"EVALUATION OF ALVEOLAR BONE CHANGES AFTER FIXED APPLIANCE THERAPY IN ORTHODONTIC PATIENTS -A PROSPECTIVE STUDY"

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AIIMS, JODHPUR **DR. HIMANI GUPTA**

ALL INDIA INSTITUTE OF MEDICAL SCIENCES

JODHPUR

CERTIFICATE

This is to certify that thesis entitled "EVALUATION OF ALVEOLAR BONE CHANGES AFTER FIXED APPLIANCE THERAPY IN ORTHODONTIC PATIENTS- A PROSPECTIVE STUDY" is an original work of **Dr. Himani Gupta** carried out under our direct supervision and guidance at Department of Dentistry, All India Institute of Medical Sciences, Jodhpur.

GUIDE

Dr. Vinay Kumar Chugh
Additional Professor
(Orthodontics and Dentofacial Orthopedics)
Department of Dentistry
AIIMS Jodhpur

CO-GUIDE

Dr. Pravin Kumar
Professor & Head
Department of Dentistry
AIIMS Jodhpur

ALL INDIA INSTITUTE OF MEDICAL SCIENCES, JODHPUR

DECLARATION

I, hereby declare that the work reported in the thesis entitled **"Evaluation of Alveolar Bone Changes after Fixed Appliance Therapy in Orthodontic Patients -A Prospective Study"** embodies the result of original research work carried out by me in the Orthodontics and Dentofacial Orthopaedics section, Department of Dentistry, All India Institute of Medical Sciences, Jodhpur.

I further state that no part of the thesis has been submitted either in part or in full for any other degree of All India Institute of Medical Sciences or any other Institution/ University.

Dr. Himani Gupta,

Junior Resident,
Orthodontics and Dentofacial Orthopaedics,
Department of Dentistry,
All India Institute of Medical Sciences,
Jodhpur.

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Dr. Himani Gupta

Dedicated

to

My Guide

and

Mentor

Dr. Vinay Kumar Chugh

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LIST OF ABBREVIATIONS

ABBREVIATIONS	FULL FORM
CBCT	Cone beam computed tomography
CT	Computed tomography
PA	Postero-anterior
2D	Two dimensional
3D	Three dimensional
NiTi	Nickel-Titanium
SS	Stainless-steel
3M	Minnesota, Mining and Manufacturing
Vs	Versus
CEJ	Cemento-enamel junction
FMA	Frankfort mandibular plane angle
Hrs	Hours
TM	Trademark
GAC	Gulf Agency Company
FOV	Field of view
DICOM	Digital Imaging and Communications in Medicine
IOPA	Introral Periapical Radiograph
OPG	Orthopantomogram
SD	Standard Deviation
EARR	External Apical Root Resorption
CI	Confidence Interval
ICC	Intra-class correlation coefficient
P-value	Probability value

INTRODUCTION

To achieve optimal stability, the incisors must be located in the medullary portion of the alveolar bone in alignment with the labial and lingual muscles. The alveolar bone is the anatomical restriction of orthodontic tooth movement in the mandibular anterior region (1,2). Since mandibular incisors are placed in the limited space in the mandibular arch, their position plays a major role in diagnosis and treatment planning. In addition, these teeth significantly impact esthetics and stability (3). Bone remodeling auxiliary to tooth movement is fundamental for orthodontic treatment. The morphology of alveolar bone and orthodontic procedures dominantly influences it.

A basic hypothesis in orthodontics states that "bone traces tooth movement," which means that in an ideal scenario, bone resorption and deposition should be in an equal ratio with orthodontic tooth movement (4). When a tooth moves in alveolar bone, a cell-free hyaline zone occurs on the pressure side, brought up by osteoclast resorption of the adjacent alveolar bone and bone apposition by osteoblasts on the tension side (5). If there is any inconsistency between the apposition and resorption of alveolar bone during orthodontic tooth movement, the tooth will move out of the alveolar envelope (6).

Therefore, the final placement of the lower incisors should be determined by the amount of adaptation possible within the alveolar bone. It will avoid adverse tissue reactions such as gingival recession, pulpal reaction, root resorption, marginal bone loss and alveolar bone loss (7).

Over the years, studies have been conducted to analyze the morphology of the alveolar bone around the incisors. Before the advent of cone-beam computed tomography (CBCT), studies evaluated the alveolar bone changes and root resorption using bitewing or periapical radiography and found a significant reduction in crestal alveolar bone levels and increased root resorption after comprehensive orthodontic treatment (8–12). Drawbacks of conventional radiography, such as magnification and distortion, have restricted assessment of proximal bone surfaces (13–15). Fuhrmann et al. (15) also stated that three-dimensional radiographic imaging is free from superimposed structures and permits better marginal bone assessment.

The effective dose of CBCT is about seven to eight times smaller than that of multi-slice CT (16). CBCT is a useful approach for evaluating the alveolar bone qualitatively and quantitatively (17). Cheng et al. (18) found that bone density reduction is maximum in the direction of tooth movement and concluded that CBCT is useful for evaluating bone density changes around teeth induced by orthodontic treatment.

Castro et al. (19) found an increased distance between the cementoenamel junction and bone crest of the buccal and lingual surface after non-extraction orthodontic treatment in Class I patients. Maspero et al. (20) evaluated the correlation between tooth inclination and alveolar bone remodelling and found up to 2.5mm of bone loss on the labial aspect in the apical region. Garlock et al. (21) assessed the reduction in buccal and lingual bone height and cortical bone thickness around mandibular incisors after non-extraction orthodontic treatment. Matsumoto et al. (22) evaluated the labial side of mandibular incisors after non-extraction orthodontic treatment and found variable degrees of vertical bone loss and dehiscence.

Lund et al. (23) found a decrease in alveolar bone crest levels on the buccal and lingual aspects of the anterior mandibular teeth in patients after premolar extraction. Zhang et al. (24) evaluated the whole configuration of alveolar bone before and after fixed orthodontic treatment with premolar extraction patients. After treatment, their results showed a significant decrease in bone thickness and vertical marginal bone on the lingual side. In addition, a greater change was observed in the shape of lingual alveolar bone on mandibular incisors than on the maxillary incisors.

Orthodontically induced external apical root resorption is an unavoidable pathologic consequence of orthodontic tooth movement. It results from a combination of individual biologic variability, genetic predisposition, and the effect of mechanical factors. External apical root resorption is considered undesirable because it can affect the long-term viability of the dentition, and reports in the literature indicate that patients undergoing orthodontic treatment probably have severe apical root shortening (25–27). Kurol et al. (28) have stated that external apical root resorption is a relatively common iatrogenic problem after fixed appliance orthodontic treatment. Histologic studies have reported greater than 90% occurrence of external apical root resorption (29). There are also several reported orthodontic treatment-related risk factors suggested in the literature, such as treatment duration (30), the magnitude of applied force (31), and the amount of apical movement that could lead to external apical root resorption (30).

Most of these studies are based on 2D assessment. Dang et al. (32) evaluated the root resorption after comprehensive orthodontic treatment using CBCT and concluded that the tooth length and root volume are reduced after an orthodontic intervention. Castro et al. (31) found apical root resorption in all patients after non-extraction orthodontic treatment using CBCT. It is believed that orthodontic tooth movement in extraction cases may result in more root resorption than in non-extraction cases but the literature assessing this effect is quite limited.

Therefore this prospective study aims to assess the alveolar bone changes and root resorption in the anterior mandibular region after extraction treatment.

AIMS AND OBJECTIVES

AIMS

To compare the pre and post treatment changes in alveolar bone and root resorption in mandibular anterior region after fixed orthodontic treatment.

OBJECTIVES

The study was carried out to assess:

Primary objective

- To assess alveolar bone thickness and alveolar bone height in mandibular anterior region after fixed appliance therapy in orthodontic patients.

Secondary objective

- To evaluate the root resorption in mandibular anterior region after fixed appliance therapy in orthodontic patients.

RESEARCH HYPOTHESIS

Null Hypothesis:

- There is no difference in alveolar bone dimensions and root length in mandibular anterior region before and after fixed orthodontic treatment.

REVIEW OF LITERATURE

- **Polson et al.** (33) in 1984 studied the crestal alveolar bone levels in 104 patients (study group) who had completed orthodontic treatment at least 10 years previously and compared them with adults who had untreated malocclusions (Control group = 76). On assessing the bitewing and periapical radiographs from the cementoenamel junction to the alveolar crest, there was no significant difference between crestal alveolar bone levels between the 2 groups, it stated that the orthodontic treatment during adolescence had no detrimental long-term effects.

- **Sarpe et al.** (7) in 1987 studied the relationship between orthodontic relapse and the parameters of increased root resorption and decreased crestal alveolar bone levels. Thirty-six persons were studied who had completed the retention phase of orthodontics for at least I0 years. They were divided into two groups, based on the amount of relapse in crowding of the mandibular anterior teeth. Group 1 (relapse group) exhibited 2 mm or more of relapse in mandibular anterior crowding, and Group 2 (non-relapse group) exhibited no crowding. On recall, full-mouth series of periapical and bitewing radiographs were assessed. It was found that the relapse group had undergone long treatment periods and exhibited a greater prevalence of root resorption.They also found significantly greater loss of bone support in relapse group than in the non-relapse group.

- **Remington et al.** (34) in 1989 studied the long-term status of teeth with root resorption during orthodontic treatment. Nearly, hundred patients were recalled at a mean period of 14.1 years after the treatment, which showed root resorption during appliance therapy. Full mouth periapical radiographs and tooth mobility were evaluated. For examining and comparing changes in root length and contour at pre-treatment, post-treatment and long-term follow-up, periapical radiographs were taken. Scores were given on a scale from 0 to 4, depending on the degree of resorption at each stage. It was shown that during active treatment, maxillary incisors were affected more frequently and to a greater degree than the rest of the teeth. No apparent changes after appliance removal were observed in the long-term evaluation except remodeling of rough and sharp edges.

- **Wehrbein et al.** (35) in 1996 assessed the morphologic findings of the dry mandibular incisors, alveolar bone, and symphysis complex after routine orthodontic treatment with an edgewise appliance. He concluded that in cases of narrow and high symphysis, bone support may already be reduced before treatment, labially and lingually. They concluded that de-rotation and sagittal movement of incisors are critical in the progressive loss of lingual and labial bone.

- **Lupi et al**. (36) in 1996 assessed the frequency of root resorption and alveolar bone loss in Eighty eight adults who had undergone orthodontic treatment. Pretreatment and post-treatment periapical radiographs showed root resorption, including blunting, increased from 15% before treatment to 73% after treatment. The anterior sites in which loss of alveolar bone height exceeded 2 mm from the cementoenamel junction to the alveolar crest increased from 19% to 37% after treatment. On assessing the bitewing radiographs, loss of alveolar bone height in posterior sites was found 7% before and 14% after treatment. Overall, the study states bone loss of more than 1.5 mm in 11% of the incisors and 3% in the posterior sites.

- **Sun et al.** (37) in 2011 conducted an animal study to find out the accuracy of alveolar bone-height measurements from CBCT images with varied bone thicknesses and imaging resolutions. Eleven maxillary specimens from 6-month-old pigs were measured for alveolar bone height (distance between drilled reference holes and alveolar crests) at 6 locations with a digital calliper, followed by CBCT scanning at 0.4 mm and 0.25 mm voxel sizes. The buccal alveolar bone of these locations was then reduced approximately by 0.5 to 1.5 mm, followed by CBCT rescanning with the same voxel sizes. The specimens were subsequently cut into bucco-lingual sections at reference hole levels, and direct bone height and thickness were measured from these sections. Intra-rater and inter-rater repeatability and the differences between CBCT and direct measurements were assessed. It was found that Before alveolar bone reduction, the thickness was much greater than the CBCT voxel size (0.4 mm), and bone-height measurements from the CBCT images were 0.5 to 1 mm more than the direct measurements (paired t-tests). In the presence of bone reduction, the thickness at the sub-crest 1-mm level was close to or below the size of the CBCT voxel (0.4 mm), and bone height measurements were 0.9 to 1.2 mm lower than direct measurements.

Therefore, it was concluded that conventional clinical CBCT images with 0.4-mm voxel sizes might overestimate alveolar bone height loss caused by rapid palatal expansion.

- **Sarikaya et al.** (38) in 2002 evaluated the changes in alveolar bone thickness due to the retraction of anterior teeth. Nineteen patients with dentoalveolar bimaxillary protrusion treated by extracting the 4 first premolars were evaluated with lateral cephalogram and computed tomography was taken before treatment and 3 months after retraction of the incisors. The labial and the lingual alveolar plates at crest level (S1), midroot level (S2), and apical level (S3) for bone-thickness changes were assessed during retraction of the maxillary and mandibular anterior segments. In the mandibular arch, it was found that the labial bone maintained its original thickness, except for the S1 measurements, which showed a significant decrease in bone thickness (P.001), while in the maxillary arch; the labial bone thickness remained unchanged. There were statistically significant decreases in lingual bone width in both arches after retracting the incisors.

- **Smale et al.** (39) in 2005 conducted a research on Two hundred ninty patients to find the reason for the observed variation in apical orthodontic root resorption. Digitized periapical radiographs were taken before treatment (T1) and at a mean period of 6.4 months after placement of maxillary incisor brackets (T2). They concluded that root resorption could begin during the initiation of leveling of orthodontic treatment. Teeth with long, narrow and deviated roots are at a greater risk of resorption during this early stage, with less than 25% risk factors. Parameters such as the use of rectangular wire, incisor irregularity and a history of trauma were not identified as risk factors.

- **Lund et al.** (40) in 2010 assessed the precision and accuracy of CBCT for measurements of root length and marginal bone level in-vitro and in-vivo during orthodontic treatment.A dry skull was examined with CBCT in Thirteen patients with mean age of 15 years, using multi-planar reformatting for root length and marginal bone level measurements. A modification of the index was used developed by Malmgren et al. for in vivo evaluation of changes in root length. It was shown that the CBCT technique exhibits a high level of reproducibility despite changes in tooth positions proving highly useful in orthodontic research.

- **Sherrard et al.** (41) in 2010 compared the accuracy and reliability of tooth-length and root-length measurements from CBCT volumetric data. Scans were made for Sevenporcine heads with ani-CAT machine at 0.2, 0.3 and 0.4 mm voxel sizes. Two film-acquired periapical radiographs were taken for selected incisors and premolars (28 and 24 incisors). The CBCT scans were oriented twice for each tooth using the mesial, distal, labial and lingual CEJ as reference points using Dolphin imagingTM software. After all surrounding bone had been carefully removed; root and tooth lengths were derived from these points and compared with actual teeth measurements with digital callipers. No significant difference between CBCT tooth-length and root-length measurements was found from the actual lengths, with a mean difference of < 0.3 mm. The periapical measurements significantly overestimated tooth lengths and underestimated root lengths. Errors found were 2 times greater for the periapical radiographs than for the CBCT scans within-trial method, which was greatest for the 0.4-mm CBCT scans and for PA radiographs it was within 0.1mm. It was concluded that for tooth-length and root-length determinations, CBCT scans were as accurate and reliable as periapical radiograph.

- **Guo et al**. (42) in 2011evaluated the (3D) dehiscence of upper anterior alveolar bone during incisor retraction and intrusion in adult patients with absolute anchorage using miniscrews. The study was conducted on 20 patients with bimaxillary dentoalveolar protrusion along with first premolars extraction. On comparing pre-CT and post-CT data, the amounts of upper incisor retraction at the edge and apex were 7.64 and 3.91 mm, respectively, and 1.34 mm of upper central incisor intrusion. Upper alveolar bone height loss at labial alveolar ridge crest (LAC) and palatal alveolar ridge crest (PAC) were 0.543 and 2.612 mm respectively. The shape deformations of labial cortex and palatal cortex were 15.37° and 6.43° respectively. They concluded that the mechano-biological responseof anterior alveolus should be taken into account during incisor retraction and intrusion in patients with bimaxillary protrusion.

- **Lund et al**. (23) in 2012 investigated the incidence and severity of root resorption during orthodontic treatment on 152 patients with Class I malocclusion by means of cone beam computed tomography (CBCT). The factors affecting orthodontically induced inflammatory root resorption (OIIRR) were also studied.

All roots from incisors to first molars were assessed; it was observed that up to 91% of all teeth showed some degree of root shortening, but few teeth had root shortenings of more than 4 mm. According to the study, slanted root resorption was found on root surfaces that could be evaluated only by a tomographic technique and hence, CBCT technique can provide more valid and accurate information about root resorption.

