients experience pain during the treatment.[1,2] A previous study highlighted that pain was the most disliked aspect of orthodontic treatment, and it was ranked fourth in a list of apprehensions and fears prior to treatment.[3] This situation affects both private and social lives as well as the treatment approach and cooperation. Many patients prefer soft foods because they believe that they will cause less pain; however, soft and sticky foods increase the risk of plaque formation and contribute to the deterioration of oral hygiene. In addition, pain is one of the major factors for the discontinuation of treatment.[4]

**Corresponding author**: Fatih Çelebi, e-mail: fatihcelebi5860@gmail.com


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Orthodontic pain can be present both in the initial alignment phase[4] and at the end of the treatment.[5] Previous studies showed that pain that occurred during the initial alignment phase usually begins at the second hour of treatment and increases gradually with time. It reaches the peak level at 24-36 hours, then gradually decreases until it disappears on the seventh day.[1-3,6] Although opinions vary, the most widely accepted hypothesis about how orthodontic pain occurs is related to the algogenes.[6] According to this hypothesis, orthodontic tooth movement causes the release of algogenes—such as leukotrienes, histamine, substance P, dopamine, prostaglandin E's (PGEs), serotonin, glycine, glutamate gamma-aminobutyric acid, and cytokines—at the site of the periodontium. These chemicals create a hyperalgesic response, and as a result of hyperalgesia, pain occurs when the orthodontic force is applied.[6] Additionally, orthodontic pain is affected by many factors such as age, gender, pain threshold, the magnitude of the applied force, and cultural differences.[6,7]

To date, many methods have been used to eliminate orthodontic pain. These approaches can be grouped into 2 subsets: pharmacological and non-pharmacological interventions. While pharmacological methods are effective at relieving pain, it was shown that some of them have adverse effects on tooth movement.[8,9] Also, their usage may lead to other side effects that might be detrimental to the whole body such as bleeding disorders, allergies, duodenal or gastric ulceration, asthma, renal insufficiency, congestive heart problems, atherosclerosis, and hypertension.[10] Due to this, researchers have recently been focusing on non-pharmacological methods. Vibration devices, transcutaneous electrical nerve stimulation (TENS), chewing gum, low-level laser therapy (LLLT), and viscoelastic bite wafers have all been investigated as alternative pain relief to drugs.[11-13]



Various vibration devices have been launched by manufacturers with claims that they reduce orthodontic pain and accelerate tooth movement. Yet, publications related to the effectiveness of these devices are very limited, and the results of the existing literature are also contradictory.[11,14-16] In addition, they are expensive devices compared to other pain-relief methods. Chewing gum is a similar method to the use of vibration devices in terms of its pain-relieving mechanism; however, research relating to them is equally scarce.

The aim of this study was to analyze the effects of mechanical vibration and chewing gum on orthodontic pain caused by an initial archwire and also to examine whether chewing gum can be a viable alternative to mechanical vibration devices. The hypothesis of the study was that both methods are effective in relieving orthodontic pain.

## METHODS

This study was approved by the Clinical Research Ethics Committee of Tokat Gaziosmanpaşa University (19-KAEK-121). Based on the previously reported effect size for pain,[17] power analysis showed that 19 participants were necessary per group for an alpha of 0.05 and a power of 80%. Power calculation was performed by using the PASS Power Analysis and Sample Size Software (NCSS, Kaysville, Utah, USA). The minimum amount of subjects per group was calculated to be 19 participants to achieve a power of 80% for a clinically significant difference. In this study, 57 patients aged between 12 and 24 years, who had 3-6 mm maxillary crowding, non-extraction treatment modality, and permanent dentition were selected from the patient population of the orthodontic department. Patients who used painkiller for medical causes and were planned to use an orthodontic appliance that could be a source of pain such as band, transpalatal arch, headgear, and mini-screw were excluded from the study. Informed consent was obtained from the patients and parents who accepted to participate in the research.

Fifty-seven patients were randomly divided into 3 groups: those using mechanical vibration, those utilizing chewing gum, and the control group. Nineteen subjects were allocated into each group in such a way that they all included 10 females and 9 males. Randomization was provided by using a blue raffle box containing the names of the males and a red raffle box holding the names of their female counterparts. The pressure pain thresholds of the participants were measured using an algometer device (JTECH Medical, Salt Lake City, Utah, USA). In case, the pain thresholds of the participants were not equally distributed among the groups, plans were made to exclude any disruptive subjects from the sets and include new patients. Pressure algometry was introduced as a means of measuring pain thresholds in muscles, joints, tendons, and ligaments. The pressure algometer device is an apparatus that quantifies the sensitivity levels of muscles, joints, tendons, and ligaments, thereby documenting an individual's pain threshold. The measurement is performed by applying continuous pressure at a constant rate on the patient's skin.

In all of the patients, a non-extraction fixed treatment was started by placing $0.018 \times 0.025$-inch Roth prescription brackets and tubes (American Orthodontics, Sheboygan, Wis, USA). Only the upper arch was included in the study, and bracket bonding was implemented to a total of 12 teeth, from the right first molar to the left first molar. No application took place on mandibular teeth. Elastic ties were used to engage the 0.014-inch-round nickel–titanium archwire (TP Orthodontics, La Porte, Ind, USA) in the bracket slots. Then, the residual tips of the archwire were cut at the distal aspect of the first molar tubes in such a way that they did not irritate the buccal mucosa. The patients were instructed about oral hygiene maintenance and were warned to refrain from taking painkillers.

In the first group, mechanical vibration (Good vibrations, Dentsply Sirona, Charlotte, NC) was applied for 20 minutes just after the beginning of treatment (Figure 1). The procedure was also repeated 24 and 48 hours later and administered for a total of 60 minutes. The vibration device was operated with a battery-powered motor and ran within a set of 111 Hz and 0.06 N parameters. All vibration sessions were conducted at the clinic under the same supervisor. Meanwhile, the second group was assigned as the chewing gum group. Just after initiating fixed orthodontic treatment, patients chewed sugar-free gum for 20 minutes. As was the case with the vibration group, the procedure was

**Figure 1.** Application of the mechanical vibration

repeated 24 and 48 hours later, and the gum was chewed for a total of 60 minutes. All chewing gum sessions were conducted at the clinic and under the same supervisor. Lastly, the third group served as the control. No procedure was implemented on these participants aside from routine orthodontic treatment.

Ten-centimeter Visual Analog Scale (VAS) diaries, each with 6 sheets, were prepared to evaluate the pain perceptions that occurred at the second and sixth hours of treatment, and on the first, second, third, and seventh day of treatment. The Visual Analog Scale was stated as suitable for dental pain measurement and children's use in terms of mental status.[18,19] Therefore, we have preferred VAS for measuring the degree of pain. Participants were instructed about how they must mark the VAS forms. Before the measurements were taken, they were asked to tap their teeth 10 times by opening and closing their mouths and applying pressure to each tooth using their thumb.

**Statistical Analysis**

Statistical analysis was performed using the Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY, USA: IBM Corp.). The distribution of the data was evaluated using the Shapiro–Wilk test. The Kruskal–Wallis test was utilized for the comparison of age, algometer scores, and pain levels among the groups, since the parametric test preconditions were not met. Repeated measurements were evaluated by means of the Friedman test. *P* values of less than .05 were considered statistically significant.

## RESULTS

There was no statistically significant difference between groups in terms of age (*P* = .138) and pressure pain threshold (*P* = .155) (Table 1). The mean ages were 15.20, 15.10, and 14.11 years in the control, chewing gum, and mechanical vibration groups, respectively. The mean algometer scores were 15.5, 17.2, and 14.1 in the control, chewing gum, and mechanical vibration groups, respectively.

**Table 1.** Comparison of the age and algometer score among the groups

| | Group | Mean ± Standard Deviation | $P^a$ |
|---|---|---|---|
| Age (year) | Control | 15.2 ± 1.9 | .138 |
| | Chewing gum | 15.10 ± 2.5 | |
| | Mechanical vibration | 14.11 ± 2.9 | |
| Algometer score | Control | 15.5 ± 5.7 | .155 |
| | Chewing gum | 17.2 ± 3.0 | |
| | Mechanical vibration | 14.1 ± 4.7 | |

[a]Evaluated by Kruskal–Wallis test.

At all of the time points, there were no statistically significant differences among the groups in terms of pain levels (2nd hour = .814, 6th hour = .126, 24th hour = .279, 2nd day = .204, 3rd day = .620, 7th day = .440) (Table 2).

For all groups, the peak points of VAS scores were recorded at the twenty-fourth hour of treatment (Figure 2 and Table 2). Additionally, the general pattern of the pain experienced

**Table 2.** Comparison of the VAS scores among the groups

| | Group | Mean ± Standard Deviation (cm) | $P^a$ |
|---|---|---|---|
| Second hour | Control | 1.39 ± 1.88 | .814 |
| | Chewing gum | 0.89 ± 1.06 | |
| | Mechanical vibration | 1.25 ± 1.34 | |
| Sixth hour | Control | 3.75 ± 2.93 | .126 |
| | Chewing gum | 2.92 ± 2.00 | |
| | Mechanical vibration | 2.13 ± 2.18 | |
| First day | Control | 5.26 ± 2.11 | .279 |
| | Chewing gum | 5.21 ± 2.42 | |
| | Mechanical vibration | 4.03 ± 2.95 | |
| Second day | Control | 4.40 ± 2.23 | .204 |
| | Chewing gum | 4.28 ± 2.08 | |
| | Mechanical vibration | 3.25 ± 2.49 | |
| Third day | Control | 3.50 ± 2.29 | .620 |
| | Chewing gum | 2.94 ± 1.66 | |
| | Mechanical vibration | 2.89 ± 2.41 | |
| Seventh day | Control | 1.27 ± 1.82 | .440 |
| | Chewing gum | 1.47 ± 1.52 | |
| | Mechanical vibration | 0.96 ± 1.33 | |

[a]Evaluated by Kruskal–Wallis test.
VAS, Visual Analog Scale.

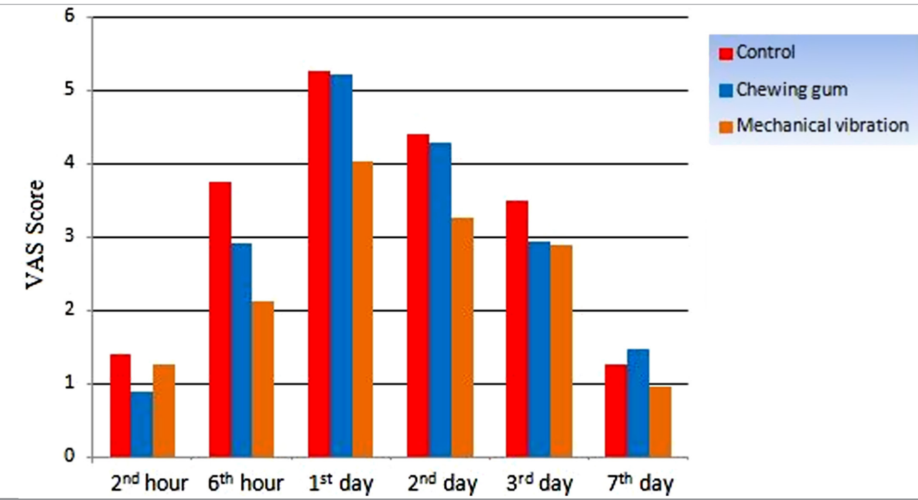


**Figure 2.** Graphic representation of pain patterns of the groups



was similar in all 3 groups. The pain detected at the 2nd hour increased gradually and reached the highest point at the 24th hour. It progressively decreased after reaching the peak level and came down to a clinically insignificant degree around the seventh day.

## DISCUSSION

Mechanical vibration, chewing gum, and bite wafers are actually similar methods and they are based on the same principle. It was claimed that all of these methods displace the teeth temporarily and loosen the compressed periodontal areas including nerve fibers and occluded blood vessels, thus enabling the blood to flow more easily. In this way, biochemical agents that cause the pain process are removed more quickly by means of increased blood flow, and their actions at the site are prevented.

Various methods such as photobiomodulation, desensitizing agents, non-steroidal anti-inflammatory drugs (NSAIDs), bite wafers, TENS, and vibratory stimulation have been proposed to reduce orthodontic pain, showing moderate results.[6,20,21] One of the most effective of these methods is the use of NSAIDs. However, it has been reported that this method can cause some detrimental effects on the whole body such as allergy, bleeding disorders, gastric or duodenal ulceration, renal insufficiency, asthma, congestive heart problems, hypertension, and atherosclerosis.[10] That is why researchers began to investigate noninvasive methods. Alternatively, the present study tested vibrational and chewing forces, and it can be questioned why a comparison of 2 similar methods on orthodontic pain was performed in the present study.

In answer to the aforementioned query, the research had 2 main objectives. The first aim was to contribute to the existing literature by testing whether these processes are actually useful. This is because there are conflicting results in previous studies about the efficacy of the principle.[11,14,15,22,23] While some articles have reported no effect,[14,23] there are also some examples of research which suggest that vibration has particularly positive repercussions on both pain and tooth movement.[16,22] Based on the studies reporting positive outcomes, manufacturers have started to produce expensive devices. However, their effectiveness has not been fully proven in the relevant literature.

The second objective was to determine whether chewing gum can be an alternative to vibration devices. The thought process behind this is that generally high-cost vibration devices are difficult to find, especially in countries where low incomes are prevalent. Moreover, there are significant advantages of using chewing gum instead of other non-pharmacological methods. First of all, it is easy to supply and is low cost. Unlike TENS, LLLT, and mechanical vibration, it does not require the use of a device. Additionally, it was shown that chewing gum stimulates saliva flow, contributes to oral hygiene with the potential to promote remineralization, and helps to reduce white spot lesion formation relating to fixed orthodontic appliances.[24] Researchers have also been interested in the different ingredients contained in chewing gums, such as fluoride, xylitol, and chlorhexidine, since it is thought that they may contribute to oral hygiene in orthodontic patients.[25,26] Also, there is no remarkable evidence that chewing gum causes breakages to appliances.[27]

There is no clear consensus on how mechanical vibration must be applied. Marie et al.[11] used the vibration device just once for 15 minutes, immediately after archwire placement. Meanwhile, Miles et al.[14] made their subjects use the vibration device for 20 minutes per day during the 10-week study period. We thought that multiple applications could be more effective than a single application in terms of pain management, because it is not likely that a single application immediately after archwire placement, and before algogens are released, could alleviate orthodontic pain. On the other hand, it would be unnecessary to intervene the pain after the third day, as there seems to be a trend where orthodontic pain decreases notably after the second day, even if there is no intervention.[6] Consequently, our preferred protocol of applications was 3 times: immediately after engagement of the initial archwire, 24 hours later, and then 48 hours later. The gum was chewed utilizing the same protocols performed in the vibration group to ensure the equality of the applications.

The hypothesis of this study was rejected. A statistically significant decrease in pain could not be detected in both the vibration and chewing gum groups; an outcome that is inconsistent with some of the articles in related literature.[11,12,16,27] Those publications have shown that vibration and chewing gum are effective in alleviating orthodontic pain, but we think that this conflict between our results and their outcomes is due to differences in study design. In the design of these studies, individual variations, such as gender distribution, amount of dental crowding, and the pain threshold of the participants, were not taken into consideration. Benson et al.[27] concluded that chewing gum significantly decreased the pain caused by fixed appliances. Nevertheless, gender equality between the groups was not considered in their research. While 9 females and 19 males were included in the non-chewing gum group, there were 17 females and 12 males in the chewing gum group.

Lobre et al.[16] also found that micropulse vibration devices significantly lowered pain scores. However, gender-age distributions between the experimental and control groups, as well as dental crowding of the participants, were not mentioned in their study. Similar drawbacks existed in other studies.[12,15] One of the great challenges associated with researching pain is that it is a subjective phenomenon and can be greatly affected by individual variations. It has been stated that orthodontic pain is affected by gender, initial tooth positions and force levels, and physiological and psychological susceptibility.[6] In this study, we tried to preclude these conditions and to make the groups homogeneous in terms of individual variability. The groups constituted of an equal number of female and male participants, and only patients with 3-6 mm maxillary crowding were included in the study. Moreover, patients' pressure pain thresholds were measured, and subjects who disrupted the homogeneity of the groups were excluded from the study, with new participants being brought in their place.

As well as the studies that present opposing outcomes,[11,12,16,27] there are also studies that exhibited similar findings to the results of our own research.[14,15,23,28] Miles et al.[14] have stated that there appears to be no clinical advantage in using vibrational appliances for the alleviation of pain during initial alignment. Woodhouse et al.[15] have found that the use of a vibration device had no remarkable effect on orthodontic pain and analgesic consumption, during initial alignment with fixed appliances. Furthermore, Alqareer et al.[28] investigated the efficacy of chewing gum to reduce orthodontic pain, and they determined that chewing gum 3 times a day did not seem to reduce pain significantly.

In terms of our own research, we believe there may be a few noteworthy reasons why we attained negative results regarding the usefulness of the investigated methods (mechanical vibration and chewing gum). First, temporary displacement of teeth does not really work with regards to being a reliever of orthodontic pain. In some musculoskeletal disorders, the vibration method has especially been shown to increase blood flow and alleviate pain,[29] but this does not prove that vibration will also work in relation to orthodontic discomfort. Due to anatomical difficulties, even if the occluded blood vessels and nerves at the crown proportion of the root surface loosen in a limited manner, the vibration effect may not reach the compressed vessels and nerves in the deeper region.

Another possible reason for obtaining negative results may be the low number of participants in our study. We might have achieved statistically significant differences with a larger number of patients. Yet, when the number of participants of previous studies that obtained meaningful outcomes is examined, it becomes clear that the number of subjects in this study was sufficient. Farzanegan et al.[12] used just 10 patients per group, and they have determined that chewing gum is effective for pain alleviation. Moreover, even if we had achieved statistically significant differences with more patients, we do not think that these differences would have been clinically significant.

We think that there are 2 main limitations of the present study. The first limitation is that we could not control whether the participants used painkillers throughout the study. Prior to the study, we have advised them to avoid taking a painkiller and excluded subjects who needed medication for medical reasons from the study. Nevertheless, there may be subjects who used the painkiller and did not report it. The second limitation is the pain measurement method we have used in the study. Unfortunately, a method that can measure pain with objective data and that can be used in orthodontic pain has not been developed yet. In this study, we had to use the VAS, which is one of the subjective methods. However, we could have studied chemical substances present in the gingival crevicular fluid and considered as pain biomarkers. Thus, we would have had the opportunity to support our subjective outcomes with objective data.



## CONCLUSION

The results of this study suggest that both chewing gum and mechanical vibration have no pain-relief effect on orthodontic pain.

**Ethics Committee Approval:** Ethics committee approval has been received from the Clinical Research Ethics Committee of Tokat Gaziosmanpasa University (19-KAEK-121).

**Informed Consent:** Written informed consent was obtained from the patients and parents.

**Peer-review:** Externally peer-reviewed.

**Declaration of Interests:** The author has no conflicts of interest to declare.

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Case Report

# Management of Anterior Open Bite and Skeletal Class II Hyperdivergent Patient with Clear Aligner Therapy

Sudha Gudhimella[1], Vaibhav Gandhi[1], Nichole Leigh Schiro[2], Nandakumar Janakiraman[1]

[1]Division of Orthodontics, University of Louisville School of Dentistry, Louisville, Kentucky, USA
[2]Private Practice, Denver, Colorado, USA

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Main Points

- This Invisalign case represents the biomechanical aspect to consider for the open bite and hyperdivergent case.
- An asymmetric mechanism is used to correct the anteroposterior discrepancy.
- Utilizing the advantages of the active biteblocks helped to maintain and improve the vertical molar positions.



## ABSTRACT

In orthodontics, patients with hyperdivergent facial types or problems in the vertical dimension are often challenging to treat with predictable treatment results. Conventionally along with fixed appliances, a headgear, posterior bite block, extraction, temporary anchorage devices, or orthognathic surgery are preferable approaches to treat such patients. This case report illustrates a non-extraction, non-surgical orthodontic treatment of 5 mm anterior open bite in a non-growing adult patient, utilizing clear aligner therapy.

**Keywords:** Open bite, clear aligner therapy, molar intrusion, sagittal discrepancy

## INTRODUCTION

The management of problems in the vertical dimension is often challenging to treat, and more importantly, the stability of correction is unpredictable. Traditionally, these patients are treated with headgear, posterior bite blocks, and extraction of premolar teeth, mini-implants-assisted molar intrusion, or orthognathic surgery.[1] With the introduction of mini-implants, the mild to moderate skeletal open bite cases can be treated predictably with molar intrusion, as documented by numerous case reports.[2,3] Buschang et al.[4] documented favorable facial changes in Class II retrognathic and hyperdivergent subjects after mini-implant-assisted molar intrusion.

Recently, clear aligners or aligners combined with mini-implant have shown some promising results in managing mild to moderate skeletal Class II hyperdivergent cases.[5-7] Most of the patients treated were mild cases with incisor extrusion and minimal evidence of posterior teeth intrusion. However, recent retrospective studies evaluated the dental and associated skeletal changes after clear aligner treatment.[8,9] The open bite malocclusion improved due to a combination of maxillary and mandibular molar intrusion and maxillary and mandibular incisor extrusion.

Based on the current evidence, the clear aligners may be successful in managing patients with mild to moderate skeletal open bite. Hence, the aim of this case report is to document the management of skeletal open bite in an adult patient with clear aligner treatment.