- **Lee et al**. (43) in 2012 evaluated the alveolar bone loss around lower incisors incurred during surgical orthodontic treatment in patients with prognathic mandible. Twenty five patients (13 men, 12 women) with mean age of 26 years) were treated with jaw surgery and orthodontic treatment. On comparing before and after presurgical orthodontic treatment CBCT images, it was found that the vertical alveolar bone level and the alveolar bone thickness of the labial and lingual plates in central and lateral incisors were reduced after presurgical orthodontic treatment but were not deteriorated during postsurgical orthodontic treatment. They also emphasized that the excessive forward movement of lower incisors during presurgical orthodontic treatment could cause alveolar bone loss around the lower incisors.

- **Makedonas et al.** (44) in 2013 diagnosed root resorption in hundred fifty-six patients with the extraction of four premolars using CBCT taken 6 months later and at the end of orthodontic treatment with fixed appliances. The Malmgren Index was used to assess the degree of root resorption. Results showed significant resorption in 25.6% of the patients. However, there were no correlations in the resorption seen after 6 months with the length of treatment. Root resorption was observed more frequently in the maxillary incisor region.

- **Freitas et al.** (45) in 2013 studied the frequency of apical root resorption with periapical radiograph and CBCT after orthodontic treatment at 52-288 months. Radiographic images obtained before (T1) and after orthodontic treatment (T2) from 58 patients analyzed by three members of the Brazilian Board of Orthodontics. Evaluation of apical structures by peri-apical radiographic images (T2 and T3) was made using Levander and Malmgren scores. The presence of apical root resorption on CBCT images was detected only at T3. More frequent apical root resorption was noted with periapical radiographs with scores 1 in T2

(51.6%) and T3 (53.1%), respectively. The differences were significant for maxillary and mandibular premolar groups and the mandibular molar group when comparing the frequencies of apical root resorption at T3 using periapical radiographs and CBCT. Maxillary lateral incisors (94.5%) and mandibular central incisors (87.7%) showed the highest, while the premolars showed the lowest frequency of root resorption using CBCT images. The teeth involved in orthodontic treatment with extraction presented a higher frequency of root resorption as per CBCT. Therefore, the results proved that periapical radiographs showed more frequency of apical root resorption in posterior teeth groups compared to CBCT images.

- **Castro et al.** (31) in 2013 studied the frequency of apical root resorption due to orthodontic treatment with the help of CBCT in 1256 roots from thirty patients having Class I malocclusion with crowding to be treated with non-extraction treatment. Before and after orthodontic treatment and apical root resorption were determined using axial guided navigation of CBCT images. It was seen that all patients had apical root resorption after orthodontic treatment. There was a no significant association between resorption frequency, gender and age. Forty-six percent of all roots that underwent orthodontic treatment, root resorption were detected with CBCT. It was reported that CBCT was efficacious for detecting even minimal degrees of root resorption due to orthodontic treatment in-vivo and allowed three-dimensional evaluation of dental roots and visualization of palatine roots of maxillary molars. Incisors and distal roots of the first maxillary and mandibular molars showed the highest frequencies and the most significant root resorption.

- **Yu et al.** (46) in 2013 studied the correlations between root resorption and the amount of tooth movement during orthodontic treatment around six maxillary anterior teeth after seven months of orthodontic treatment using CBCT. It was shown that the root resorption was largest in the lateral incisors, which were followed by the central incisors and then the canines. It was shown that larger tooth movement might be associated with increased severity of root resorption after orthodontic treatment. Hence, CBCT proved to be a useful tool for evaluating apical root resorption after orthodontic treatment.

- **Lombardo et al.** (47) in 2013 conducted a study on Twelve (Class II) division 1 malocclusion patients who underwent orthodontic treatment with extraction, and the control group comprised of ten (Class II) division 1 patients who underwent orthodontic treatment without extraction. On assessing before (T1) and after (T2) treatment CBCT images, it was found that the orthodontic treatment in patients who underwent extractions appear to have a greater degree of root resorption. The bone at the extraction site showed greater resorption in the study group with respect to the control group, along with the appearance of intra-osseous defects in the former.

- **Krishna et al.** (48) in 2013 studied the changes in alveolar bone of maxillary and mandibular incisor by using lateral cephalogram. The study included ten patients with bimaxillary protrusion treated with extraction of four first premolars. On assessing the labial and lingual cortex of all the incisors on the CT scan with measurements taken at site adjacent to the widest point of the labio-lingual root in three slices separated by 3 mm at crest level (S1), mid root level (S2), and apical level (S3). It was found that, in the mandibular arch, after lingual movement of the incisors, the bone labial to the anterior teeth decreased in thickness at the coronal level of the left central and lateral incisors. Left lateral incisor showed significant changes in all the three levels. In the maxilla, the change in the labial bone thickness was not statistically significant. Lingual bone of all the incisors showed significant changes in S1 level and S3 levels.

- **Castro et al.** (19) in 2015 studied the distance between the cementoenamel junction and the alveolar bone crest before and after orthodontic treatment using cone beam computed tomography (CBCT). The study comprised thirty patients with Angle Class I malocclusion and mild to moderate crowding. The study database comprised dental CBCT scans obtained before and after orthodontic treatment. It was found that the distance between the cementoenamel junction and the bone crest increased in 57% of the surfaces after orthodontic treatment. The buccal surface of the lower central incisors had the greatest frequency of increased distance of about 75%, and the lingual surface of lateral incisors had the lowest of approx 40%. The distance between the cementoenamel junction and the alveolar bone crest was greater than 2 mm (alveolar bone dehiscence) in 11% of the surfaces before orthodontic treatment and 19% after treatment.

- **Ma et al.** (49) in 2015 studied the 3-D imaging of dental alveolar bone change after fixed orthodontic treatment in patients with periodontitis: A total of Eighty one patients, including Forty patients with chronic periodontitis (group 1) and Forty one patients with normal periodontal tissues (group 2), were selected. CBCT scanning for anterior teeth was taken before and after orthodontic treatment, and it was found that the group 1 presented a statistically lesser bone density and bone height when compared to group 2 before treatment. There was a significant loss of bone density for both groups after orthodontic treatment was assessed but bone density loss was significantly greater in the group 1.

- **Garlock et al.** (21) in 2016 did a study to evaluate anterior mandibular marginal alveolar bone height of Fifty seven orthodontic patients with a mean age of 18.7 years using cone-beam computed tomography images. They assessed correlations between morphologic and treatment changes in cortical bone thickness, ridge thickness, distance from the apex to the labial cortical bone, and the distance from the cementoenamel junction to the marginal bone crest. Alterations in the cementoenamel junction to the marginal bone crest distance were correlated with pretreatment and post treatment measurements. They concluded that orthodontic treatment causes changes in alveolar bone height and cortical bone thickness around the mandibular incisors. It was also found that pretreatment cortical bone thickness, ridge width thickness, and specific tooth movements played important role in maintaining alveolar bone height during treatment.

- **Ahn et al.** (50) in 2016 evaluated the effects of augmented corticotomy on the decompensating pattern of mandibular anterior teeth, alveolar bone, and surrounding periodontal tissues during presurgical orthodontic treatment for skeletal Class III patients. Thirty skeletal Class III adult patients were divided into 2 groups i.e experimental group with augmented corticotomy and control group without augmented corticotomy. On comparing the Lateral cephalogram and cone-beam computed tomography images taken before and after orthodontic treatment a significant proclination was found for mandibular incisors in both groups ($P < 0.001$) however, the labial movement of the incisor tip was greater in the experimental group ($P < 0.05$). Significant vertical alveolar bone loss was observed only in the control group ($P < 0.001$). The middle and lower alveolar bone thicknesses and labial alveolar bone area increased in the experimental group. In the control group, the upper and middle alveolar thickness and labial alveolar bone area decreased significantly. The significant difference for root length in the experimental group ($P<0.05$) concluded that the augmented corticotomy provided a favorable decompensation pattern of the mandibular incisors, preserving the periodontal structures surrounding the mandibular anterior teeth for skeletal Class III patients**.**

- **Oliveira et al.** (51) in 2016 assessed changes in tooth length and alveolar thickness after retraction of maxillary incisors in eleven patients with severe maxillary dentoalveolar protrusion. A month after end of incisor retraction (T2), CBCT examination was performed through 7 axial slices using Dolphin Imaging™ software for assessing the premaxilla. Five measurements were made by evaluating the distance from the buccal cortical bone to the palatal cortical bone. There were no significant changes in the length of the roots of maxillary incisors or premaxilla alveolar thickness.

- **Witek et al.** (52) in 2017 studied the influence of incisors and canine positioning on the dimensions of the cortical and spongious bone of the anterior mandibular alveolar process. They evaluated 100 CBCT volumes (61 females and 39 males), using a Gendex GXCB-500 machine and analyzed using i-CAT Vision and Corel DRAW 9 software. It was found that the position of teeth had little influence on the vestibular bone thickness and is only significant around central incisors. They have also assessed that the thickness of lingual spongious bone around teeth declined as the angle of curvature of the cortical bone decreased.

- **Hammad et al.** (53) in 2018 conducted a randomized clinical trial to evaluate the labial alveolar bone thickness (LABT) and apical root resorption (ARR) between two types of brackets using CBCT. Twenty one Angle's Class I patients with anterior crowding of 3–5 mm and a mean age of 17.58 years were included in the study and randomly divided into two groups: Group I -self-ligating brackets and Group II -conventional pre adjusted brackets. On evaluating LABT and ARR at two levels i.e cervical (L1) and mid root level (L2) in 152 incisors by using CBCT scans, significant changes in the ARR of lower incisors were found but not clinically significant for the conventional group. However, no significant changes were observed between both groups regarding LABT at L1, LABT at L2 and ARR of upper incisors.

- **Deng et al.** (32) in 2018 conducted a meta-analysis to evaluated root resorption after comprehensive orthodontic treatment using CBCT. Twelve studies were included in this meta-analysis and the results showed that the length of all teeth after the intervention was significantly shorter after fixed orthodontic treatment ($P < 0.00001$). The sequence of root resorption from heaviest to lightest was maxillary lateral incisors, maxillary central incisors, mandibular anterior teeth, and maxillary canines. Studies were divided into two subgroups based ontooth extraction. Root shortening after treatment was observed in both groups, and extraction caused more root resorption than in the non-extraction group.

- **Puttaravuttiporn et al.** (54) in 2018 in evaluated upper incisor root resorption, volume loss and the relationship between root volume loss and tooth movement in thirty patients along with marginal bone loss after a year of orthodontic treatment. Reconstruction of pre- and post-treatment CBCT images was done using MIMICS software^{TM}. Superimposition of upper incisors at pre-and post-treatment and sectioned to labio-and palato-apical, middle and coronal third root volumes. From lateral cephalometric radiographs and CBCT, tooth movement and alveolar bone height were measured. There was a significant decrease in mean root volume on the labio- and palato-apical aspects of the right lateral incisors and labio-apical aspects of left central and lateral incisors. There was a greater palato-apical segment volume loss on lateral than central incisors. The tooth movement amount and percentage root volume loss showed no significant relationship.

- **Adarsh et al.** (55) in 2018 conducted an in-vitro study to evaluate the reliability and accuracy of tooth length measurements using conventional (IOPA and OPG) and CBCT imaging techniques. Fifty extracted single-rooted premolar teeth were mounted on the dry human mandible, and measurements were made for tooth length, crown length and root length using a vernier caliper. A significant difference in the tooth length measurements was seen between CBCT and IOPA and between IOPA and OPG. Root length measurements taken by IOPA and OPG and by CBCT showed highly significant differences. However, no significant difference was seen between the crown length measurements taken by vernier caliper and CBCT and between IOPA and OPG.

- **Morais et al.** (56) in 2018 assessed the changes in the maxillary buccal alveolar bone during alignment without extractions. Twenty-two adolescents with crowded permanent dentitions were treated without extractions with Damon 3MX brackets. On comparing before and after treatment CBCT images, a significant decrease in bone thickness and an increase in bone height were noted for the incisors and mesio-buccal root of the first molars. They also found a generalized increase in arch dimensions with tipping.

- **Atik et al.** (57) in 2018 investigated the changes in alveolar bone after maxillary incisor intrusion to determine the related factors in deep-bite patients. Fifty maxillary central incisors of twenty five patients were evaluated retrospectively and were divided into 2 groups. In Group I, intrusion was performed with a base-arch, while in Group II, intrusion was performed with mini-screws. Changes in the alveolar envelope were assessed using pre-intrusion and post-intrusion CBCT images. On evaluating the labial, palatal, and total bone thickness at the crestal (3 mm), mid-root (6 mm), and apical (9 mm), it was found that the upper incisor inclination and intrusion changes were significantly greater in Group II than in Group I. With treatment, the labial bone thickness decreased significantly in Group II ($p < 0.001$) as compared to Group I.

- **Zhang et al.** (24) in 2019 evaluated changes in shape and alterations in thickness and vertical marginal bone levels of the alveolar bone around maxillary and mandibular incisors in thirty-six patients with Class I bimaxillary protrusion who underwent orthodontic treatment with premolar extraction using CBCT. They used five fixed landmarks and seventy semi-landmarks to represent the morphology of the alveolar bone around the maxillary and mandibular incisors. They concluded that there was a significant difference in shape change on lingual alveolar bone of mandibular incisors and reduction in vertical marginal bone level on anterior maxillary and mandibular incisors before and after treatment**.**

- **Ma et al.** (58) in 2019 evaluated the difference in the alveolar bone of the anterior teeth between high-angle adults with severe skeletal Class II malocclusions and Class III malocclusions by using CBCT. The sixty two, high angle adult subjects were taken for this study and further divided into 2 groups based on their sagittal jaw relationships: severe skeletal Class II and severe skeletal Class III. Vertical bone level (VBL), alveolar bone area (ABA), and thickness of alveolar bone were measured at 2 mm, 4 mm, and 6 mm below and above the (CEJ) level, as well as at the apical level. Their studies revealed that the ABA and the alveolar bone thickness of the mandibular anterior teeth were significantly thinner in the severe high-angle group of skeletal Class III adult patients than in the Class II adult cases.

- **Maspero et al.** (20) in 2019 evaluated the correlation between dental vestibular-palatal inclination changes and cortical bone remodeling after fixed orthodontic treatment using CBCT in twenty two patients with Class I malocclusion and mild to moderate crowding. They evaluated bone dimensions by CBCT scans taken before and after orthodontic treatment. The torque values were evaluated by digital models using 3D Vista Dent software. The result showed significant correlations between torque variation and buccal bone thickness at the apical level of incisors and canines. But no significant correlation between torque variation and buccal bone height, palatal bone height and root length was observed.

- **Matsumoto et al.** (22) in 2019 evaluated the presence of dehiscence and changes in alveolar bone height and width in the area of the mandibular central incisors pre- and post-orthodontic treatment. In Sixty skeletal Class II patients, cone-beam computed tomographic (CBCT) images were obtained and the patients were divided into four groups based on the presence of dehiscence at pre- and post-orthodontic treatment. The alveolar bone height and width were measured on CBCT in cross section along the long axis of the teeth. On analyzing the lateral cephalogram, it was found that the changes in L1-NB and IMPA appeared to be correlated with vertical bone loss and dehiscence. Similarly, an increase in L1-NB or IMPA correlated with decreases in alveolar bone width with an estimated 50% probability of vertical bone loss at an L1-NB change of 2 mm or equivalently an IMPA change of 8.028 was estimated.

- **Zasciurinskiene et al.** (59) in 2019 examined alveolar bone level (ABL) changes after orthodontic treatment in fifty patients with periodontal disease. In Control group, patients received final periodontal treatment before the start of orthodontic treatment. While in the test group, patients received periodontal treatment simultaneous to the orthodontic treatment. Straight-wire appliance was used along with the placement of micro-implants or temporary crowns for posterior anchorage. On measuring ABL of 3821 tooth surfaces in cone beam computed tomography images, There was a small ABL changes was noticed after periodontal–orthodontic treatment in patients with periodontal disease. ABL gain was more observed on mesial and distal surfaces and a significant ABL loss was noticed on buccal and lingual surfaces.