**Corresponding author**: Vaibhav Gandhi, e-mail: drvaibhavgandhi88@gmail.com


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## Diagnosis and Etiology

A 26-year-old female patient sought orthodontic treatment with the chief complaint of anterior open bite and underbite. The patient was in good health, exhibited good oral hygiene, and had no harmful oral habits, caries, or periodontal problems that contraindicated orthodontic treatment. There was no history of trauma to the oral region.

The patient had a convex soft tissue profile with competent lips and reverse smile arc on extraoral examination. Intraoral examination showed a full step Class II molar relationship on the left side and half-cusp Class II on the right side, with a narrow maxillary arch. Overjet of 5 mm and 5 mm anterior open bite were observed extending from the upper second premolar on the left side to the first premolar of the right side. The model analysis revealed 6 mm of crowding in the upper arch with 2 mm of lower midline shift toward the left side and flat curve of Spee (Figures 1 and 2).

The cephalometric analysis revealed that the patient had a skeletal Class II malocclusion (ANB = 7.9°, Wits appraisal = 4.7 mm) with mild hyperdivergent growth pattern (Mandibular plane [MP] to SN = 34.5°) and upright upper and slightly proclined lower incisors (U1-PP 102.4°, Incisor mandibular plane angle [IMPA] = 96.6°) (Table 1, Figure 3). No significant pathology was found in the panoramic radiograph (Figure 4). Based on clinical and cephalometric findings, our diagnosis was skeletal Class II



Figure 1. Pretreatment photographs

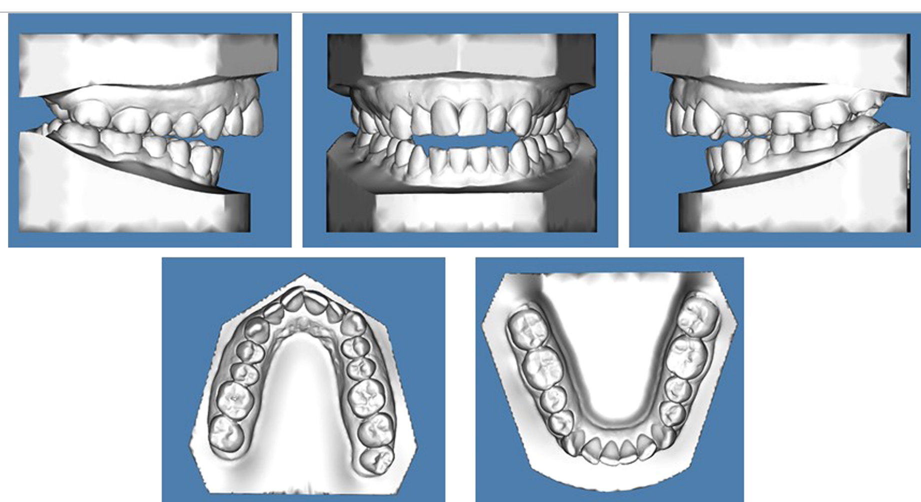

Figure 2. Pretreatment dental casts

**Table 1.** Cephalometric measurements

| Parameter | Pretreatment | Posttreatment | Change |
|---|---|---|---|
| SNA (°) | 84 | 83.4 | −0.6 |
| SNB (°) | 76.2 | 76.8 | 0.6 |
| ANB (°) | 7.9 | 6.6 | −1.3 |
| Wits appraisal (mm) | 4.7 | 0.8 | 3.9 |
| Angle of convexity (°) N-A-Pog | 15.6 | 14.7 | 0.9 |
| MP-SN (°) | 34.5 | 33.1 | −1.4 |
| U1-PP (°) | 102.4 | 97.7 | −4.7 |
| IMPA | 96.6 | 100.4 | 3.8 |
| LAFH (ANS-Me) | 70.7 | 70.5 | −0.2 |
| U1-PP (mm) | 30 | 33.6 | 3.6 |
| U6-PP (mm) | 24.8 | 22.7 | −2.1 |
| L1-MP (mm) | 37.6 | 38.9 | 1.3 |
| L6-MP (mm) | 33.1 | 32.7 | −0.4 |
| Ar-Go-Me (°) (gonial angle) | 127 | 122.9 | 4.1 |

U6-PP, Upper first molar to palatal plane; L1-MP, Lower incisor to mandibular plane; L6-MP, Lower first molar to mandibular plane.

due to retrognathic mandible and mild hyperdivergent growth pattern, Angle's Class II molar relation with increased overjet and anterior open bite with convex soft tissue profile, and non-consonant smile arc.

**Treatment Objective**

The treatment objectives were (1) to correct the anterior open bite and achieve ideal overjet and overbite, (2) to achieve Class I molar and canines bilaterally, (3) to improve or prevent worsening of lower anterior facial height, and (4) to maintain the facial balance, improve the soft tissue profile, and achieve a consonant smile arc.

**Treatment Alternatives**

The patient was offered 3 treatment options which were: orthognathic surgery, a non-surgical, non-extraction option with mini-implant-assisted molar intrusion, and clear aligner.

1. Orthognathic surgery: Bimaxillary surgery with Lefort 1 maxillary posterior impaction and segmental osteotomy and bilateral sagittal split osteotomy of mandible with advancement was recommended to the patient. This can lead to autorotation of the mandible and correct the anterior open bite. The major advantage of this approach was predictability and shorter treatment duration. However, the comorbidities associated with orthognathic surgery are a significant limitation.
2. Non-extraction, non-surgical treatment with Temporary Anchorage Device (TADs): Although the outcome of molar intrusion using TADs is comparable with surgery, appropriate biomechanical consideration is critical for the success of the treatment. Numerous variables such as the number of TADs, area of placement (buccal or palatal), type of anchorage should be considered in order to obtain optimum

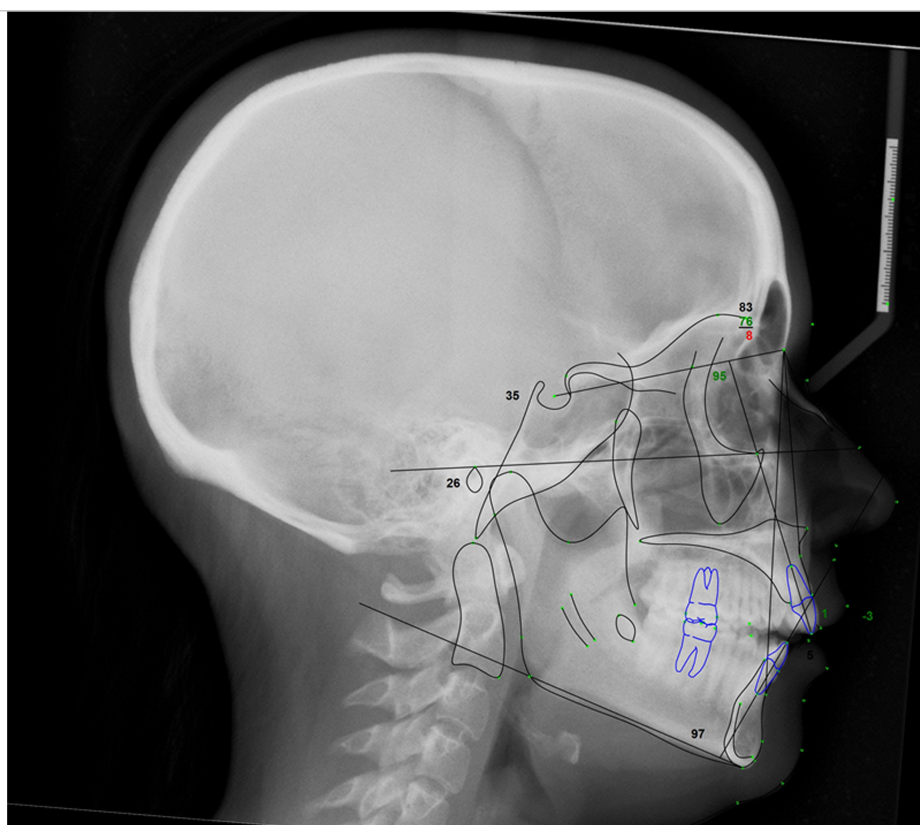


**Figure 3.** Pretreatment lateral cephalometric radiograph


**Figure 4.** Pretreatment panoramic radiograph

outcome and minimize the treatment time. Additionally, TAD failures can prolong the treatment time.

3. Non-extraction, non-surgical treatment with clear aligners: This was the most conservative approach for dentoalveolar correction without any surgical intervention or TAD placement. Molar intrusion and bite block effect produced by aligners on posterior teeth may lead to autorotation of the mandible and help with the anterior open bite correction. Also, upper and lower anterior uprighting and extrusion will help to close the bite further.



All of these options were presented to the patient, and benefits to risk assessment of each of the options were discussed. The patient specifically demanded an aesthetic treatment approach using clear aligner therapy and did not want any surgical intervention or fixed orthodontic treatment. After the discussion with the patient, she elected for clear aligner treatment, and written informed consent was obtained from the patient before beginning the treatment.

## TREATMENT PROGRESS

In the first ClinCheck, a significant amount of upper and lower molar intrusion and incisor extrusion was programmed (Figure 5 and Table 2). The rationale was to correct the anterior open bite with the combination of mandibular autorotation and upper and lower anterior teeth extrusion. Initial Clincheck instructions included 5 mm rectangular vertical attachments on the occlusal surface of maxillary and mandibular first and second molars to contact each other throughout treatment to get the posterior bite block effect (Figures 6 and 7). A total of 43 sets of aligners, including 3 overcorrection aligners, were staged in the initial ClinCheck approval. The patient was instructed to wear trays 20-22 hours a day and change to the next set every 7 days. She was advised to wear 1/4-inch, 4.5 oz Class II elastics with the initial trays.

At the end of the initial set of trays, the patient still had end-on molar on the right side and slight improvement on the left side, premature contact at the upper left canine, and a large dark triangle between upper central incisors with 2 mm open bite. The first refinement was planned with instructions to expand the upper arch and an Interproximal reduction (IPR) of 0.5 mm between upper central incisors to address premature contact and black triangle (Figure 7, Table 3). Also, an IPR of 0.2 mm per contact was planned between lower first premolar to premolar to allow mesial movement of lower posterior teeth with class II elastics. To resolve issues with asymmetric molar relationship and lower midline, asymmetric Class II elastics (right side:

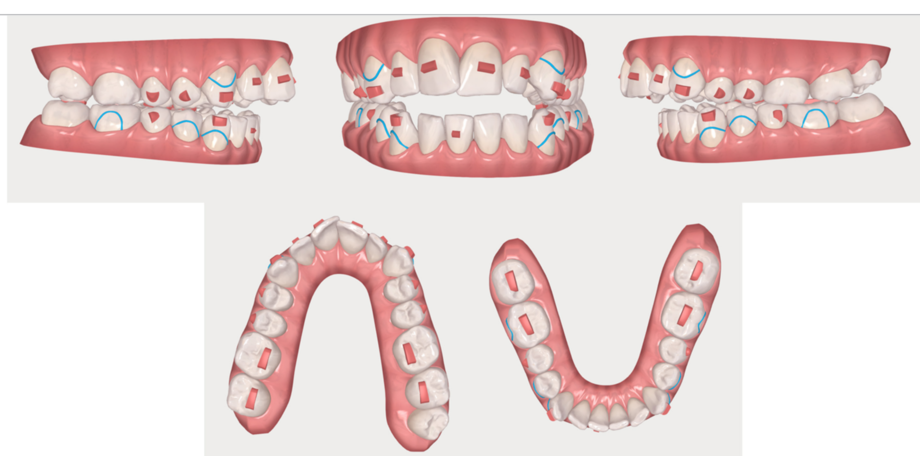

**Figure 5.** Pretreatment ClinCheck images

**Table 2.** Programmed crown movement in the ClinCheck software

| Programmed Crown Movement | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Teeth** | **UR8** | **UR7** | **UR6** | **UR5** | **UR4** | **UR3** | **UR2** | **UR1** | **UL1** | **UL2** | **UL3** | **UL4** | **UL5** | **UL6** | **UL7** | **UL8** |
| Extrusion/ intrusion (mm) | - | **1.1 I** | **0.8 I** | 0.1 I | 0.4 E | 0.1 E | **0.9 E** | **0.8 E** | **0.8 E** | **1.3 E** | 0.2 E | 0 | 0 | **0.7 I** | **1.2 I** | 0.6 I |
| Translation buccal/lingual | - | 0.5 B | 0.9 B | 2.4 B | 2.3 B | 1.6 B | 1.2 B | 0.8 L | 0 | 0.9 B | 0.1 B | 2.6 B | 2.6 B | 2.2 B | 1.3 B | 0.9 B |
| Translation mesial/distal | - | 0.1 D | 0.2 D | 0.2 D | 0.4 D | 0.5 D | 1.0 D | 0.9 D | 0.6 D | 0.4 D | 0.4 D | 0.2 D | 0.1 M | 0.1 D | 0.1 D | 0.4 D |
| Rotation (°) | - | 12.1 D | 13.7 D | 5.3 D | 3.1 M | 29.9 D | 2.7 D | 28.6 M | 15.1 M | 15.8 M | 0.3 D | 3.8 M | 4.1 D | 9.6 D | 4.5 D | 1.6 D |
| Angulation (°) | - | 2.0 D | 2.7 D | 1.1 M | 0.4 D | 8.7 D | 4.4 D | 0.3 M | 0.3 M | 6.4 D | 7.4 D | 3.0 D | 2.1 D | 2.7 D | 0.5 D | 0.7 D |
| Inclination (°) | - | 1.0 L | 0.2 L | 7.1 B | 10.4 B | 7.1 B | 2.6 B | 5.0 B | 5.9 B | 3.0 B | 0.1 B | 13.4 B | 8.6 B | 5.3 B | 0.4 L | 2.4 L |
| Teeth | **LL8** | **LL7** | **LL6** | **LL5** | **LL4** | **LL3** | **LL2** | **LL1** | **LR1** | **LR2** | **LR3** | **LR4** | **LR5** | **LR6** | **LR7** | **LR8** |
| Extrusion/ intrusion (mm) | - | **0.8 I** | **1.4 I** | 0.9 I | 0 | 0.2 E | **0.9 E** | **1.2 E** | **1.2 E** | **1.2 E** | 0.7 E | 0.1 E | 0.5 I | **1.2 I** | **1.3 I** | - |
| Translation buccal/lingual | - | 3.4 L | 1.6 L | 0.1 B | 0.4 B | 0 | 0.6 B | 0.8 B | 0.6 B | 0.3 B | 0.1 L | 0.8 B | 1.5 B | 1.5 B | 1.8 B | - |
| Translation mesial/distal | - | 0.5 D | 0 | 0.1 M | 0.2 M | 0 | 0.1 M | 0.1 D | 0.4 M | 0.5 M | 0.2 M | 0.2 M | 0 | 0.2 D | 0.1 M | - |
| Rotation (°) | - | 24.3 D | 17.5 D | 18.2 D | 17.9 D | 14.2 M | 12.6 M | 10.5 M | 12.4 M | 16.1 M | 21.3 M | 11.4 D | 0.6 D | 4.2 D | 4.7 D | - |
| Angulation (°) | - | 2.4 M | 0.2 D | 1.5 M | 2.1 D | 2.8 D | 1.8 M | 1.8 D | 0.4 M | 0.4 M | 1.4 D | 5.0 D | 1.8 M | 1.1 M | 0.5 M | - |
| Inclination (°) | - | 5.7 L | 3.2 L | 2.1 L | 0.6 B | 0.6 L | 1.6 B | 2.3 B | 0.9 L | 1.4 B | 1.7 L | 0.7 L | 1.1 L | 1.4 B | 0.5 L | - |

UR, Upper right; UL, Upper left; LL, Lower left; LR, Lower right; I, Intrusion; E, Extrusion; B, Buccal; L, Lingual; M, Mesial; D, Distal.
Teeth with the significant intrusion or extrusion programmed in the ClinCheck are highlighted in this table. Alphabets used in Table 2 are tooth numbering.

3/16 inch, 4.5 oz; left side: 1/4 inch, 6 oz) were started throughout the first and second refinements. The patient developed centric interferences after the first refinement aligners due to hanging premolar palatal cusps caused by insufficient expression of planned buccal root torque during dental expansion in the upper arch. Additional buccal root torque was programmed in the second refinement for upper premolars to address the occlusal interferences (Figure 7). Asymmetric Class II elastics led to the significant forward movement of the left posterior segment assisted by IPR space in the lower arch and flaring of lower anteriors. As a result, a bilateral Class I molar relationship with 2 mm overbite was obtained in the second refinement. The final series of 30 aligners were used to achieve good posterior intercuspation and to improve the occlusion (Figure 7).

In the retention phase, the patient was asked to wear Essix retainers full time for the first 6 months, followed by Hawley's retainers with posterior bite block. A total of 117 trays were used in 3 refinements to finish the case (Figure 7). The patient's compliance was exemplary during the entire treatment duration. The overall treatment time was 3 years, and all the treatment objectives were fulfilled without any complication. Normal overjet and overbite were achieved with Angle's Class I molar relationship while maintaining the facial balance. Soft tissue profile was improved, and a consonant smile arc was achieved (Figures 8-14).

There was a 1 mm intrusion of maxillary molars and slight intrusion of mandibular molars, which caused the counterclockwise rotation of the mandible (Figures 6 and 7). This effect led to decreased Wits appraisal, increased the chin projection, increased the SNB angle, and decreased the lower anterior face height and angle of convexity (Figures 8-13). Regional superimposition of maxillary dentition showed intrusion and distalization of maxillary molar. Maxillary and mandibular incisors were extruded with the clear aligner treatment (Figure 14).

## DISCUSSION

Management of skeletal open bite malocclusion in adults is often challenging with conventional treatment options. Mild to moderate open bite cases in Class II hyperdivergent and retrognathic patients can be successfully treated with mini-implants. Umemori et al.[10] used mini plates for the intrusion of mandibular posterior teeth, whereas Erverdi et al.[11] and Sherwood et al.[12] documented the correction of an open bite by the intrusion of maxillary molars with mini-implants placed in the infrazygomatic region.

Recently, the clear aligners have become popular, and clinicians are attempting to treat the open bite cases with aligners either in conjunction with mini-implants or standalone with aligners.[13] However, the comprehensive orthodontic treatment mechanics are generally extrusive for posterior teeth, leading to an increase in the mandibular plane angle, worsening the facial profile, and decreasing the overbite. To counteract these side effects, extensive extrusion of anterior teeth needs to be done to improve the overbite, comprising the long stability of attained results.

On the contrary, beneficial results are reported with aligner treatment of open bite subjects. Harris et al.[8] observed the amount

**Figure 6.** Intraoral progress photographs



of molar intrusion of 0.47 ± 0.59 mm and a reduction in SN-MP by 0.73 ± 0.94°, along with the decrease in SNB, Lower anterior facial height (LAFH), and favorable auto-rotation of the mandible. Although the amount of intrusion of posterior teeth was minimal based on the above study, the results are promising compared to comprehensive orthodontics. Mild to moderate open bite cases can be successfully corrected with clear aligner treatment, as documented by numerous case reports.[14] However, Garnett et al.[15]