- **Al-Okshi et al.** (60) in 2019 evaluated the reliability and measurability of root length and marginal bone level using CBCT, periapical and bitewing radiographs. A total of 10 adolescents with mean age of 13.4 years were recruited and various radiographs were taken for baseline examinations of orthodontic treatment using CBCT of jaws, posterior bite wing radiographs and periapical radiographs of maxillary incisors. Measured root length and marginal bone level were assessed by six raters. It was noted that the measurability for CBCT was 100% and for periapical radiographs of maxillary incisors for root length was 95%. The measurability for marginal bone level was 100%, 76% and 86% in CBCT, periapical radiographs and posterior bitewing radiographs, respectively. It was concluded that CBCT can be the method of choice for scientific analyses in orthodontics as measurability and reliability was found to be high for root length.

- **Yao et al.** (61) in 2020 compared alveolar bone changes around mandibular anterior teeth in patients with vertical facial pattern. The CBCT scans and STL files of digital dental models, taken before (T1) and after (T2) presurgical orthodontic treatment, were imported into Dolphin imaging software to reconstruct dentoskeletal images. T1 and T2 images were superimposed and analyzed for bone thickness and height in mid-sagittal slice of six mandibular anterior teeth. The study showed that alveolar bone at all tooth sites was significantly greater in the low-mandibular plane angle group and thickness and height alveolar bone were smaller in high-mandibular plane group patients. All the parameters lingual thickness, total thickness, labial height and lingual height of the alveolar bone significantly decreased after presurgical orthodontic treatment.

- **Kuma et al.** (62) in 2020 investigated the relationship between the thicknesses of the mandibular alveolar bone in all the teeth of adult female patients with different vertical skeletal patterns using cone-beam computed tomography (CBCT). Based on the mandibular plane angle, before treatment, CBCT images of 50 patients were divided into three groups i.e Low, average, and high-angle. On measuring the thicknesses of the alveolar and cancellous bones of the mandible at the apices of the teeth, a significantly larger value was found in the low-angle group than in the high-angle group in all areas. At the incisal and canine areas, the thicknesses of the alveolar bones were significantly larger in the average angle group than in the high-angle group. Whereas in the canine and first premolar areas, the thickness of the alveolar bone was larger in the low-angle group than in the average angle group.

- **Wang et al.** (63) in 2021 studied the morphometric changes in maxillary and mandibular anterior alveolar bone after orthodontic treatment and after retention phase of 18-24 months using CBCT. Thirty-four patients (12 males and 22 female) with mean age of 14.29 years with bimaxillary dentoalveolar protrusion who required extractions of the first premolars were included in the study. The labial and lingual (palatal) alveolar bone thickness, height and root length of the maxillary and mandibular anterior teeth were assessed using CBCT imaging at the pre-treatment (T1), post-treatment (T2) and retention phases (T3). After orthodontic treatment, it was noticed that the labial and lingual (palatal) bone height decreased significantly ($P < .05$), and the labial thickness at the crestal (L1), midroot (L2), and apical levels (L3) had no significant change. In contrast, the lingual (palatal) bone thickness at all three levels decreased significantly ($P < .05$). Significant increase in the lingual (palatal) height and thickness at the crestal (L1) level was noticed after 18-24 months of retention. There were no obvious incisal and apical movements of the anterior teeth found between T2 and T3, indicating no incidence of relapse.

- **Zhang et al.** (64) in 2022 studied detailed correlation between the movement of maxillary and mandibular central incisors and alveolar bone resorption in adults who had orthodontic premolar extraction treatment. Sixty-three patients with mean age of 24.4 years who underwent first premolars extraction with moderate anchorage were included in the study. CBCT images were obtained before and after treatment. Four points were used to describe the incisor movement: C (cusp point), R (root apex point), M (mid-point of root neck), and L (labial cementoenamel junction point). The thickness of labial and palatal alveolar bone was assessed at the crestal, mid-root, and apical levels of incisors. They found significant correlation was observed in maxillary incisor movement and labial alveolar bone resorption with the movement of Point L and apical level was correlated with Point M. For mandibular central incisors, the labial alveolar bone resorption at the apical level was correlated with the movement of Point M and R, the palatal alveolar bone resorption at the mid-root level with Point M and the palatal alveolar bone resorption at the apical level with Point R. This study concluded that it is potentially helpful for orthodontists to have a relatively accurate prediction of alveolar bone resorption based on the specific movements of central incisors and to reduce the risk of alveolar bone resorption by better adjusting the three-dimensional movement types of incisors.

MATERIALS AND METHODS

Setting and Location

Participants were recruited from those attending for routine fixed appliance orthodontic treatment in the post graduate orthodontic clinic of Department of Dentistry at AIIMS, Jodhpur. Ethical approval was obtained from the Institutional Ethics Committee, AIIMS Jodhpur (AIIMS/IEC/2021/3304). Written informed consent was obtained from all patients' parents and guardian prior to enrollment.

Study Design

This prospective cohort study compared changes in alveolar bone dimension after fixed orthodontic treatment.

Study Duration

Consecutive patients being treated with fixed orthodontic appliances were enrolled. Follow-up for this study included the period from the acquisition of baseline records and appliance placement up to the appliance removal and placement of retainers.

Study Population

Thirty-five patients of both sexes requiring fixed orthodontic treatment for correction of malocclusion were recruited. The mean age at the start of treatment was 17. 3 years. (14 years and older)

Participants

The subjects were enrolled based on the following criteria:

Inclusion Criteria-

1. Age 14 years and older, at the beginning of fixed orthodontic treatment.
2. Moderate (4-7 mm) to severe (>8 mm) mandibular anterior crowding.
3. Patients requiring extraction of mandibular first premolars.
4. In the permanent dentition.
5. Good oral hygiene with normal healthy periodontium.
6. No history of previous orthodontic treatment.

Exclusion Criteria-

1. Patient whose treatment plans included extraction of a mandibular incisor
2. Patients with recession in mandibular incisor region.
3. Patient with missing or impacted teeth in mandibular anterior region.
4. Patients under any medications that can interfere with bone metabolism and gingival tissue health
5. Patients with systemic diseases, cleft lip and palate or with any other craniofacial anomaly.

After satisfying inclusion and exclusion criteria and obtaining informed consent, patients were enrolled in the study.

Interventions

All patients were bonded with 0.022 x 0.028-inch slot MBT prescription brackets (3M^{TM}Unitek^{TM} Gemini metal brackets, California, USA). Mandibular first premolar extractions were performed to provide space to alleviate mandibular anterior crowding. Leveling and alignment phase was initiated with nickel-titanium (G4™ Nickel-titanium, G&H, Franklin, Indiana, USA) archwires ligated in the sequence of 0.014-inch, 0.016-inch, 0.018-inch and 0.019x0.025-inch, respectively. Once initial alignment and leveling was completed, 0.019x0.025-inch stainless steel archwires (S3^{TM} Stainless Steel, Franklin, Indiana, USA) were ligated. Spaces left after relieving of crowding were closed by sliding mechanics using an elastomeric chain (Closed Space Powerchain, Ormco, Glendora, CA) on 0.019x0.025-inch stainless steel arch wire. Anchorage was managed as per the individual need of the case. After finishing and detailing, and settling of occlusion, fixed appliances were removed. Oral hygiene was reinforced and maintained throughout the treatment. The mean treatment duration was 25.6 months. Cone-beam computed tomogramphy (CBCT) images were taken at T0-baseline (pre-treatment) and T1-immedeatly after removal of fixed orthodontic appliance. Three-dimensional changes in alveolar bone dimensions and root resorption were assessed for all mandibular incisors after fixed orthodontic treatment.

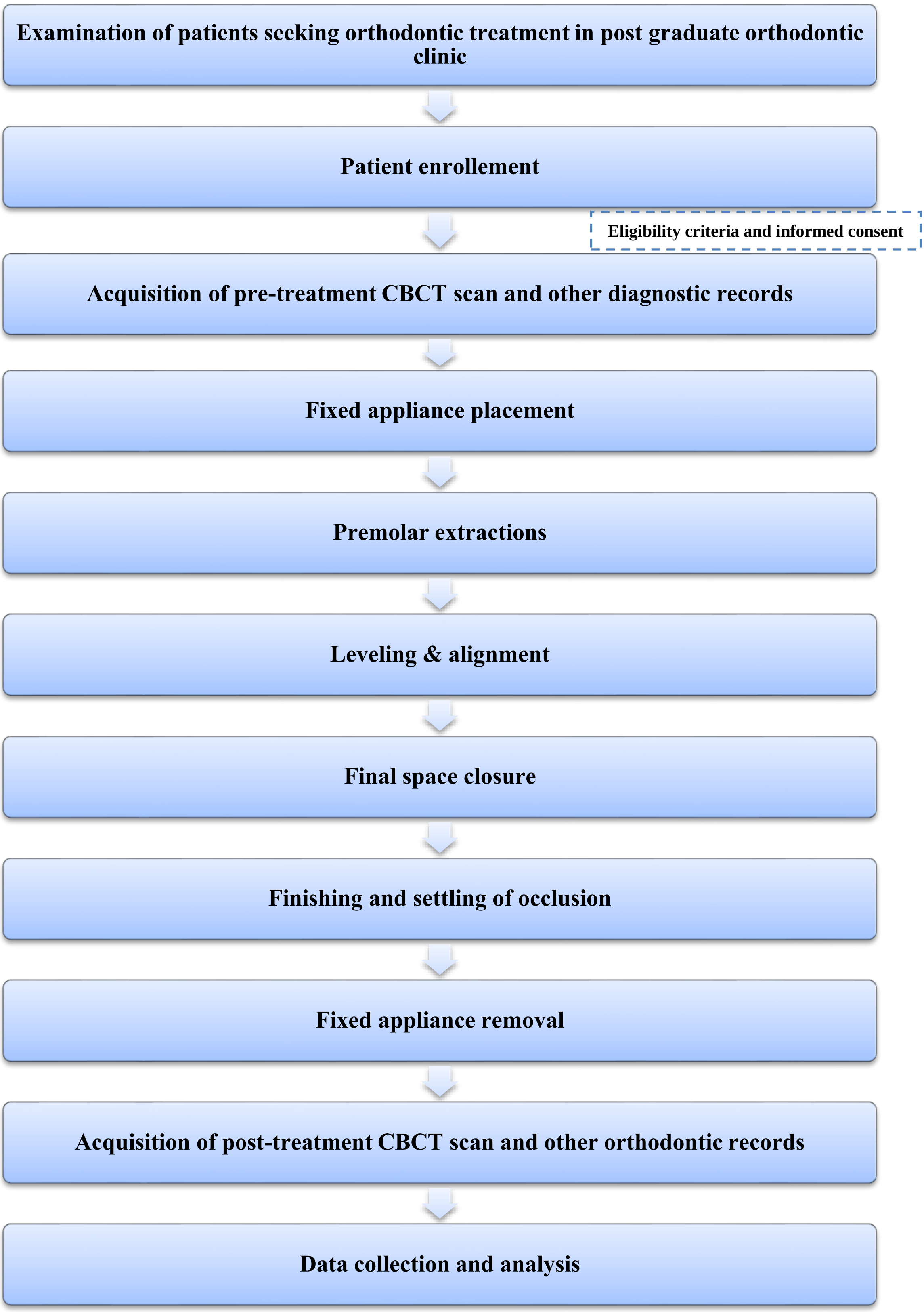

Figure 1: Patients recruitment and follow up flowchart

Procedure for CBCT acquisition and orientation

CBCT Acquisition:

CBCT images (CS 9600 3D®; Carestream Health, Inc., Marne-la-Vallée, France) of the mandibular anterior region were acquired following a low dose protocol (exposure time 10 seconds, voltage 120 kV, current 8 mA; field of view (FOV): 5x5 cm ; voxel size: 0.15 mm) before treatment (T0) and after treatment (T1). Positioning of the patient was made according to standard operating procedure and adjustments of the X-ray beam positioning were made so that four mandibular incisors were included in one imaged volume.

The selected images were converted to DICOM (Digital Imaging and Communications in Medicine) format. The computed images were analyzed using Dolphin imaging software (Version 11.95, Dolphin Imaging & Management Solutions, Chatsworth, Calif). For all images a HP (Hewlett-Packard, 27yh, China) 27.0 inch flat-panel monitor with Windows 10 enterprise and an integrated Intel(R) Core(TM) i7-8700 CPU was used. All measurements were performed with ADS-black light LED, wide angle anti-glare display and a resolution of 1920x1080pixel.

CBCT Orientation:

CBCT scans were oriented in the sagittal, axial and coronal planes. To examine the morphological features of alveolar bone, each CBCT image was oriented along the long axis of the each mandibular incisor (bisecting the pulp and the canal) in the sagittal and coronal planes, and bisecting the canal in a labio-lingual direction in the axial plane at the same time. To achieve optimal visualization of alveolar bone around the tooth, first a tooth is selected and placed in the middle of a 3-dimensional (3D) view box which helps to view the tooth in 3 planes of space, the axial, sagittal and coronal planes (Fig 2). The landmarks were drawn for each mandibular incisor and outcome variables were measured (Table 1 & 2).

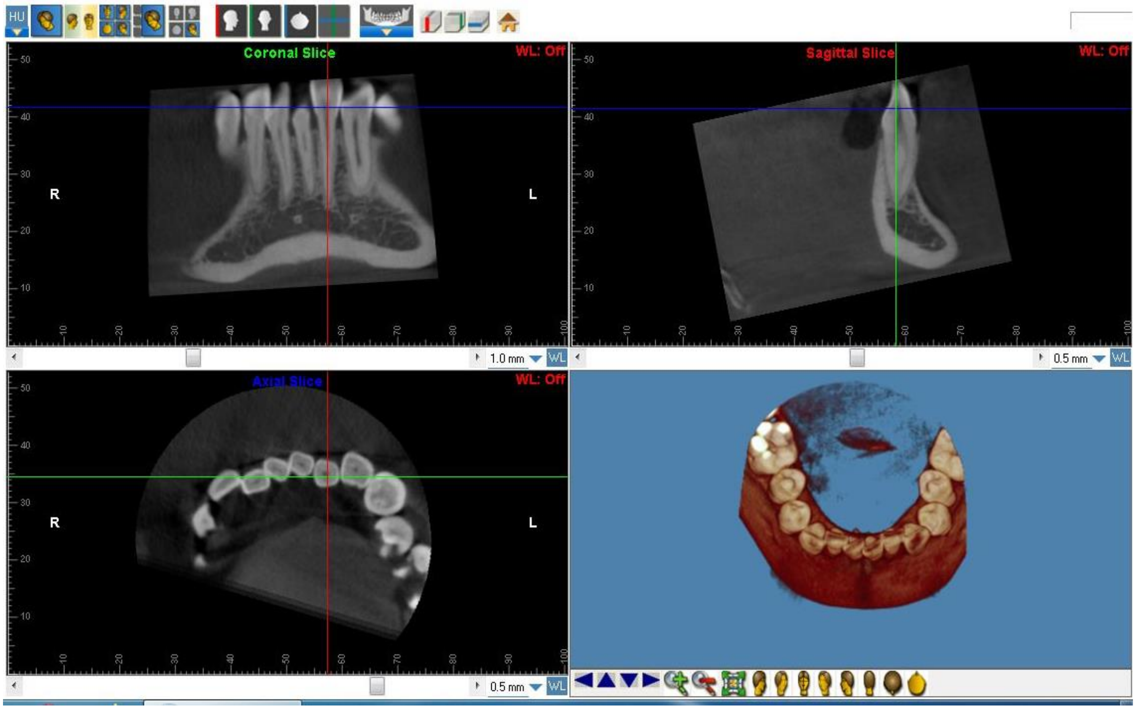

Figure 2: All 3 planes of space on the CBCT were oriented simultaneously. A sagittal section x-ray was built from the CBCT oriented along these planes.