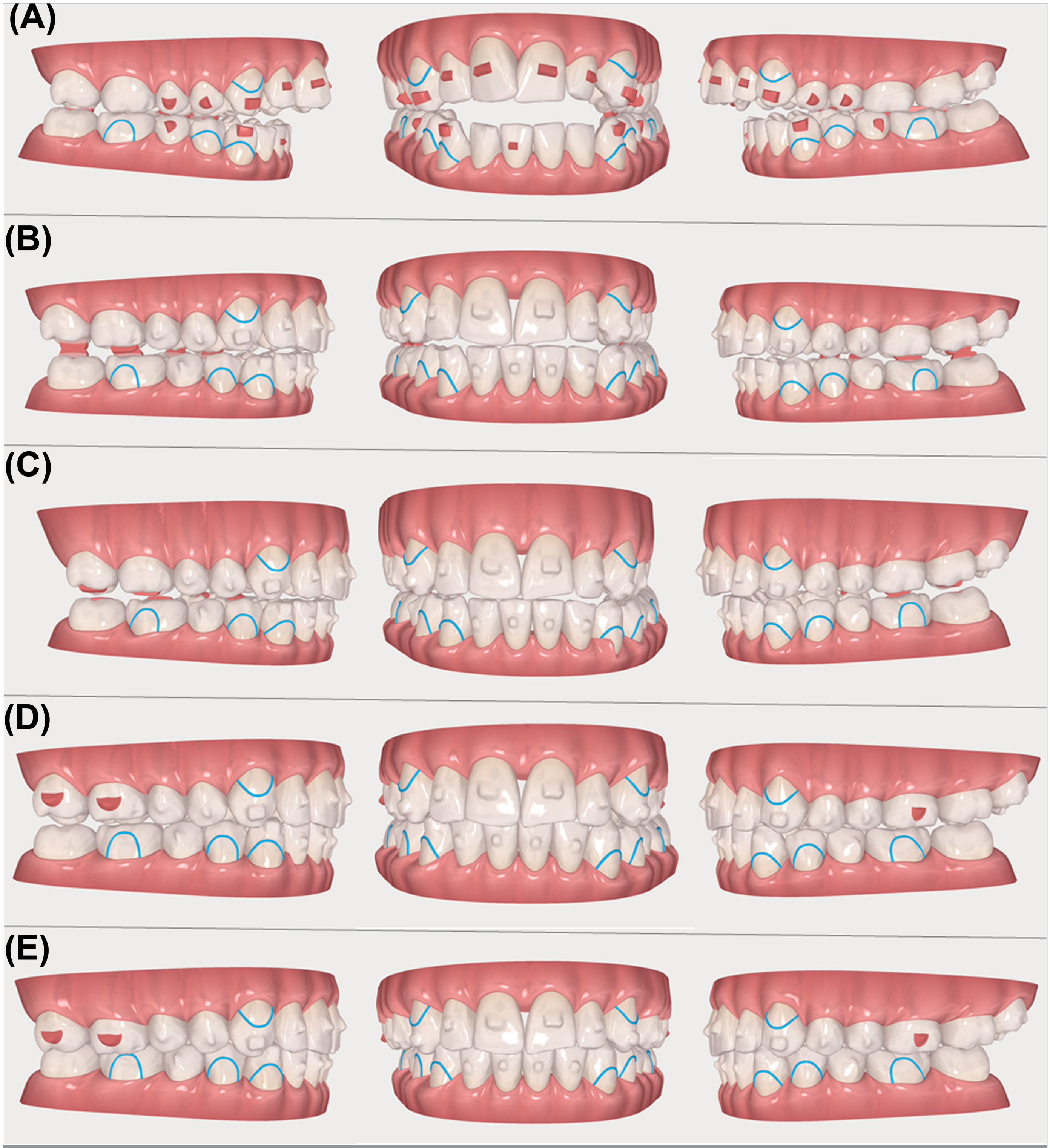


**Figure 7. A-E.** ClinCheck progress images (A: pretreatment, B: first refinement, C: second refinement, D: third/final refinement, E: final results)



compared the anterior open bite treatment between fixed appliances and clear aligner therapy, they did not find a significant difference in outcome between the 2 groups. The evidence is controversial regarding the effectiveness of aligners for the treatment of skeletal open bite. With the improvement in technology[16] and greater biomechanical understanding and the expertise of clinicians, complex vertical dimension malocclusion can be successfully treated as documented in this report.

The effectiveness of clear aligner treatment for various tooth movements has to be understood before treatment planning. This step is critical as overcorrections can be programmed in the ClinCheck to minimize the refinements, thereby increasing the efficiency of the appliance. In a recent study looking at the efficacy of tooth movement with Invisalign,[16] they found improved accuracy compared to a decade back. This was made possible by introducing smart force features that include

**Table 3.** Arch measurements programmed in ClinCheck Refinement 1

| Arch Width (mm) | | | | |
|---|---|---|---|---|
| **Arch** | **Teeth** | **Initial, Stage 1** | **Align Final, Stage 40** | **Difference** |
| Upper arch | UR3-UL3 | 29.1 | 32 | 2.9 |
| | UR4-UL4 | 29.1 | 34.7 | 5.6 |
| | UR5-UL5 | 32.7 | 37.9 | 5.2 |
| | UR6-UL6 | 38.1 | 41.2 | 3.1 |
| Lower arch | LR3-LL3 | 25.4 | 25.5 | 0.1 |
| | LR4-LL4 | 27.8 | 28.9 | 1.1 |
| | LR5-LL5 | 31.5 | 33 | 1.5 |
| | LR6-LL6 | 37 | 37.1 | 0.1 |

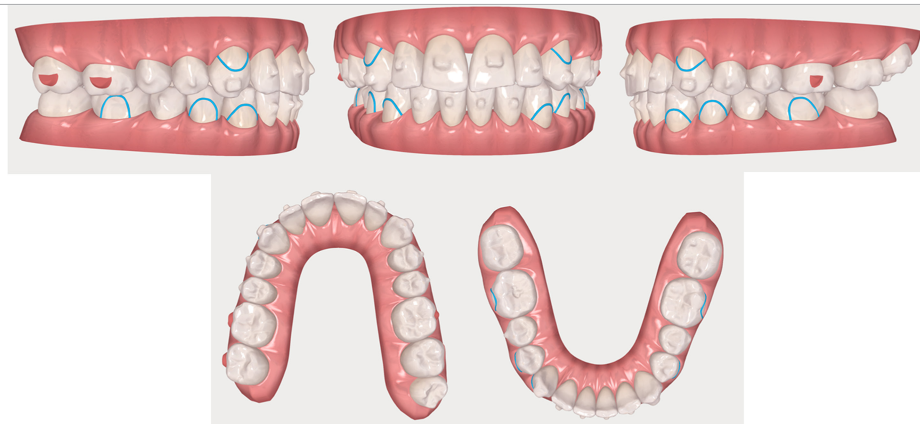

**Figure 8.** Final ClinCheck projection

**Figure 9.** Posttreatment photographs

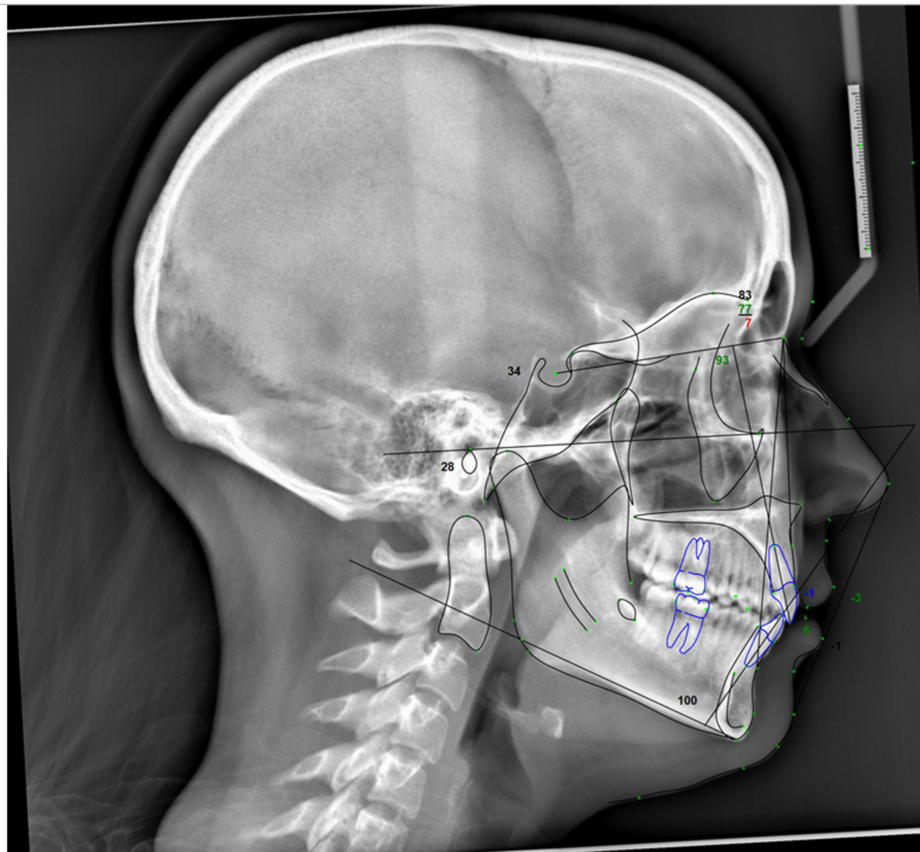


**Figure 10.** Posttreatment lateral cephalometric radiograph


**Figure 11.** Posttreatment panoramic radiograph

optimized attachments, pressure zones, customized staging, and SmartTrack aligner material, allowing a better working range and improved fit of trays. The accuracy was highest for buccolingual tipping (56%), whereas the intrusion of maxillary molar and incisor was at least 35% and 33%, respectively. To offset the drawback, overcorrection can be planned for the molar intrusion.

The clear aligners have a specific advantage for molar intrusion. The occlusal forces can be applied simultaneously along with the desired tooth movement since aligners entirely cover the occlusal surfaces. Also, the counterclockwise rotation of the mandibular due to molar intrusion will not interfere with the correction of the anterior open bite, as happens with the conventional braces.[17]

The patient in this report had a mild skeletal open bite with 5 mm of overbite and an overjet of 8 mm. The treatment was planned as recommended by Buschang et al.[4] who used mini-implants for posterior teeth intrusion, leading to the autorotation of mandible, which aided in the correction of skeletal and dental class