Table 1: Definition of landmarks used:

S.No.	Landmarks	Definition
1.	BO	Outermost buccal cortex point at the level of apex.
2.	LO	Outermost lingual cortex point at the level of apex
3.	BC	Alveolar crest on the buccal side.
4.	LC	Alveolar crest on the lingual side.
5.	TBT	Total bone thickness of alveolar bone at the level of apex.
6.	TBBT	Total buccal bone thickness of alveolar bone at the level of apex.
7.	TLBT	Total lingual bone thickness of alveolar bone at the level of apex.
8.	BCBA	Buccal cortical bone thickness at the level of apex.
9.	LCBA	Lingual cortical bone thickness at the level of apex.
10.	BCBM	Buccal cortical bone thickness at the mid root level.
11.	LCBM	Lingual cortical bone thickness at the mid root level.
12.	BCBH	Distance from cementoenamel junction to buccal alveolar crest.
13.	LCBH	Distance from cementoenamel junction to lingual alveolar crest

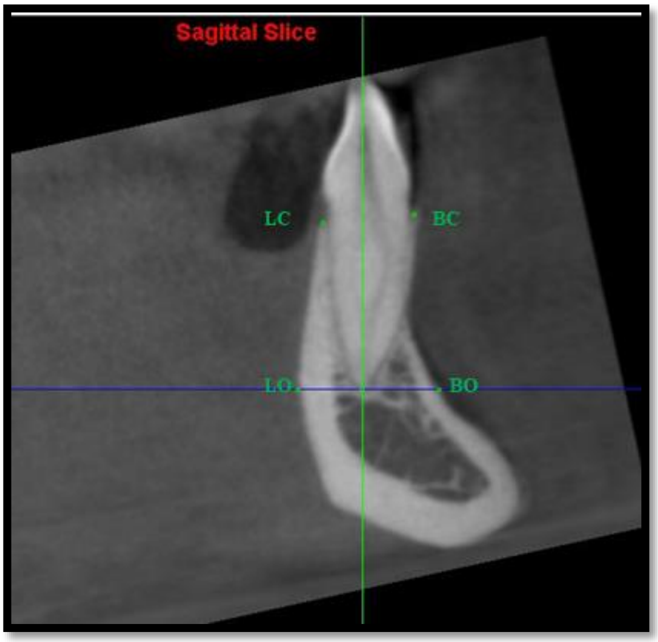

Figure 3: Landmarks on outermost crestal and cortical bone

Table 2: Definition of variables used:

S.No.	Outcome variable	Definition
1.	Total bone thickness (TBT)	A horizontal line joining outermost buccal and lingual cortex at the level of apex.
2.	Total buccal bone thickness (TBBT)	A horizontal line joining outermost buccal cortex to the tooth apex.
3.	Total lingual bone thickness (TLBT)	A horizontal line joining outermost lingual cortex to the tooth apex.
4.	Buccal cortical bone thickness at apex (BCBA)	A horizontal line joining outermost cortex to internal cortical border on buccal side at apex.
5.	Lingual cortical bone thickness at apex (LCBA)	A horizontal line joining outermost cortex to internal cortical border on lingual side at apex.
6.	Buccal cortical bone thickness at mid-root level (BCBM)	A horizontal line joining outermost cortex to internal cortical border on buccal side at mid-root level.
7.	Lingual cortical bone thickness at mid-root level (LCBM)	A horizontal line joining outermost cortex to internal cortical border on lingual side at mid-root level.
8.	Buccal crestal bone height (BCBH)	The vertical distance from the CEJ to the outermost buccal alveolar crest
9.	Lingual crestal bone height (LCBH)	The vertical distance from the CEJ to the outermost lingual alveolar crest
10.	Root length in sagittal section (RS)	The distance from incisal edge to apex in sagittal section.
11.	Root length in coronal section (RC)	The distance from incisal edge to apex in coronal section.

MEASUREMENTS

1. Alveolar bone dimension at apex:-

After orientation, a sagittal cross section of each mandibular incisor was produced. Two landmarks were identified; one on the outermost buccal cortex (BO) and other on the lingual cortex (LO) at the level of apex. A horizontal line was drawn at the level of the apex joining the point BO and LO. This represented the total bone thickness (TBT) (Fig 4). On this horizontal line total buccal bone thickness (TBBT) was measured from tooth apex to the point BO and the total lingual bone thickness (TLBT) was measured from tooth apex to the point LO (Fig 5). These measurements was repeated for all the mandibular incisors at pretreatment (T0) and after completion of fixed orthodontic treatment (T1).

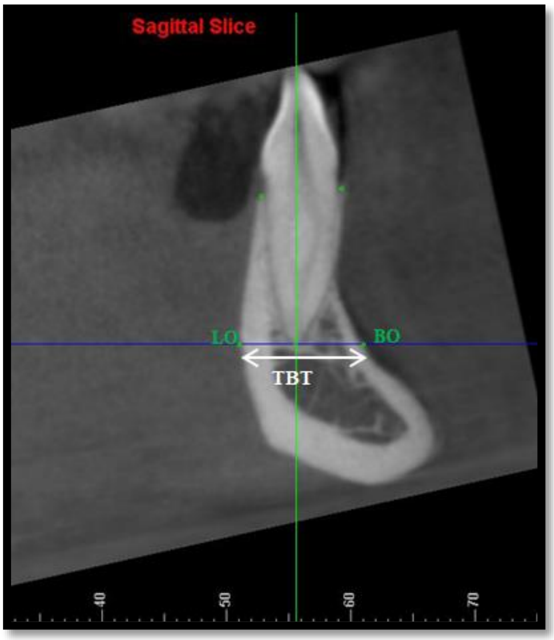

Figure 4: Total bone thickness

Figure 5: Total buccal bone thickness and total lingual bone thickness

2. Cortical bone thickness:-

After orientation, a sagittal cross section of each mandibular incisor was produced. A horizontal reference line was drawn through most apical portion of the cementoenamel junction (CEJ). From this horizontal line a vertical distance (a) from the labio-lingual midpoint of the pulp canal to the apex of the root was measured. This distance was halved (b), and a horizontal line was drawn demarking the height at which the mid root-level cortical bone thickness (BCBM and LCBM) were measured. Another horizontal line was drawn at the level of apex. This height was used to measure apex-level buccal and lingual cortical bone thickness (BCBA and LCBA) [Fig 6 & 7].

Cortical bone thickness was measured as the line from the point where the horizontal line intersected the internal border of the cortical plate, horizontal to the external border of the cortical plate. These measurements was repeated for all the mandibular incisors at pretreatment (T0) and after completion of fixed orthodontic treatment (T1).

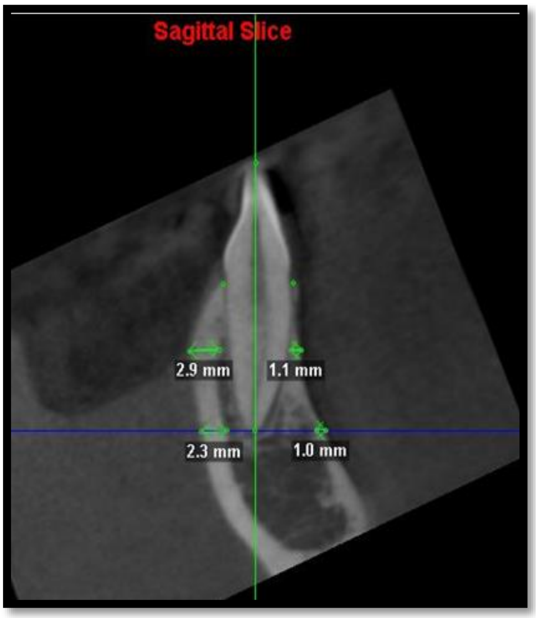

Figure 6: Buccal and lingual cortical bone thickness at mid-root and apex level

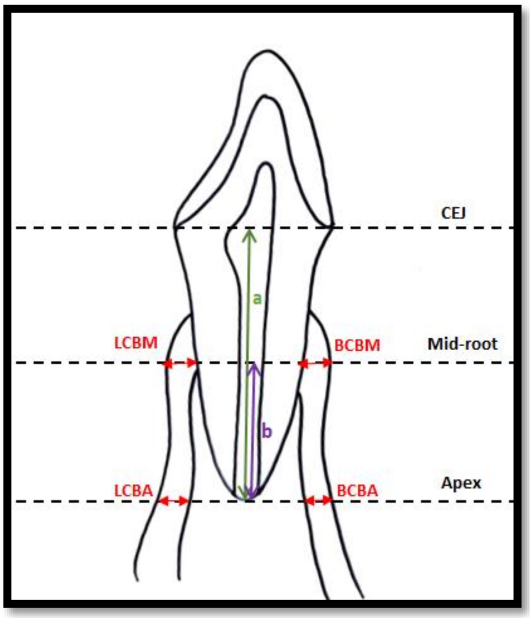

Figure 7: Schematic diagram showing buccal and lingual cortical bone thickness at mid-root and apex level

3. Alveolar bone height:-

After orientation, a sagittal cross section of each mandibular incisor was produced. Two landmarks were identified; one on the outermost buccal alveolar crest (BC) and other on the lingual alveolar crest (LC). A horizontal line was drawn at the height of cementoenamel junction (CEJ). The buccal crestal bone height (BCBH) was measured from CEJ to point BC. The lingual crestal bone height (LCBH) was measured from CEJ to point LC (Fig 8 & 9). The same methodology was followed to analyze the buccal and lingual crestal bone height of all the mandibular incisors at pretreatment and after completion of fixed orthodontic treatment.

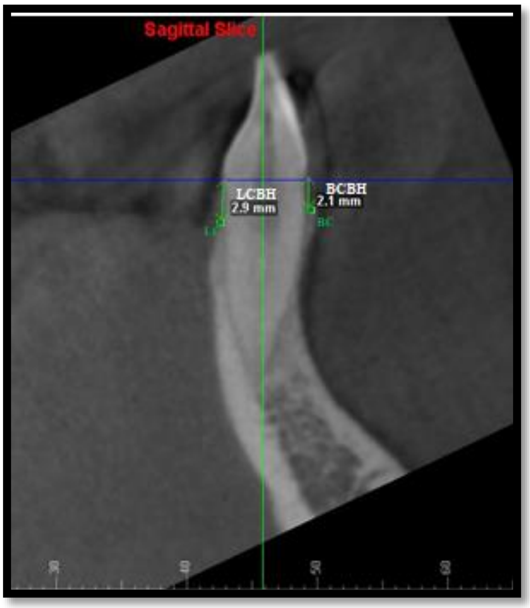

Figure 8: Buccal crestal bone height and lingual crestal bone height

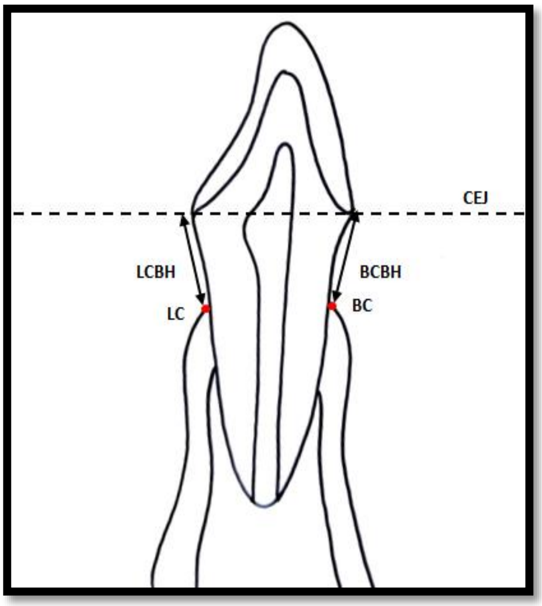

Figure 9: Schematic diagram showing buccal crestal bone height and lingual crestal bone height

4. Root resorption:-

Sagittal section (Length of root: from incisal edge to apex):

After orientation, a sagittal cross section of each mandibular incisor was produced. A horizontal reference was drawn through incisal edge of the tooth. Further, the length of the root was measured along the long axis of the tooth, starting from a point on this reference line passing through the labio-lingual midpoint of the pulp canal till the most apical point of the root. This represented the root length of the tooth in sagittal section (RS) (Fig 8). This procedure was followed for measuring root length of all the incisors at pretreatment (T0) and after completion of fixed orthodontic treatment (T1).

Coronal section (Length of root: from incisal edge to apex):

After orientation, a coronal cross section of each mandibular incisor was produced. A horizontal reference line was drawn by joining the mesial and distal outline of incisal edge of the tooth. From this horizontal line a vertical distance was measured through the mesio-distal midpoint of the pulp canal to the most apical point of the root. This represented the root length of the tooth in coronal section (RC) (Fig 9). The same methodology was followed to analyze the root length of all the mandibular incisors pretreatment (T0) and after completion of fixed orthodontic treatment (T1).

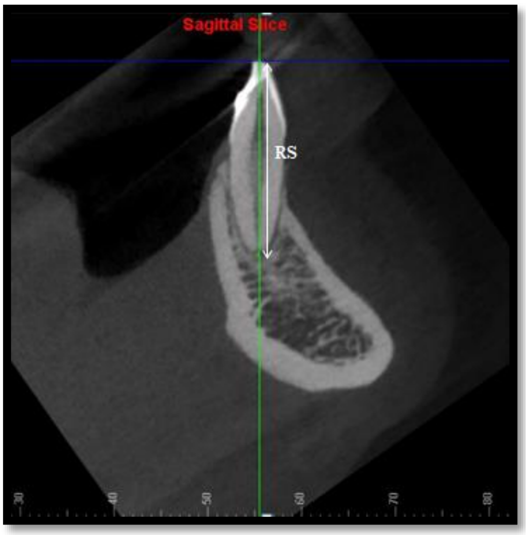

Figure 10: Root length in sagittal section

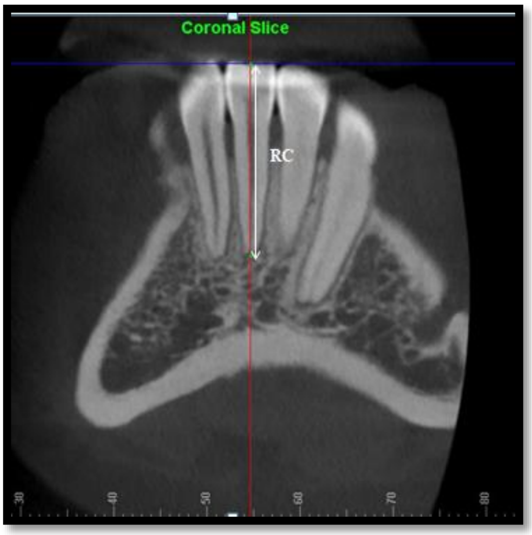

Figure 11: Root length in coronal section

Sample Size

The sample size was calculated based on the previous study of Garlock et al (21). Assuming a mean difference of 1.16 mm, a standard deviation of 2.19, an effect size of 0.53 with 80 percent power and an alpha error of 5 percent, the sample size was estimated to be 31 subjects. Assuming a dropout rate of 15%, 35 patients were recruited in the study.

Statistical Analysis

Data was analyzed using the Statistical Package for Social Sciences for Windows, version 23.0 (Armonk, NY: IBM Corp.). During the whole study period there was no dropout. Analysis of before and after treatment differences of alveolar bone variables in all mandibular incisors was done using Paired t-test.

Reliability statistics:

For assessment of reliability, landmark location and measurements was made on fifteen randomly selected CBCT scans (repeated after two weeks) for the alveolar bone variables.

- Dahlberg's formula was used to assess method error.
- Intra-examiner reproducibility was assessed using Intra-class correlation coefficients (ICC) with two-way mixed model for absolute agreement between variables.

Descriptive statistics:

These included parametric variables like number, mean and standard deviation. The following tests were used:

1. Paired t-test: To compare pre-treatment and post treatment alveolar bone changes and root resorption in study population.
2. The significance level was set as $P < 0.05$.

Materials used in the present study

1. MBT Prescription Bracket System (3M™ Unitek™ Gemini metal bracketsMBT prescription with 0.022-inch slot, CA, USA)
2. Etchant, (3M™ Scotchbond™ Universal Etchant, Monrovia, California, USA)
3. Bonding agent and Bonding adhesive (3M™ Unitek™ Transbond XT LightCure Adhesive, Monrovia, California, USA)
4. Conventional NiTi arch wire (G4™ Nickel-titanium, G&H, Franklin, Indiana,USA)-sizes 0.014-inch, 0.016-inch, 0.018-inch, 0.019 x 0.025-inch
5. Stainless Steel arch wire (S3™ Stainless Steel, G&H, Franklin, Indiana, USA) -size 0.019 x 0.025-inch
6. Elastomeric modules and Stainless-steel ties (G&H wire company, Franklin,Indiana, USA)
7. Elastomeric chain Elastomeric Chains (Closed space Powerchain, Ormco, Glendora, CA)
8. Digital caliper (to the nearest 0.01 mm) (Standard Digital Caliper Series:EC16)

RESULTS

BASELINE CHARACTERSTICS

Table 3: Baseline characteristics of participants in study

Baseline characteristics	**(n=35)**
Age Group n (%)	
12-17 years	19 (54.3)
18-24 years	16 (45.7)
Sex n (%)	
Male	13 (37.1)
Female	22 (62.9)
FMA n (%)	
Low (≤ 22°)	9 (25.8)
Average (22°-28°)	13 (37.1)
High (≥ 29°)	13 (37.1)
Severity of crowding n (%)	
Moderate (4-7 mm)	20 (57.1)
Severe (>8 mm)	15 (42.9)

Table 3 shows the total number of subjects in the study was 35, in which 54.3% belonged to the 12-17 years, and 45.7% belonged to the 18-24 years age group. The sample comprised of 37.1% males and 62.9% females.

Based on the value of the FMA angle, the subjects were divided as: low-angle (≤22°), average angle (22°–28°), and high-angle (≥29°). The baseline crowding of the subjects was calculated in mandibular anterior region using anterior crowding index (65). Moderate and severe crowding was seen in 57.1% and 42.9% of subjects, respectively.

Table 4: Method error according to Dahlberg's formula

Parameters	Method errors Tooth 31	Method errors Tooth 42
Total bone thickness	0.10	0.11
Total buccal bone thickness	0.10	0.10
Total lingual bone thickness	0.11	0.09
Buccal cortical bone thickness at apex	0.09	0.10
Lingual cortical bone thickness at apex	0.10	0.10
Buccal cortical bone thickness at mid root level	0.07	0.06
Lingual cortical bone thickness at mid root level	0.05	0.11
Buccal crestal bone Height	0.13	0.14
Lingual crestal bone Height	0.10	0.11
Root length in sagittal section	0.09	0.10
Root length in coronal section	0.10	0.11

Table 4 shows Dahlberg's values method error for the alveolar bone variables. Landmark locations and measurements were repeated 2 weeks after the first measurement on 15 randomly selected CBCT scan. Dahlberg's method error ranged from 0.05 mm to 0.14 mm.

Table 5: Intra-class correlation coefficients for intra-examiner reliability (reproducibility).

Parameters	ICC(95%CI) Tooth 31	P-value*	ICC(95%CI) Tooth 42	P-value*
Total bone thickness	0.999(0.996-1.000)	<0.001**	0.998(0.995-0.999)	<0.001**
Total buccal bone thickness	0.999(0.996 – 1.000)	<0.001**	0.999(0.996– 0.999)	<0.001**
Total lingual bone thickness	0.993(0.978 – 0.997)	<0.001**	0.994(0.982 – 0.998)	<0.001**
Buccal cortical bone thickness at apex	0.969(0.912-0.989)	<0.001**	0.935(0.810-0.978)	<0.001**
Lingual cortical bone thickness at apex	0.978(0.939-0.993)	<0.001**	0.981(0.943-0.993)	<0.001**
Buccal cortical bone thickness at mid root level	0.982(0.944-0.994)	<0.001**	0.984(0.953-0.994)	<0.001**
Lingual cortical bone thickness at mid root level	0.991(0.956-0.997)	<0.001**	0.977(0.933-0.992)	<0.001**
Buccal crestal bone height	0.996(0.979-0.999)	<0.001**	0.996(0.988-0.999)	<0.001**
Lingual crestal bone height	0.999 (0.997-1.000)	<0.001**	0.999 (0.997-1.000)	<0.001**
Root Resorption in sagittal section	0.996(0.988-0.999)	<0.001**	0.997(0.990-0.999)	<0.001**
Root Resorption in coronal section	0.994(0.982-0.998)	<0.001**	0.996(0.987-0.999)	<0.001**

*P-value <0.05 is considered as significant; ICC correlation was analysed using two-way mixed model with absolute agreement.

Table 5 shows reproducibility of the main examiner was excellent (>0.9) for all the alveolar bone variables. ICC values ranged from 0.93 to 0.99 depicting excellent reproducibility.

Table 6: Comparison of mean values of mandibular alveolar bone thickness at the level of apex before (T0) and after completion of orthodontic treatment (T1)

S.No	Measurements	Mean± SD			P-value*	95% confidence interval of the difference (CI)	
		T0 (n=35)	T1 (n=35)	Mean difference		Lower	Upper
1.	**Total bone thickness (TBT)**						
	Tooth41	9.0±2.85	8.5±3.04	0.5±1.17	0.011**	0.13	0.94
	Tooth31	9.2±2.68	8.6±3.09	0.6±1.60	0.032**	0.05	1.15
	Tooth42	9.0±2.48	8.5±2.97	0.5±1.59	0.047**	0.01	1.10
	Tooth32	9.1±2.73	8.3±2.99	0.77±1.66	0.009**	0.20	1.34
2.	**Total buccal bone thickness (TBBT)**						
	Tooth41	5.1±2.38	5.4±2.68	-0.2±1.60	0.344	-0.81	0.29
	Tooth31	5.3±2.15	5.8±2.85	-0.5±2.04	0.133	-1.23	0.17
	Tooth42	5.1±2.18	5.6±2.91	-0.5±2.13	0.156	-1.25	0.21
	Tooth32	5.3±2.45	5.4±2.84	-0.1±2.33	0.703	-0.95	0.65
3.	**Total lingual bone thickness (TLBT)**						
	Tooth41	4.0±1.70	2.7±1.55	1.3±1.31	<0.000**	0.91	1.81
	Tooth31	3.9±1.41	2.7±1.6	1.1±0.93	<0.000**	0.82	1.47
	Tooth42	3.9±1.05	2.7±1.42	1.2±1.26	<0.000**	-1.25	0.21
	Tooth32	3.8±1.05	2.5±0.94	1.3±1.20	<0.000**	0.93	1.75

*P value of difference in means, before and after treatment is calculated using Paired t-test. **P<0.05 is considered significant, SD indicates Standard deviation, CI: Confidence Interval, T0: Pre-treatment, T1: Post-treatment.

Table 6 shows comparison of mean values of the alveolar bone variables between pre and post treatment. Total bone thickness decreased significantly (P< 0.05) from pre to post treatment for all mandibular incisors (Fig 12).

Total buccal bone thickness at apex increased from pre to post treatment however the results were not statistically significant (P>0.05) (Fig 13).

Total lingual bone thickness at apex decreased significantly (P<0.001) from pre to post treatment for all mandibular incisors (Fig 14).

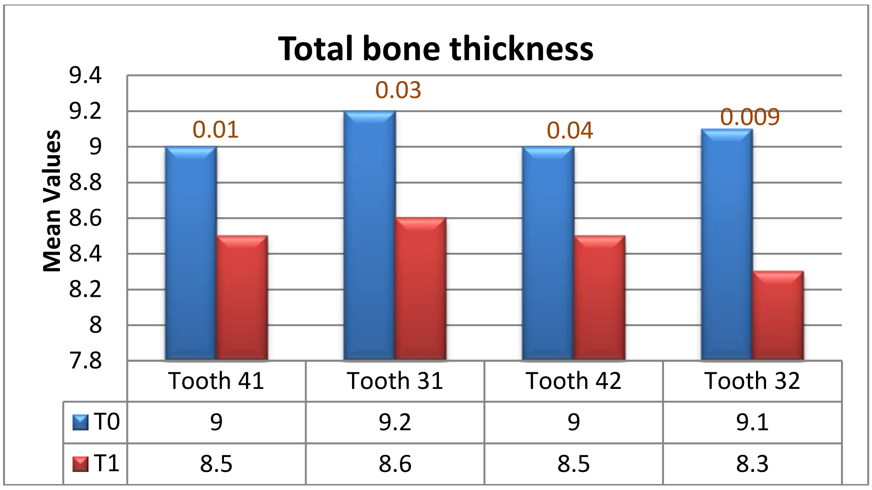

Figure 12: Plot of comparison of total bone thickness before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

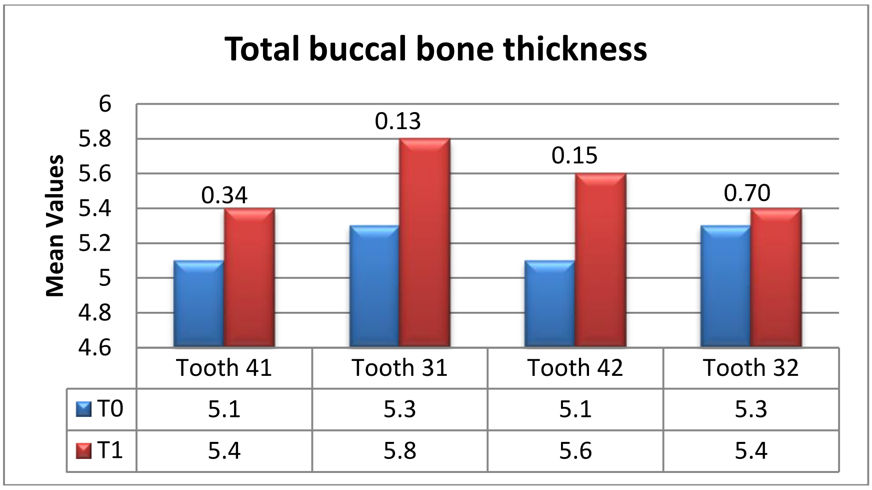

Figure 13: Plot of comparison of total buccal bone thickness before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

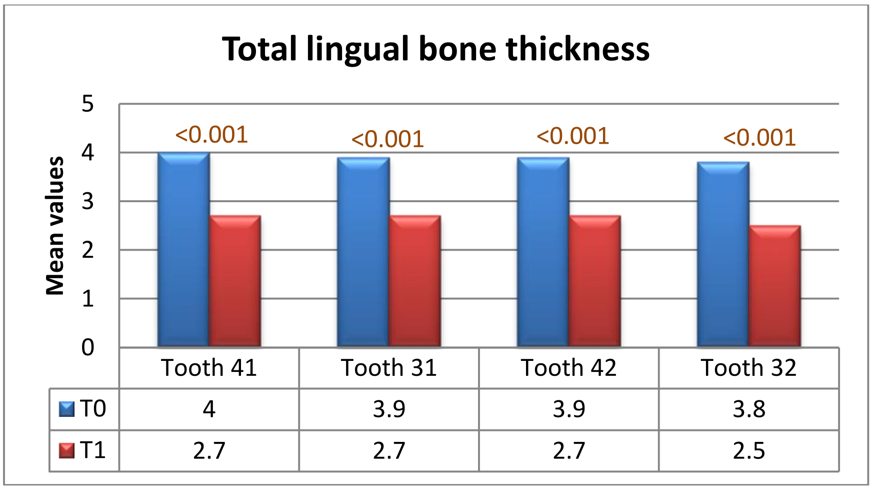

Figure 14: Plot of comparison of total lingual bone thickness before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

Table 7: Comparison of mean values of mandibular cortical bone thickness at level of apex before (T0) and after completion of orthodontic treatment (T1)

S.No	Measurements	Mean± SD			P-value*	95% confidence interval of the difference (CI)	
		T0 (n=35)	T1 (n=35)	Mean difference		Lower	Upper
1.	Buccal cortical bone thickness at apex (BCBA)						
	Tooth41	1.5±0.49	1.7±0.75	-0.2± 0.64	0.059	-0.43	0.01
	Tooth31	1.6±0.60	1.7±0.63	-0.02±0.68	0.805	-0.26	0.20
	Tooth42	1.7±0.56	1.8±0.56	-0.1±0.43	0.119	-0.26	0.03
	Tooth32	1.6±0.52	1.7±0.54	-0.03±0.53	0.684	-0.22	0.15
2.	Lingual cortical bone thickness at apex (LCBA)						
	Tooth41	2.1±0.51	1.9±0.69	0.1±0.55	0.073	-0.01	0.37
	Tooth31	2.1±0.46	1.9±0.93	0.2±0.81	0.079	-0.02	0.52
	Tooth42	2.4±0.59	2.1±0.84	0.2±0.90	0.113	-0.06	0.55
	Tooth32	2.2±0.43	2.1±0.82	0.1±0.79	0.269	-0.12	0.42

*P value of difference in means, before and after treatment is calculated using Paired t-test. **P<0.05 is considered significant, SD indicates Standard deviation, CI: Confidence Interval, T0: Pre-treatment, T1: Post-treatment

Table 7 shows comparison of the buccal and lingual cortical bone thickness at the level of apex between pre and post treatment. Buccal cortical bone thicknessat the level of apex increased from pre to post treatment however the results were not statistically significant (P> 0.05) (Fig 15).

Lingual cortical bone thicknessat the level of apex decreased from pre to post treatment however the results were not statistically significant (P> 0.05) for all mandibular incisors (Fig 16).

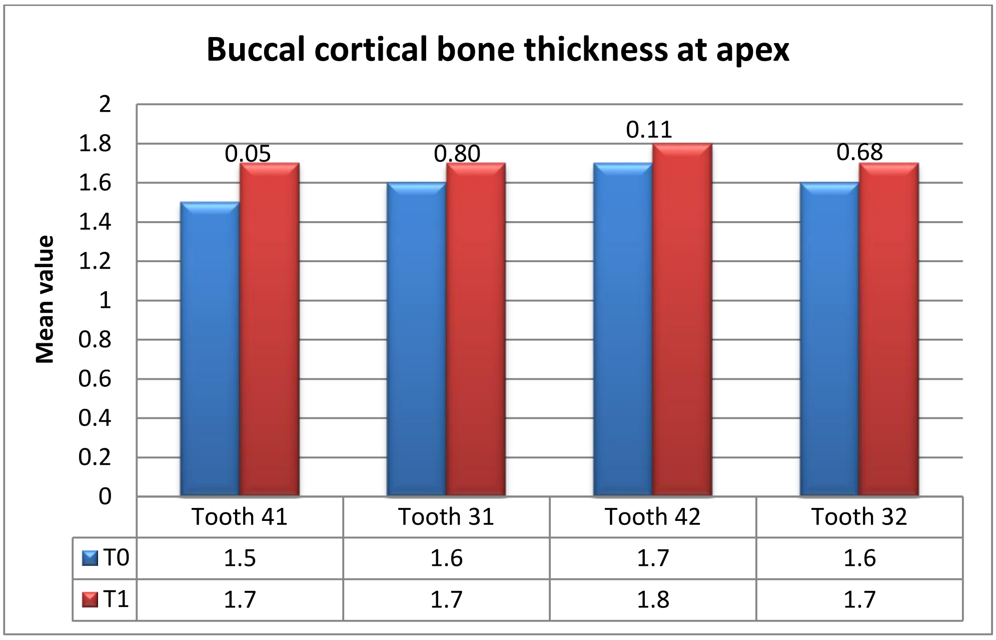

Figure 15: Plot of comparison of buccal cortical bone thickness at apex before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

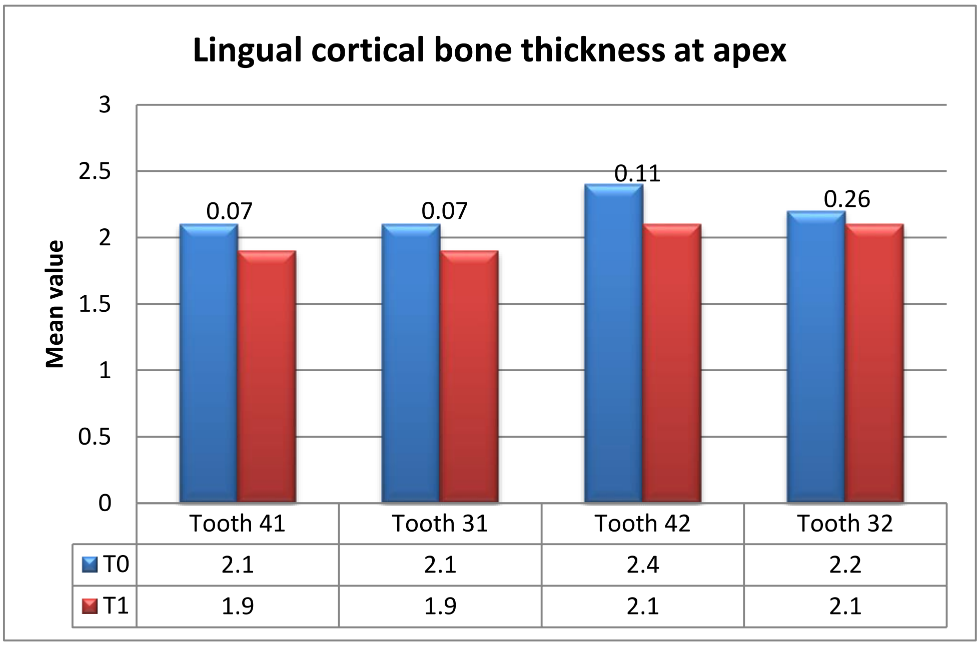

Figure 16: Plot of comparison of lingual cortical bone thickness at apex before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

Table 8: Comparison of mean values of mandibular cortical bone thickness at mid root level before (T0) and after completion of orthodontic treatment (T1)

S.No	Measurements	Mean± SD			P-value*	95% confidence interval of the difference (CI)	
		T0 (n=35)	T1 (n=35)	Mean difference		Lower	Upper
1.	**Buccal cortical bone thickness at mid root level (BCBM)**						
	Tooth41	0.4±0.51	0.6±0.80	-0.2±0.81	0.093	-0.52	0.04
	Tooth31	0.5±0.52	0.5±0.72	-0.0±0.63	0.508	-0.29	0.15
	Tooth42	0.3±0.51	0.5±0.62	-0.1±0.54	0.061	-0.36	0.01
	Tooth32	0.3±0.44	0.4±0.59	-0.1±0.59	0.216	-0.33	0.07
2.	**Lingual cortical bone thickness at mid root level (LCBM)**						
	Tooth41	1.1±0.85	0.5±0.74	0.63±0.74	<0.001**	0.38	0.89
	Tooth31	1.1±0.70	0.6±0.92	0.52±0.68	<0.001**	0.28	0.75
	Tooth42	1.4±0.79	0.7±0.82	0.72±0.79	<0.001**	0.45	0.99
	Tooth32	1.6±0.94	0.8±0.77	0.85±0.77	<0.001**	0.58	1.11

*P value of difference in means, before and after treatment is calculated using Paired t-test. **P<0.05 is considered significant, SD indicates Standard deviation, CI: Confidence Interval, T0: Pre-treatment, T1: Post-treatment.