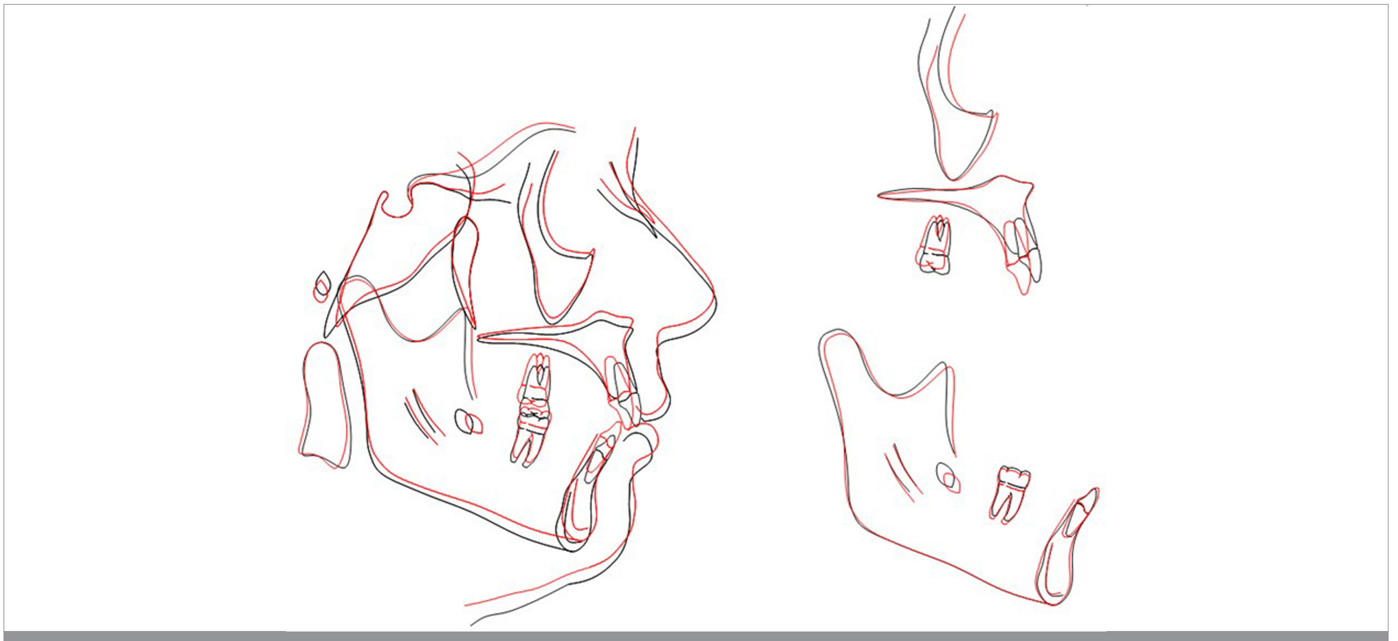

**Figure 12.** Superimposed lateral cephalometric tracings



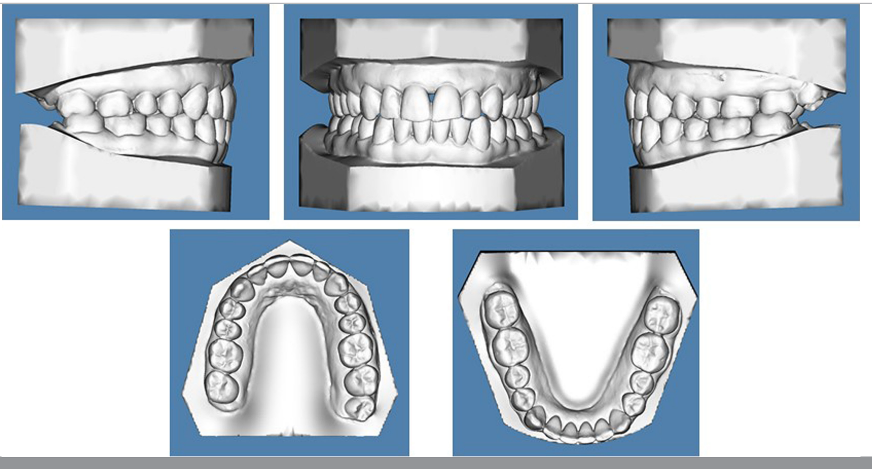

**Figure 13.** Posttreatment dental casts

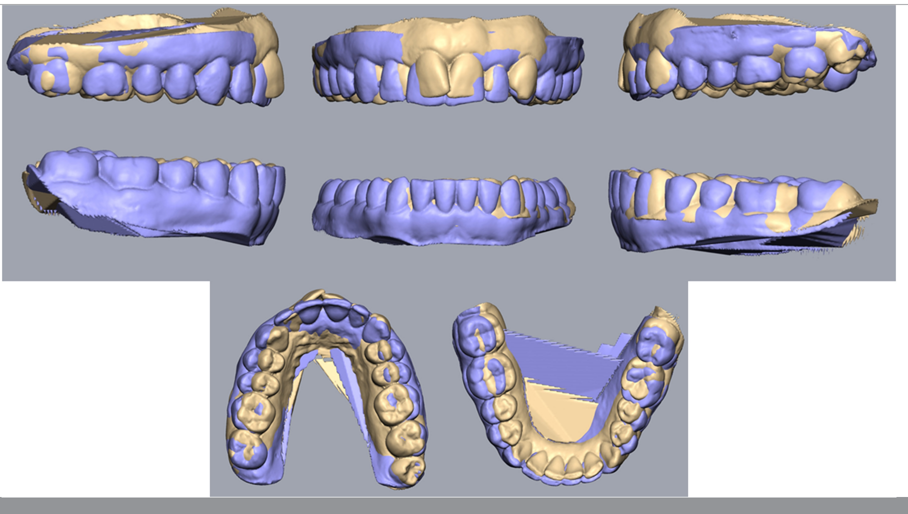

**Figure 14.** Superimposed dental casts

II relationships. However, we planned intrusion of maxillary and mandibular posterior teeth using clear aligners by having passive bite blocks of 5 mm thickness. Maxillary molar intrusion of 1 mm and slight intrusion of lower molars were achieved due to the bite block effect from raised clear aligner trays on posterior teeth and planned intrusion with aligner therapy in our patient (Figures 12 and 14). In the presented case, correction of the Class II molar relation could be due to a combination of the number of factors such as (1) the intrusion of posterior teeth caused counterclockwise rotation of the mandible, decrease in mandibular plane angle, a reduction in lower anterior facial height, and an increase in SNB angle, (2) derotation of the maxillary molars, (3) distalization of maxillary molars, (4) expansion of the maxillary arch, and (5) forward movement of the mandibular arch due to Class II elastics (Tables 1-3, Figure 10).

A meta-analysis reported that the success rates of both surgical and non-surgical approaches for the long-term stability of treatment of anterior open bites were greater than 75% (with an 82% mean stability value for patients surgically treated and 75% for patients treated only with orthodontics).[18] Relapse has been reported in 20-44% of conventionally treated patients.[19,20] Stability of anterior open bite correction using clear aligners has not been reported. Therefore, further research is needed for the long-term follow-up studies on open bite cases treated by clear aligner therapy.

## CONCLUSION

Treatment planning with careful biomechanical consideration for open bite hyperdivergent patients with Angle's Class II molar relationship is crucial. Incorporating occlusal attachments on molars as bite blocks will help prevent vertical movement and apply intrusive forces on the posteriors. Furthermore, while correcting Class II molar relation using elastics, bite blocks can also help counter the side effects by preventing extrusion of the posteriors with Class II elastics.

With the improvements in the technology with clear aligner systems, mild to moderate skeletal open bite patients could be a treatment of choice, especially in adults. However, more research is necessary to develop protocols to achieve the results predictably.

**Informed Consent:** Written informed consent was obtained from the patient to publish her records including photographs as part of this case report.

**Peer-review:** Externally peer-reviewed.

**Author Contributions:** Concept – S.G., V.G., N.L.S., N.J.; Design – S.G., V.G., N.L.S., N.J.; Supervision – S.G., V.G., N.L.S., N.J.; Data Collection and/or Processing – S.G., V.G., N.L.S., N.J.; Analysis and/or Interpretation – S.G., V.G., N.L.S., N.J.; Writing – S.G., V.G., N.L.S., N.J.; Critical Review – S.G., V.G., N.L.S., N.J.

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**Declaration of Interests:** The authors have no conflict of interest to declare.

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Review

# Maxillary Incisor Intrusion Using Mini-Implants and Conventional Intrusion Arch: A Systematic Review and Meta-Analysis

Prateek Shakti[1], Abhinav Singh[2], Abhishek Purohit[3], Nidhi Shah[3]

[1]Department of Dentistry, All India Institute of Medical Sciences (AIIMS), Bhopal
[2]Regional Training Centre for Oral Health Promotion (M.P) & Oral Health Data Bank (M.P), All India Institute of Medical Sciences (AIIMS), Bhopal
[3]Department of Dentistry, All India Institute of Medical Sciences (AIIMS), Bhopal



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Main Points

- Multiple studies have been conducted to assess maxillary intrusion using mini-implants and conventional intrusion. However, no comparative assessment has been made of the achieved maxillary intrusion using the 2 techniques.
- Mini-implants were compared with the Connecticut intrusion arch specifically as there is some amount of variation in mechanics and force application in all the conventional methods of incisor intrusion. This meta-analysis will assist in the creation of new evidence in the field.
- Incisor intrusion and overbite correction were found to be higher with mini-implants as compared to Connecticut intrusion arches.

## ABSTRACT

The aim of this analysis was to evaluate the maxillary incisor intrusion and change in overbite achieved by micro-implants compared to Connecticut intrusion arches among post-pubertal patients with deep bite. Medline, PubMed, Cochrane, and Google scholar were searched for studies falling under the inclusion criteria. Randomized controlled trials (RCTs) and controlled clinical trials (CCTs) comparing maxillary incisor intrusion among post-pubertal deep bite cases treated by mini-implants and Connecticut intrusion arches were to be included. Outcome data were extracted using guidelines published by the Cochrane Collaboration. A systematic review was conducted using Cochrane Program Review Manager, version 5. A random effects model was used to assess the mean difference in the amount of incisor intrusion and overbite correction achieved between the 2 methods. Statistical significance was set at $P < .05$. Assessment of certainty of evidence was conducted using GRADE analysis. Six trials met the inclusion criteria. Mean differences for incisor intrusion −0.67 [95% CI, 0.97, 0.38] $I^2 = 31\%$; $P < .00001$) and overbite correction −0.51 [95% CI, 0.85, 0.16] $I^2 = 50\%$; $P = .004$) achieved with mini-implants were found to be significantly effective when compared to the Connecticut intrusion arch. Low to moderate heterogeneity was noted for incisor intrusion and change in overbite analysis respectively. High certainty of evidence was noted for higher association of mini-implants with incisor intrusion and overbite correction. Our meta-analysis suggests that mini-implants are superior to the Connecticut intrusion arch with respect to the amount of incisor intrusion and overbite correction. Further studies are still needed to confirm the superiority.

**Keywords:** Incisor intrusion, mini-implants, connecticut intrusion arch

## INTRODUCTION

The aesthetics and attractiveness of the smile is one of the major demands in contemporary orthodontic treatment. One of the most frequent demands for orthodontic treatment is obtaining a more beautiful appearance in order to overcome psychosocial problems due to dentofacial abnormalities.[1] The smile being one of the most important facial functions, is often the measure of success or failure, especially in the patient's point of view.[2] At the beginning of the 21st century, an intention toward the soft tissue paradigm became the base of diagnosis and treatment planning in orthodontics.[3]

**Corresponding author**: Abhinav Singh, e-mail: drabhinav.singh@gmail.com


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Although treatment of choice depends on multiple factors such as smile line, incisor display, and vertical dimension, the correction of deep overbite with incisor intrusion has its own role during orthodontic treatment.[4] Depending on the diagnosis and treatment objectives, a deep overbite can be corrected by intruding the incisors, extruding the buccal segments, or combining these treatments.

Extrusion of incisors, which results in a pseudo deep bite, can be corrected by various appliances like the utility arch, Mulligan arch, Connecticut arch, three-piece intrusion arch, and implants. By using implants, true intrusion is brought about by passing the force close to the center of resistance. In the conventional methods, true intrusion is obtained by maintaining the moment-to-force ratio. Maxillary incisor intrusion should be the preferred treatment in non-growing patients with anterior deep bites caused by over eruption of the maxillary incisors.[5]

Al Maghlouth et al.[6] conducted a systematic review with only 2 studies and reported insufficient evidence for use of mini-implants for incisor intrusion. Atalla et al.[7] and Sosly et al.[8] compared the effectiveness of mini-implants with all other conventional intrusion methods combined, in a meta-analysis, and reported superior but not clinically significant intrusion results with mini-implants. However, the 2 meta-analyses did not specifically compare the Connecticut intrusion arch with mini-implants for incisor intrusion. Variation exists in the mechanics and method of force application in all the methods of incisor intrusion, and a comparison of different conventional methods is essential.

The Connecticut intrusion arch and mini-implants have shown conflicting results with regard to the obtained mean levels of maxillary incisor intrusion. The variation in mean level of incisor intrusion might be due to several factors like magnitude of force applied, different mini-implant locations, direction of force applied, and treatment duration. This paper is a meta-analysis to evaluate the amount of incisor intrusion and change in overbite achieved using mini-implants, compared specifically to Connecticut intrusion arches, among post-pubertal patients with deep bite.