Table 8 shows comparison of the buccal and lingual cortical bone thickness at the level of apex between pre and post treatment. Buccal (labial) cortical bone thickness at midtroot level increased from pre to post treatment however the results were not statistically significant (P>0.05) (Fig 17).

Lingual cortical bone thickness at mid root level decreased significantly (P<0.001) from pre to post treatment for all mandibular incisors (Fig 18).

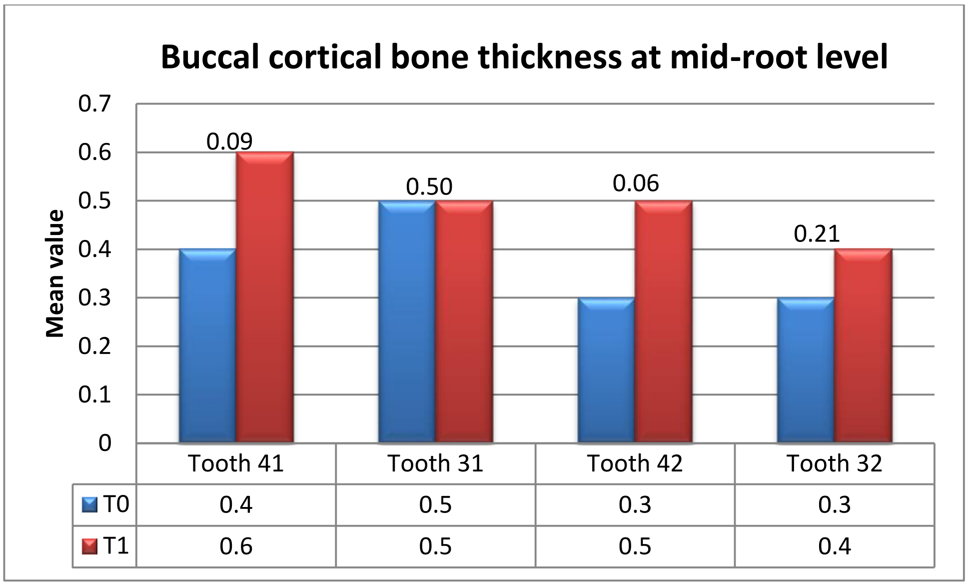

Figure 17: Plot of comparison of buccal cortical bone thickness at mid-root level before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

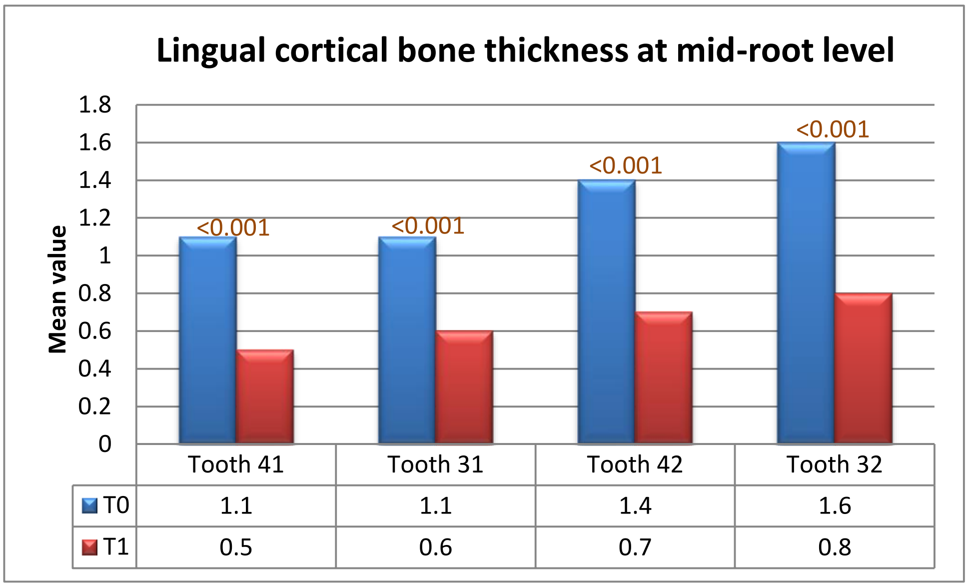

Figure 18: Plot of comparison of lingual cortical bone thickness at mid-root level before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

Table 9: Comparison of mean values of buccal and lingual crestal bone height (from CEJ to alveolar crest) before (T0) and after completion of orthodontic treatment (T1)

S.No	Measurements	Mean± SD			P-value*	95% confidence interval of the difference (CI)	
		T0 (n=35)	T1 (n=35)	Mean difference		Lower	Upper
1.	**Buccal crestal bone height (BCBH)**						
	Tooth41	5.5±1.56	5.8±1.69	-0.3±1.70	0.239	-0.93	0.24
	Tooth31	5.1±1.75	5.6±1.99	-0.4±2.03	0.158	-1.19	0.20
	Tooth42	5.3±2.61	5.6±2.12	-0.2±2.77	0.570	-1.22	0.68
	Tooth32	5.4±2.73	5.9±2.60	-0.4±2.86	0.373	-1.42	0.54
2.	**Lingual crestal bone height (LCBH)**						
	Tooth41	2.8±1.93	5.9±3.08	-3.0±3.32	0.001**	-4.23	-1.94
	Tooth31	2.6±1.52	5.4±3.17	-2.8±3.10	0.001**	-3.89	-1.76
	Tooth42	2.8±1.55	4.6±3.27	-1.7±2.99	0.001**	-2.81	-0.76
	Tooth32	2.3±1.53	4.7±3.38	-2.3±2.90	0.001**	-3.32	-1.32

*P value of difference in means, before and after treatment is calculated using Paired t-test. **P<0.05 is considered significant, SD indicates Standard deviation, CI: Confidence Interval, T0: Pre-treatment, T1: Post-treatment. [Negative values represent an increase in distance from CEJ to alveolar crest (bone loss)]

Table 9 shows comparison of the buccal and lingual bone height between pre and post treatment. BCBH decreased from pre to post treatment for all mandibular incisors (Bone loss depicted by increase in height from CEJ to alveolar crest) however the results were not statistically significant (P> 0.05) (Fig 19).

LCBH also decreased from pre to post treatment for all mandibular incisors and results were statistically significant (P< 0.001) (Fig 20).

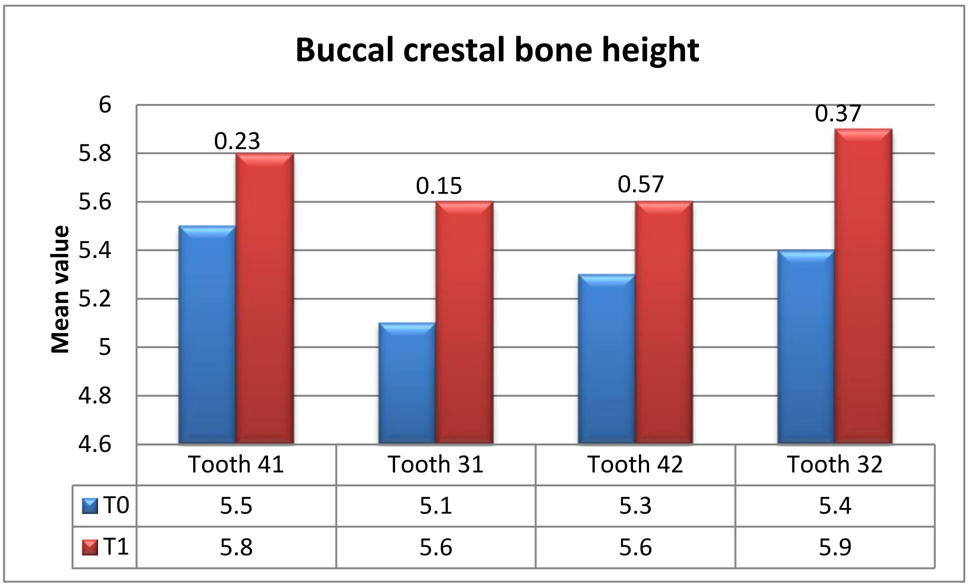

Figure 19: Plot of comparison of buccal crestal bone height before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

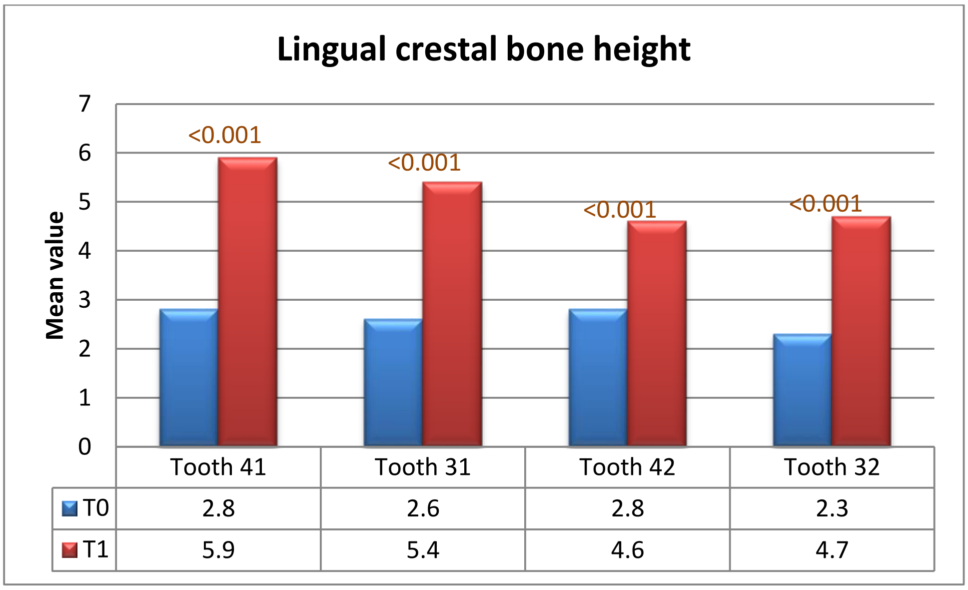

Figure 20: Plot of comparison of lingual crestal bone height before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

Table 10: Comparison of mean values of change in root length (root resorption) in sagittal and coronal section before (T0) and after completion of orthodontic treatment (T1)

S.No	Measurements	Mean± SD			P-value*	95% confidence interval of the difference (CI)	
		T0	T1	Mean difference		Lower	Upper
1.	**Change in root length (Sagittal section)**						
	Tooth41	21.6±1.41	20.8±1.65	0.8±0.68	<0.001**	0.57	1.04
	Tooth31	21.5±1.27	20.7±1.52	0.8±0.70	<0.001**	0.58	1.07
	Tooth42	22.7±1.53	21.5±1.76	1.2±0.93	<0.001**	0.87	1.51
	Tooth32	22.6±1.43	21.4±1.67	1.2±0.99	<0.001**	0.89	1.57
2.	**Change in root length (Coronal section)**						
	Tooth41	21.7±1.44	20.2±3.49	1.4±3.14	<0.011**	0.35	2.51
	Tooth31	21.6±1.26	20.7±1.49	0.9±0.70	<0.001**	0.68	1.17
	Tooth42	22.7±1.54	21.4±1.72	1.2±1.4	<0.001**	0.90	1.62
	Tooth32	22.7±1.41	21.3±1.74	1.4±0.95	<0.001**	1.06	1.72

*P value of difference in group, before and after treatment is calculated using Paired t-test. **P<0.05 is considered significant, SD indicates Standard deviation, CI: Confidence Interval, T0: Pre-treatment, T1: Post-treatment.

Table 10 shows comparison of mean values of the change in root length (root resorption) in sagittal and coronal section between pre and post treatment. Root length was decreased from pre to post treatment in both sagittal and coronal section for all the mandibular incisors and the results were statistically significant (P< 0.001) (Fig 21, 22).

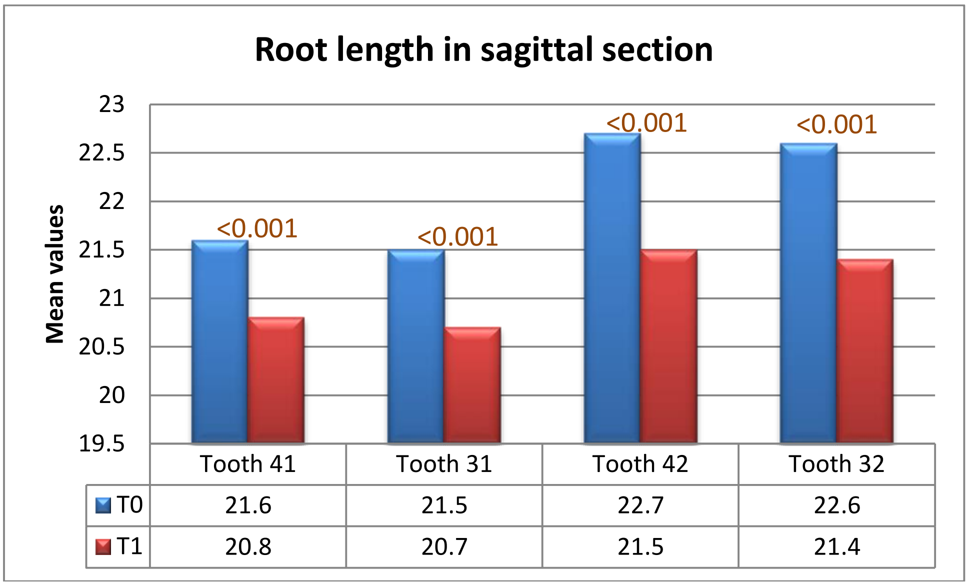

Figure 21: Plot of comparison of root length in sagittal section before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

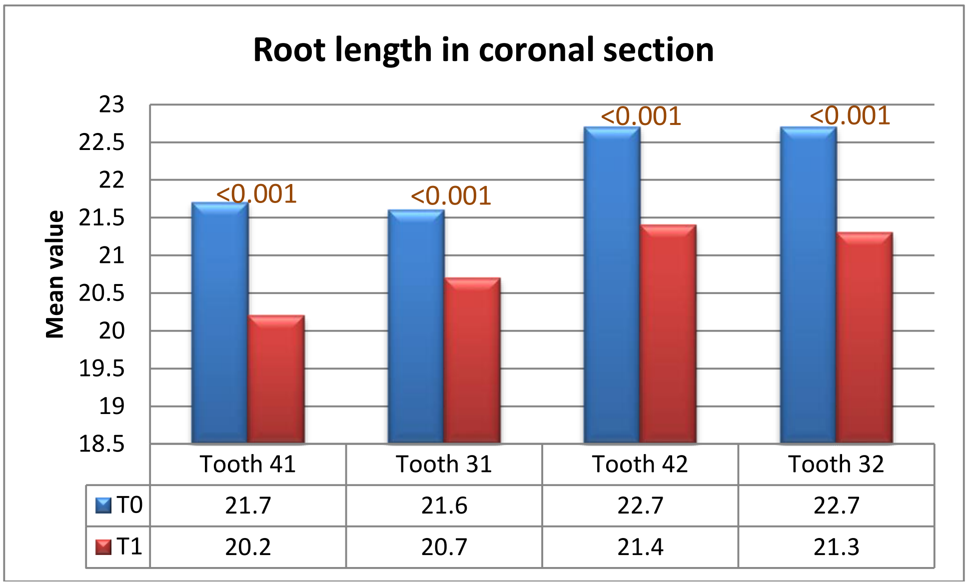

Figure 22: Plot of comparison of root length in coronal section before (T0) and after completion of orthodontic treatment (T1). P-value labeled above the graph.

DISCUSSION

Orthodontic tooth movement induces alveolar bone remodeling in which bone formation occurs on the tension side and the pressure side manifests bone resorption. Anatomically, the alveolar bone is thinner in the anterior region than the posterior region in the mandible (66). During alignment and retraction phase of mandibular incisors, unlimited tooth movement is not possible, due to the restrictions established by the cortical bone in the symphysis region. Therefore, orthodontic tooth movement in the anterior mandibular region can easily exceed the biological limits of the alveolar process based on its direction and amount. Our aim was to evaluate changes in alveolar bone dimensions around the mandibular incisors after orthodontic treatment in patients requiring mandibular premolar extraction.

For critically evaluating this area, one of the popularly used diagnostic modalities is CBCT imaging. Timock et al. (67) found good agreement between CBCT imaging and direct measurements on cadavers while assessing buccal bone height and alveolar bone thickness., The mean absolute error between both the measurements on buccal bone height and alveolar bone thickness was found to be small (0.30 mm and 0.13 mm, respectively) and showed no statistically significant differences. CBCT has shown high reliability in the linear measurement of alveolar bone dimensions in numerous studies (32,68). A previous study (69) found that precision, reproducibility, and accuracy of alveolar bone measurement were good with a minimum of 0.3-mm voxel. The voxel size of 0.15 mm used in the present study provided high-resolution images to evaluate alveolar bone dimension and root resorption.

Premolar extraction is usually indicated in patients with severe protrusion and crowding. About 25 per cent of orthodontic cases require extractions, and 8.9–13.4% undergo four first premolar extractions (70). During fixed orthodontic treatment, the extraction space closure depends on the distal movement of the anterior teeth and the mesial movement of the posterior teeth (71). It is a known fact that alveolar bone resorption is a risk associated with orthodontic tooth movement(72,73). Before recruiting the patients for the study, pre-treatment crowding was measured using anterior crowding index (65). In addition, it was ensured that the baseline cephalometric characteristics of subjects were similar to exclude the influence of skeletal and dental factors. All patients underwent fixed orthodontic treatment with first premolar extraction to provide space to alleviate mandibular anterior crowding and retraction. Alveolar bone dimensions were measured using CBCT images, which had excellent intra-observer reproducibility and reliability (>0.9) and method error (0.05-0.14) for landmark location and measurements of alveolar bone variables.

Assessment of alveolar bone thickness:

It is widely accepted that whenever orthodontic tooth movement occurs, the alveolar bone around teeth remodels to similar extent. However, it is unclear whether the tooth movement-to-bone remodeling ratio is 1:1 in all orthodontic tooth movements. According to a systematic review by Guo et al. (42), fixed orthodontic treatment with extraction of first premolars leads to significant alveolar bone changes around mandibular incisors. In the present study, a combination bone resorption (bone loss) and bone formation (gain in bone) was observed around the mandibular incisors.

After completion of fixed orthodontic treatment, it was noted that there was a significant decrease in bone thickness on the lingual side and the average decrease was 1.2 mm. Although an increase in buccal (labial) bone thickness was noted in all mandibular incisors, the results were not statistically significant. Zhang et al. (24) also found similar results and reported an average of 1.25 mm decrease in total lingual bone thickness in the mandibular central incisors. Wang et al. (63) also found similar decrease in total lingual bone thickness in relation to central and lateral incisors of 1.13 mm and 1.12 mm, respectively. Sarikaya et al. (38) and Nayak et al. (48) also found a decrease in alveolar bone thickness on the lingual side in mandibular incisors, but the results were insignificant. This might be due to difference in methodology used to evaluate alveolar bone thickness, in which they measured the bone thickness at three different levels from crestal bone of teeth using computed tomography scans.

The results from this study showed that after alignment and residual space closure, the mandibular incisors showed an increase in buccal alveolar bone thickness, a decrease in lingual bone thickness and an overall decrease in total bone thickness at the root apex. Premolar extraction helps to reposition the crowded and proclined mandibular incisors so that they are upright in the basal bone, leading to alveolar bone remodelling around incisors. In addition, teeth appear to have moved bodily towards the lingual side, and some tipping also occurred during orthodontic treatment. These tooth movements increased buccal alveolar bone thickness, indicating that the incisor retraction is synchronized with the buccal alveolar bone remodeling process. However, lingual alveolar bone exceeded the bone remodeling process.

Lee et al. (43) reported 1.15 and 1.25 mm alveolar bone loss on the lingual side at the apex level in central and lateral incisors, respectively. However, they evaluated alveolar bone changes after surgical orthodontic treatment in skeletal class III patients with crowding of less than 3 mm in the mandibular arch. Increased alveolar bone loss on the lingual side suggests that the mandibular incisors crown moves labially and root towards the lingual cortical bone due to uncontrolled tipping during decompensating the class III malocclusion. So results of this study cannot be directly correlated to our study.

In the present study, total buccal bone thickness increased by 0.35 mm and 0.3 mm for central and lateral incisors, respectively. Wang et al. (63) also found similar findings of 0.39 mm increase in total buccal bone thickness in mandibular incisors. Zhang et al. (24) found more increase in total buccal bone thickness (0.69 mm) in the mandibular central incisors compared to our study which could be due to greater tipping movement in which tooth apex moved towards the lingual side, causing an increase in alveolar bone on the buccal side.

In contrast to our study, Nayak et al. (48) found that buccal alveolar bone thickness decreased for all mandibular incisors; however, the results were not statistically significant. In their study, incisor extraction was done after individual canine retraction, which might cause more force on the incisors, leading to a decrease in buccal bone thickness. In addition, they measured the bone thickness at different levels of teeth using computed tomography scans which may cause errors in the precise localization of the landmarks.

The results of the present study showed that the total bone thickness decreased (0.57 mm) significantly after fixed orthodontic treatment for all mandibular incisors. In this study, total bone thickness (TBT) was measured as the sum of total buccal bone thickness (TBBT) and total lingual bone thickness (TLBT). To best of our knowledge, we could not find any study that has evalauated total bone thickness at apex.

Cortical bone thickness:

In the present study, after orthodontic treatment buccal cortical bone thickness increased and lingual cortical bone thickness decreased at the apex in the central and lateral incisors. However, the results were insignificant. To best of our knowledge, there is no study that has evaluated buccal and lingual cortical bone thickness at apex. Only one study by Garlock et al. (21) reported a decrease in both buccal and lingual cortical bone thickness at the apex. However, these results cannot be directly compared to our study because cortical bone evaluated after non-extraction orthodontic treatment.

In our study, buccal cortical bone thickness at the mid-root level was also increased by 0.1 mm in both central and lateral incisors. Only two studies (24,63) evaluated the alveolar bone thickness at mid-root level that included both cortical and cancellous bone thickness. Our findings are in affirmation with the result found by Zhang et al. (24) (reported-1.15 mm increase in buccal alveolar bone thickness at the mid-root level) and Wang et al. (63) (reported 0.15 mm increase in buccal alveolar bone thickness at the mid-root level) after retraction of mandibular incisors in premolar extraction cases. However, the assessment method of cortical bone at the mid-root level differed from our study. Also, a 0.3 mm of voxel size was used in their study, which could have underestimated the minute measurement. Smaller voxel size detects thin cortical bone around mandibular incisors and provides great image resolution (74). Swasty et al. (75) found that patients with thin mandibular symphysis are associated with thinner cortical plates and are more prone to bone loss after orthodontic treatment.

Lingual cortical bone thickness decreased at the mid root level. At the mid-root level lingual cortical bone thickness decreased by 0.57 mm and 0.78 mm in central and lateral incisors, respectively. These results are in corroboration with the study of Zhang et al. (24) (reported-0.87 mm decrease in lingual alveolar bone thickness at the mid-root level) and Wang et al. (63) (reported 1.05 mm decrease in lingual alveolar bone thickness at the mid-root level). Both studies (24, 63) measured alveolar bone which is sum of cancellous and cortical bone, thereby more decrease compared to our study. To the best of our knowledge, no study has assessed cortical bone thickness after completion of orthodontic treatment involving premolar extractions. Only one study by Garlock et al. (21) reported a decrease in both buccal and lingual cortical bone thickness at the mid-root level. However, these results cannot be directly compared to our study because cortical bone evaluated after non-extraction orthodontic treatment.

It appears from results that approximately similar amount of change in the form of bone loss and bone gain was observed for all mandibular incisors, probably because periodontal ligament area is similar of all four incisors and had received the same amount of pressure and tension while alignment and space closure.

Buccal and lingual crestal bone height

In the present study, both buccal and lingual crestal bone height decreased after completion of orthodontic treatment. A greater amount of bone loss was seen on the lingual crestal bone height as compared to buccal crestal bone height. Bone loss was more evident on the marginal crest because forces applied to mandibular incisors for alignment and lingual movement were concentrated at the alveolar crest, leading to greater pressure accumulation and significant bone loss. Mandibular central and lateral incisors observed bone loss of buccal crestal bone height however results were not significant.

Lund et al. (23) evaluated marginal bone crest levels in the mandibular anterior region for patients treated with premolar extractions. They found a significant decrease of 0.8 and 1.1 mm bone loss on the buccal surface of central and lateral incisors, respectively. Zhang et al. (24) and Wang et al. (63) also reported a significant decrease in buccal crestal bone height. These studies (23, 24, 63) found significant differences because of the inclusion of bimaxillary protrusion cases only, which required significant retraction of mandibular incisors. In our study, there was a minimal retraction of mandibular incisors as our inclusion criteria were based on the inclusion of moderate to severe crowding cases. Therefore, the extraction space was not completely utilized to retract mandibular incisors. The lingual tooth movement of incisors might be synchronized with the buccal alveolar bone remodelling process.

In the present study, significant amount of bone loss observed on lingual crestal bone height in central (2.9 mm) and lateral incisors (1.9 mm). It infers that mandibular incisors moved lingually during alignment after premolar extraction. The results are in corroboration with the study of Lund et al. (23) (reported 5.7 and 5.1 mm bone loss on the lingual surface for central and lateral incisors, respectively) and Zhang et al. (24) (reported 2.4 and 1.6 mm bone loss on the lingual surface for central and lateral incisors, respectively). Wang et al. (63) also reported a similar decrease in lingual crestal bone height.

In another study Garlock et al. (21) also reported significant decrease in buccal and lingual crestal bone height however they evaluated non-extraction orthodontic patients. They reported increase in inclination of mandibular incisors but did not mention about severity of crowding in their subjects, so results cannot correlated to the present study. Lee et al. (43) also reported a significant decrease in buccal crestal height (1.43 mm and 1.58 mm) and lingual crestal height (0.94 mm and 0.98 mm) for central and lateral incisors, respectively although evaluated surgical class III patients with crowding of less than 3 mm after alignment. Their finding suggested that the lower incisors decompensated pre-surgically by labial tipping, causing a greater bone loss on the labial side. Yao et al. (61) also found a significant decrease in buccal crestal height (2.70 mm and 3.45 mm) and lingual crestal height (1 mm and 1.35 mm) for the central and lateral incisors, respectively in surgical class III patients. This increase in loss of crestal height could be due to the difference in the measurement method, as they evaluated the crestal bone height from the root apex to the crestal bone and did not consider the effects of orthodontic treatment on the root length. These results cannot be directly compared to the present study. It can be interpreted with the results of present study that lingual movement of mandibular incisors cause more extensive bone loss of lingual crestal height than the buccal crestal height.

Root resorption

The root length was decreased from pre- to post-treatment in mandibular incisors in both coronal and sagittal section. These results are in accordance with the previous study by Zhang et al. (24) who found 1.15 mm of root resorption in mandibular incisors after completion of orthodontic treatment. Wang et al. (63) also found decrease in root length after fixed orthodontic treatment with premolar extraction. Castro et al. (31) found 0.40 mm and 0.47 mm decrease in root length after non-extraction orthodontic treatment. A systematic review by Deng et al. (32) reported that extraction cases have more resorption compared to non-extraction cases. Jiang et al. (76) found a statistically significant correlation of treatment duration with post-treatment root resorption and therefore, extraction cases have more severe root resorption when compared to non-extraction cases. Orthodontic treatment and root resorption have been widely studied, but comparing the results is difficult due to differences in treatment methods, radiographic evaluation criteria, and diagnostic imaging techniques (77-84)

Root resorption is expected to cease after fixed orthodontic treatment (85). Wang et al. (63) studied the root length 18-24 months after retention and found no significant difference in root length post-treatment and post-retention phase. They reported that there might only be an increase in the smoothness of the root apex or sealing of the apical foramen; the root length did not restore by cementum repair. To best of our knowledge there is no study on long-term prognosis of the teeth that underwent root resorption. Therefore, future follow-up studies should be undertaken to evaluate the long-term health of the teeth.

Strengths and limitations of the study

The present study has a prospective study design. To alleviate moderate to severe crowding, first premolars are commonly extracted to gain space. To the best of our knowledge, there is no prospective study in the existing literature that has evaluated alveolar bone changes before and after orthodontic treatment in patients involving premolar extraction. The alveolar bone morphology was extensively studied around mandibular incisors, where the cortical and alveolar bone was measured at the root apex and the mid-root level.

The sample size was calculated based on the previous study (21) and seemed adequate. However, the power of the study could be increased to include more subjects. As the present study is a prospective design, a control group would have added further information. The CBCT images were taken just after debonding of the patients. However, long term studies can eliminate the effect of ongoing osteoclastic activity after the completion of orthodontic tooth movement. The alveolar bone remodelling process lags behind orthodontic tooth movement; therefore, further long-term studies can be taken up to evaluate the patient's alveolar bone regeneration during follow-up.

CONCLUSIONS

The following conclusions were drawn from the study:

1. At the apex level, total bone thickness and total lingual bone thickness decreased significantly in all mandibular incisors after completion of orthodontic treatment while increase in total buccal (labial) bone thickness was not statistically significant.
2. Buccal and lingual cortical bone thickness changes at apex level were not statistically significant for all mandibular incisors after completion of orthodontic treatment.
3. At mid root level, lingual cortical bone thickness decreased significantly for all mandibular incisors after completion of orthodontic treatment.
4. Significant decrease in buccal and lingual crestal height bone was observed in all mandibular incisors after completion of orthodontic treatment.
5. Significant decrease in root length (in coronal and sagittal plane) was observed in all mandibular incisors post orthodontic treatment.

SUMMARY

Objectives: To evaluate the alveolar bone thickness, alveolar crestal bone height and root resorption in mandibular incisors after fixed orthodontic treatment.

Materials and Methods: A total of Thirty-five patients (14 year and older) with moderate to severe mandibular anterior crowding who underwent orthodontic treatment with first premolar extraction were included. Cone beam computed tomography scans were obtained from the patients before and after orthodontic treatment. The labial and lingual alveolar bone thickness, alveolar crestal bone height and root resorption was assessed quantatively. Cortical bone thickness was assessed at apex and at midroot level in all mandibular incisors before and after fixed orthodontic treatment. Paired t-test was used to compare pre-treatment and post treatment alveolar bone changes and root resorption.

Results: There was significant decrease in total bone thickness and lingual alveolar bone thickness in all mandibular incisors ($P < 0.05$) and an increase in total buccal bone thickness was not statistically significant ($P > 0.05$). Lingual cortical bone thickness decreased at mid root level significantly for all mandibular incisors after completion of orthodontic treatment. Significant decrease in buccal and lingual crestal height bone and root length was observed in all mandibular incisors after completion of orthodontic treatment.

Conclusion: Fixed orthodontic treatment with premolar extraction cause loss of total alveolar bone thickness and alveolar crestal bone height around the mandibular incisors. Significant decrease in root length was observed in all mandibular incisors post orthodontic treatment.