## METHODS

### Search Strategy

A comprehensive search was conducted in Medline, PubMed, and Cochrane databases and Google scholar through February, 2021. PRISMA guidelines were followed while conducting the meta-analysis. A literature search was conducted using the keywords: incisor intrusion, mini-implants, and Connecticut intrusion arch. Studies were selected independently by 2 investigators (P.S. and A.S.). Abstracts were pre-screened to determine studies that would be retrieved in full and to exclude ineligible studies. The retrieved articles were read prior to inclusion in the review. Differences between investigators were resolved by discussion. The references in the selected articles were manually reviewed and retrieved if found possibly relevant. The search was done using English keywords. No restrictions were placed on language of publications. An attempt was made to search gray literature for unpublished articles, and one relevant study was found to be included in the systematic review.

### Inclusion Criteria

The inclusion and exclusion criteria were determined prior to the literature search. The criteria followed for selection of studies were as follows:

1. Study design: Randomized controlled trials (RCT) and controlled clinical trials (CCT).
2. Participants: Post-pubertal patients with deepbite of at least 4 mm requiring intrusion of maxillary incisors.
3. Intervention: Maxillary incisor intrusion with mini-implants.
4. Comparison: Maxillary incisor intrusion with Connecticut intrusion arch.
5. Exclusion criteria: Case series, case reports, animal studies, syndromic patients, periodontally compromised patients, and deepbite cases treated with orthognathic surgery.
6. Outcome measure: Amount of Maxillary incisor intrusion.
7. Outcome parameter: The measure of the perpendicular distance from the point of center of resistance of the central incisor to the palatal plane.



The Population, Intervention, Comparison, and Outcome were population: post-pubertal patients with deepbite of at least 4mm requiring intrusion of maxillary incisors; intervention: incisor intrusion using mini-implants; comparison: incisor intrusion using Connecticut intrusion; and outcome: achieved upper incisal intrusion.

### Data Extraction and Quality Assessment

Outcome data were extracted by 2 investigators (P.S. and A.S.) using guidelines published by Cochrane Collaboration.[9] Differences between the 2 investigators were resolved by discussion. The characteristics of the trials included in the meta-analysis are presented in Table 1. The quality assessment tool by Cochrane Collaboration was used for the clinical trials, with the following assessment criteria: sequence generation, allocation concealment, blinding of participants, blinding of assessors, incomplete outcome data, selective reporting of outcomes, and other potential sources of bias.[10] The quality of the controlled clinical trials (CCTs) was assessed according to the methodological index for non-randomized trials (MINORS).[11] It contains a list of 12 items with scores of 0 (not reported), 1 (reported but inadequate), and 2 (reported and adequate). A maximum score of 24 is achievable. Studies with a score of 13 points or below are considered to be of low quality, studies with a score between 14 and 19 points are considered to be of moderate quality, whereas studies with a score of 20 points and above are considered to be of high quality.

### Statistical Analysis

Meta-analysis was conducted using Cochrane Program Review Manager, version 5.[12] A random effects model was used to assess mean difference in the amount of maxillary incisor intrusion achieved by the 2 treatment modalities (mini-implants and Connecticut intrusion arch). Heterogeneity among

**Table 1.** Characteristics of studies icluded in the meta-analysis

| Study | Type of Study | Sample Size (Patients) | Age | | Intrusion (mm) | | Overbite Correction (mm) | |
|---|---|---|---|---|---|---|---|---|
| | | | Mini-Implants (MI) | Connecticut Intrusion Arch (CIA) | Mini-Implants (MI) | Connecticut Intrusion Arch (CIA) | Mini-Implants (MI) | Connecticut Intrusion Arch (CIA) |
| Gupta et al., 2017, India[16] | CCT | 24 | 17.75 ± 3.49 | 18.75 ± 3.47 | −2.46 ± 1.21 | −1.75 ± 0.72 | −2.46 ± 1.21 | −2.04 ± 1.37 |
| Gurlen et al., 2016, Turkey[13] | RCT | 32 | 12y 6m–16y 5m | 12y 5m–16y | −2.45 ± 0.59 | −1.49 ± 0.98 | −3.27 ± 0.86 | −2.05 ± 1.09 |
| Kaushik et al., 2015, India[15] | CCT | 14 | 14y-25 y | 14y–25y | −2.46 ± 1.11 | −1.84 ± 0.36 | −4.14 ± 1.20 | −3.20 ± 0.77 |
| Kumar et al., 2015, India[14] | RCT | 30 | 15y–20y | 15y–20y | −3.10 ± 0.67 | −2.07 ± 0.53 | - | |
| Senisik et al., 2012, Turkey[5] | RCT | 45 | 20.13 ± 2.48 | 20.32 ± 3.22 | −2.47 ± 0.81 | −2.20 ± 0.90 | −2.27 ± 0.59 | −2.10 ± 1.20 |
| Shakti et al., 2015, India[17] | CCT | 10 | 16y–25y | 16y 25y | −1.7 ± 0.44 | −1.4 ± 0.41 | −1.90 ± 0.41 | −1.90 ± 0.65 |



studies included in the analysis was evaluated using the $I^2$ test. The Cochrane guide was used for interpretation of the $I^2$ test: values ranging from 0% to 40% represented no heterogeneity, between 30% and 60% represented moderate heterogeneity, between 50% and 90% represented substantial heterogeneity, and between 75% and 100% represented considerable heterogeneity. The number of studies included in the analysis was less than 10; therefore, publication bias was not assessed. Assessment of certainty of evidence was conducted using GRADE analysis. Statistical significance was set at $P < .05$.

## RESULTS

A total of 384 articles were identified through the database search. Duplicates were removed and 376 citations were taken for screening. Out of these 376 titles, 364 articles were not relevant and excluded on abstract screening (first level of screening) for the current meta-analysis. The remaining 12 studies were included for the next level of screening (full text screening). Out of these 12 studies, 6 studies were excluded based on differences in methodologies and interventions used. Eventually, a total of 6 studies were obtained, including 3 RCTs and 3 CCTs. The flow chart depicting the complete search strategy is presented in Figure 1. Demographic and outcome data extracted from the included studies are presented in Table 1.

The quality of studies included in the analysis is presented in Tables 2 and 3. Randomized sequence generation was made in the included trials. However, allocation concealment was found to be unclear in the included RCTs. Blinding of outcome assessment was ensured in all the 3 included randomized trials. Blinding of participants and personnel was inadequately reported by Gurlen et al.[13] and Kumar et al.[14] Incomplete outcome data and selective outcome reporting were not noted in any of the included RCTs (Table 2). Quality assessment of the included CCTs using the methodological index for non-randomized trials (MINORS) tool is presented in Table 3. All the 3 included studies had scores ranging between 14 and 20, suggestive of moderate quality.[15-17]

The meta-analysis of 6 trials (3 RCTs, 3 CCTs) which evaluated the amount of incisor intrusion using mini-implants and the Connecticut intrusion arch is presented in Figure 2. Incisor intrusion with mini-implants was found to be significantly effective when compared to use of the Connecticut intrusion arch (pooled mean difference: −0.67 [95% CI, 0.97, 0.38], $P < .00001$; Figure 2). The test for heterogeneity showed low heterogeneity ($I^2 = 31\%$).

The meta-analysis of clinical trials (2 RCTs, 3 CCTs) which evaluated change in overbite following incisor intrusion using mini-implants and the Connecticut intrusion arch is presented in Figure 3. Correction in overbite was found to be significantly higher while using mini-implants compared to use of the Connecticut intrusion arch (pooled mean difference: −0.51 [95% CI, 0.85, 0.16], $P = .004$; Figure 3). The test for heterogeneity reflected a moderate heterogeneity ($I^2 = 50\%$). High certainty of evidence was noted for higher association of mini-implants with incisor intrusion and overbite correction (Table 4).

## DISCUSSION

The present meta-analysis is the first in scientific literature to compare maxillary incisor intrusion and overbite correction between mini-implants and the Connecticut intrusion arch. It suggests mini-implants to be superior with respect to the extent of achieved incisor intrusion and overbite correction. It was also evident from the included studies that true incisor intrusion is achievable with both the mini-implant and the Connecticut intrusion arch. Ng et al.[18] conducted a meta-analysis to quantify the amount of true incisor intrusion obtained during orthodontic treatment, but the review was not specific regarding methods of intrusion.

Conflicting results exist in the literature about mean levels of maxillary incisor intrusion achieved by the Connecticut intrusion arch[19] and mini-implant treatments.[20-24] Several factors, such as different mini-implant locations,[21,23] force magnitudes,[19,21,23,24] force directions,[21,22,24] treatment durations,[21,22,23] and different methods[19-24] used to evaluate the amounts of maxillary incisor

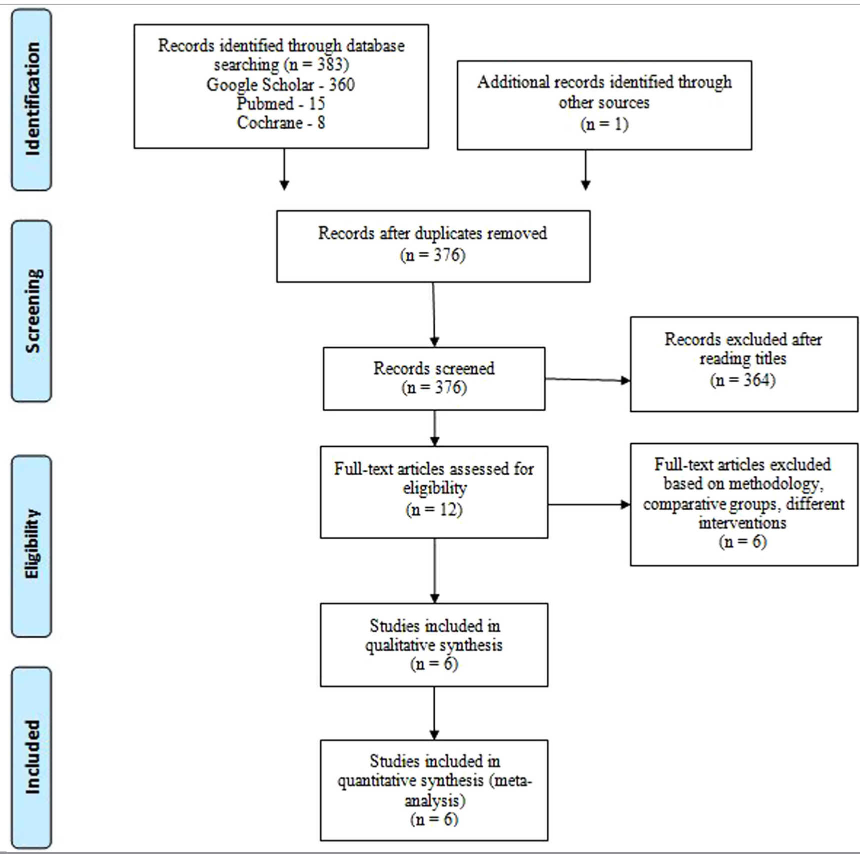


**Figure 1.** Flow diagram of study selection process



intrusion, might have accounted for the different rates of incisor intrusion. Based on the included studies, an average range of 2.0 mm to 3.1 mm of true incisor intrusion was achieved by both the techniques. The exception was Shakti et al.[17] who achieved incisor intrusion of 1.7 and 1.4 mm by mini-implants and Connecticut intrusion arch respectively. The reason for this variation may be the smaller study sample and less treatment duration (4 months) as compared to the remaining included studies (average 5-6 months).