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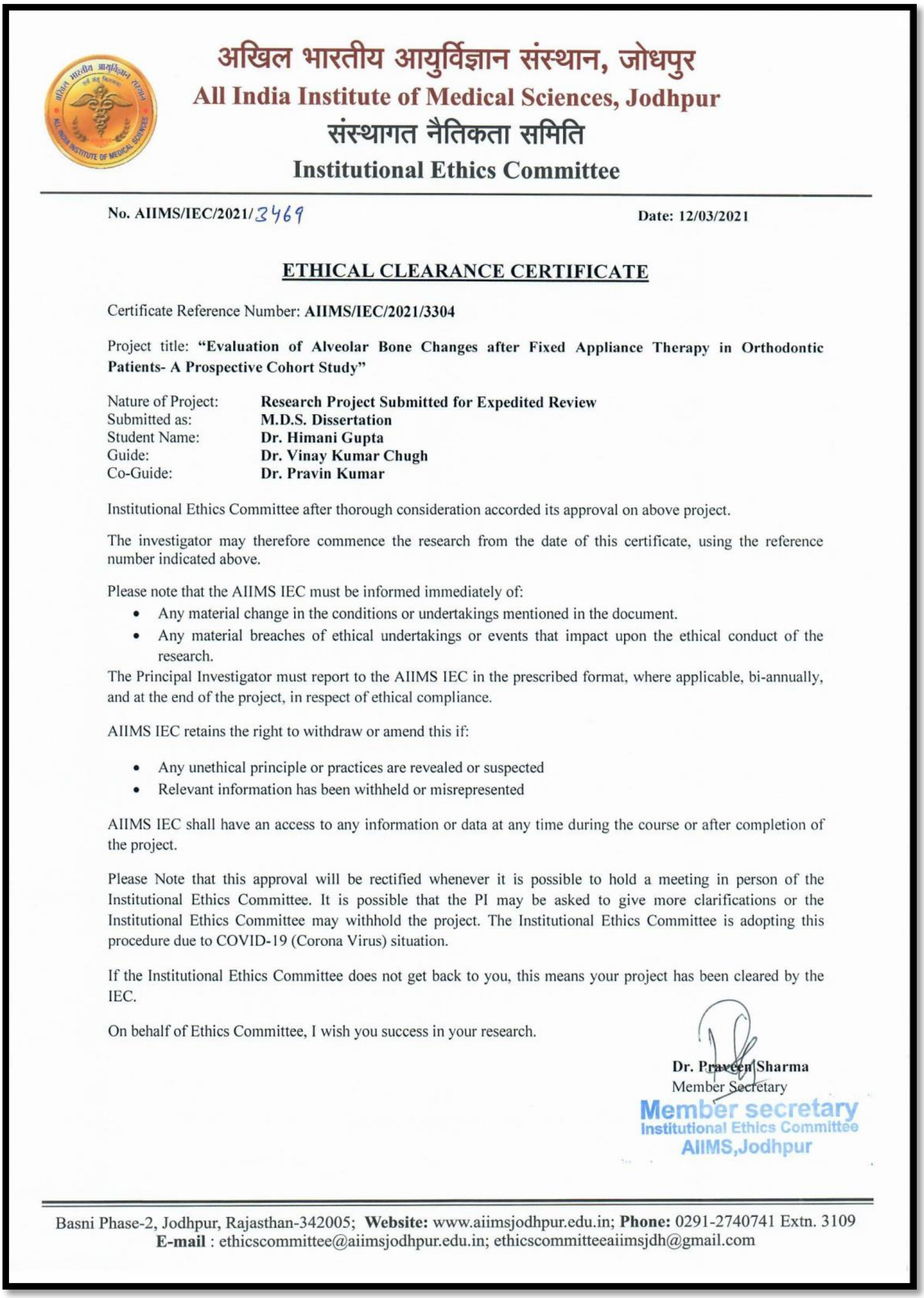
ANNEXURES

Annexure I: Institutional Ethical Clearance Certificate



अखिल भारतीय आयुर्विज्ञान संस्थान, जोधपुर
All India Institute of Medical Sciences, Jodhpur
संस्थागत नैतिकता समिति
Institutional Ethics Committee

No. AIIMS/IEC/2021/3469 **Date: 12/03/2021**

ETHICAL CLEARANCE CERTIFICATE

Certificate Reference Number: **AIIMS/IEC/2021/3304**

Project title: **"Evaluation of Alveolar Bone Changes after Fixed Appliance Therapy in Orthodontic Patients- A Prospective Cohort Study"**

Nature of Project:	**Research Project Submitted for Expedited Review**
Submitted as:	**M.D.S. Dissertation**
Student Name:	**Dr. Himani Gupta**
Guide:	**Dr. Vinay Kumar Chugh**
Co-Guide:	**Dr. Pravin Kumar**

Institutional Ethics Committee after thorough consideration accorded its approval on above project.

The investigator may therefore commence the research from the date of this certificate, using the reference number indicated above.

Please note that the AIIMS IEC must be informed immediately of:

- Any material change in the conditions or undertakings mentioned in the document.
- Any material breaches of ethical undertakings or events that impact upon the ethical conduct of the research.

The Principal Investigator must report to the AIIMS IEC in the prescribed format, where applicable, bi-annually, and at the end of the project, in respect of ethical compliance.

AIIMS IEC retains the right to withdraw or amend this if:

- Any unethical principle or practices are revealed or suspected
- Relevant information has been withheld or misrepresented

AIIMS IEC shall have an access to any information or data at any time during the course or after completion of the project.

Please Note that this approval will be rectified whenever it is possible to hold a meeting in person of the Institutional Ethics Committee. It is possible that the PI may be asked to give more clarifications or the Institutional Ethics Committee may withhold the project. The Institutional Ethics Committee is adopting this procedure due to COVID-19 (Corona Virus) situation.

If the Institutional Ethics Committee does not get back to you, this means your project has been cleared by the IEC.

On behalf of Ethics Committee, I wish you success in your research.

Dr. Praveen Sharma
Member Secretary

Member secretary
Institutional Ethics Committee
AIIMS,Jodhpur

Basni Phase-2, Jodhpur, Rajasthan-342005; **Website:** www.aiimsjodhpur.edu.in; **Phone:** 0291-2740741 Extn. 3109
E-mail : ethicscommittee@aiimsjodhpur.edu.in; ethicscommitteeaiimsjdh@gmail.com

Annexure II: Patient Information Leaflet (English)

All India Institute of Medical Sciences, Jodhpur

Department of Dentistry

Patient Information Leaflet

You are being invited to willing fully participate in the study entitled

"Evaluation of Alveolar Bone Changes after Fixed Appliance Therapy in Orthodontic Patients -A Prospective Study"

You have been requested to volunteer for a research study since you are willing for fixed orthodontic treatment. Orthodontic treatment causes tooth movements within the alveolar bone by remodeling. It may cause the change in morphology of alveolar bone and root length. There is less literature about the change in alveolar bone and root resorption in the mandibular anterior region after orthodontic treatment. So this study is aimed to evaluate the alveolar bone changes after fixed appliance therapy in orthodontic patients.

Confidentiality

Your medical records and identity will be treated as confidential documents. They will only be revealed to other doctors/scientists/monitors/auditors of the study if required. The results of the study may be published in a scientific journal but you will not be identified by name.

Ethics committee approval has been obtained for the study.

Your participation and rights

Your participation in the study is fully voluntary and you may withdraw from the study anytime without having to give reasons for the same. In any case, you will receive the appropriate treatment for your condition. You will not be paid any amount for the participation in the study. You will have to pay for the routine investigations that will be done.

Contact Person: for further queries-

Dr. Himani Gupta
Post Graduate Resident
Orthodontics & Dentofacial Orthopaedics
Department of Dentistry,
AIIMS, Jodhpur
Mobile no: 8854034789
Email: himanigupta2692@gmail.com

Annexure III: Patient Information Leaflet (Hindi)

अखिल भारतीय आयुर्विज्ञान संस्थान, जोधपुर
दंत चिकित्सा विभाग
रोगी सूचना पत्र

आपको अध्ययन में पूरी तरह भाग लेने के लिए आमंत्रित किया जा रहा है

शीर्षक: **"Evaluation of Alveolar Bone Changes after Fixed Appliance Therapy in Orthodontic Patients -A Prospective Study"**

आपसे शोध अध्ययन के लिए स्वयंसेवक बनने का अनुरोध कर रहा है क्योंकि आप फिक्स्ड ऑर्थोडॉन्टिक ट्रीटमेंट करवा रहे है । फिक्स्ड ऑर्थोडॉन्टिक ट्रीटमेंट के कारण आल्वेओलार बोन के अंदर रिमॉडलिंग होती हैं । जिसकी वजह से आल्वेओलार बोन की सरंचना एवं दांत की लम्बाई में बदलाव आ सकता है । बहुत कम लिटरेचर या स्टडी है जो फिक्स्ड ऑर्थोडॉन्टिक ट्रीटमेंट के बाद निचले जबड़े के आगे के दांतो की आल्वेओलार बोन की सरंचना एवं दांत की लम्बाई के बारे में बदलाव दर्शाता है, इसीलिए यह स्टडी का लक्ष्य है मरीज़ो में ऑर्थोडॉन्टिक ट्रीटमेंट के बाद आल्वेओलार बोन की सरंचना एवं दांत की लम्बाई में बदलाव देखना । यह स्टडी कोन बीम कंप्यूटराइज्ड टोमोग्राफी की मदद से की जाएगी।

गोपनीयता

आपके मेडिकल रिकॉर्ड और पहचान को गोपनीय दस्तावेज माना जाएगा। यदि आवश्यक हो तो वे केवल अध्ययन के अन्य डॉक्टरों / वैज्ञानिकों / मॉनीटर / लेखा परीक्षकों को ही प्रकट किए जाएंगे। अध्ययन के परिणाम वैज्ञानिक पत्रिका में प्रकाशित किए जा सकते हैं लेकिन आपको नाम से पहचाना नहीं जाएगा। अध्ययन के लिए नैतिकता समिति की मंजूरी प्राप्त की गई है।

आपकी भागीदारी और अधिकारअध्ययन में आपकी भागीदारी पूरी तरह से स्वैच्छिक है और आप इसके कारणों के बिना किसी भी समय अध्ययन से वापस ले सकते हैं। किसी भी मामले में, आपको अपनी स्थिति के लिए उचित उपचार प्राप्त होगा। अध्ययन में भागीदारी के लिए आपको कोई राशि नहीं दी जाएगी। आपको नियमित जांच के लिए भुगतान करना होगा जो किया जाएगा।

संपर्क व्यक्ति: आगे के प्रश्नों के लिए-

डॉ. हिमानी गुप्ता
पोस्ट ग्रजुएट छात्र
ऑर्थोडोंटिक्स और डेंटोफेशियल ऑर्थोपेडिक्स
दंत चिकित्सा विभाग
एम्स, जोधपुर
मोबाइल नंबर: - 8854034789
ईमेल आईडी:- himanigupta2692@gmail.com

Annexure IV: Informed Consent Form (English)

All India Institute of Medical Sciences, Jodhpur
Department of Dentistry
Informed Consent Form

Subject**: "Evaluation of Alveolar Bone Changes after Fixed Appliance Therapy in Orthodontic Patients -A Prospective Study"**

Patient OPD No: ____

I, ______________________________S/o or D/o___________________________

R/o _________________________give my full, free, voluntary consent to be a part of the study. "Evaluation of Alveolar Bone Changes after Fixed Appliance Therapy in Orthodontic Patients -A Prospective Study"

The procedure and nature of which has been explained to me is in my own language to my full satisfaction. I confirm that I have had the opportunity to ask questions. I give my permission for the use of orthodontic records, including photographs, made in the process of examinations and treatment for the purposes of research, education, or publication in professional journals.

I understand that my participation is voluntary and I am aware of my right to opt out of the study at any time without giving any reason.

I understand that the information collected about me and any of my medical records may be looked at by responsible individual from AIIMS Jodhpur or from regulatory authorities. I give permission for these individuals to have access to my records.

Date: _____________ Place: ______________

Signature/Left thumb impression (Patient) (Caregiver)

This is to certify that the above consent has been obtained in my presence.

Date: _____________ Place: ______________

Signature of Principal Investigator

1. Witness 1
Name: _____________
Address: ____________

2. Witness 2
Name: ______________
Address: ____________

Annexure V: Informed Consent Form (Hindi)

अखिल भारतीय आयुर्विज्ञान संस्थान, जोधपुर
दंत चिकित्सा विभाग
<u>सूचित सहमति प्रपत्र</u>

शीर्षक: **"EVALUATION OF ALVEOLAR BONE CHANGES AFTER FIXED APPLIANCE THERAPY IN ORTHODONTIC PATIENTS -A PROSPECTIVE STUDY"**

रोगी / स्वयं सेवी पहचान संख्या: ______________________

मैं,____________________________ पुत्र/पुत्री_________________________________

निवासी____स्वयं को अध्ययन का हिस्सा होने के लिए अपनी पूर्ण स्वैच्छिक सहमति देता हूँ। इस अध्ययन का शीर्षक है

"EVALUATION OF ALVEOLAR BONE CHANGES AFTER FIXED APPLIANCE THERAPY IN ORTHODONTIC PATIENTS -A PROSPECTIVE STUDY"

मेरी पूर्ण संतुष्टि के लिए मेरी खुद की भाषा में मुझे समझाया गया है।मैं इस बात की पुष्टि करता/करतीहूं कि मुझे सवाल पूछने का पूर्ण अवसर मिला है।

<u>मैं पेशेवर पत्रिकाओं में अनुसंधान, शिक्षा, या प्रकाशन के प्रयोजनों के लिए परीक्षाओं और उपचार की प्रक्रिया में किए गए फोटोग्राफ सहित ऑर्थोडोंटिक रिकॉर्ड्स के उपयोग के लिए मेरी अनुमति देता/देती हूं।</u>

मैं यह समझता/समझतीहूँ कि मेरी भागीदारी स्वैच्छिक है और बिना कोई कारण बताए किसी भी समय इस अध्ययन से स्वयं को वापस लेने के लिए मेरे अधिकार के बारे में मुझे पता है।

मैं यह समझता/समझती हूँ कि मेरे मेडिकल रिकॉर्ड की एकत्रित की गई जानकारी "अखिल भारतीय आयुर्विज्ञान संस्थान जोधपुर" यानि यामक अधिकारियों द्वारा देखी जा सकती है।मैं इन व्यक्तियों को मेरे रिकॉर्ड के उपयोग के लिए अनुमति देता/देती हूँ।

दिनांक: स्थान :

हस्ताक्षर / वाम अंगूठे का निशान (मरीज)

यह प्रमाणित किया जाता कि इस संस्करण की सहमति मेरी उपस्थिति में प्राप्त की गयी है।

दिनांक: स्थान :

प्रमुख अन्वेषक के हस्ताक्षर

1. साक्षी1	2. साक्षी2
हस्ताक्षर: _______________	हस्ताक्षर: ______________
नाम:_______________	नाम:_______________
पता: _______________	पता: _______________

Annexure VI: CBCT record form

CASE RECORD FORM

Sr. No.: …………   Date: …………………   AIIMS ID…………………

Name: …………   Age/Sex: ……………..   Doctor:……………………..

FMA: ………….   Duration of T/T: …………

Baseline Crowding: ………..   Treatment Plan (Ext/ Non Ext): ………………

S.No	Alveolar Bone Thickness	Pre Treatment (T0) Date:				Post Treatment (T1) Date:			
		32	31	41	42	32	31	41	42
1	Total thickness at apex (TBT)								
2	Total buccal bone thickness at apex (TBBT)								
3	Total lingual bone thickness at apex (TLBT)								
4	Buccal cortical bone thickness at apex (BCBA)								
5	Lingual cortical bone thickness at apex (LCBA)								
6	Buccal cortical bone thickness at mid root level (BCBM)								
7	Lingual cortical bone thickness at mid root level (LCBM)								
8	Buccal crestal bone height (BCBH)								
9	Lingual crestal bone height (LCBH)								
10	Root length in sagittal plane (RS)								
11	Root length in coronal plane (RC)								

Annexure VII: Plagiarism Certificate

Evaluation of alveolar bone changes after fixed appliance therapy in orthodontic patients: A prospective study

ORIGINALITY REPORT

10%
SIMILARITY INDEX

PRIMARY SOURCES

1	dentistrykey.com Internet	204 words — 2%
2	www.ncbi.nlm.nih.gov Internet	69 words — 1%
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