The age and facial type play an important role in incisor intrusion. In order to avoid any theoretical bias, the present meta-analysis included studies which had subjects with mean age above 14 years, that is, post-pubertal. Senisik et al.[5] had used hand wrist radiographs to evaluate skeletal developmental age.[5] Skeletal developmental age was not evaluated by authors of the other included studies in the analysis. Otto et al.[25] had suggested that skeletal maturity has no correlation with the amount of intrusion. In growing children, the amount of true incisor intrusion usually is greater than what might be recorded, because of vertical growth of maxilla and mandible simultaneous to the actual intrusion mechanics. Otto et al.[25] suggested that neither patient's age nor facial type was related to incisor intrusion. Furthermore, skeletal pattern could influence the relative incisor intrusion compared to molar extrusion in overbite reduction. Hence, incisor intrusion is indicated in patients with deepbite due to over-erupted incisors and not due to inadequately erupted molars, which is usually seen in a horizontal growth pattern.

True intrusion occurs when forces are directed through the center of resistance.[26] When implants are placed bilaterally between

**Table 2.** Quality assessment of randomized controlled trials (RCT) included in the meta-analysis

| | Criteria | | | | | | |
|---|---|---|---|---|---|---|---|
| Studies | Sequence Generation | Allocation Concealment | Blinding of Participants | Blinding of Outcome Assessment | Incomplete Outcome Data | Selective Reporting | Free of Other Bias |
| Gurlen et al., 2016, Turkey[13] | Low | Unclear | Unclear | Low | Low | Low | Unclear |
| Kumar et al., 2015, India[14] | Low | Unclear | Unclear | Low | Low | Low | Unclear |
| Senisik et al., 2012, Turkey[5] | Low | Unclear | High | Low | Low | Low | Unclear |

**Table 3.** Quality assessment of controlled clinical trials (CCTs) included in the meta-analysis (MINORS)

| | Kaushik et al., 2015, India | Gupta et al., 2017, India | Shakti et al., 2015, India |
|---|---|---|---|
| 1. A clearly stated aim | 2 | 1 | 2 |
| 2. Inclusion of consecutive patients | 2 | 2 | 2 |
| 3. Prospective collection of data | 2 | 2 | 2 |
| 4. Endpoints appropriate to the aim of the study | 2 | 2 | 2 |
| 5. Unbiased assessment of the study end point | 0 | 0 | 0 |
| 6. Follow-up period appropriate | 2 | 2 | 2 |
| 7. Loss to follow-up less than 5 % | 2 | 2 | 2 |
| 8. Prospective calculation of the study size | 0 | 0 | 0 |
| 9. An adequate control group | 0 | 0 | 0 |
| 10. Contemporary groups | 2 | 2 | 2 |
| 11. Baseline equivalence of groups | 2 | 2 | 2 |
| 12. Adequate statistical analyses | 1 | 1 | 1 |
| Total | 17 | 16 | 17 |

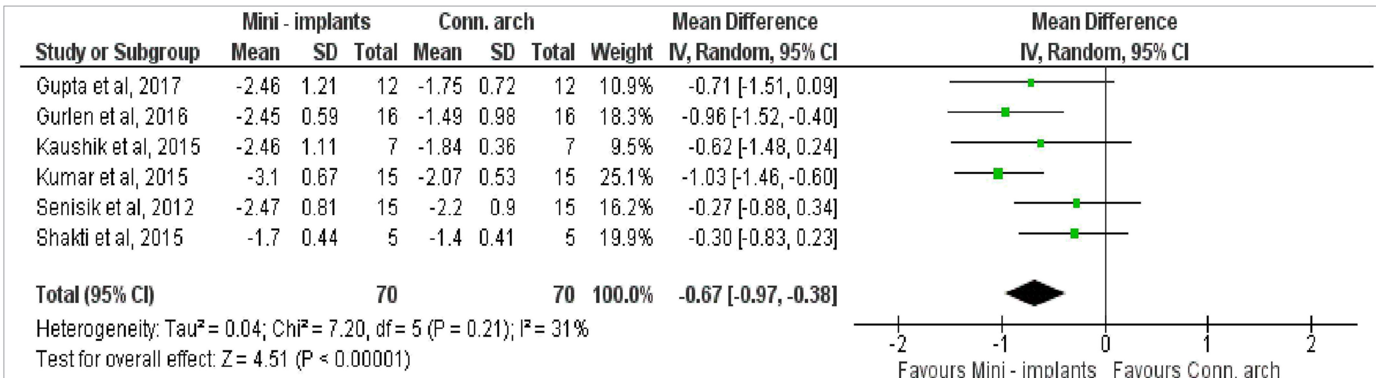

**Figure 2.** Incisor intrusion achieved by mini-implants versus Connecticut intrusion arch

the canine and lateral incisors, the point of application of force is closer to the center of resistance.[27] In the present meta-analysis, all the included studies, except Gurlen et al.[13] had mini-implants placed bilaterally between the canine and lateral incisors, facilitating the direction of force to pass through the center of resistance. However, in the study conducted by Gurlen et al.[13], the mini-implants were placed between the central and lateral incisors bilaterally. The point of force application was the same in cases treated by the Connecticut intrusion arch in all the included studies.

Very light forces of 15-25 g per tooth have been recommended for intrusion.[26,28,29] It has been documented that heavier forces may lead to root resorption. In agreement with the above-mentioned findings, all the studies included in our meta-analysis used force levels in the range of 15-25 g per tooth for intrusion of 4 incisors. Variation in the cephalometric reference planes selected to determine the amount of incisor intrusion may contribute to differences in results. All the studies included in our meta-analysis used the same reference plane—the palatal plane—for evaluation of incisor intrusion, to maintain the homogeneity of the

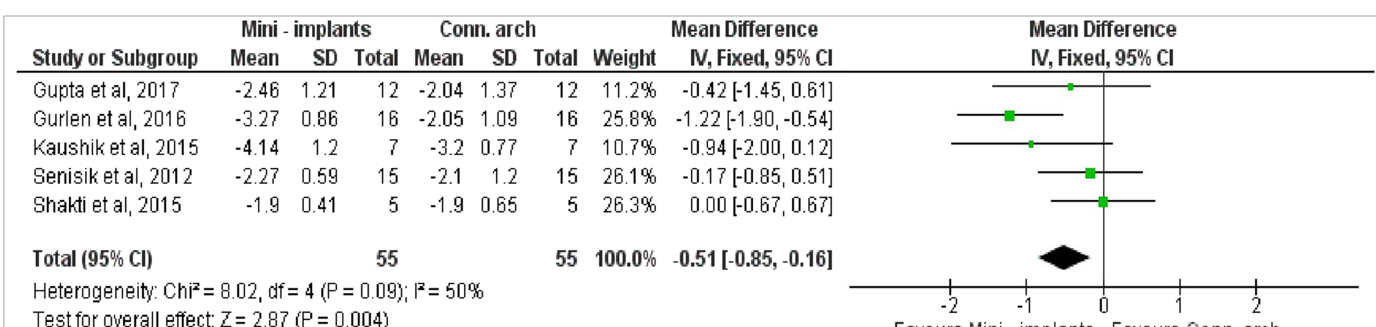

**Figure 3.** Overbite correction achieved by mini-implants versus Connecticut intrusion arch

**Table 4.** GRADE analysis for certainty of eevidence for association between mini-implants versus connecticut intrusion arch

| Certainty Assessment | | | | | | | Number of Patients | | Effect | |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of Studies | Study Design | Risk of Bias | Inconsistency | Indirectness | Imprecision | Other Considerations | Mini-Implants Group | Connecticut Intrusion Group | Absolute (95% CI) | Certainty |
| Mini-implants versus Connecticut Intrusion Arch for Incisor Intrusion | | | | | | | | | | |
| 6 | Randomized Trials | Not serious | Not Serious | Not serious | Not serious | Strong association, all plausible residual confounding would suggest spurious effect | 70 | 70 | MD 0.67 lower (0.97 lower to 0.38 lower) | ⨁⨁⨁⨁HIGH |
| Mini-Implants Versus Connecticut Intrusion Arch for Overbite Correction | | | | | | | | | | |
| 5 | Observational studies | Not serious | Not serious | Not serious | Not serious | Strong association, all plausible residual confounding would suggest spurious effect | 55 | 55 | MD 0.51 lower (0.85 lower to 0.16lower) | ⨁⨁⨁⨁HIGH |

obtained results. Perpendicular distance from the centroid point of the central incisor to the palatal plane was measured in order to evaluate true incisor intrusion. Studies using reference points other than the centroid, that is, incisal edge[21,23,30] or root apex,[25] were excluded from the meta-analysis, to avoid causing a false perception of intrusion.

Assessment of the consistency of effects across studies is an essential part of a meta-analysis; the $I^2$ value of 0% indicated no observed heterogeneity, and larger values reflected increase in heterogeneity. Low heterogeneity is always appreciated, as it demonstrates consistent finding across studies. Low to moderate level of heterogeneity was observed for extent of incisor intrusion and overbite correction. A significant reduction in $I^2$ value was noted when findings of Shakti et al.[17] were excluded from the meta-analysis due to small sample size and treatment time.

The overall quality of the included studies was moderate. Thus research in future, with well conducted methodology, may alter the evidence in hand. The limitations of the present study included the limited number of analyzed studies, and the fact that the study protocol was not registered. More randomized clinical trials should be conducted in future to quantify the amount of incisor intrusion with the least number of confounding factors like random patient selection, controlled treatment time and force, similar intrusion requirement, and growth factor consideration.

## CONCLUSION

Maxillary incisor intrusion can be carried out by both mini-implants and the Connecticut intrusion arch. Mini-implants were found to be superior to the Connecticut intrusion arch with respect to the amount of maxillary incisor intrusion and overbite correction. Further studies are still needed to confirm the superiority.

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**Author Contributions:** Concept - P.S., A.S.; Design - P.S., A.S.; Supervision - P.S., A.S.; Data Collection and/or Processing - P.S., A.S., A.P., N.S.; Analysis and/or Interpretation - P.S., A.S., A.P., N.S.; Literature Review - P.S., A.S.; Writing - P.S., A.S., A.P., N.S.; Critical Review - P.S., A.S., A.P., N.S.

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